DISTURBANCE REJECTION ANALYSIS FOR WASTEWATER TREATMENT PLANT

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"I hereby declare that I have read through this report entitled "Disturbance Rejection Analysis for Wastewater Treatment Plant" and found that it complies the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering"

Signature : ....

Supervisor's Name : ....

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I declare that this report entitled "Disturbance Rejection Analysis for Wastewater Treatment Plant" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Name : ....

Date : ....

To my beloved mother and father

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ABSTRACT

Wastewater Treatment Plant is an important system need to be implemented nowadays as the level of water pollution is at peak because of different kind of activities. Efficiency and performance of a plant always need to be excellent so that the effluent discharging from the plant is meeting the quality requirement of contaminant free water. Thus implementing a good controller that can control the system performance is necessary for best performance. In this project a Proportional Integral Derivative (PID) controller which commonly used in industries is used as feedback controller. There are two kind of PID controllers used which are Davison and Penttinen-Koivo. Feedback controllers will affect the output response before eliminating the error. Thus for prevention and better performances purpose, an observer is integrated with PID controller to reject the disturbance present in the plant before the output performance become undesirable. The closed loop performance of both Davison and Penttinen-Koivo with observer was analysed to compare the performance. It can be observed that Penttinen-Koivo controller with the observer shows better results in rejecting the high level of oscillation as well as the overshoot that exist in the plant compared to Davison controller with observer. With the observer, the injected constant value which act as disturbance can be rejected and the system able to be tracked back to the desired condition.

ABSTRAK

Loji Rawatan Air Sisa adalah satu sistem penting yang perlu dilaksanakan pada masa kini kerana tahap pencemaran air berada di puncak oleh sebab pelbagai jenis aktiviti. Kecekapan dan prestasi tumbuhan sentiasa perlu menjadi sangat baik supaya efluen yang dikeluarkan dari kilang memenuhi keperluan kualiti air simpan. Oleh itu, melaksanakan pengawal yang baik yang dapat mengawal prestasi sistem diperlukan untuk prestasi terbaik. Dalam projek ini, pengawal Proportional Integral Derivatif (PID) yang digunakan secara berleluasa dalam industri digunakan sebagai pengawal maklum balas. Terdapat dua jenis pengawal PID yang digunakan iaitu Davison dan Penttinen-Koivo. Pengawal maklum balas akan mempengaruhi tindak balas output sebelum menghapuskan ralat. Oleh itu untuk tujuan pencegahan dan pencapaian yang lebih baik, pengawal berasaskan Observer diintegrasikan dengan pengawal PID untuk menolak gangguan yang dikenalpasti di dalam loji terlebih dahulu sebelum mengganggu prestasi output. Prestasi kedua-duanya pengawal Davison dan Penttinen-Koivo dengan observer dianalisis untuk membandingkan kecekapannya. Ia dapat diperhatikan bahawa pengawal Penttinen-Koivo dengan observer menunjukkan hasil yang lebih baik dalam dalam menolak tahap ayunan tinggi serta overshoot yang ada pada sistem berbanding dengan pengawal Davison dengan observer. Dengan observer, nilai tetap yang disuntik dalam system sebagai gangguan boleh ditolak dan sistem dapat dikesan kembali ke keadaan yang diinginkan.

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MIMO	-	Multivariable Input Multivariable Output
SISO	-	Single Input Single Output
PI	-	Proportional Derivative
PD	-	Proportional Integral
PID	-	Proportional Integral Derivative
MPID	-	Multivariable Proportional Integral Derivative
DO	-	Disturbance Observer
DOBC	-	Disturbance Observer Based Control
NDOBC	-	Nonlinear Disturbance Observer Based Control
ESO	-	Extented State Observer
SMC	-	Sliding Mode Control
MPC	-	Model Predictive Control
ADRC	-	Active Disturbance Rejection Control
WWTP	-	Wastewater Treatment Plant
TD	-	Tracking Differentiator
LADRC	-	Linear Active Disturbance Rejection Control
TDF	-	Two-Degree of-Freedom
IMC	-	Internal Model Control
LQR	-	Linear Quadratic Regulator
GPC	-	General Predictive Control
LMI	-	linear matrix inequality
AHV	-	Air-breathing Hypersonic Vehicle
ENMPC	-	Explicit Nonlinear Model Predictive Control
D	-	Dilution rate
W	-	Air flow rate
RGA	-	Relative Gain Analysis
ANN	-	Artificial Neutral Network
DMC	-	Dynamic Matrix Control
QDMC	-	Quadratic Dynamic Matrix Control
NLMPC	-	Non Linear Model Predictive Control

DO	-	Dissolved Oxygen
S	-	Substrate
RARFNN	-	Rule Adaptive Recurrent Neural Network
BOD	-	Biological Oxygen Demand
ASM1	-	Activated Sludge Model no.1
DRGA	-	Dynamic Relative Gain Array
R	-	Resonant
SOC	-	Self-Optimized Control
G1	-	Substrate Concentration System
G2	-	Dissolved Oxygen Concentration System
K1	-	Controller Gain Value of G1
K2	-	Controller Gain Value of G2
L1	-	Observer Gain Value of G1
L2	-	Observer Gain Value of G2

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CHAPTER 1

INTRODUCTION

In this chapter introduction of project, problem statement, objective, scope and project schedule will be discussed and presented. Basically, the description related to the project will be discussed here where the purpose of this project will be identified.

1.1 Introduction of Project

Among the natural resources, water is the most essential element where it is an alternative word of life. As we all know, human being can live without food but life is impossible to continue without water because it is needed for all living organisms including human, food production and economic development. The problem in shortage of water had become severe in most of the country because of the drastic increase in number of population, development of country itself as well as pollution of water [1][2][3]. As speak about pollution of water, the quality of water influenced by human exercises and is declining because of the ascent of urbanization, populace development, mechanical creation, environmental change and different components. This water contamination is danger to both the earth and its populace [1]. An article stress out that progressing and developing country which has lesser capability to implement management of water quality causes the quality of water degradation [4]. Furthermore, another article recommend that this issue can only be handled by enforcing water resources policy [2][5]. Water pollution or quality of water can be upgraded by implementing wastewater treatment plant. This plant can be an effective way to cut down pollution and had been attract attention of most of the country [6]. Some country also suggest that enhancing the function and productivity of the treatment plant is an excellent method for water quality upgradation [7].

As mentioned above, water pollution issue faced by most of the nation worldwide. There are lots of research have been carried out regarding water pollution concerning severity of the problem. For instance, in Malaysia rivers are the main source of water resource and it has found that half of the rivers in Malaysia are polluted[8][9]. Apart from that, Nile River in Egypt which is the main source of fresh water become shortage of water because of human population explosion, urbanization as well as water pollution by organic materials[10]. Not only this issues, country such as China, Northern Brazil and Bangladesh also faces such impact toward their water source and their environment[1][11][12]. Thus, this shows that not only Malaysia but the country worldwide are lacking somewhere in taking care of their water resources and serious action should be taken before it is too late. To take such measures to enhance water quality, the factor that contribute to pollution should be studied. In most of the articles stated that industrialization, urbanization, dumping of domestic waste and oil released into the water source are the major reason for pollution to occur [1][2][11][12][13][14][15][16]. Moreover, a consolidation for mismanagement, apathy, low necessity with respect to administration agendas, absence of funds, poor open association and poor enforcement also extremely corrupts waterway [9].

Surely lots of thoughts would be going through about reasons of lots of concern directing towards quality of water. The world giving importance to the quality level of water because it might give huge bad impact towards mankind. In an articles stated that residents around the Huaihe River in China passed away in significantly higher proportion due to colon tumour than people miles stone away from the respected river which is very polluted by the factors listed above [11]. Besides, another research also pinpoint that excessive expel of oil into water because of technical and management defect, it endanger aquatic resources, human health, affecting crop production as well as destroy natural landscape [1][17]. Another journal mention that seventy percent of the people involved in this research were suffered from dangerous health issues such as skin infections, the runs, gastric ulcers or other gastric issues at the time that the exploration was occurring [1]. Contaminated drinking water could also affect human heart and kidney which might lead to dead [18].

The parameters counting conductivity, add up to broke up solids, temperature, saltiness, disintegrated oxygen, pH, turbidity, ammoniacal-nitrogen, organic oxygen request, chemical oxygen request and total suspended solid usually determines the quality of water [3][8][12][13][15][19]. The properties of water depend on the concentration and character of water constituent [20]. The Table 1.1 shows the water quality parameter standard index that water should have [1]:

Table 1.1 Standard Parameter for Good Water Quality

Parameter	**Standard**
DO	6 mg/L
pH	6.5-8.5
Colour	15 ptcu
Turbidity	10 NTU
BOD	0.2 mg/L
Hardness	200-500 mg/L
TDS	1000 mg/L
CL-	0.2 mg/L
CO2	-
COD	4 mg/L

Pollution of water brings lots of disadvantages, so to maintain the above standard index for the respected parameter some measures need to be taken. Due to this, the government of people's Republic of China announced and released ten point of water pollution prevention and control action in April of 2015 [11]. In addition, further research made by Bangladesh inferences that epidemiological studies are crucial to determine impact that industries having on the environment and to warn the people who against the policy of environment. Banning poisonous chemicals and pollutant concentrations from industrial discharge into water source as well as implementation of legislation on safety precautions are also the best way to improve water quality [1][21]. Besides, in an article stated that wastewater treatment plant is also effective way to treat water [5].

Wastewater treatment plant (WWTP) is actually a plant where the wastewater from different sources such as industrial waste, domestic waste and plantation waste to be recycled, cleaned , purified and return back to the river with less contamination. In Malaysia, according to Indah Water Consortium, the preliminary, primary as well as secondary are the dominant treatment process [22]. In doing the wastewater treatment, in an article stated that Malaysia faces some constraints such as low sewerage tariff which unable to support the high operational and maintenance cost and do not have grease traps or do not maintain grease traps adequately. Apart from that sewage service collection by operators is not conductive as many Malaysians fail to realize the importance of this treatment system. Moreover, the risk factor of quality being compromised as the plant constructed by private developers and handed over to public operator [22].Thus, it seems that full cost recuperation for sewage treatment is yet far way to be accomplished in Malaysia [16].

After all this facts and information it is clearly understandable that the sewage system should be enhanced for better water quality. For that, in this project disturbance rejection analysis need to done to wastewater treatment plant to minimize the error in the system and tract back according to the initial input of the WWTP.

1.2 Motivation

Water as an important source of life is similar to human as crucial as cell to body. Many incident from different places around the world had occurred related to water. To start with, Malaysia faces the most serious issue where half of the rivers are polluted [9]. The issue of water quality degradation of surface water and rivers had become hot topic to be discussed [8]. To be more specific water quality index in progressing area such as Malacca, Alor Setar and Kota Baharu is in worst state because of pollution [13]. Moreover, in Egypt the Nile River provides 55.5 billion cubic metre of fresh water every year. Because of increase in human population, urbanization, water polluted by domestic waste and agricultural waste the people around the area faces shortage of water [10].

Apart from that, Burullus Lake, the second largest of northern lakes in Egypt also faces significant challenges where the diversity of fishes was decreased from 32 to 25 species as a direct effect of pollution. The lake act as dump site for drainage waters and discharging from agricultural areas. This causes the level of suspended solids to be very high and high pollution of organic and inorganic matter [20]. Traditional population had to leave their homes in the city of Barcarena, Northern Brazil because of industrial and port activities [12]. In addition, river pollution is also a serious issue discussed in Dhaka the capital city of Bangladesh [1]. Lastly, in an article it also stated that ground water and surface water recognized as being the most severely degraded natural resources in China and among most heavily polluted water resource in the world [11]. All this problems have become the motivation to enhance the management of polluted water or wastewater treatment. For that, efficient wastewater treatment plant is always necessary in order to purify the wastewater and minimize the effect on environment.

1.3 Problem Statement

In this era of modernization, we can obviously say that pollution issues are increasing tremendously especially to water, air and land. This is because as discussed before the rate of industrialization, urbanization, dumping of domestic waste and oil released is also increased along with world development [1][2][11][12][13][14][15][16]. Inefficient wastewater treatment plant become one of the major reason to do this project [22]. An article release a statement that full cost recovery for sewage treatment is still a long way to be achieved in Malaysia [16]. Inefficient plant result in release of contaminated water into the environment. Contaminated water result in many health issues, destroy of aquatic living and many more [1][11][17]. In some cases when the effluent from a plant or company is filthy, respected bodies which related to regulation and enforcement of water quality can sue and take legal action toward the company or organization to cause pollution to the environment. This action will eventually causes problems to the respected company as it might involve handsome amount of money to be paid for the penalty. This consequences is surely an unwanted procedure by any company which might also lead to fractured image in industries. Since inefficient purifying plant might cost a lot to a company, it is wise to enhance the plant for a better results. Hence, a better controller is obviously needed to avoid the consequences and come out with better performances [23].

In a plant, where it might be any kind of plant especially wastewater treatment plant, there will always be errors encountered. Errors means the difference in output from the plant to the desired set point. Although controller are designed to control the output value of the plant to the desired value, the plant always shows errors. This is because treatment of wastewater is a complicated process that is biological in nature and difficult to monitor and control. Treatment plant is also multivariable, non-linear and dynamic in nature [24]. Not only that, the continuous variation of wastewater flow which depend on the weather which changing seasonally, daily and hourly is another issue that distract and lead to disturbance. This influences the wastewater treatment plant to be extremely complicated in term of demonstrating and control purpose [25]. As a matter of fact general standards of control from industrial processes can be connected to wastewater treatment plant, but due to various and unique methods required, special control design always needed in that plant [25]. Thus, to detect error or compensate error suitable feedback controller installation is always needed.

As we know, feedback controller sense and read the output and calculates the error to be compensated by the controller. Normally this type of error occur due to the disturbance occur at the plant. The disturbance might be internal disturbance or external disturbance which can be from any kind of sources [47]. Using only feedback controller to the plant might be a huge drawback because as we know feedback controller detect the error only after it influenze and affect the output of the plant. There is no prevention action could be taken to the plant to avoid the disturbance. However observer can detect and reject disturbance effectively said in an article [26]. Thus, this encourages to do the project so that the disturbance encountered eliminated at early stage and track back to the desired output performance.

Apart from that, a Multivariable Input Multivariable Output (MIMO) plant is denoted as having two or more variables which must be controlled and manipulated[27]. Few year back research studies regarding MIMO was not that popular because of the complexity due to complex interaction between the controller parameters and the system's variable and the lack of knowledge about it [28][29] and at that time only Single Input Single Output (SISO) was investigated a lot. But recently MIMO has been a hot topic because obviously now plant influenzed by multiple variables. In the case for wastewater treatment plant, MIMO plays an essential role as this plant affected by various variable depending on what we want to investigate. Moreover, there are so little investigation of MIMO on wastewater treatment plant. So this is also one of the reason to research on this topic.

As such, this project is all about implementing a controller which able to reject disturbance effectively in MIMO wastewater treatment plant. Not only compensate error from the internal system but also able to eliminate error caused by external source so that the effluent discharged is safe to be used.

1.4 Objective

This project will be carried on few objectives. Objectives have been set as a guideline to complete the project. Below are the following objectives;

1) To study and understand the theory and operation of wastewater treatment plant and disturbance rejection controller.

2) To design and analyse the performance of two types of controller which are Davison and Penttinen-Koivo in wastewater treatment plant.

3) To design and analyse the disturbance rejection ability as well as the ability of state variables estimation of observer in wastewater treatment plant system.

1.5 Scope

This project is about disturbance rejection analysis for wastewater treatment plant. Firstly, PID controller and observer were planned to be implemented in wastewater treatment plant. For that pole placement design method will be used to find the controller gain as well as the observer gain. Two linearize system of non-linear wastewater treatment plant will be used to implement the controller and observer design. The controller and observer gain values will be obtained using m-file in MATLAB Software. After that, Simulink block diagram will be designed for two types of PID controller with state observer design. The values obtained in the m-file simulation will be exported to Simulink block diagram to compare the performance of the Davison and Penttinen-Koivo controller. Not only that a disturbance will be injected to the system in term of constant values to evaluate the performance of observer design.

1.6 Project Schedule

Table 1.2 Project Schedule for Final Year Project Semester 1

Number	**Project Activities**	**Semester 1**
1	Project title selection	Week 1&2
2	Meeting and discussion with supervisor and registration of title	Week 3
3	Research regarding title Find journals, reference and articles Literature review	Week 4,5 & 6
4	Start to do chapter 1: Introduction	Week 6 &7
5	Start to do chapter 2: Literature review	Week 7&8
6	Start to do chapter 3: Methodology	Week 8&9
7	Submission of draft report to supervisor	Week 10
8	Correction of report and preparation of slide for presentation	Week 11&12
9	Presentation week	Week 12
10	Further correction after supervisor comments	Week 12& 13
11	Final submission of report	Week 14

Table 1.3 Project Schedule for Final Year Project Semester 2

Number	**Project Activities**	**Semester 2**
1	Final Year Project 2 briefing	Week 1
2	Meeting and discussion with supervisor	Week 2&3
3	Research regarding methodology Find the suitable and approachable way for the simulation in MATLAB	Week 3,4,5 & 6
4	Start to do WWTP system in state space	Week 6,7&8
5	Start to do Integrator	Week 7,8&9
6	Start to do observer design	Week 8,9&10
7	Simulation of whole system with correction	Week 10,11&12
8	Submission of draft report to supervisor Correction of report and preparation of slide for presentation	Week 12,13&14
9	Presentation week	Week 15
10	Further correction after supervisor comments	Week 16
11	Final submission of report	Week 17

CHAPTER 2

LITERATURE REVIEW

2.1 Disturbance

When we hear of disturbance the first thought would be any kind of interruption to a settled and peaceful condition or in a system. To be more elaborate disturbance can occur in any kind of situation either in the form of physical, mechanical or chemical. Disturbance usually divided into external and internal disturbance [30][47]. The changes in the parameter values of certain component of the system are called internal disturbance while external disturbances effect the performance of the control system [47]. Disturbance which is a form of energy variations is also referred as upsets or load changes. To be specific disturbance can be seen frequently in most of the control system. For instance, change in set point, supply, demand as well as environmental changes are described as disturbance.

2.1.1 Effect of Disturbance to System

Disturbance which is interruption to a peaceful condition or system is obviously giving bad effect to a system as this interruption influenze the desired output value [47].When disturbance is detected in a system, it effect the system by changing the purpose or reduce the efficiency of the output [31]. It is essential to aware of disturbance basic system so that simple to detect and check out interruption which occur in the control system [31]. A system become more stable when disturbance is reduced and stability become high when disturbance near to zero [31]. A journal [26] stated that countless industrial process need improvised control design to achieve the system requirements and specification. In such circumstance the control framework should protect the controlled factors as impeccable as possible to the desired esteem acting against exterior or interior interference that influence process variables. Hence, in any control architecture disturbance play an important role and should be considered to avoid inaccuracy.

2.1.2 Disturbance Rejection Analysis

The productivity of a system rely mostly on the controller of the system. The controller control the system by altering the system parameter to its optimum function. As discussed above disturbance clearly deteriorate the performance of a control system. Thus, to minimize and reduce the disturbance effect in a system a proper method and analysis is crucial in order to attain maximum results. In a journal the disturbance rejection ability is given emphasis for the high controllability of a process[32]. Disturbance rejection done in numerous different kind of controller method where each and every controller has its own pros and cons. Usually the types of controller to be used is determined by the characteristic of the plant and what kind of disturbance need to be rejected [26][32]. In the same journal, the importance of suitable controller was mentioned forcefully [32]. In general controller will be in the form of closed loop transfer function rather that open loop transfer function as this system has feedback mechanism which enable the control system to monitor the disturbance and processing system as to cut down or compensate the error caused by the obstacles in the system [31]. The difference between desired value and output signal is the input signal to the compensator and the processed output from compensator serve as input to the plant [33]. It is also stated in [33] that the sensitivity of the system towards internal and external disturbance reduced by using closed loop controller.

An open loop configuration absolutely not suitable for disturbance rejection as the output signal will not fed back to minimize the error [33]. Disturbance rejection is detrimental to a system, thus it is not shocking at all that disturbance rejection and uncertainty attenuation is an essential matter in controller design. As consequences, many improved control approaches have been investigated to overcome disturbance as well as uncertainties of a system such as linear, non-linear system and many more [23]. Recently, because of the severity of the problem, a lot more new methods being proposed by researcher where one of them is feedforward system which become hot topic to be researched on disturbance rejection analysis and said to be very effective [26]. Methods such as Proportional Integral (PI), Proportional Derivative (PD), Proportional Integral Derivative (PID) control, Sliding Mode Control (SMC), Active Disturbance Rejection Controller (ADRC) and Model Predictive Control (MPC) controllers are some of the way to reduce disturbance in a system [23][34][35][36][37][38]. Not only this, some of the controller above had also attached with other controllers such as Disturbance Observer (DO) and Extended State Observer (ESO) to improve the performance of a system [30][34][39][40]. Since, there are many methods, it is important to choose the best controller for the particular plant so that the results are optimum.

Deterioration of water quality become a global issues particularly within progressing country which typically have less resources available to implement management of water quality [4][41]. Some articles [2][5] emphasis that ongoing assessment of water resource policy is needed to curb this problem. Developing country like Malaysia is also facing a serious impact on the maintainability of water resources, living matter, health of population as well as the economy because of the water pollution [18]. Malaysia has a populace of 28.3 million in view of the Report of Census 2010 by the Branch of Statistics. The evaluated volume of wastewater produced by city and firm located areas is 2.97 billion cubic meters for every year [22]. Thus, government has set a goal to have 99 percent of the natives served by hygienic and treated water by 2020. But the goal would be just a dream as Malaysia experienced a shortage of water in year 2016 because of the 'El Nino phenomenon' which brought drought and cause the water level to decrease at critical level. This is basically because of the poor infrastructure of the system.

To address and overcome the issue, Malaysia is working on enhancing the water sector by improving water infrastructure, rehabilitating and expanding existing drinking water treatment plants and distribution networks. The Ministry of Health is aware of the presence of the rules on safe utilization of wastewater which created by WHO and is very much aware of the wellbeing ramifications of utilizing untreated wastewater [41]. But through achieving the planned goal, Malaysia still facing some obstacles such as low sewage tariff which unable to support the high operation and maintenance costs, ignorance of resident about the importance of such treatment as well as inefficient system of industries which do not trap oil or grease substance. Moreover, The flow of the sewerage business where sewerage infrastructure are built by private engineers and gave over to people in general administrator (for operations and upkeep) opens up the hazard factor of value being traded off, which would along these lines have effect on the treatment procedures and operations [22].

In addition, countless effort had been taken by water sector bodies and organization to encounter the wastewater produced by various kind of source. For instance, Indah Water Consortium has been carrying out activities like internal housekeeping or non-portable use, watering of plant, for landscaping and many more from the recycled wastewater out of their own plant. Moreover, the sewage sludge is used as fertilizer for various crops and a regulation has been released by the Environmental Quality Act 1974 and its regulations such as the Environmental Quality (Sewage) Regulations 2009 and Environmental Quality (Industrial Effluent) Regulations 2009 where the wastewater from urban areas to be treated before discharged into the surface water. Not only this, since Malaysia well know with vast area of rubber plantation, a Research is being led to examine the productivity of utilizing sewage slime in rubber estate, its influenze on soil water science and water quality, development reaction of rubber trees, capacity of rubber trees in collecting lethal components and substantial metals, impact of heavy metals on amount and nature of latex, and to investigate the physical, synthetic and natural attributes of soil as for bio-natural compost application. This are few method of many methods implemented to treat the wastewater and prevent drastic pollution of water as a way to promote and give awareness to the public on seriousness of water pollution [22].

Other countries such as Egypt, Bangladesh, India and Brazil also not to be leave alone in the case of water pollution [1][10][11][12][42]. India as a progressing country taken action by enforcing a particular regulation to assess the quality of water resources, and to check the effectiveness of water treatment and supply by the concerned authorities. This action has been stricken because 1.230 million people were without safe water supplies and suffer from health issues [43]. It is not surprising that a lot of country in worldwide is affected by water pollution because of the rapid increase of industrialisation and obviously tremendous increase in population level. This factor had been pinpoint in many journals and articles as one of the main reasons for water pollution [1][2][5][41][43][44]. There are also other factors that ending up becoming the reasons for water pollution like discussed in [9]. Thus, something need to be done to overcome this ongoing problem.

2.2 Wastewater Treatment Plant

All these factor above had actually induced the world to take action on solving the problem of wastewater [44]. In this article [7] suggest that enhancing the productivity level of wastewater treatment plant is a better way to maintain quality of water as well as lower the cost of services. Wastewater treatment has received growing attention as one of the path to ensure environmental maintainability [20][41]. Although there are lots of complain regarding inefficiency of wastewater treatment plant, on the other hand there are also advanced treatment plant such as DC Water's Plains Advanced Wastewater Treatment plant in Columbia which is the largest plant in the world where it can treat up to 300 million gallons of wastewater per day. We have to understand that not all country having or could afford to build such sophisticated treatment plant, but it is not impossible to build one if the related bodies make eye to eye with each other.

Fundamentally the function of wastewater treatment plant is to process, treat and discharge the non-filthy water back to the river [25][45][46]. Wastewater treatment plant is largely nonlinear system exposed to significant perturbation to the flow and load, together with the variation in the composition of the incoming wastewater [47]. To discharge quality effluent from a plant obviously a tighter regulation and practice need to be implemented either physically or financially [41] [45][47]. The productivity of wastewater treatment plants is a crucial matter still need to be developed. The operating fee usually become costly that the actually needed in order to follow the legal rules and regulation for large load. Thus, optimization of wastewater treatment plant would provide a significant cost reduction [46]. All the above factor had attract the development of new technologies and improvement of the existing wastewater treatment plant [43].

In an article [48], it is also mentioned that wastewater treatment plant instrumentation and control system become popularly investigated as it can control the efficiency of a plant [25][48]. Moreover, predicting the performance of the plants' facilities is essential in order for the effluent to attain the quality index of environmental regulatory organization [49]. In a nutshell, waste water treatment plant can become the most efficient and futuristic method to treat water as out of 100% of water available worldwide only 2% can be used by human being in their daily life. Although there are lots of drawbacks being discussed about wastewater treatment plant, it is our responsibility of engineers to find ways to overcome this obstacles.

2.2.1 Types of Wastewater Treatment Plant

As we know, wastewater treatment plant have different kind of methods that minimize the contaminants to the restricted level, with the goal that the release of filtered liquid won't impact the surrounding. Wastewater sources from various factor that collected and directed to a treatment plant so that water either can be discharged to the river or reused back for certain purposes. Usually the wastewater flow from industrialization, domestic waste, agricultural waste and so on. Basically there are different types of wastewater treatment plant available to treat contaminated water from different sources.

One of them is sewage treatment plant. Sewage are usually from different source such as domestic waste or municipal waste which is produced from community of people. It contained mostly of greywater (tubs, shower, dish and cloth washer), black water (flashed water from toiled combined with faeces), soap and detergent, toilet paper and many more. This plant may comprise of primary treatment where solid material being removed and secondary treatment to process mixed, suspended natural particles and the supplements nitrogen as well as phosphorus. At times the cleansing of pathogenic microscopic organisms happens seldom. Moreover the sewage delivered will experience sludge treatment. This treatment plant might also have tertiary treatment which is rarely found because of the high cost and complication of the process. This tertiary treatment is a polishing method after going through primary and secondary treatment. The common technologies used are micro filtration or synthetic membranes.

The industrial wastewater treatment plant is the second type of treatment plant. Here the industrial waste is disposed. Basically waste from industrial plant is difficult and costly to clean as the content might be dangerous chemicals, grease, oil and so on. Discharging the chemical directly into the river might be against the law as this the normal sewage plant could only process the lesser contaminated water. Waste from industries need special method accordingly before releasing to the rivers, lakes or oceans. Thus to overcome the problem, most of the petroleum refineries, chemical and petrochemical plants, have onsite facilities to treat their waste water. This means before discharging the wastewater from their company, the water will be treated with their very own infrastructure which is best suit the contaminants present. Furthermore, there are some companies reuse back the treated water for their own production. Other plant such as paper and pulp production where contamination is common, they also have recycling system within their plant. By doing this, industrial wastewater plants may diminish crude water cost by changing over chosen recycled wastewater for various purposes. Rather that primary, secondary treatment, industries normally have methods such as oil-water separator, clarifier, roughing filter, carbon filtration and electro-dialysis reversal system. In the end, industrial treatment plant provide lesser expenses and preserve higher quality of water discharged to the surrounding

Apart from that farming wastewater treatment plant, for constant confined animal operation, for example, milk and egg, automated treatment units like those portrayed under industrial treatment can be utilized. Leachate treatment plant are utilized to treat leachate from landfills. This treatment procedure incorporates natural treatment, mechanical treatment by ultrafiltration, treatment with active carbon filter and reverse osmosis utilizing tube module innovation. Leachate is any liquid that, in the course of passing through matter, extracts soluble or suspended solids or any other component of the material through which it has passed. Although they are few type of wastewater plant, the purpose of them are almost same which is to conserve the well-being of environment.

2.2.2 Process Involved in Wastewater Treatment Plant

Although there are different type of wastewater treatment plant, fundamentally they all have almost the same process. Basically wastewater from the toilet, bathing, detergents, dish washer, storm water, agricultural waste, oil, grease and petroleum residue goes into pipe which joins a larger sewer pipe under the road. The larger pipe join a major pipe that leads to the treatment centre. Wastewater treatment plant consists of multiple stage of treatment depending on the kind of waste contained in the water[44]. There are usually a basic standard of preliminary, primary and secondary treatment present in a treatment plant [50]. Not only that, some of the processes like mechanical, chemical and biological are also become a part of the main treatment method [44]. In the article [22], according to Indah Water Consortium, the dominant wastewater treatment are also same in Malaysia which is preliminary, primary and secondary treatment. There is also treatment called tertiary treatment but most of the plants do not imply this treatment, similar to Malaysia which does not consider to build one yet. Figure 2.1 below shows that the basic structure of a treatment process.

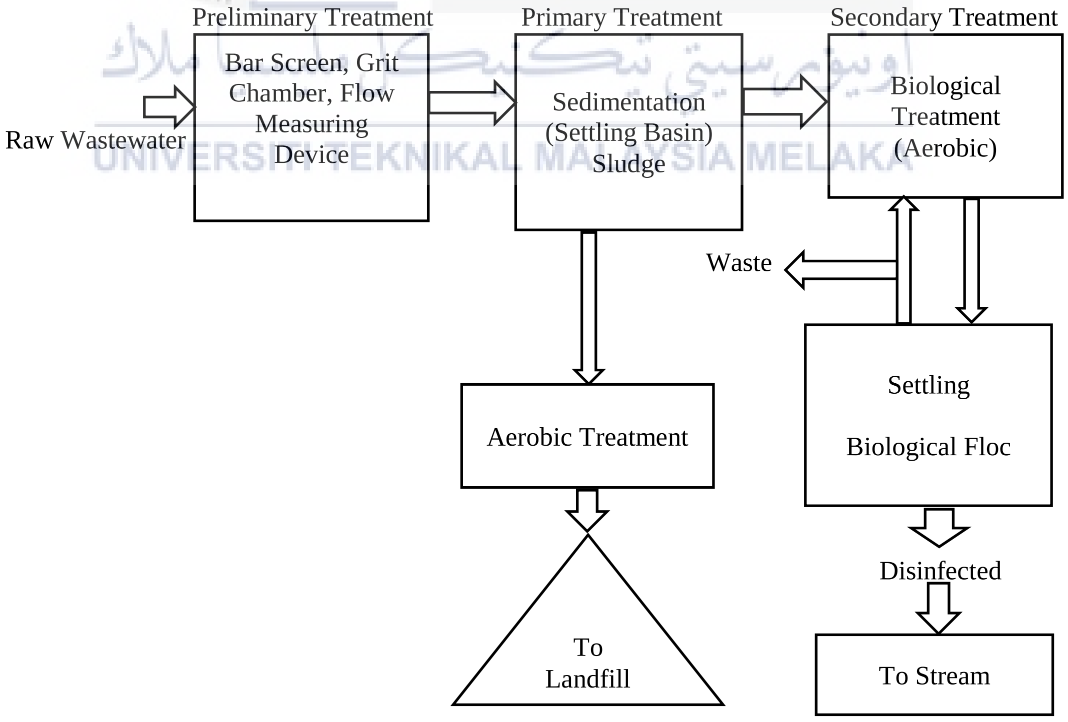

Figure 2.1 Process Involved in WWTP

Preliminary treatment first remove the course solid and other huge materials which regularly found in crude wastewater. Bigger material, for example, diapers, napkies, sanitary items, cotton buds, face wipes and even broken jugs, bottle tops, plastics and clothes that may square or damage gadgets will be filtered here. Evacuation of these materials is important to upgrade the operation and upkeep of ensuing treatment units. Ordinarily course screening, grit removal and at times comminution of expansive items will be a portion of the best approach to channel this vast materials. In grit chambers, the maintenance of sufficiently high air is to keep the settling of most natural solids. Comminutors are here and there used to supply course screening and serve to diminish the extent of vast particles with the goal that they will be evacuated as an ooze in resulting treatment forms. In this stage, usually flow measurement devices also plugged.

In the primary treatment, the natural solid matter(human squander) are isolated from wastewater [50]. This is typically done by putting the wastewater into extensive settlement tank for the solids to sink to the base of the tank. The settled protuberance are called 'sludge'. Gigantic scrappers ceaselessly rub the floor of the tank at the base of these round tanks and push the ooze towards inside where it is drawn away for promote treatment. Some natural nitrogen, natural phosphorus, and substantial metals related with solids are likewise evacuated yet colloidal and dissolved constituents are not influenced. The rest of the water is then moved to the secondary treatment.

For the secondary part, the primary gushing put into extensive rectangular tanks. This are called aeration paths. This procedure included evacuation of biodegradable disintegrated and colloidal organic matter utilizing oxygen consuming organic treatment process. Aerobic biological treatment is performed within the sight of oxygen by microorganisms that process the organic matter in the wastewater, in this manner delivering more microorganisms and inorganic end-products (Carbon Dioxide, Alkali and water). Secondary treatment varies that primary treatment since oxygen is provided to the microorganisms. This procedure is additionally called as activated sludge process where it is a type of natural process. A simple activated sludge is including an aerator and a settler. The secondary settler in bioreactor hold the biomass in the framework while delivering a high quality discharge. A portion of the settled biomass is re-used to permit the correct concentration of microorganism in the aerated tank [51]. In an article it is expressed that the broke down oxygen fixation in the aerobic portion of an activated sludge process ought to be sufficiently adequate to supply oxygen to the microorganisms so organic matter broke down and ammonium is changed over to nitrate [44][47][50][52]. High level disintegrated oxygen will make the natural matter not set and formation of smell which turn into an unhygienic stench[24]. Typically this activated sludge process are worked conservatively to keep up the effective operation of the plant within the sight of changing plant loads [45].

As for tertiary or advanced treatment, the wastewater which cannot be cleaned by secondary treatment is flowed to it. But most of them does not imply this system as it is costly and contain difficult process. It sometimes referred to as tertiary treatment because follows high-rate secondary treatment. Wastewater treatment plant comprises of various treatment process with high specification. Hence high level of control system is necessary to enhance the system efficiency.

2.2.3 Disturbance in Wastewater Treatment Plant

Efficiency of wastewater treatment plant is important factor to be considered as to ensure that the effluent discharged from the plant safe enough to be released into the river or even reused. Typically the performance deteriorate when there is complication and disturbance present in the plant which cause the process to lack and does not perform appropriately. In an investigated journal state that the use of biological activated process which happen in secondary treatment is the most common process as well as complex system too. This is because in this process, normally their flow rate and feed concentration become various hugely. Due to this complications, it is concluded that modelling and controlling of a treatment system is really challenging and need high proficiency [25].

Like discussed earlier in the process section, the secondary treatment plant mainly responsible to reduce the biological residue from the primary effluent to an accepted limit. The microorganism culture present in the aeration tank help to eliminate the organic matter by transforming it into inorganic matter which can be easily removed. This article also address that among the process involved, this particular process is one of the complex process and prone to various disturbance such as the influent flow variation and large variations of the time constants [24][25] [44][53]. The growth of the microorganism has strong nonlinear behaviour [47][53]. The release of dissolved oxygen into the water by blower is an utmost indicator regarding the state of the biological treatment process [50][53][54][55]. The activity of the microorganism culture is emphatically connected to it [56]. Observing and controlling the dissolved oxygen concentration is an advantageous method to screen and control the treatment procedure [44]. Sufficient oxygen level will assists in degradation of organic matter, but at the same time excessive dissolved oxygen which requires a high wind stream rate, prompts a higher vitality utilization and may fall apart the sludge quality. In addition, spike in dissolved oxygen leads to less performance in the denitrification process. From this we eventually can learn that acute amount of dissolved oxygen is always a specification and without that the plant face both economical and process complication [47][50]. On the other hand, the fundamental aggravation of the WWTP that impacts the effluent quality is the concentration of the substrate in the effluent [53].Thus obviously oxygen control as well as concentration of substrate are utmost factor to be optimized and controlled [44][47].

Apart from that, another journal address that, even wastewater control system itself encountering diverse problems. One of them is wastewater treatment plant require specific consideration in the design of control system although general principles from control of industrial processes can be applied to wastewater treatment technologies. Furthermore, due to the complexity of processes where different parameters interact and a limited variables can be manipulated, it is difficult to develop an optimal treatment technology as a one unit system that influence each other. Not only that, continuous variation of the wastewater flow and its characteristic that varying seasonally, daily and even hourly, driven by the values of the specific parameters of the pollutant is another challenges faced by some treatment plant that underpins the difficulty of the wastewater treatment problems and coherently the control system of wastewater treatment plant [25]. To support the fact mentioned above journal [41] stated that, the applications have been restricted by many factors such as processing efficiency, energy requirement, engineering expertise, economic benefit and infrastructure, all of which precludes their use in much of the world.

Besides, when we discussed about the complications outside the plant which effect the plant, agricultural play and important role where it become one of the solid reason for the pollution of water to occur [52]. Although it can be removed by various type of treatment such as granular carbon filtration and reverse osmosis, because of the high cost process this article [52] suggest that source control is a better approach to decrease the impact. In spite, the idea was a best want, but that statement clearly a drawback to wastewater treatment plant. The high cost factor obviously discourage the people from using or implementing the treatment plant and eventually dimmer the future for waste water treatment plant. Thus from this a low cost treatment plant is brightly needed so that people will start to have faith on treatment plant and moreover make use of it in their daily life.

Furthermore, not to leave the most complicated disturbance to the water and the associated treatment plant which is industrialization, urbanization, dumping of domestic waste and oil released into the water source which are the major reason for pollution to occur [1][11][12][13][14][15][16][43]. The waste and chemicals used from the companies and firms are getting hazardous day by day in the name of improving the process of production. It is true that companies are having their rules and regulation to discharge the effluent from their company, but not all companies are following the rules most of the time because of the concern of spending a lot for the treatment infrastructure [53]. Moreover the chemical discharged not really suitable to be treated in a normal treatment plant due to its high contaminant level [41]. Thus certainly this factor is a complication to the future treatment industry and sophisticated technologies are necessary [43].

To add on inefficient plant system, the constructers who build the plant also play an importance role. In Malaysia specifically, normally this kind of plants are constructed by private sectors developers and after the completion hand in to government sector to operate it regularly. This open up risk factor of value being bargained which would therefore affect the treatment plant. The low sewage tariff unfit to help the high operation and the maintenance cost as well as unawareness if public about the essentialness of the sewage management become a complication to the system [22]. Clearly the are lots of complication and disturbance faced by developers of wastewater treatment plant to build an optimized wastewater treatment plant.

Nevertheless, it is a job of engineers and technologies to make use of knowledge earned by enhancing the system and overcome the problems faced so that in future when the need of this system peak off, there is a solution for it.

2.3 Type of Controller Used for Disturbance Rejection Analysis on Different Control System

Fundamentally any type of controller with feedback mechanism has the ability to reject disturbance. But it all depends on the kind of control system whether the system is linear, non-linear, SISO, MIMO, complex, simple and so on. Deciding on which controller to be used is a difficult task to figure out as we have to well known about the system in where we going to implement the control algorithm. In a journal, mentioned that integral controller for nonlinear system is developing extensively because of its need but most of them do not ensure a good performance with the presence of nonlinear parameter variation and unknown external disturbance [50].

Disturbance play a critical part in the productivity of a controller. In the presence of instability and uncertainties, the controller which able to attenuate error of the system will play safe while the controller which could not encounter error will fail to produce a good result. Integration of feedback controller together with observer usually implemented to enhance the system performance [23]. Controller hold a crucial role in system productivity where the system can be any kind of system. In the next subtopic, adaptation of different types of controller are discussed.

2.3.1 Active Disturbance Rejection Control (ADRC)

Active Disturbance Rejection Control (ADRC) is originally proposed by J. Han where it is an enhance system from PID control as shown in Figure 2.2 below. It has three components which are tracking differentiator, nonlinear feedback control, and nonlinear extended state observer [39]. The consolidated capacity of these three parts turns out to be an intense device for disturbance rejection control. Tracking differentiator (TD) is the most obvious part inherited from PID directly. ESO is an extension of the state observer in modern control theory. A state observer is an auxiliary system that provides an estimation of the internal state of a given real system from its input and output. This disturbance rejection features enables the client to treat the specific framework with a less complex model. This is due to the unnecessariness for exact analytical description of the system, as it is hard to accept the unknown parts of flow as the interior disturbances in the plant.

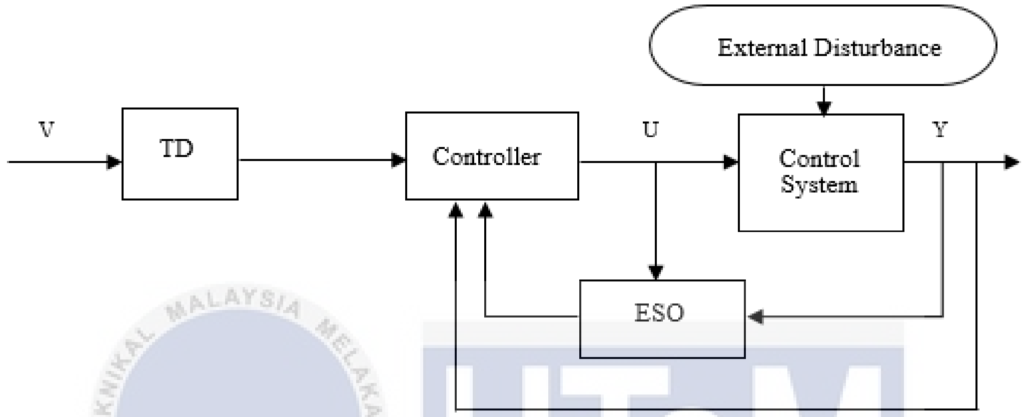

Figure 2.2 General Structure of ADRC

Ideally the concept of ADRC is to focus on the disturbance attenuation as the primary task, where even the 'active' phase is referred to as removal of disturbance before it affect the specific system [57]. ADRC basically inherits from the PID controller. The control performance of ADRC mainly depends on the rational selection of parameters, and the adjustment of parameter mainly depends on the designer's engineering experience and the continuous use of simulation [39]. Moreover it is also a useful digital control system where the total disturbance include internal dynamics and external disturbance and both estimated together before cancelled out in the feedback system. Control system with uncertainty become the most fundamental issue in control science and ADRC made a breakthrough for the control of nonlinear, uncertain and strong coupling system [58][59]. ADRC has a drawback where it is not appropriate for steps with substantial time delay which is very common in industrial process control [34].

ADRC contain ESO which predict the generalized disturbance (internal and external) and feedback with the aim to reject disturbance quickly [39] while tracking differentiator used to get the desired response for the set point. All this algorithms works together to impose better performance. Since time delay become a disadvantage to ADRC system, a few techniques are accessible to deal with time delays for ADRC. One technique is to overlook the time-delay and plan the ADRC for the elements immediately. This prompts restricted execution. Another technique is to supplant the time-delay with a pad approximation and receives a higher request ADRC plan. Different strategies attempt to anticipate the framework yield or the control signal based on the Taylor series. In this case, it has just been fruitful when the time-delay is little. Thus an effective, simple, and practical solution is obtain by making a small adjustment in the ESO input signal, enabling a significant increase in the achievable observer bandwidth and therefore the performance of ADRC [34].

Basically for this journal, first the configuration of TD and ESO parameters were done until the two parts reach a good results and then the system parameter can be set up finally. Simulink in MATLAB is used to simulate the above control system. Moreover PI controller is also stimulated to compare the result with ADRC. From the experiment, it is shown that ADRC magnificiently enhance the productivity of the system compared to PI controller where the stability time is shorter, the steady state accuracy is higher, the robustness is at high as well improved the overall performance[39].

In this journal [58], a grey ADRC design strategy with the known modelling information and its frequency domain analysis are proposed for the mass-damper. The sensitivity and transfer functions are derived. The grey ADRC compared with the black ADRC where there is only minimum information regarding the modelling plant. In the end stimulation result shows the viability of the proposed strategy, when the parameter vary significantly, the bandwidth and stability margin of looping gain changed a little only. Not only that, the output noise as well as sensitivity to input disturbance also vary a little when the parameter changes. From this we can conclude that grey Linear Active Disturbance Rejection Control (LADRC) has strong robustness against the large variation of parameter in the plant than the black LADRC. Moreover, the frequency response simulation result portray that grey LADRC has better tracking effect and disturbance attenuation than the other [58].

Most industrial plant in actual world are not just time varying and non-linear but also highly uncertain. Most of the existing control system always need good amount of details and accurate mathematical model of the plant available. The purpose of this paper is to show that even when the plant is unknown with nonlinear and time varying behaviour, LADRC poses excellent performance. Both design scenarios, with and without a detailed mathematical model of the plant, are considered. When the mathematical model of a system is known the asymptotic stability of LADRC is proven whereas, the upper bounds of errors are derived when the plant information are unknown. The primary outcome in this paper is the investigation of the stability and tracking characteristics of a specific class of such observer, linear ESO, and the related feedback control system, LADRC. It is demonstrated that the asymptotic stability is guaranteed in the previous estimation. Moreover, it is demonstrated that the following tracking error diminishes with the control loop bandwidth [60].

This paper [61] investigate on LADRC to show that LADRC can be interpreted in the frame work of a two-degree of-freedom (TDF) internal model control (IMC) where a simple multiple integral control become the nominal model for controller design. Further, the inverse of the two times constants for the set point filter and the disturbance rejection filter in TDF-IMC are the tuning method. Finally to achieve better control performance an extra dynamics of the controlled plant is derived and incorporated. In another paper [62] an ADRC with an acceleration feedforward block has been analysed and implemented for noncircular turning application. By frequency-domain analysis and experimental machining results, the significant tracking and disturbance rejection performance are achieved.

The flight could be unfolded by the wings of loitering munition. ADRC is proposed to diminish the impacts of the model parameter variation caused by structural change and outer disturbance. The vehicle's lateral motion equations is built after analysing the operating mode of the loitering munition. And then the characteristics of ADRC is analysed. Especially, in Simulink six degrees of freedom nonlinear were simulated. A progression of examinations was directed, and relative investigation between designed controller and PID controller is made. Simulation results demonstrate active disturbance rejection control algorithm not just precisely evaluate and repay the inward/outside aggravations yet in addition enhance the robustness of the framework with uncertainties and the execution of the flight control framework. So it has high useful esteem. In addition the technique for controller design and parameter tuning is a decent reference [63].

Linear active disturbance rejection control (LADRC) method is investigated for the load frequency control of power systems. Considering the model and the structure of the system, a second-order LADRC is adopted and the design procedure is introduced. It is found that LADRC is a model-independent control method with only two tuning parameters, thus it is very practical in industrial control. Simulation examples show that LADRC can damp the load disturbance very well but there are some limitations in the LADRC method. It is shown that LADRC can damp the load disturbance very well, however, LADRC can only place the dominant poles of the closed-loop system into part of the-plane. Further research should be done to solve the problem [64].

This paper [65] exhibits a common sense verification of an ADRC technique in overseeing a multidimensional framework. The analysis were led on a two degrees of a freedom planar controller with just incomplete learning about the mathematical model of the plant. This multi input multi output framework was controlled with an arrangement of two, autonomous, single input single output ADRC controllers, each managing one of the controller degree of freedom. Demonstrating uncertainties (nonlinearities, cross-coupling effects, and so forth) and outside disturbance were thought to be a piece of the aggravation, to be evaluated with an observer and scratched off on-line in the control loop. The ADRC robustness was tentatively contrasted and the outcomes got from utilizing two decentralized, classic PID controllers. Both control techniques were tried under different condition influences. Significantly better outcomes, as far as parametric robustness, have been accounted for the ADRC approach.

PID controllers are widely utilized as a part of the majority of the industrial applications. Regularly, PID outline work neglects to address some difficult issues like weakness to noise and shakiness because of integral term. On the other hand, ADRC addresses these issues effectively. The issue considered in this work is to control Automatic Voltage Regulator with LADRC under nearness of plant parameter vulnerabilities and sudden load variation. A fifth-order ESO was composed which estimates generalized disturbance which incorporates both framework vulnerabilities and outer aggravations. This data is utilized to effectively cross out the impacts of aggravations. The adequacy of LADRC plot has been shown by contrasting and regular PID tuning strategy within the sight of plant parameter and sudden load variation. Further to examine the frequency response attributes of control framework, transfer function of LADRC has been derived. From the simulation it can be watched that there is noteworthy change in framework reaction which can be reconfirmed from the frequency response examination. Viability of LADRC has been confirmed for both set point tracking and disturbance rejection problem. Further, from frequency response examination reconfirms the prevalence of LADRC over traditional level stage PID controller [37].

ADRC is a quiet different design concept that shows much promise in obtaining a consistent response in a control system with many uncertainties. For the lack of frequency-domain analysis, in this paper, starting from the frequency domain methods, the tracking ability of linear extended state observer and the disturbance rejection quality of linear ADRC with the changing of the ADRC parameters are analysed based on the closed-loop transfer function and frequency response. So the relationship between the system dynamics characteristics and the control parameters is obtained, contributing to the tuning parameters. Finally, the proposed method is applied to the system, in order to verify the effectiveness of this method which has excellent outcome [66].

2.3.2 Sliding Mode Control (SMC)

Sliding mode control (SMC) is a nonlinear control strategy that adjusts the progression of a nonlinear framework by a set-valued control signal that weights the framework to slide along a cross-area of the framework ordinary behaviour. In this control framework, the state-feedback control law isn't a consistent function of time. Rather, it can change starting with one continuous structure then onto the next in light of the position of current in the state space. In this way, we can infer that it is a variable structure control technique. Additionally, the various control structures are designed so the direction won't exist totally inside one control structure. Rather, it will slide along these limits of the control structures. The movement of the framework as it slides along the limits is known as the sliding surface.

SMC which referred as Variable-Structure Control does not need the information about the framework parameters and portray countless convincing characteristics such as better productivity against unmodelled dynamics, less sensitive to parameter variation and an excellent external disturbance rejection properties[35].

Another strategy for SMC plot for wavering water column has been proposed in paper [35]. The control is strong under vulnerabilities caused by parametrical errors or framework disturbance due to the nature of Variable- Structure Control. Lyapunov stability theory has been used to prove the closed-loop stability of the presented design. The controller has been effectively approved and contrasted with the generally utilized PI-based vector control both by numerical recreations and examinations, showing its predominant execution and power in various agent contextual investigations. Taking everything into account, results demonstrates that SMC-based vector control technique gives a superior dynamic reaction, which is obtuse to parameter vulnerabilities and aggravations of the framework, enhancing the power extraction when connected for greatest power generation purposes.

2.3.3 Model Predictive Control (MPC)

Model predictive control (MPC) is an ideal control based strategy to choose control inputs by limiting a goal work. The target work is characterized as far as both present and anticipated system variables and is assessed utilizing an explicit model to predict future process yields. PID controllers don't have this predicting capacity. The models utilized as a part of MPC are planned to speak the conduct of complex dynamical framework. MPC models as shown in Figure 2.3, foresee the adjustment in the dependant factors of the modulated system that will be caused by changes in the independent factors. MPC is likewise a multivariable control algorithm that uses an internal dynamic model of the procedure, history of past control moves and optimization cost function J over the retreating forecast skyline to compute the ideal control moves. When we contrast MPC and linear quadratic regulator (LQR), LQR upgrades in a settled time window (horizon) while MPC streamlines in a subsiding time window, though LQR utilizes the single (ideal) answer for the entire time horizon. Accordingly, MPC permits real-time optimization against hard constrains, in spite of the fact that it normally takes care of the optimization issue in littler time windows than the entire horizon and consequently acquires a suboptimal solution.

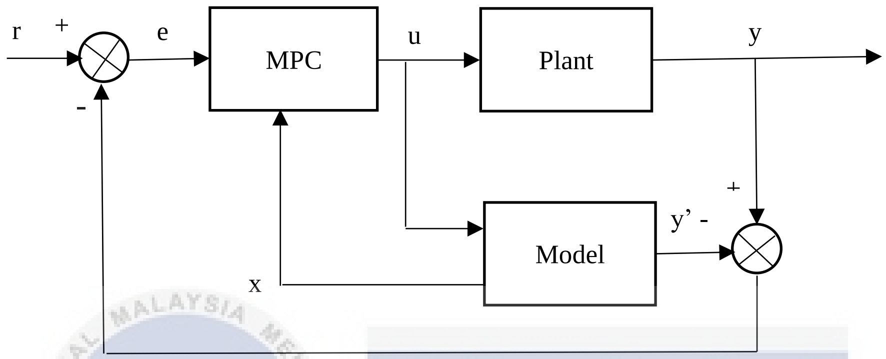

Figure 2.3 General Structure of Model Predictive Control

MPC is being popular in process control since it provide cumulative results of both feedback and feedforward control [30]. MPC can consider in many process complication such as time delay, ability to easily control manipulated and control variable and even deal with multivariable system [26][30][32][67]. Usually MPC taken action at intervals called control interval. Moreover, it also calculate an objective function based on the estimation of the output sample and then determines the discrete moves of the input manipulated variables in such a way that the objective function is minimized [36]. MPC also poses a simple modelling plant which generally depend on step or impulse response. But as other control system MPC does not handle the disturbance directly and even become unstable if the variable fluctuate a lot or meet strong disturbance [30]. Moreover relying on model of the plant become a major drawback of the system, inaccurate information of the plant model will result in deterioration of the system performance [34].

In the present paper [36] it has been watched that the MPC system has fantastic disturbance dismissal capacities. The procedure taken up as the contextual investigation is a lime kiln process. Further, the hugeness of progress in control horizon, expectation horizon and inspecting interval on the disturbance dismissal execution has been watched and it was discovered best at biggest estimation of control horizon and minimum value of sampling interval.

A composite cascade of anti-disturbance control comprising of MPC, PID control, and DO has been proposed to control the first-order in addition to time-delay process. Taking care of dead-time forms because of its prediction component is favourable position of MPC. Estimation of the disturbance and the forecast has been utilized for feed-forward compensation design to dismiss aggravation is done by DOB. Such a disturbance observer-enhanced model predictive control method has been connected to control the level tank which may experience the ill effects of strong disturbance. Both simulation and experimental investigations have been done, and the outcomes have shown that the proposed strategy displays brilliant disturbance dismissal execution, for example, a littler overshoot and a shorter settling time. The following is control diagram of the experiment conducted. In this system, disturbance observer-enhanced MPC is known as the primary or external-loop controller, while the PID controller is the secondary or inward circle controller. We can see that the disturbance influences the primary output level [68].

In this paper [26], we abridged some design rules for PID in addition to feedforward and General Predictive Control (GPC) in addition to feedforward controllers to enhance disturbance dismissal capacities when the perfect feedforward compensator cannot be shaped due to a non-realizable delay inversion. In the first part, the traditional compensator configuration is analysed, calling attention to the disadvantages that can show up in both control approaches. Next, a concise outline of the propelled tuning technique is given. To feature the conceivable points of interest for those plans, a few reproductions have been performed considering distinctive feedforward configurations. Through those cases, it was demonstrated that significant upgrades can be acquired in control performance depending on the selected approach. Considering the obtained outcomes, it is difficult to demonstrate the ideal configuration or tuning standard, since this relies upon the individual procedure properties and control framework objectives. However, the outcomes gave in this work ought to encourage the choice of the perfect configuration.

In [69], a closed-loop two-tank water level system is designed and build up using a MATLAB software. MPC and PID controller method was implemented in the system to compare the results in term of settling time, overshoot and steady-state error under various operational condition including time delays. The results showed that MPC is best in dealing with the system dynamic and also more complex and fast system even in the presence of disturbance compare to PID controller.

2.3.4 Proportional Integral Derivative Control (PID)

Proportional-Integral-Derivative (PID) control is the most well-known control algorithm utilized in industry and has been generally acknowledged in industrial control. The fame of PID controllers can be credited completely to their vigorous execution in an extensive variety of working conditions and mostly to their practical straightforwardness, which enables specialists to work them in a basic, clear way. PID comprises of three fundamental coefficients; proportional, integral and derivative which are shifted to get ideal reaction. The proportional part depends just on the difference between the set point and the procedure variable. This distinction is pointed as the error term. The proportional gain (Kc) decides the ratio of output response to the error signal. The integral component sums the error term over time. The integral reaction will consistently add up after unless the error is zero, so the impact is to drive the Steady State Error to zero. Steady State Error is the final distinction between the procedure variable and set point.

The derivative part makes the output diminish if the procedure variable is increasing quickly. The derivative reaction is corresponding to the rate of progress of the procedure variable. Increasing the derivative time (Kd) parameter will make the control framework respond more firmly to changes in the error term and will build the speed of the general control framework reaction. In the case of multivariable PID controller, the input and output of the framework are various, for example, more than one factors.

It well-known by all that, PID control is still in dominant place although many advanced control theory has been made much improvement lately [44][51][61]. This is due to the fact that, most of them hard to be controlled or tuned and implementation in real practice become complicated. The three parameters of the PID controllers are straightforwardly identified with the execution of the control framework, so control architects can undoubtedly tune them when needed without knowing much about the controlled framework [26][61]. Nevertheless, PID controller not suitable for complex system due to the limitation of the controller itself. Limitation such as action taken only after the disturbance effect the plant, inefficiency in predicting the uncertainties and disturbance as well as unproductive behavioural in term of large time delay become a major drawback to the system itself [61]. Usually PID design using two simple techniques which are direct pole-placement based on reduced-order models and dominant pole design [70].

In paper [38], a control framework for the impact of a time delay compensation utilizing predictor and DO is proposed. The time delay in the controlled plant is one of the difficult issues diminishing the control stability. In this way, numerous control strategies for controlled plants with a period delay have been proposed to date. We proposed a productive control system for impact of time delay by associating estimator and a DO to a PID control system. It reduces the impact of the time delay on the target response and disturbance reaction. We have proposed control framework to counter the impacts of the time delay. Two cases were investigated where in both the cases the proposed method was superior that the contrasted want. It is demonstrated that the proposed strategy has positive results in both the input and disturbance reactions and it is productive in controlling a plant with a period delay.

Movement control typically incorporates the exact control of position/speed and acceleration control while precise acceleration control is not valuable in numerous applications. Conventional position/speed control is inferred by feedback based, PID controllers. However, DO additionally builds the stability and robustness of controller. In this paper we evaluate the viability of the DO cooperating with a tuned PID controller. Speed reaction is contrasted with and without the DO. The proposed DO based speed controller deliver preferable outcomes over the traditional speed controller. This technique can be extremely helpful in applications where DC engine is very nonlinear. Since DO makes up for load variation, contact and modelling errors, framework reaction has turned out to be exceptionally better as found in the outcomes[71].

2.3.4.1 Multivariable PID Controller (MPID)

Out of the controller used outside, PID is the most popular controller until now which applied in all kind of physical system just because the properties such as simplicity, clear functionality as well as ease of use. As we know the processes involved in most of the industrial processes are multivariable system where system like MPID control design is necessary. This technique is actually a powerful control strategy for nonlinear system. Basically static inverse model is used for conventional MPID controller design. But the desired control performance is difficult to attain with this technique. Thus in this journal [50], an improvement has been made where dynamic inverse matrix and singular perturbation method is analysed for MPID system. It is shown that the enhancement is able to control the dynamic system where the output follow the desired criteria.

2.3.5 Proportional Integral Control

PI control is required for non-integrating procedures, which means any procedure that comes back to a similar yield given a similar arrangement of sources of input and aggravations. A proportional controller is most appropriate to integrating forms. PI controllers have two tuning parameters to change. It might be difficult to tune P-Just controller and not as mind boggling as the three parameter PID controller.

Since the actual system parameters dependably vary from those from the information sheet utilized for PI tuning, a fine tuning over the real equipment is the most required part to accomplish a satisfactory execution. In addition, some tuning strategies require a definite displaying of the system, and it is notable that, contingent upon the tuning strategy utilized, PI controllers may exhibit an impressive absence of robustness [35].

This journal [72] has grown new outcomes on the control of differential linear repetitive procedures. These comprise of the structure and design of PI based control activity which brings about a closed loop stable process which can also dismiss aggravations which are steady from pass to pass. The significance of these outcomes is that they demonstrate that beforehand known stabilization design in view of a LMI setting do reach out to permit the design of the control law to likewise meet execution specifications. In addition, the control law itself just includes proportional plus integral action on accessible signal with ensuing benefits as far as real execution. These outcomes are the first in the general territory and there are numerous perspectives to be tended to before their actual potential can be set up.

2.3.6 Disturbance Observer Based Control (DOBC)

In control theory, an observer is a framework that gives a prediction of the interior condition of a given real system, from estimations of the info and yield of the real framework. It is commonly computer actualized, and gives the premise of numerous practical applications. Knowing the framework state is important to take care of numerous control theory issues; for instance, stabilizing a framework utilizing state feedback. In practical cases, the physical condition of the framework cannot be dictated by direct observation. Rather, indirect impacts of the internal state are seen by method for the framework yields. If a framework is observable, it is conceivable to completely remake the framework state from its yield measurement utilizing the state observer. Because of its capacities to remunerate disturbance and uncertainties, disturbance observer based control (DOBC) is viewed as a standout among the most encouraging methodologies for disturbance lessening. As the name recommends it watches the estimation of the disturbance. When we know the estimation of the aggravation, at that point we can remunerate it and work the system effectively.

DO is known as a phenomenal procedure to assess disturbance and has been generally in feedforward remuneration design to eliminate error [30]. DOBC approach has two distinct feature which other robust controller schemes does not have. One of them is the baseline controller of the plant which perhaps used before no need to be replaced instead, DOBC can just combined with the existing controller. The nominal performance of the baseline controller can be regained in when DOBC is removed. Moreover, DOBC is not worst-case based design without being over conservative[73].

This journal [39] considers the DOBC approaches for a class of MIMO nonlinear system. The nonlinear flow is depicted by known and obscure nonlinear functions, individually, and the disturbance which are not confined to being consistent, harmonic or neutral stable are spoken to by a linear exogenous framework. In the wake of reformulating the DOBC design issue for the known nonlinearity case, two linear matrix inequality (LMI) based configuration plans are proposed in light of full-order and reduced-order disturbance observer, individually. For the dubious nonlinearity case, a strong DOBC approach is produced to upgrade vigorous execution. In view of the estimation of disturbance, composite control laws can ensure that composite closed-loop system are universally steady even with the sight of disturbances.

In another journal [74] the novel robust flight control plan strategy has been proposed for the longitudinal dynamic models of a non-specific AHV framework through NDOBC technique. It has been demonstrated that the mismatched uncertainties in the AHV framework can be expelled from the yields by the proposed technique with appropriately picked disturbance compensation gain matrix. The proposed technique has acquires not just great strength against mismatched disturbance and uncertainties but also the property of nominal control execution recovery.

In granulating procedure, unpredictable and unmeasurable disturbance normally have unwanted effects on closed loop system. Numerous current strategies including MPC show a few constraints within the sight of solid aggravations. To enhance the disturbance dismissal property, a strategy called DO has been presented for feedforward compensation design. A composite control plot comprising of a feedforward compensation based on DO and a feedback regulation part based on MPC has been produced. Other than outside disturbance, interior disturbance caused by model mismatches are converged into the terms of disturbance and viewed as a piece of the lumped disturbance. Thorough investigation on aggravation dismissal property have likewise been given with the consideration of both model mismatches and outer disturbance. simulation demonstrate that, contrasted the control impacts of MPC strategy, the proposed technique has acquired remarkable greatness in dismissing the lumped disturbance in pounding circuits [30].

By suitably outlining a disturbance compensation gain, DOBC strategy has been proposed to understand the disturbance, dismissal issue of the uncertain system that contains jumbled disturbance. Here, mismatches means the lumped disturbance enter the framework through various channels from the control inputs. It has likewise been confirmed that the mismatched lumped disturbance can be lessened from the yield channels with a legitimately planned disturbance compensation gain. To demonstrated the plausibility and effectiveness of the proposed strategy, application configuration is completed for a mechanical MAGLEV suspension framework, which is basically a framework with mismatched disturbance including outer disturbance (caused by track inputs), nonlinear dynamics (neglected nonlinearities amid progression), and parameter perturbations (caused by load variety). At the point when controlled by such reasonable MAGLEV suspension framework, simulation have demonstrated that the proposed technique accomplishes a greatly improved execution of outer disturbance dismissal and strength against load variety than those of the conventional integral control technique (LQR+I) [40].

This section [75] has depicted a composite control system for direction following of independent helicopters. The nonlinear tracking control has been accomplished by an unequivocal MPC calculation, which has killed the computational-concentrated online streamlining in the conventional MPC. On the usage side, the presenting of disturbance observer has explained the challenges of applying model-based control strategy into the viable condition. The outline of ENMPC has given a consistent method for incorporating the disturbance data. On the other hand, the power and disturbance weakening of the controller has been improved by the nonlinear disturbance observer. Simulation and investigation comes about show promising execution of the mix of ENMPC and DO. Aside from the dependable tracking that the proposed controller ensures, it likewise has the capacity of assessing the helicopter trim condition during the flight, which encourages the controller to manage the variety of the helicopter status like payload changing and part upgrades.

Anti-disturbance control for dynamic frameworks subject to aggravations and unmodelled dynamic is a central issue in control theory. Up to this date, the internal model control, output regulation, adaptive compensation and DOBC approaches have concentrated on such issues and have been connected to numerous handy fields. In any case, it is as yet an on-going issue for MIMO nonlinear robotic frameworks subject to obscure sinusoidal disturbance and unmodelled dynamics. This section gives a novel DOBC strategy for inborn MIMO nonlinear robotic frameworks subject to obscure sinusoidal disturbance and unmodelled dynamics. The proposed technique methodically changes over this issue to a sort of DOBC design issue by developing a two-step disturbance observer. Both the nonlinear disturbance observer and controller are designed just by methods of algebraic expression or parameter selection. The simulation comes about demonstrate that in spite of the fact that there are aggravations and displaying uncertainties in the framework all the while, the sinusoidal disturbance dismissal execution is enhanced and acceptable framework reactions can be accomplished utilizing our introduced method[76].

2.4 Controller Used for Wastewater Treatment Plant

In this paper [32], a method for tuning MPC controller considering norm based indexes for disturbance rejection has been developed. This method has been tested in the MPC applied to a simulated activated sludge process and the closed loop responses for the substrate concentration in the reactor show that the obtained controllers are properly tuned, taking into account the large magnitude of the influent disturbance. The methodology proposed here is a general one and any other performance criteria can be considered.

In this article [53], two of the most utilized industry control techniques have been actualized to control the dissolved oxygen concentration in an activated sludge process which are gain planning PI control and predictive control. Three issues are stressed in this paper. The first studies was the dynamical exhibitions of the closed loop, the second one respected to the conduct of the two control techniques to the disturbance dismissal and the last one manages the effectiveness of the wastewater treatment process in two circumstances: with consistent and variable setpoint for the dissolved oxygen control loop. Based on the steady-state study, a variable setpoint for the dissolved oxygen focus has been planned. For this situation, the control variable D takes esteems. By adjusting the aeration rate (W) and the dissolved oxygen concentration setpoint an effluent with a relatively steady quality and stream has been acquired. The substrate focus in the effluent stays beneath the most extreme esteems forced by law (20 mg/l), for the two techniques: gain scheduling and predictive control. The gain scheduling controller has been composed in light of a group of straight PI controllers, utilizing the air circulation rate as scheduling variable. For the MPC control, the order nonlinear model has been utilized to figure the expectations and consecutive quadratic programming has been utilized to take care of the on-line enhancement issue. The two strategies require just estimations of the oxygen concentration which can be effectively gotten. The substrate concentration in the effluent is indirectly controlled, along these lines no estimations of the gushing substrate concentration are required. The wastewater treatment process productivity has been considered when wastewater volume treated with the same electricity. In every one of the simulation two cases were viewed as: steady and variable setpoint for the dissolved oxygen control loop. The best outcomes were acquired with variable setpoint.

Water treatment and wastewater treatment is a complex industrial process including countless technologies, plants and gadgets, sorted out into a few methods or stages through which the water is decontaminated. In spite of being distinctive in size and advancements, the greater part of the wastewater treatment plants is having comparable valuable design. An approach for creating decentralized control structures utilizing PI controllers that first examine the conditions among manipulated and controlled factors utilizing the RGA analysis was exhibited and demonstrates to give great outcomes for both a linearized version of the biological treatments stage and the medium fidelity first principle non-linear model. The examination was made by simulation of the decentralized controllers on the nonlinear model of the procedure, whose parameters where fitted the procedure estimations, and on a linearized model for the two coupled control loop. The approach displayed here could convey extraordinary incentive to wastewater forms that are keep running under typical operation and an execution of essential controllers is conceived, or where the control loop planned without a legitimate investigation of the associations among manipulated and controlled factors. A similar line of approach is additionally important when designing multi-layer control models, for example, plan-wide control, where the manipulated factors from the supervisory control layer are the set points of the controllers from the administrative layer [25].

The issue of triangular decoupling with simultaneous disturbance rejection has been contemplated for general neural multi delay system by means of feasible dynamic multi delay controller nourishing back quantifiable aggravations and the plant measured yields. The important and adequate conditions for the issue to have an answer have been built up and the general explanatory articulation of the feasible multi defer dynamic controllers taking care of the issue has been inferred. The outcomes have effectively been connected to control an activated sludge process with changing dissolved oxygen concentration at the influent. The activated sludge process considered in this paper comprises of an aerator tank where biodegradation happens and a settler where the solids are isolated from the wastewater and reused by flowing to the aerator. In light of the nonlinear mathematical model of the procedure, a linear approximant of the procedure will be utilized as a part of request to deliver a dynamic controller of the shape that full fills the outline objective introduced. As for the model of the procedure it will be accepted that the influent substrate fixation (first unsettling influence) stays steady. This suspicion is conceivable considering that the influent substrate focus is gradually shifting. Moreover, it is expected that the influent dissolved oxygen concentration can be measured progressively [77].

The purpose of this paper [44] was to demonstrate that a well-tuned model of the WWTP can lead to very simple control strategies like the well-known PI controller. A more complex fractional order PI is presented that is more robust and leads to better performances. The controller was used to maintain the DO concentration on the specified reference. In manual operation the blower is working on constant speed providing excess of air in order to meet the regulations for the discharged water and tackle the variations of the influent organic load and flow rate. By introducing the automated control of the DO, the blower’s speed is allowed to be lowered when the operating conditions of the WWTP permits. As a result the total costs of the plant are reduced.

The motivation behind this article [49] is to decide the attainability of utilizing ANN in the expectation of execution of wastewater treatment plant utilizing trickling filter process in treating high quality wastewaters and to decide the impact of parameters influencing treatment plant execution. To test the legitimacy of ANN show, the ANN comes about were contrasted with multiple regression analysis. This article has exhibited the straightforwardness of utilizing ANN models in foreseeing the wastewater treatment plant execution. In this examination the wastewater displaying result obviously demonstrates that ANN models were better than the regression wastewater show in foreseeing the trickling filter effluent concentration. The expectation error with ANN models acquired in this examination can be decreased by expanding the quantity of training cycles utilized in training. The processing speed can be drastically enhanced by utilizing a PC outfitted with a math co-processor.

This paper [67] traces the after effects of MPC system Benchmark Stimulation Model 1(BSM1) of WWTP. The strategies for DMC, QDMC and NLMPC in case of without and with feedforward compensation have been tried. After a time of steady influence attributes, huge disturbance of the influent qualities taken from dry climate file imposed. The control execution of MPC to a great degree changes when disturbance initiated. Indeed, even DMC need to force limits on the contributions at control time to keep away from blast. QDMC does not demonstrate any advantages contrasted with DMC. At the point when a feedforward is added to the accompanying control, it demonstrates a superior outcome than without the controller. Obviously from the reaction, feedforward as for ammonium concentration is considerably more proficient than with the stream rate. The best was gotten by considering both the ammonium and stream rate as measured disturbance in the feedforward strategy.

The fundamental usage of wastewater aeration system utilizing microprocessor based control hardware have been studied. The setups of the inactive control system with one-step and two-step blowers and the frameworks with PID controllers and additionally fuzzy controllers have been introduced. The correlation of the operational experience for the aeration arrangement control options displayed legitimizes the thesis PID controller or fuzzy controller are the alternative to the system. It empowers to guarantee the better automatic control accuracy, smaller disturbances in the electric power mains and more gainful drive working conditions. All frameworks talked about suitable running of the waste water treatment process since the last does not require serious support of the waste water oxidation level [56].

The purpose of this paper [78] is to present an on-line modelling and controlling scheme based on the dynamic recurrent neural network for wastewater treatment system. A control strategy based on rule adaptive recurrent neural network (RARFNN) is proposed in this paper to control the dissolved oxygen (DO) concentration and nitrate nitrogen concentration. The structure of the RARFNN itself organized by a rule adaptive algorithm, and the rule adaptive algorithm considers the overall information processing ability of neural network. Furthermore, a stability analysis method is given to prove the convergence of the proposed RARFNN. By application in the control problem of wastewater treatment process (WWTP), results show that the proposed control method achieves better performance compared to other methods. The proposed on-line modelling and controlling method uses the RARFNN to model and control the dynamic WWTP. The RARFNN can adjust its structure and parameters according to the changes of biochemical reactions and pollutant concentrations. And, the rule adaptive mechanism considers the overall information processing ability judgment of the neural network, which can ensure that the neural network contains the information of the biochemical reactions. In the end, the simulation results show that, compared to the control scheme of MPC, NNOMC, E-HDP and SOFC, the proposed control system achieves better control performance.

This paper [45] has displayed an incorporated model predictive control and monitoring system for a wastewater treatment plant, executed with the point of decreasing operational expenses and expanding process steadiness. The online utilization of the predictive control procedure proposed was exhibited for a wastewater treatment plant in Lancaster, North England. The control procedure is actualized in real time, together with a plant monitoring system for the motivations of process supervision. This way to deal with plant control has conveyed a decrease in air circulation costs at low BOD load levels and provides predictive capacities in managing dynamic process conditions. In addition to the substantial advantages of budgetary investment funds from process control, the monitoring system has given valuable data on sensor quality, which has been used for the maintenance. The connected process control system brought about smoother operation of the wastewater treatment plant, decreasing variability in process factors. This contextual investigation features the achievement of real time control on WWTPs is the strength of the instruments and data foundation at each site. Distinguishing 'suspect' sensors or process conduct empowers both the administrator and control system to settle on educated choices to guarantee the process operation stays in a proficient and safe working area.

Computer methodology of the dissolved oxygen concentration has been quantitatively researched on two simulation contextual analysis which is the dissolved oxygen concentration must be kept up at 2mg/I in the aerobic part and a alternating dissolved oxygen level must be kept up in an activated sludge process. To assess the outcomes, execution criteria were set up and ascertained during the simulations concerning the execution of the controller. A few tuning parameters of the controller were additionally researched. As indicated by the outcome, MPC can successfully connected in the control of dissolved oxygen concentration of wastewater treatment plant [47].

The goal of the investigation in [51] was to utilize MPID controllers to enhance closed loop performance and diminish loop communication. Three tuning methodologies were contrasted with one new method introduced. The strategies depend on decoupling the framework at various frequency point. To distinguish the best control methodology, RGA investigation were performed. It was proposed to utilize DRGA to locate the best frequency point for decoupling. A method was additionally created to calibrate the controllers utilizing an optimization strategy. Simulation studies on a nonlinear ASM1 model exhibited that the proposed technique performed essentially better in set point tracking properties and disturbance dismissal and gave the best execution concerning decoupling capacities. The outcomes recommend extensive change can be accomplished as far as vitality reserve funds and nitrogen evacuation with an appropriately tuned MPID controller. The strategies show that the controller tuning impacts multi-loop framework execution.

An indispensable procedure in wastewater treatment is the organic treatment with initiated muck. In Romania, there are still a lot of situations where the natural treatment stage is worked physically, prompting wasteful operation and verifiably to higher operational costs, expanded trouble in keeping up the nature of the effluent and less disturbance dismissal abilities. In our paper, we demonstrate that utilizing a medium-fidelity first rule model and via doing a RGA examination so as to locate the best pairings among manipulated and controlled factors, a decentralized control system utilizing PI controllers can be effortlessly developed and tried before usage, the control methodology giving great outcomes in disturbance rejection and trajectory tracking[25].

Utilizing the PI+R controller in the control structure of the urban WWTPs is a characteristic arrangement because of the way that the disturbance from the control loop (i.e. inflow rate and ammonium fixation) have a noteworthy occasional part. The aftereffects of the numerical simulation utilizing the SIMBA test system, demonstrates a huge increment in control framework execution of the nitrate concentration, yet in addition of the entire control structure, when utilizing the PI+R controllers, contrasted and the utilization of PI controllers. In this paper a sufficient arrangement was built up for the recognizable proof of the procedure from the nitrate concentration control loop, in the state of the disturbance activity, and were assessed the adjustments in the distinguished model parameters with the working administration. Given the particularities of the PI+R controllers, it was viewed as that the most fitting strategy for the combination of a robust controller in this classification is the frequency approach [48].

The point this journal [46] is to full fill effluent quality directions with sensible monetary costs. One conceivable way to deal with the re-optimization of the plant when a few disturbance happen by applying Real Time Optimization methods which can be extremely requesting computationally, or play out the set point improvement disconnected. In this work, the approach considered is the determination of some controlled factors that when kept steady, the financial misfortune is little concerning costs when the operation is re-optimized. The system used to discover these factors is the self-optimization method. The WWTP model considered for its application is the generally utilized Benchmark Simulation Model BSM1. In this work, the SOC system has been connected to locate the ideal controlled factors as a mix of measurement in a wastewater treatment plant. A pre-screening of the most reasonable estimations to keep away from unfeasibilities when substantial load disturbance show up has been performed. The dynamic controllability of these factors has likewise been considered, by executing a multivariable incorporated nonlinear MPC, and a conveyed control structure with PI control for the active constrain and a nonlinear MPC for the self-optimizing factors. The outcomes demonstrate that both control structures give great set point tracking, in spite of a long transient especially for the most serious disturbance. The appropriated NMPCPI control demonstrates better execution in light of the different treatment of the diverse time sizes of the procedure and the less demanding tuning of the controllers. Specifically, the overshoots for the self-optimized factors are significantly littler than those for the brought centralized NMPC.

2.5 Comparative Analysis between Controllers

Table 2.1 Comparison between Controllers

Type of controller	**PID**	**ADRC**	**MPC**	**SMC**
Suitable for simple/complex system	Simple system	Both	Both	Both
Linear/non-linear	Both	Both	Both	Both
SISO/MIMO	Both	Both	Both	Both
Disturbance rejection capabilities	Inefficient rejection	Excellent	Excellent (Does not handle disturbance directly)	Excellent
Dependency on system information	Not needed	Not needed	Needed	Not needed
Time delay	Not suitable for large time delay	Not suitable for large time delay	Excellent	Excellent

As we can see in the Table 2.1 of characteristic comparison, there are lots of similarities and differences can be found among the controllers. Since PID controller is the oldest creation among the others, it poses the lowest performance in most of the situation because the after invention such as ADRC, MPC and SMC are the improved version in controllers' history which able to perform in more complex and higher level controlled situation. In a journal, a comparison is made between the MPC and PID in water-level maintenance in a two-tank system. From the research, it has been proved that PID applied directly to the non-linear system automatically get rid of the steady state error in a time delay whereas MPC does not eliminate the error as the time delay increased. In decreasing time delay, inversely MPC poses better performance and able to withstand the changes in the processes with stable settling time, acceptable steady state error and no undershoot. While PID shows to have undershoot that largely affected settling time which proves that MPC better in capturing the dynamic changes in a system. PID need adjustment of its parameters for any changes during the system operation [69]. This clearly shows that MPC is way advanced than PID controller.

Apart from that, a comparison between SMC and PID is made in some article and believe that both the controller capable of controlling the nonlinear inverted pendulum system and linear position. But SMC shows more advance performance than PID controller [79][80][81]. It is undeniable that enhancement need to done in both controller. In PID maximum overshoot and maximum undershoot for linear and angular positions do not have very high range as required by the design criteria. On the other hand, SMC need to be improved in term of the settling time so that it can be as faster as PID controller [79].

A comparative analysis is made between ADRC and PID on a flight which could be unfolded by the wings of loitering munition. ADRC proposed so as to lessen the impacts of the model parameter variation caused by basic change and external disturbance. Simulation result shows that ADRC calculation not just precisely predict and compensate the interior and in addition outer disturbance yet additionally enhance the robustness of the system with model uncertainties and the execution of the flight control framework over PID controller [37][63] .

As per above comparison, we can clearly see that there are more advanced controller that PID controller but PID still widely used as major type of controller. Even though MPC, SMC and ADRC is more efficient until now PID controller is the dominant controller in the industry as it is more simple to be implemented in an application and also to be controlled [44][51][61]. Thus obviously, there are reasons for the popularity of the controller. PID controller can be used in many controlled system such as to regulated flow, temperature, pressure, level and many other industrial process variables. Moreover it had survived many changes in technologies from mechanical and pneumatic to microprocessers although it has been invented years ago. As PID made of microprocessor, it is an advantage as additional characteristic like automatic tuning, gain scheduling and continuous adaptation found in the controller. In addition, the full details of the system is unnecessary when using PID controller [26][61]. Usually this procedure could be done by tuning manually or automatically via a tuning/optimization algorithm. Furthermore features like less sensitive to perturbation, unnecessariness of complex modelling as well as ability to work together as two are advantages of PID controller although some situation is not suitable for PID requirement.

As we know even the others controllers have their disadvantages and limitation in some incidents. So do PID controller. PID has poor disturbance rejection capability said in an article [61]. Thus to improve this limitation observer might be a suitable controller to work together with PID so that disturbance attenuation happens successfully. As in table, other controller can successfully minimize the errors in the system. Although PID can compensate error, at first it will affect the system and the signal send back for the feedback process to occur after the adjustment in the system controller so that the error become zero. This triggers more to investigate about the PID controller together with observer in a water treatment system to study disturbance rejection capabilities. The purpose is to compare between the presence and absence of observer in the PID system since according to the table, PID has poor disturbance rejection features.

2.6 Summary

In conclusion, WWTP is a complex, nonlinear, multivariable with lots of uncertainties. It takes lots of effort with lots of algorithms need to implemented to handle such a complex system. Thus wiser choice of controller is always a better way to reject disturbance as there are countless amount of controller exist in today life.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter basically the methods carried out to do this project is discussed. Firstly related equation is derived from the standard model of activated sludge process where basically it is a non-linear system. Then appropriate method is used to convert the system to linear system. This is necessary for the ease of process control as non-linear system is hard to be controlled. Moreover two types of PID controller is designed so that a disturbance observer can be implemented to the system for performance comparison and evaluate the disturbance rejection ability of the system. This project is carry out to limit the level of substrate and dissolved oxygen concentration by controlling the two inputs which is dilution rate and air flow rate. Examination of the yields and error signals done after controller design was implemented utilizing MATLAB and Simulink.

3.2 Project Activity and Planning

The chorus of the project started when the title is chosen and finalised to the respective lecturer. At first some research and studies was carried out to figure out what is the title all about. To be more organized a timetable was created so that the task can be completed on time. This project is solely depends on the simulation. Thus necessary methods and simulation need to be implemented so that the problem proposed can be easily solved.

Literature Review

- Studies of other experiment related to the title chosen.

Software Development

- A design of observer together with PID controller to obtain better output performance using MATLAB software.

Testing and Troubleshooting

- The problematic part/section is troubleshoot and analysed. Alternative ways are tried out one by another to test the applicability.

Result and Discussion

- After successful software stimulation, the data was collected and analysis was made referring the data.

Conclusion

- Final conclusion was made based on the result obtained during the analysis.

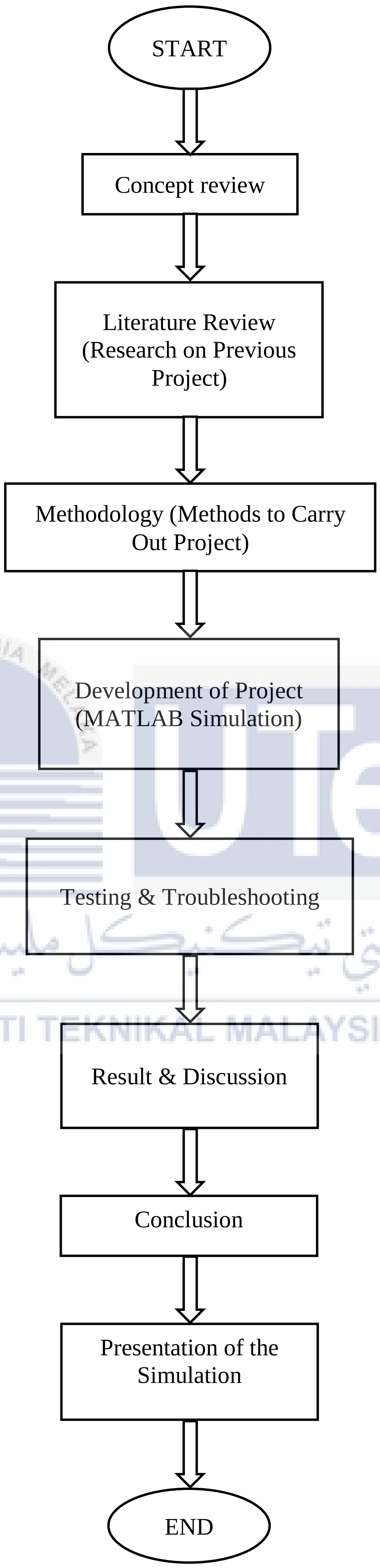

Figure 3.1 Flow Chart of Work Progress for The Entire System

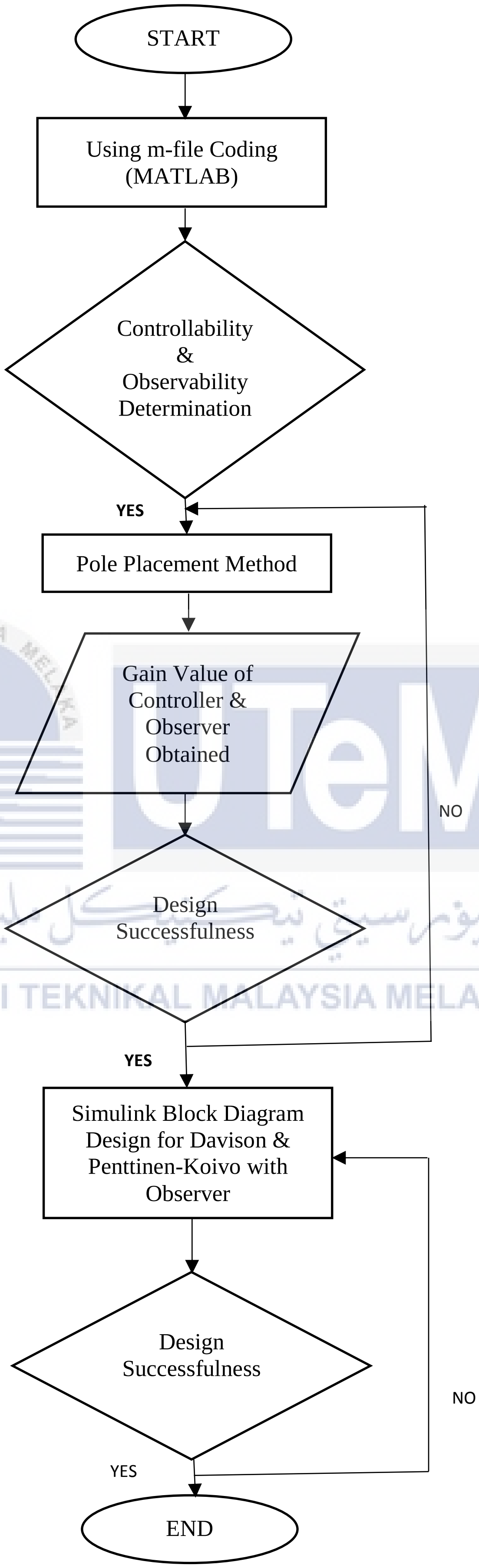

Figure 3.2 Flowchart of Development of Simulation Design

3.2.1 Milestone

Milestone is a significant or important fixture or event during the progress of the project. Specific stage along a project timeline marked using milestone.

Table 3.1 Activities with duration required

NO	ACTIVITIES	DATE/PERIOD
1	Identification of design need to be used in the simulation design	Nov 2017
2	Software development	Jan 2018
3	Testing functionality of software simulation	Feb 2018
4	Troubleshooting problem	Feb 2018
5	Alternative to overcome problems	Mar 2018
6	System completion	Mar 2018
7	Run the experiment and collect data	Apr 2018
8	Analyse data and conclusion	May 2018

3.3 Wastewater Treatment Plant Introduction

Basically the aim of our project is to implement the design of PID controller with the presence of observer in a common Wastewater Treatment Plant (WWTP). PID controller in the outer loop have to control the output of the WWTP which is substrate (S) and dissolved oxygen (DO) concentration by controlling the dilution rate (D) as well as the air flow rate (W). The state observer integrated with the system to deliver the accurate estimated state variables so that the WWTP system operates efficiently.

3.3.1 Wastewater Treatment Plant System

The Figure 3.3 demonstrate the activated sludge process in the wastewater treatment plant. Fundamentally this process exist in secondary treatment plant where it is the most crucial and complicated process among the processes in WWTP. As we can see in the Figure 3.3, the basic activated sludge process consists of several interrelated components which is aeration tank as well as clarifier or settler. The biological process occurs in the aeration tank while in settler the solid floac separated by sedimentation process. Usually in aeration tank, microorganism live and propagate to feed on organic waste substance present in the wastewater and transform the waste substrate into solid lump. To do so, microorganism need dissolved oxygen (DO) injected by blowing air into the system. The bacteria present in the aeration play important role in purifying the wastewater and it usually multiply rapidly with sufficient food and oxygen.

The motive of the activated sludge process can either be removal of carbon or nitrogen. In this project the focus is to remove carbon ignoring the nitrogen factor. The control plant output are substrate, S and dissolved oxygen, DO. Normally the substrate affect the growth of microorganism that are responsible for treating the wastewater and too many substrate concentration lead to a drop in microorganism growth rate. The standard amount of S is around 51 mg/l. In term of DO concentration which also an important factor in microorganism growth, degradation in quality of pollution occur if the count is low for DO. On the other hand, it also can cause too much of sludge production and the consumption of energy will be higher where it will increase the cost for the treatment if DO is excessive. Thus it is vital to have the DO concentration in the range of 1.5mg/l – 4.0mg/l [50].

In the settler some of the activated sludge will recycled back to the aeration tank called return activated sludge (RAS) or remove other excessive sludge from the settler called waste activated sludge (WAS) by processes such as flocculation and gravity sedimentation. To maintain the process in the aeration tank the concentration of microorganisms need to be maintained constant. Hence some of the activated sludge recycled back to the aeration tank and obviously not all the sludge is recycled since new sludge is continuously produced in the aeration tank. The relatively clear liquid above sludge is sent on for further treatment as required by the effluent.

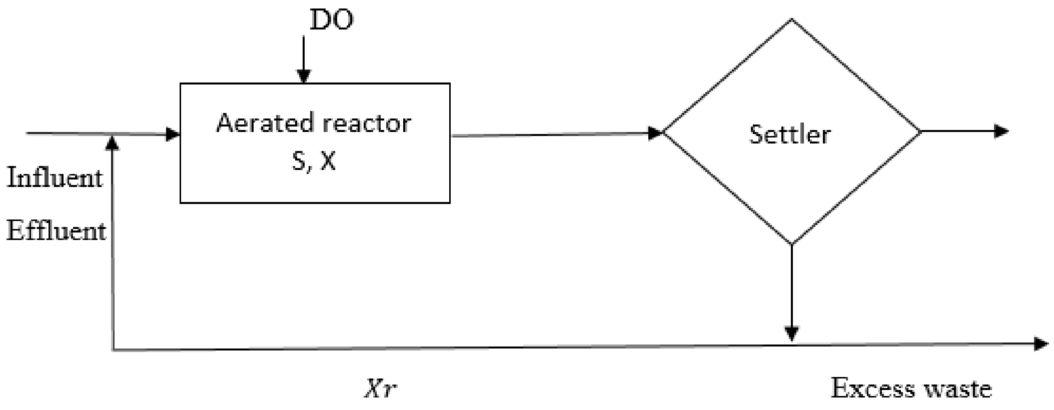

Figure 3.3 Activated Sludge Process

3.3.2 Non-Linear System of Wastewater Treatment Plant

As we know, activated sludge system is non-linear system. Thus we can derive non-linear differential equations for the system in Figure 3.3 above. The related equations are as from equation (3.1) to (3.4) [50].

$$\dot{X}(t) = \mu(t)X(t) - D(t)(1+r)X(t) + rD(t)X_r(t) \tag{3.1}$$

$$\dot{S}(t) = -\frac{\mu(t)}{Y}X(t) - D(t)(1+r)S(t) + D(t)S_{in} \tag{3.2}$$

$$\dot{DO}(t) = -\frac{K_0\mu(t)X(t)}{Y} - D(t)(1+r)DO(t) + \gamma W\big(DO_s - DO(t)\big) + D(t)DO_{in} \tag{3.3}$$

$$\dot{X}_r(t) = D(t)(1+r)X(t) - D(t)(\beta + r)X_r(t) \tag{3.4}$$

Where,

$X(t)$ = Biomass

$S(t)$ = Substrate

$DO(t)$ = Dissolved oxygen

$X_r(t)$ = Recycled biomass

$D(t)$ = Dilution rate

W = Air flow rate

$\mu(t)$ = Specific biomass growth rate

S_{in} = Substrate concentrations in influent steams

DO_{in} = Dissolved oxygen concentrations in influent steams

DO_s = Maximum dissolved oxygen concentration

Y = Rate of microorganism growth

K_0 = Model constant

γ = Constant, $\gamma > 0$

r = Ratio of recycled flow to the influent flow

β = Ratio of waste flow to the influent flow

3.3.3 Linearized Model

Since non-linear model difficult to be controlled, the activated sludge process need to be linearized to ease the control process. To do so first we need to find the initial input values of dilution rate, D and air flow rate, W using the four non-linear differential equation above describing the model. It is easy to find the values by equating the differential equation to zero. The initial condition of the state variables are as follows:

Biomass, $X(0) = 215\ \mathrm{mg}^{-1}$

Substrate, $S(0) = 55\ \mathrm{mg}^{-1}$

Dissolved oxygen, $DO(0) = 6\ \mathrm{mg}^{-1}$

Recycled biomass, $X_r(0) = 400\ \mathrm{mg}^{-1}$

From above value, using MATLAB and Simulink we can produce the non-linear model by calculating initial condition of the plant. The non-linear models are also can be derived using Taylor Series approximation.

The steady state models are represented in equations (3.5) and (3.6) while equation (3.7) and (3.8) is the representation of $\Delta Z(t)$ and $\Delta u(t)$.

$$\Delta \frac{d\dot{z}(t)}{dt} = A\Delta Z(t) + B\Delta u(t) \tag{3.5}$$

$$\Delta y(t) = C\Delta Z(t) + D\Delta u(t) \tag{3.6}$$

Where,

$$\Delta Z(t) = \begin{bmatrix} \frac{d\dot{X}(t)}{dt} \\ \frac{d\dot{S}(t)}{dt} \\ \frac{d\dot{DO}(t)}{dt} \\ \frac{d\dot{X}_r(t)}{dt} \end{bmatrix} \tag{3.7}$$

$$\Delta u(t) = \begin{bmatrix} D(t) \\ W(t) \end{bmatrix} \tag{3.8}$$

A, B, C and D are system matrices. The matrices from equation (3.9) to (3.12) can be used to do linear analysis by using numerical method in MATLAB software.

$$A = \begin{bmatrix} \frac{d\dot{X}(t)}{dX(t)} & \frac{d\dot{X}(t)}{dS(t)} & \frac{d\dot{X}(t)}{dDO(t)} & \frac{d\dot{X}(t)}{dX_r(t)} \\ \frac{d\dot{S}(t)}{dX(t)} & \frac{d\dot{S}(t)}{dS(t)} & \frac{d\dot{S}(t)}{dDO(t)} & \frac{d\dot{S}(t)}{dX_r(t)} \\ \frac{d\dot{DO}(t)}{dX(t)} & \frac{d\dot{DO}(t)}{dS(t)} & \frac{d\dot{DO}(t)}{dDO(t)} & \frac{d\dot{DO}(t)}{dX_r(t)} \\ \frac{d\dot{X}_r(t)}{dX(t)} & \frac{d\dot{X}_r(t)}{dS(t)} & \frac{d\dot{X}_r(t)}{dDO(t)} & \frac{d\dot{X}_r(t)}{dX_r(t)} \end{bmatrix} \tag{3.9}$$

$$B = \begin{bmatrix} \frac{d\dot{X}(t)}{dD(t)} & \frac{d\dot{X}(t)}{dW(t)} \\ \frac{d\dot{S}(t)}{dD(t)} & \frac{d\dot{S}(t)}{dW(t)} \\ \frac{d\dot{DO}(t)}{dD(t)} & \frac{d\dot{DO}(t)}{dW(t)} \\ \frac{d\dot{X}_r(t)}{dD(t)} & \frac{d\dot{X}_r(t)}{dW(t)} \end{bmatrix} \tag{3.10}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.11}$$

$$D = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \tag{3.12}$$

After obtaining values for matrices A, B, C and D, the values are substituted into the equation (3.13) so that linear system transfer function of two system which are dilution rate, D with substrate and air flow rate, W with dissolved oxygen, DO can be derived.

$$G(s) = C(sI - A)^{-1}B + D \tag{3.13}$$

3.3.4 Relative Gain Array (RGA) Analysis

Since the WWTP has two input sources and two output factors, there may be cooperation between these two manipulated and two controlled factors. Each manipulated factors can influence both controlled variable in this way making the framework unstable. So RGA analysis is the most ideal approach to limit the cooperation between factors so that better couple can be obtained. For this situation, there are two conceivable path for controller pairings.

Table 3.2 Possible Variables Pairing of WWTP

Input	Output	
	Case 1	Case 2
D	S	DO
W	DO	S

To gauge the capacity of RGA in giving the more pragmatic matching proposal, the linearized model will be calculated. RGA of non-square matrix is characterized in equation (3.14). From the analysis the outcome will be shown in matrix forms, where columns are for each input variable and rows for each output variables. This network frame can be utilized as a part of figuring out which relative gains are related to which input output factors. Subsequently it is fundamental for framework to experience RGA examination.

$$RGA = G_{RGA} \times (G_{RGA})^{T} \tag{3.14}$$

Where,

G_{RGA} = Gain matrix

${G_{RGA}}^T$= Pseudo inverse of gain matrix

3.4 Controller Structure of PID

PID can be designed using various method such as Davison and Penttinen-Koivo method. Section 3.4.1 and 3.4.2 are the methods for the design process.

3.4.1 Davison Method

Control design based on Davison method simply applies the integral term, which causes decoupling rise at low frequencies

$$K = K_i \frac{1}{s} e(s) \tag{3.15}$$

The controller expression (3.15) is plucked from [50], where K_i and $e(s)$ are integral feedback gain and controller error respectively.

$$K_i = \mu G(S)^{-1} \tag{3.16}$$

Since this exploration is centred around dynamic control, Ki is characterized as in equation (3.16), where μ is the main controller tuning parameter, which without a doubt should be tuned dynamically until the point where the finest arrangement is found. Because of the contribution of the inverse system, the control configuration is relevant for square matrix. On the off chance that the framework includes time delay, then the time delay should be disposed. Davison which act as a PID like controller has feedback gain which represent by term Ki where in Simulink the term Ki represent by a gain block. The value of the Ki depends on the output performance. Try and error method are used to find the best values of Ki for good output results.

3.4.2 Penttinen-Koivo Method

This technique is more progress than Davison strategy. In Penttinen-Koivo technique a proportional term is presented. It contains both integral and proportional term. In a roundabout way, this causes decoupling to occur at low and high frequencies. Davison and Penttinen-Koivo technique are just comparative regarding an integral term which is linearly related with the reverse of plant system.

$$K = \left(K_p + K_i \frac{1}{s}\right) e(s) \tag{3.17}$$

The controller expression in equation (3.17) is represented in, where K_p, K_i and $e(s)$ are proportional gain, integral feedback gain and controller error correspondingly.

$$K_p = (CB)^{-1}\rho$$

$$K_i = \mu G(s)^{-1} \tag{3.18}$$

Dynamic terms of Kp and Ki are expressed in equation (3.18), where ρ and μ are the tuning parameters for both proportional and integral feedback gain. Penttinen-Koivo as updated version of Davison as a PID has term Ki and K_p, where in Simulink the term K_i and K_p represent by two different gain blocks. The value of $K_i$and K_p depends on the output performance. Try and error method are used to find the best values of K_i and K_p for good output results.

3.5 Observer Design for Wastewater Treatment Plant

Observer design assist in error elimination between the actual output and the estimated output. This error is feedback through specified gains for correction purpose. The response of the observer is designed to be faster than the system, so that the estimated state variable effectively appear instantaneously at the controller. The following subtopics from Section 3.5.1 discuss about the method to design observer for WWTP system.

3.5.1 Stability of the WWTP System

Referring to theories, stability of a system is always an important aspect to be considered. A system said to be stable if the poles of the system are on the left-hand side of the s-plane. If the poles are on right-hand side, then the system is said to be unstable. This criteria especially suitable to linear, time-invariant system where this poles can be determined with the analysis of eigenvalues of the system matrix A. Basically, eigenvalues are equal to the poles of the system. Thus to determine the eigenvalues, the equation (3.19) is used.

$$\text{eigenvalue} = \det(sI - A) = 0 \quad (3.19)$$

Here A is the (4×4) matrix of the WWTP system. The eigenvalues was determined using MATLAB Simulation.

3.5.2 Controllability

Controlling the pole location is possible only if the control signal, u can control the behaviour of each of the state variables $\boldsymbol{x}$. If any of the state variables cannot be controlled by u, then the poles cannot be placed where desired. So far the controllability can be used for diagonal or parallel form with distinct eigenvalues only. In order to be able to determine controllability or to design state feedback for plant, equation below is used. The nth-order plant whose state equation is as equation (3.5) is completely controllable if the matrix equation (3.20) is of rank n, where C_m is called the controllability matrix.

$$C_m = [B \;\; AB \;\; A^2B \ldots \;\; A^{n-1}B] \quad (3.20)$$

3.5.3 Observability

As per fact, not all state variables can be measured in a system. Estimation of the values of the unknown internal state only can be done using available system output. A system is observable if the initial state, $x(t_0)$ can be determined based on knowledge of the system input, $u(t)$ and the system output, $y(t)$. The system is observable if and only if the observability matrix, O has full rank. Only after the system is observable, we can design an observer for the WWTP system. Equation (3.21) is the observability matrix where C and A are the matrix of the WWTP system.

$$O=\begin{bmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{n-1} \end{bmatrix} \quad (3.21)$$

3.5.4 Control Design Using Pole Placement

Pole placement method is a controller design method in which we determine the places of the closed loop system poles on the plane by setting a controller gain K. By designing a feedback control system via pole placement method the poles can be placed as desired by adjusting the gain values. The state space equations for the closed-loop feedback system are as equations (3.22) and (3.23).

$$\dot{x} = Ax + B(-Kx) = (A - BK)x \quad (3.22)$$

$$y = Cx \quad (3.23)$$

Since the matrices A and BK are both 4×4, there will be 4 poles for the system. For an appropriate state-feedback gain matrix K, pole can placed anywhere desired because the system is controllable. The ‘place’ command is used in m-file to find the state-feedback gain K, according to the poles decided. The criteria for the controller were settling time less than 10 second and overshoot less than 5%. So, according to that specification the poles for system G1 with the output variable of substrate were placed at -1.5-1.5j, -1.5+1.5j, -2.0-2.0j and -2.0+2.0j. For dissolved oxygen concentration system G2, the poles were placed at -0.5-0.5j, -0.5+0.5j, -1.5-1.5j and -1.5+1.5j. In some case if the poles are placed at big values, the simulation might show error because the actual system poles are of small values. From the simulation, the gain value for G1 and G2 system which are K1 and K2 respectively will be determined and exported to be used in Simulink block diagram.

3.5.5 Observer Design

Fundamentally not all the state variable can be measured accurately or directly. In that kind of case observer plays important role where it estimates the states earlier than the system. The observer is actually a copy of the plant. It has identical control input and nearly same differential equation. In the system with observer, the output of actual system is compared with the output of the observer system. Then the difference in the outputs will flow through L gain which will help to correct the estimated state, $\hat{x}$ so that it follows the actual state, x. The differential equations of observer are equations (3.24) and (3.25) respectively.

$$\dot{\hat{x}} = A\hat{x} + Bu + L(y - \hat{y}) \quad (3.24)$$

$$y = C\hat{x} \quad (3.25)$$

The error of the observer are given by the poles of $A - LC$ according to equation (3.26).

$$\dot{e} = \dot{x} - \dot{\hat{x}} = (A - LC)x \quad (3.26)$$

To design an observer, observer gain L is needed to be chosen according to the poles being placed using place command in m-file. The dynamics of the system will be faster when the poles placed at least 5 times farther to the left than the dominant poles of the system. Because of the duality between controllability and observability, we can use the same technique used to find the control matrix by replacing the matrix B by the matrix C and taking the transposes of each matrix.

$$L = place(A', C', [op1, op2, op3, op4])' \quad (3.27)$$

The terms op1, op2, op3 and op4 are the new observer pole of the system. The equations in (3.27) above is used to find gain values where it helps the observer obtain the estimate $\dot{\hat{x}}$. The estimated state for feedback, $u = -K\hat{x}$ is used since not all state variables are necessarily measured. After a little bit of algebra, the combined state and error equations for full-state feedback with an observer were derived. It is conventional to write the combined equations for the system plus observer using the original state equations plus the estimation error, $e = x - \hat{x}$. The matrices of observer with system are At, Bt and Ct which are from equations (3.28) to (3.30).

$$At = \begin{bmatrix} A - B*K & B*K \\ zeros(size(A)) & A - L*C \end{bmatrix} \quad (3.28)$$

$$Bt = \begin{bmatrix} B*Nbar \\ zeros(size(B)) \end{bmatrix} \quad (3.29)$$

$$Ct = [\, C \quad zeros(size(C)) \,] \quad (3.30)$$

After the implementation of observer in the system, the performance of the observer need to be evaluated. For that we need to use the same m-file to get the signal of original state variable, x and estimated state variables, $\hat{x}$ and plot the variables in same graph to observe the observer controller performance in tracking the real state variables. At first the initial estimate were assumed to be zero, such that the initial estimation error is equal to the initial state vector, $e = x$. Then all the state variables are plotted with the estimated variables. To get the values of, $\hat{x}$ we can compute by $x - e$.

In Simulink block diagram a constant values was injected into both Davison as well as Penttinen-Koivo method and assumed to be the disturbance of the plant to evaluate the performance of observer. The disturbance was injected right into the plant where the source are from unknown parameter which might deviated according to the weather. Here the constant disturbance was fixed to 1 for all the analysis. All the above methods were done in MATLAB to analyse the performance of the observer with and without the presence of disturbance.

3.6 Summary

Basically all this method discussed above is to concentrate on the ways to design controller as well as to compensate error caused in the system using state observer to eliminate any kind of disturbance in term of inaccurate state variables information. Not only that disturbance which injected in the system in term of constant value was also considered for observer performance evaluation. Throughout the designing of controller, when problems troubleshooted in running the system simulation, different kind of methods were used to ensure that best PID controller and trackeble observer can be simulated successfully.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Linearized Model Result

The related non-linear equations from (3.1) to (3.4) were used to find the average value of D and W by substituting the initial condition and constant values. Thus, substituting the values into the equation will resulting an average value of D = 0.0825 h^{-1} and W = 90 m^3/h .

From above calculation, using MATLAB and Simulink we able to produce the non-linear model. The non-linear models also can be simulated using Taylor Series approximation. From the simulation, we get an obtained initial value of:

$\text{Biomass}, \mathrm{X}(0) = 217.7096\ \mathrm{mg}^{-1}$
$\text{Substrate}, \mathrm{S}(0) = 41.2348\ \mathrm{mg}^{-1}$
$\text{Dissolved oxygen}, \mathrm{DO}(0) = 6.1146\ \mathrm{mg}^{-1}$
$\text{Recycled biomass}, \mathrm{X_r}(0) = 435.5791\ \mathrm{mg}^{-1}$

The steady state models are represented in equations (3.5) and (3.6) which are

$$\Delta Z(t) = A\Delta Z(t) + \mathrm{B}\Delta u(t)$$
$$\Delta y(t) = C\Delta Z(t) + D\Delta u(t)$$

Using the numerical method, linear analysis was performed. Equation (4.1) to (4.4) are the system matrix obtained from the linearization.

$$A = \begin{bmatrix} -0.0990 & 0.1234 & 0.2897 & 0.0495 \\ -0.0508 & -0.3219 & -0.4457 & 0 \\ -0.0254 & -0.0949 & -1.9748 & 0 \\ 0.1320 & 0 & 0 & -0.0660 \end{bmatrix} \quad (4.1)$$

$$B = \begin{bmatrix} -87.1159 & 0 \\ 134.0243 & 0 \\ -9.2834 & 0.0699 \\ 0.0001 & 0 \end{bmatrix} \quad (4.2)$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4.3)$$

$$D = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \quad (4.4)$$

In this project, the system matrices A, B, C and D which are from equations (4.1) to (4.4) were used to find the transfer function according to equation (3.13). But only two transfer function were given attention for this project which are D with S and W with DO. Equation (4.5) and (4.6) are the transfer function of $G_{S/D}(s)$ and $G_{DO/W}(s)$ after the linearization process.

$$G_{S/D}(s) = \frac{134s^3+295.3s^2+53.52s+0.5858}{s^4+2.462s^3+0.986s^2+0.1108s+0.000789} \quad (4.5)$$

$$G_{DO/W}(s) = \frac{0.0699s^3+0.03403s^2+0.004151s+0.00002892}{s^4+2.462s^3+0.986s^2+0.1108s+0.000789} \quad (4.6)$$

4.2 Relative Gain Array (RGA) Analysis Result

Relative gain analysis was done using MATLAB software where equation (3.14) was used. From the linearization analysis, the value of matrix B obtained were actually the value of G_{RGA} as in equation (4.7).

$$G_{RGA} = \begin{bmatrix} -87.1159 & 0 \\ 134.0243 & 0 \\ -9.2834 & 0.0699 \\ 0.0001 & 0 \end{bmatrix} \tag{4.7}$$

The above gain matrix row and column represent the variables involved in the system. Row ordered from X, S, DO and X_r while column represent D and W. From the simulation, the value obtained for RGA is in equation (4.8).

$$RGA= \begin{bmatrix} 0.2970 & 0 \\ 0.7030 & 0 \\ -0.0000 & 1.0000 \\ 0.0000 & 0 \end{bmatrix} \tag{4.8}$$

From the result obtained, we can see that DO cannot pair with D as the value shows negative which indicates worst and unstable interaction. Moreover there are no interaction between W with X, S and X_r because the gain shows zero value which indicates not suitable to be paired. From the first column the more positive value is best to be paired, thus D will be great pair with S as it have more positive value which is also near to 1. The nearer the value to 1 the more stable the interaction between the pair will be. While for the second column W is best to be paired with DO as it has and value of 1 which is stable interaction. Hence it can be concluded that, the pairs of D and S as well as W and DO is the best to be chosen for this project where case 1 will be selected.

4.3 Observer Design Analysis

For observer design, basically the design were done in m-file and Simulink block diagram of MATLAB software. The design in Simulink were done in the form of state space representation.

4.3.1 Stability Analysis of WWTP

If the poles are located at right-hand side of s-plane instead of left-hand side, then the system said to be unstable as the system will show some unstable signals. Equation (3.19) is the manual way for determining the eigenvalues of a system which are similar to the poles of the system. But, in this project MATLAB software is used to determine the eigenvalues in m-file. Equation (4.9) is the result of eigenvalues.

$$\text{Poles}=\begin{bmatrix}-1.9956\\-0.2578\\-0.2008\\-0.0077\end{bmatrix} \tag{4.9}$$

From the eigenvalues obtained, it shows that the WWTP system is stable as all the poles are located on the left-hand side of the s-plane.

4.3.2 Controllability

Pole placement design method is only applicable if the system is controllable where the control signal, u can control the behaviour of each state variable in x. Otherwise pole placement method cannot be used to design the controller of the system. Manually the controllability matrix is as in equation (4.10).

$$C_m = [B \;\; AB \;\; A^2B \;\; A^3B] \tag{4.10}$$

After the simulation of m-file, equation (4.11) is the rank obtained for the controllability.

$$C_m = 4 \tag{4.11}$$

The rank of C_m equals the number of linearly independent rows or columns. Since the rank of C_m is 4 which is equal to the order of the system, the system is concluded to be controllable. Thus, the poles of the system can placed using pole placement method to the suitable and desired place accordingly.

4.3.3 Observability

Observability is essential aspect for the design of observer similar to the concept of controllability importance for the state-variable feedback gain design. Observability is the ability to deduce the state variables from a knowledge of the input and the output signal. Equation (4.12) is the observability matrix of the system. Using stimulation, equation (4.13) is the observability rank obtained.

$$O=\begin{bmatrix} C \\ CA \\ CA^2 \\ CA^3 \end{bmatrix} \tag{4.12}$$

$$O = 4 \tag{4.13}$$

From the result obtained through simulation we can conclude that the system is observable since the rank is similar the order of the system. So from here we can implement the controller with the observer since the system is proven to be controllable and observable.

4.3.4 Controller Design Using Pole Placement

Pole placement method is basically used to obtain the gain, K values for the closed loop system according to the desired poles located.

4.3.4.1 System of Substrate Concentration with Dilution Rate

The state space equation for the closed-loop feedback system are as equation (3.22) and (3.23), where the values of the matrix A, B, C and D are from (4.14) to (4.17). This matrix values were obtained from the linear system transfer function of S with D from WWTP system.

$$A = \begin{bmatrix} -2.4620 & -0.9860 & -0.1108 & -0.0008 \\ 1.0000 & 0 & 0 & 0 \\ 0 & 1.0000 & 0 & 0 \\ 0 & 0 & 1.0000 & 0 \end{bmatrix} \tag{4.14}$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{4.15}$$

$$C = \begin{bmatrix} 134.0000 & 295.3000 & 53.5200 & 0.5858 \end{bmatrix} \tag{4.16}$$

$$D = [\ 0\ ] \tag{4.17}$$

After the determination of matrix values and poles to be placed as desired, then place command was used to find the simulation values of gain for the system. The result was as in equation (4.18).

$$K1 = [\ 0.5380 \quad 3.5140 \quad 2.8892 \quad 0.9992] \tag{4.18}$$

The closed-loop transfer function of the WWTP system related to substrate concentration and dilution rate is as in equation (4.19).

$$G_{closed-loop} = \frac{134s^3+295.3s^2+53.52s+0.5858}{s^4+3s^3+4.5s^2+3s+1} \tag{4.19}$$

4.3.4.2 System of Dissolved Oxygen Concentration with Air Flow Rate

The state space equation for the closed-loop feedback system are as in equation (3.22) and (3.23), where the values of the matrix A, B, C and D are from equations (4.20) to (4.23). This matrix values obtained from the linear system transfer function of DO with W from WWTP system.

$$A = \begin{bmatrix} -2.4620 & -0.9860 & -0.1108 & -0.0008 \\ 1.0000 & 0 & 0 & 0 \\ 0 & 1.0000 & 0 & 0 \\ 0 & 0 & 1.0000 & 0 \end{bmatrix} \quad (4.20)$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (4.21)$$

$$C = [0.069900 \quad 0.034030 \quad 0.004151 \quad 0.000029] \quad (4.22)$$

$$D = [\ 0\ ] \quad (4.23)$$

After the determination of matrix values from equation, we then can use the place command to find the simulation gain values for the system according to the poles which placed at desired location. Equation (4.24) is the result obtained from the simulation.

$$K2 = [\ -0.9620 \quad 0.1390 \quad 0.2642 \quad 0.0617] \quad (4.24)$$

The closed-loop transfer function of the WWTP system related to dissolved oxygen concentration and air flow rate is as shown in equation (4.25).

$$G_{closed-loop} = \frac{0.0699s^3+0.03403s^2+0.004151s+0.000029}{s^4+1.5s^3+1.125s^2+0.375s+0.0625} \quad (4.25)$$

4.3.5 Observer Design

Controller design relies upon access to the state variables for feedback through adjustable gain. Any misinterpretation or error in state variables can causes disturbance to the system. First the gain of the observer determined using simulation.

4.3.5.1 System of Substrate Concentration with Dilution Rate

The gain value obtained for system 1 is as in equation (4.26).

$$\text{L1} = (1.0e^{+4})\begin{bmatrix} 0.0990 \\ -0.4729 \\ 2.3711 \\ -0.9109 \end{bmatrix} \quad (4.26)$$

After the gain value simulation, the matrix value of the system with observer obtained as represented in equation (4.27) to (4.29). Equation (4.30) is the transfer function of the system with observer design.

At1= (4.27)

$$(1e^{+6})\begin{bmatrix} -0.0000 & -0.0000 & -0.0000 & -0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0000 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.0000 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.1327 & -0.2925 & -0.0530 & -0.0006 \\ 0 & 0 & 0 & 0 & 0.6336 & 1.3964 & 0.2531 & 0.0028 \\ 0 & 0 & 0 & 0 & -3.1773 & -7.0018 & -1.2690 & -0.0139 \\ 0 & 0 & 0 & 0 & 1.2206 & 2.6899 & 0.4875 & 0.0053 \end{bmatrix}$$

$$\text{Bt1} = \begin{bmatrix} 1.7071 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (4.28)$$

Ct1 = (4.29)

[134.0000 295.3000 53.5200 0.5858 0 0 0 0]

$$G_{\text{with observer}} = \frac{228.7s^3+504.1s^2+91.36s+1}{s^4+3s^3+4.5s^2+3s+1} \quad (4.30)$$

4.3.5.2 System of Dissolved Oxygen Concentration with Air Flow Rate

The gain value of system 2 is as in equation (4.31) below.

$$L2= (1.0e^{+6})\begin{bmatrix} 0.0082 \\ -0.0418 \\ 0.2217 \\ -2.5252 \end{bmatrix} \tag{4.31}$$

After the gain value simulation, the matrix value of the system with observer obtained as represented in equation (4.32) to (4.34). Equation (4.35) is the transfer function of the system with observer design.

At2 = (4.32)

$$(1e^{+5})\begin{bmatrix} -0.0000 & -0.0000 & -0.0000 & -0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0000 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.0000 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.0058 & -0.0028 & -0.0003 & -0.0000 \\ 0 & 0 & 0 & 0 & 0.0292 & 0.0142 & 0.0017 & 0.0000 \\ 0 & 0 & 0 & 0 & -0.1550 & -0.0755 & -0.0092 & -0.0001 \\ 0 & 0 & 0 & 0 & 1.7651 & 0.8593 & 0.1048 & 0.0007 \end{bmatrix}$$

$$Bt2 = (1e^{+3})\begin{bmatrix} 2.1552 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{4.33}$$

Ct2 = (4.34)

[0.0699 0.0340 0.0042 0.0000 0 0 0 0]

$$G_{\text{with observer}} = \frac{150.6s^3+73.34s^2+8.946s+0.0625}{s^4+1.5s^3+1.125s^2+0.375s+0.0625} \tag{4.35}$$

After the results of gain values such as K1, K2, L1 and L2 for controller and observer obtained, the values were exported to Simulink block diagram so than the result can be analysed from the graph simulated to compare the performance of Davison and Penttinen-Koivo method. In the next subtopic the results from the Simulink block diagram were analysed and discussed accordingly.

4.4 Open- Loop Analysis

As for the starting result, an open loop analysis was made to show that the input and output will be of different values since there is no feedback system in open loop analysis in which the output will not be corrected referring to set point so that the error obtained to be compensated. Instead the input will be as it is which only gives signal for the plant to function and produce an output which does not follow the inputs or any set points.

4.4.1 Open- Loop Analysis of Substrate Concentration

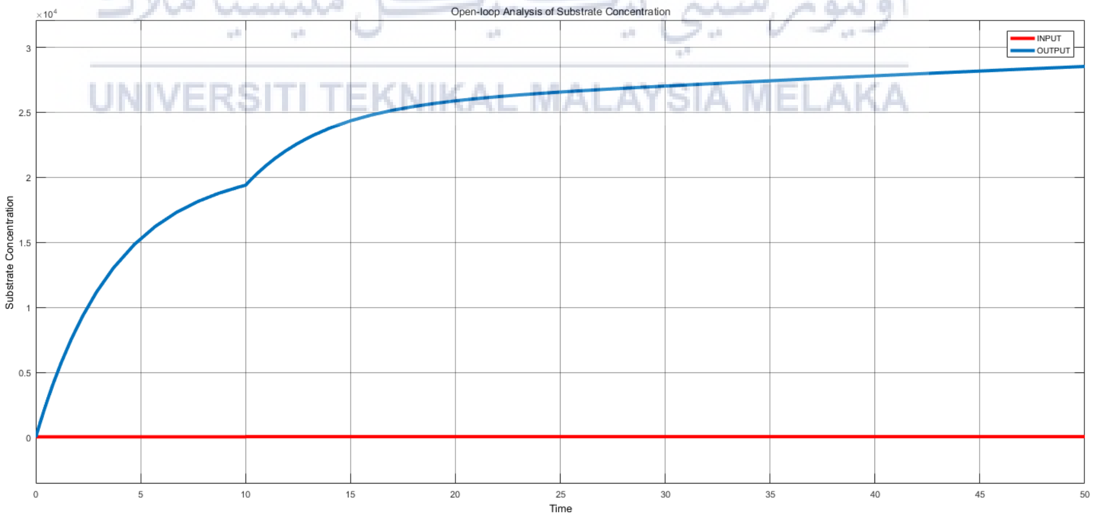

Figure 4.1 Graph of Substrate Concentration with Initial Input Values (D)

In the open-loop analysis, there is no feedback system. Usually the output will not follow the input values as there is no gain available to compensate the error and help the output variable to follow the set points. Referring to the Figure 4.1, we can conclude that the substrate concentration (blue) does not follow the initial value of dilution rate D = 41.2348 h^{-1} together with the step signal of 10 as there is no feedback system available for error compensation. According to the graph the input (red) shows a straight line although step signal is feed to the system. This is because the output of the system reacted with large value range which causes the step signal to appear straight line.

4.4.2 Open-Loop Analysis of Dissolved Oxygen Concentration

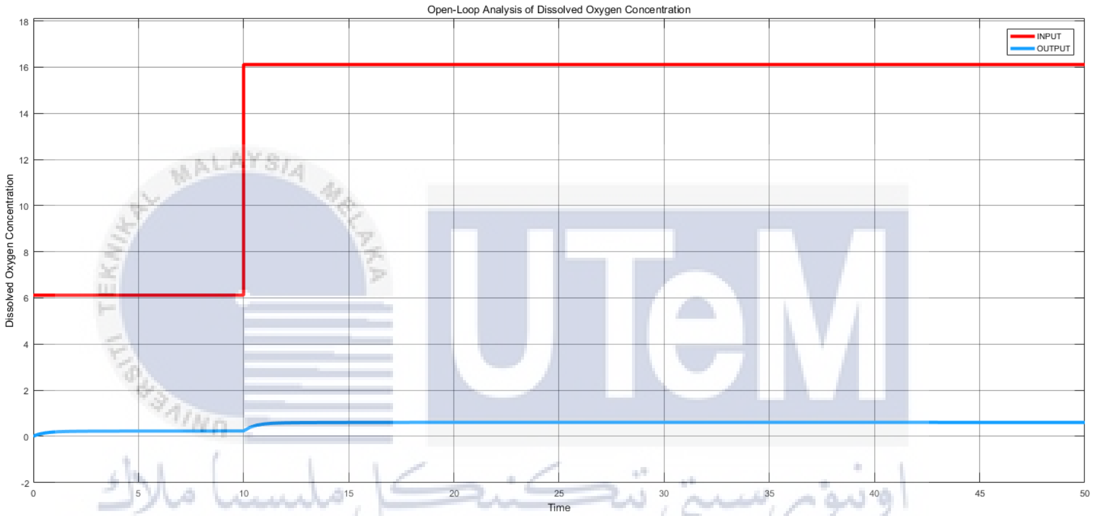

Figure 4.2 Graph of Dissolved Oxygen Concentration with Initial Input Values (W)

In the open-loop analysis, there is no feedback system. Usually the output will not follow the input values as there is no gain available to compensate the error and help the output variable to follow the set points. Referring to the Figure 4.2, we can conclude that the dissolved oxygen (blue) does not follow the initial value of air flow rate W = 6.1146 m^3/h together with the step signal of 10 as there is no feedback system available for error compensation. So the better way to overcome this problem is by making the system as closed-loop feedback system.

4.5 Closed-Loop Analysis of Davison with Observer

The difference between closed-loop compared to open-loop analysis is that it has feedback loop which can compensate error. So if the initial input injected in the system, then the output will follow the input according to the controller efficiency. In this Simulink block diagram Davison is used as controller with only integrator as gain value.

4.5.1 Davison with Observer for Substrate Concentration

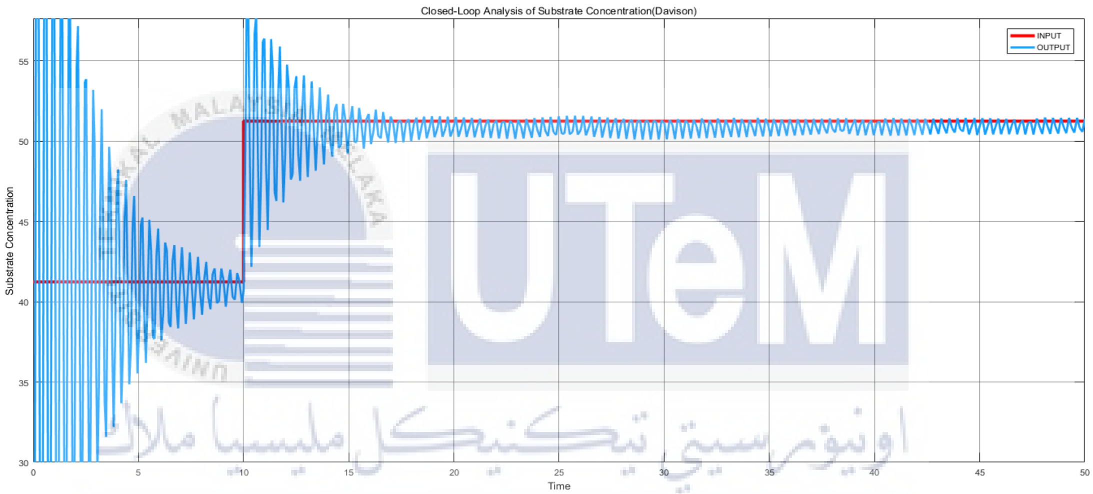

Figure 4.3 Graph of Substrate Concentration with Input of Dilution rate (Davison)

From Figure 4.3, we can see that the output of substrate concentration (blue), track and follow the input value which is the initial dilution rate value (red). But the output clearly seen to be oscillating a lot with an overshoot of more than 55%. The oscillation become lesser after 15 second of simulation. Oscillating signal is absolutely not good to the system and ways to overcome this problem should be analysed. For that a more upgraded controller must be used to minimize the overshoot values.

4.5.2 Davison with Observer for Dissolved Oxygen Concentration

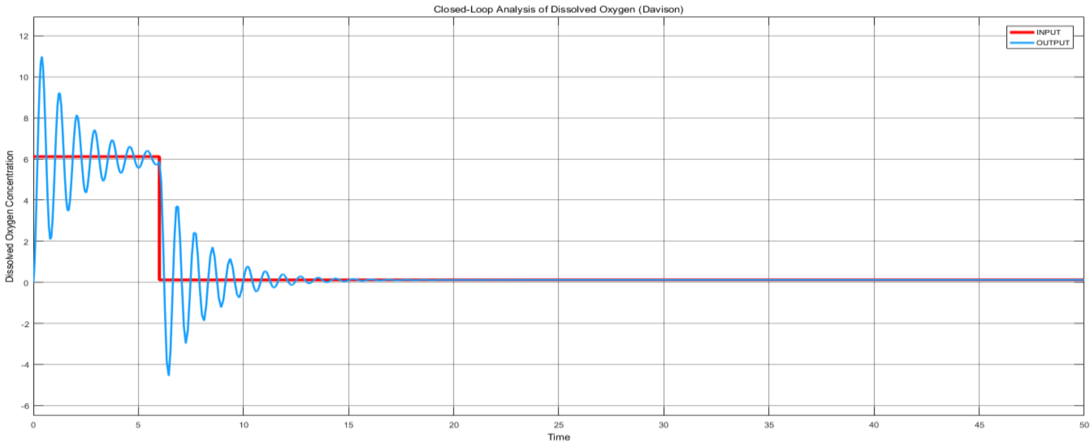

Figure 4.4 Graph of Dissolved Oxygen with Input of Air Flow Rate (Davison)

From Figure 4.4, we can see that the output of dissolved oxygen (blue), track and follow the input value which is the initial air flow rate value (red). But the output clearly seen to be oscillating with an overshoot of more than 85%. The oscillation settled after the time of 15 second. Oscillating signal is absolutely not good to the system and ways to overcome this problem should be analysed. To achieve better performance a more upgraded controller must be used to minimize the overshoot values as well as the oscillation settling time.

4.6 Closed-Loop Analysis of Penttinen-Koivo with Observer

The difference between closed-loop compared to open-loop analysis is that it has feedback loop which can compensate error. So if the initial input injected in the system, then the output will follow the input according to the controller efficiency. In this Simulink block diagram Penttinen-Koivo is used as controller with proportional and integral term as gain value. Penttinen-Koivo is upgraded with the proportional value where the output is expected to be better than Davison. Apart from that the observer which implemented together with the controller will correct the error that occur in the estimation of state variable. Wrong information of state variables can cause the system to be unstable and not efficient. Together the system output will be even better that the results before.

4.6.1 Penttinen-Koivo with Observer for Substrate Concentration

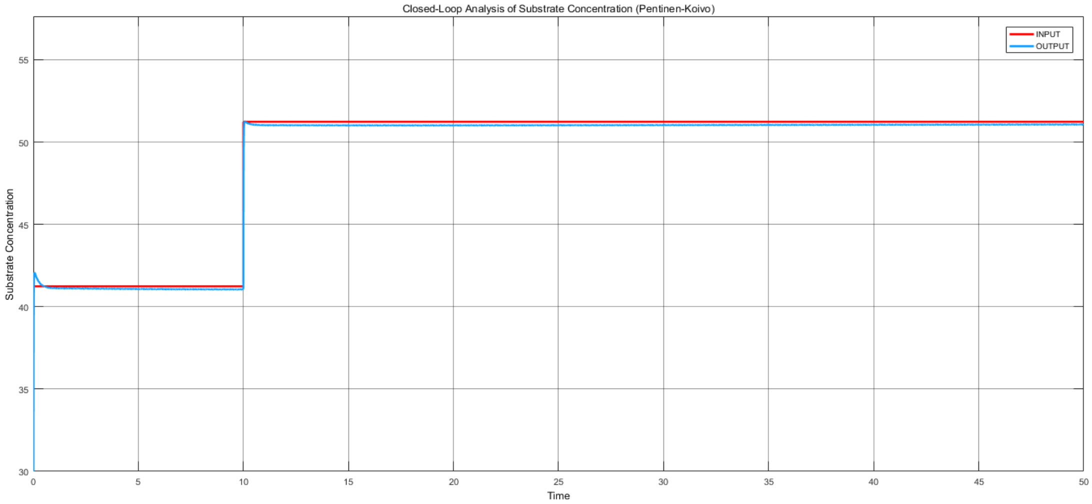

Figure 4.5 Graph of Substrate Concentration with Input of Dilution Rate (Penttinen-Koivo)

As can be seen in the Figure 4.5, when the upgraded version of controller (Penttinen-Koivo) is used the output signal (blue) does not oscillate as when Davison is used. The graph does not oscillate for even once. The overshoot decrease drastically from nearly 55% to less than 1%. Moreover the settling time was nearly 10 second compared to Davison which took over 15 second to settle down. From the graph we also can conclude that the steady state error is nearly less than 1% which show excellent output results. Hence, we can prove that Penttinen-Koivo controller shows better result compared to Davison controller outputs.

4.6.2 Penttinen-Koivo with Observer for Dissolved Oxygen Concentration

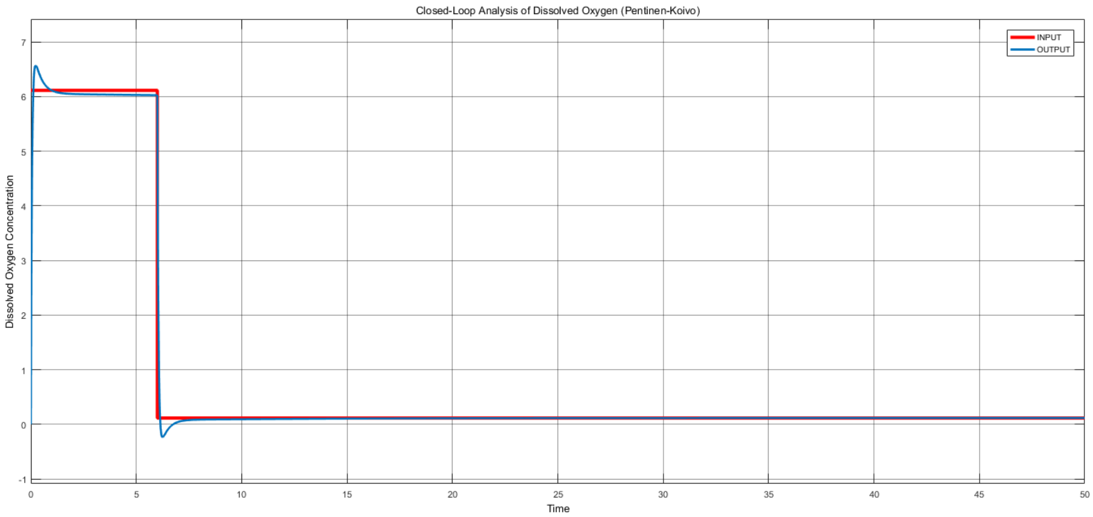

Figure 4.6 Graph of Dissolved Oxygen Concentration with Input of Air Flow Rate (Pentinen-Koivo)

As can be seen in the Figure 4.6, when the upgraded version of controller (Pentinen-Koivo) is used the output signal (blue) does not oscillate as when Davison is used. The graph does not oscillate for even once. The overshoot decrease drastically from nearly 85% to less than 9%. Moreover the output graph was very calm from the beginning which implies that the settling time was better than Davison controller. The graph show that the steady state error is also less than 1%. From the graph in Figure 4.6, we can prove that Pentinen-Koivo controller shows better result from the Davison controller outputs.

4.7 Comparison between Davison and Penttinen-Koivo Controllers

Table 4.1 Comparison of Performance between Davison and Penttinen-Koivo

Characteristic //Controller	**Davison**	**Penttinen-Koivo**
Overshoot	Very bad	Good (<10%)
Oscillation	Very bad	No oscillation
Tracking Ability	Able to track input (high oscillation)	Able to track input (without oscillation)
Settling time	higher	lower
Overall Result	Low than moderate since can only track the signal properly	Excellent result with lesser overshoot, nearly no oscillation and smooth trackability

From Table 4.1, we can conclude that in term of overshoot values Penttinen-Koivo shows excellent performance with overshoot value less than 10% compared to Davison which has higher overshoot value of more than 55% for S concentration and 88% for DO concentration. Moreover from Figure 4.4 and 4.4 we can see that the oscillation for Davison was high compared to Penttinen-Koivo which has nearly zero oscillation as in Figure 4.5 and 4.6. This results prove that Penttinen-Koivo is the better controller compared to Davison. The ability to track the reference input was done excellently by Penttinen-Koivo compared to Davison as referred to Figure 4.5 and 4.6. Not only that Pentinen=Koivo has lower settling time compared to Davison which is the desired characteristic for all kind controller system. In conclusion, it is proven that Penttinen-Koivo has much more better performance compared to Davison in term of overshoot values, oscillation, tracking ability as well as settling time.

4.8 Observer Performance Analysis

In this project observer design is implemented in the system to ensure that the state variables can be estimated as soon as possible so that the WWTP system can operate effectively without any disturbance and error.

4.8.1 Trackability of Estimated State Variables,$\hat{x}$ to Original State Variables,x

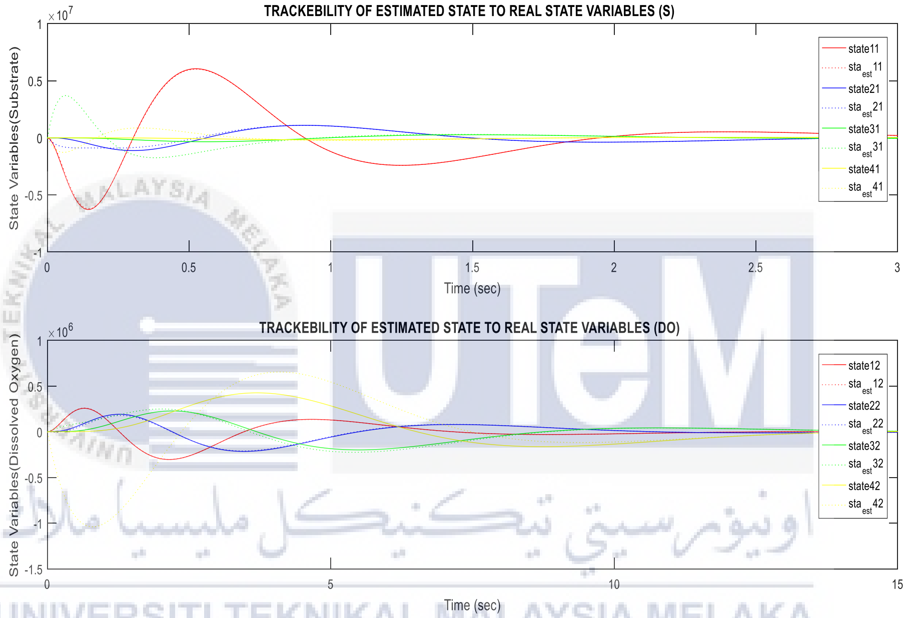

Figure 4.7 Graph of Estimated State Variables Tracking Original State Variables with State Observer

From the Figure 4.7, the graph shows us that with the help of state observer the state variable estimated from the observer regulate itself so that it can resemble the original state variables. In the first graph from the Figure 4.7, the first estimated state variable (red) able to track the real state variables from starting. The second estimated state variable (blue) took 0.5 second to resemble the original state exactly. Third estimated state variable (green) took 0.8 second to track while the last estimated state variable (yellow) track the original state variable within 0.7 second. The longest time taken was 0.8 second. After that all the state variables were tracked properly.

As for the second graph which is the system related to dissolved oxygen and air flow rate from the Figure 4.7, the first (red), second (blue) and third (green) estimated state variables were able to track the real state variables successfully from the beginning. Only the fourth estimated state variable tracked the real want at the time of 10 second. At first, the forth estimation seems to deviate a lot, but at last managed to track which proved that the observer is still efficient to be used as the time to settle is only 10 second.

This shows that the observer somehow managed to track the original state with the observer gain so that the system can operate properly although the original state variable cannot be obtained or not available. Observer causes the disturbance arise because of the unknown state variables solved systematically without interruption in a way to improve the WWTP system to operate efficiently.

4.8.2 Analysis of Observer Performance for Disturbance Rejection

In this experiment basically disturbance was injected into the system by adding a constant in the system. Any kind of output signal entered the WWTP will causes the plant to be unstable because of unexpected signal. This constant which represent as the disturbance of the system is actually assumed to be the external disturbance which could come from any type of external source. In both block diagrams which are Davison and Penttinen-Koivo, the disturbance was injected to compare the performance as well.

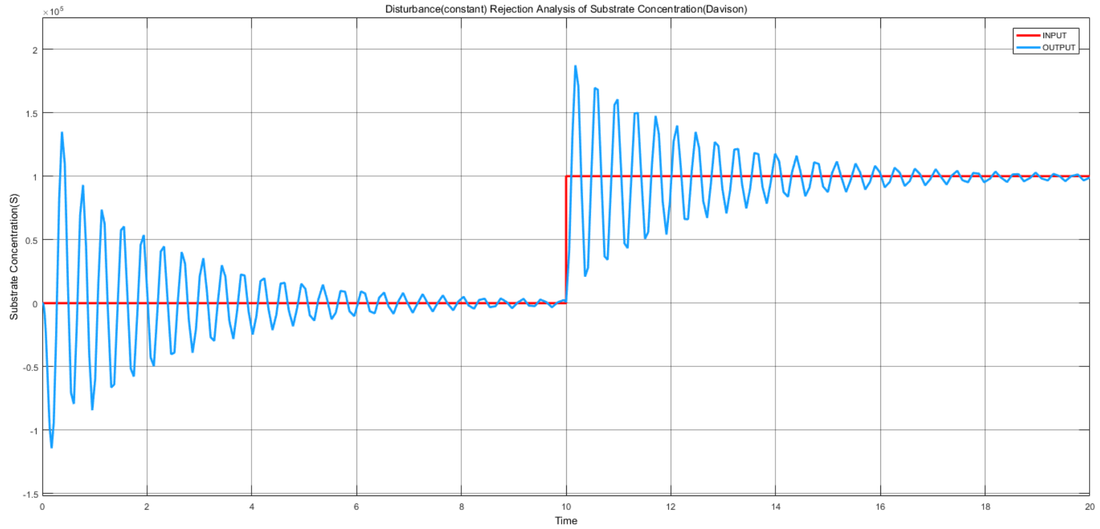

Figure 4.8 Graph of Disturbance Rejection Analysis Using Davison-Observer for S

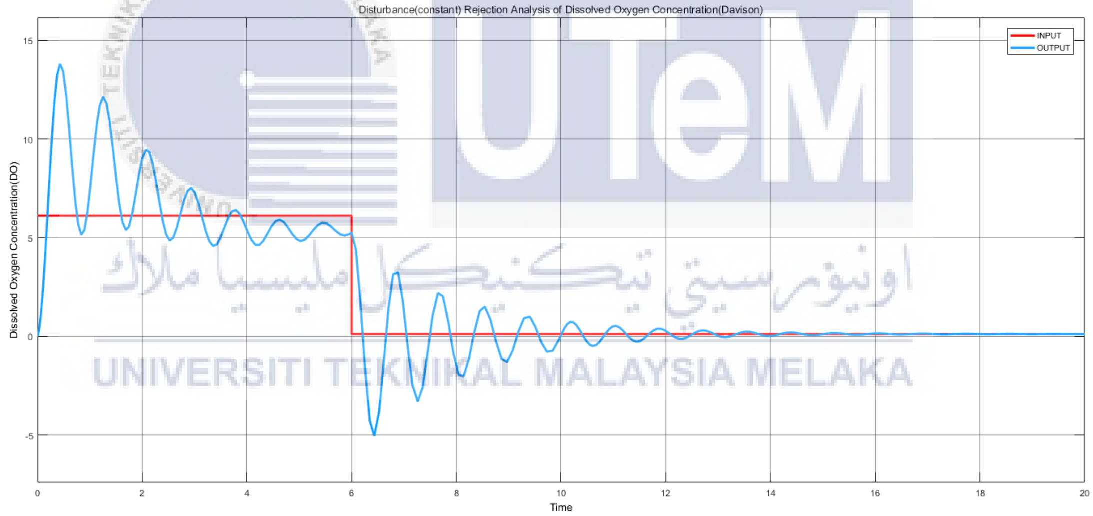

Figure 4.9 Graph of Disturbance Rejection Analysis Using Davison-Observer for DO

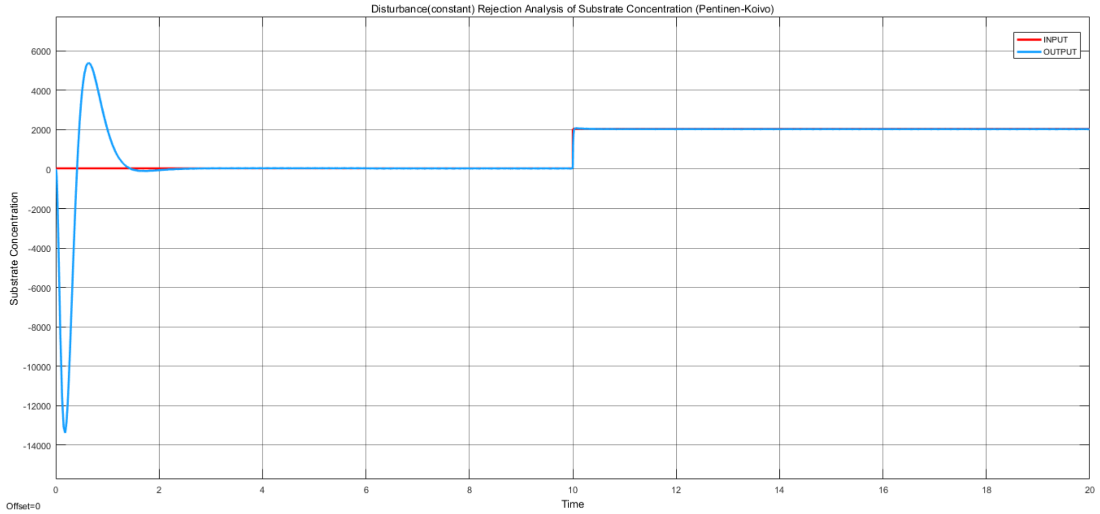

Figure 4.10 Graph of Disturbance Rejection Analysis Using Penttinen-Koivo-Observer for S

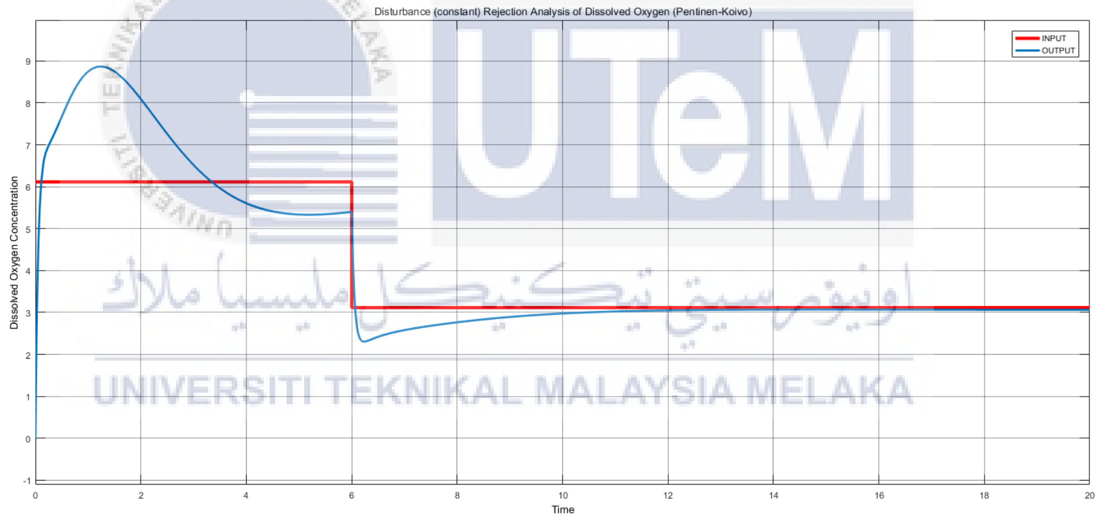

Figure 4.11 Graph of Disturbance Rejection Analysis Using Penttinen-Koivo-Observer for DO

Figure 4.3 and 4.4 are the output results without the presence of disturbance. Figure 4.8 and 4.9 are the output with disturbance of Davison controller. Comparing both, we can deduce that during the first 6 second there are disturbance signal presence which causes the actual signal to deviate as well as the overshoot to increase to over 60%. From the output performance of Figure 4.8 and 4.9 we can deduced that even with the presence of disturbance the observer work to reject the disturbance and direct the system to achieve the desired performance. As can be seen from the result, there are severe oscillation in the output result that caused by the Davison controller which has poor efficiency and tuning ability. This problem can be overcome using a better controller like the result produced in Figure 4.10 and 4.11 when Penttinen-Koivo was used.

Figure 4.5 and 4.6 shows the output response without disturbance of Penttinen-Koivo controller. Comparing to the graphs obtained in Figure 4.5 and 4.6 with Figure 4.10 and Figure 4.11 which has disturbance, we can conclude that at first the system that injected with disturbance was distracted by the injected constant value during the first 4 second where signal shows sinusoidal signal which is oscillating. Then after few seconds the signal able to track back to the desired output performance at the time of 4 second for Figure 4.10 and 10 second for Figure 4.11. This clearly proves that the observer helps to correct the difference between the real and estimated system values and reject the disturbance so that the output of plant can be tracked as desired. Apart from that, here we again can conclude that Penttinen-Koivo operates better than Davison controller. In the end, this simulation with disturbance portrays the power of observer in rejecting the disturbance.

4.9 Summary

In conclusion, from the studies and analysis it is proven that better controller will make sure that the output signal to be excellent without any oscillation and compensate error present in the system efficiently. In this project Penttinen-Koivo was the best controller compared to the Davison controller. As for the state observer, we can say that the observer estimated the state variable in time by compensating error. Moreover when disturbance injected observer manage to reject the disturbance and tract back to the desired output performance. This is important for the operation of the WWTP system as inaccurate estimation can cause inaccurate output which deviated from the desired values. Not only that, ability of observer to reject disturbance was clearly shown from the results obtained.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, we can say that feedback controller is an important algorithm that need to be implemented in any type of control system. Not only that, feedback system together with feedforward system will surely enhance the performance of control system where in this project WWTP is the control system. Feedforward system will prevent the error, uncertainties and disturbance that effect the output of the control system so that the conflicts does not influenze the output of the system. This is because, feedforward will estimate the disturbance caused from the unavailable state variables information or uncertainties earlier than the actual plant and feedback the signal so that the controller can operate properly and error eliminated as early as possible without interfacing the output. In this project Davison and Penttinen-Koivo controllers were also used as feedback controller while state observer was used as feedforward controller. From the literature review of other journals related to the disturbance rejection criteria, we can conclude that the disturbance rejection of a system and the performance of a system can be improved by integrating efficient controller and observers.

At first, the objective of studying and analysing the wastewater treatment plant was achieved where the fundamental and basic theory of WWTP had been studied. During the process, since WWTP system is a non-linear as well as multivariable system, the system were linearized to ease the conduct of the simulation and implementation. Then Relative Gain Array was analysed so that the best pair of the input and output variables can be obtained. After the above simulation, the second and third objectives were able to be achieved using the generated systems from linearized process for closed-loop simulation and observer design. The result from the simulation were then used in Simulink block Diagram to compare the performance of two types of controller which is Davison and Penttinen-Koivo controller. Not only that, disturbance was also injected into the system by adding constant to the plant. This was done to evaluate the performance of observer towards disturbance rejection.

From the simulation result, we can conclude that Penttinen-Koivo which is the upgraded version of Davison method shows the best result with no oscillation, less than 10% overshoot as well as nearly zero steady state error. While Davison controller showed so much of oscillation with greater overshoot value that is not desirable. Moreover the performance of the observer with controller surely shows a better performance since observer can tract the original state variable in lesser time during the simulation in m-file. This is important because inaccurate information of state variables will causes the system to operate inefficiently. Apart from that, an open loop analysis was made so that a comparison could be made when a closed loop analysis is made together with the controllers. The comparison between open-loop and closed-loop system obviously shows that the closed-loop system portrays excellent result in term of accuracy, stability and disturbance rejection capability. Moreover, when disturbance injected, observer operates immediately by rejecting the disturbance presence and brought back the output to the desired output performance. In conclusion, the objectives of this project have been achieved successfully. An efficient controller for a system which is whether multivariable, non-linear, linear or unstable is always necessary so that the processes of a system can be carried out as desired.

5.2 Recommendation

As for future work if any want would like to upgrade this system, it is recommended to design controller for non-linear system of WWTP itself without changing to linear system. Apart from that, more advance controllers can be used to be implemented in the system so that the system can be more efficient than what it is now. Not only that, maybe the rejection of disturbance of continuous injection or inflow of disturbance can be investigated with the new idea of controllers.

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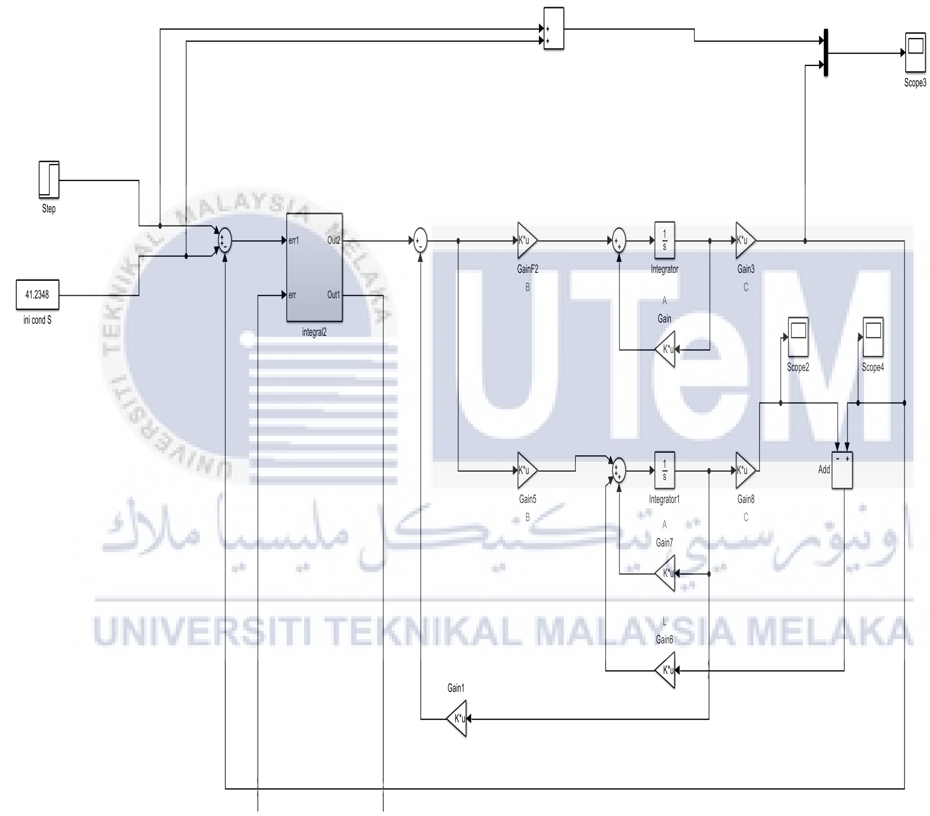
APPENDICES

APPENDICES A: Block Diagram of the Controller and Observer in Simulink (Focused View)



APPENDICES B: Block Diagram of the Controller and Observer in Simulink (Overall View)