CERTIFICATION OF APPROVAL

The Design of Automated Control System for Wastewater Treatment Plant

by
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

WENDIMU FANTA GEMECHU

ABSTRACT

Currently, because of the daily human waste to environment, the water, the air breathed by humans are not clean. Even though most developed countries are having improved system of wastewater treatment system, the treatment process is done partly by human and sometimes problem can occur during the process which reduces the quality of the effluent wastewater. In order to overcome human errors, the use of digital computer to control the process of the wastewater treatment processes is needed.

This report discusses about the process of wastewater treatment process and how to design the automated control system for the system. Domestic wastewater can be treated in many ways: physical, chemical and biological unit processes.

Since the wastewater treatment process is vast and at the same time, the most important process in wastewater treatment, activated sludge process, will be discussed.

Automated control system design for the plant is also built using activated sludge wastewater treatment process.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND NOMENCLATURES

A_a	Cross sectional area of the aeration tank
BOD	Biochemical Oxygen Demand
DO	Aeration tank oxygen concentration
DO_{in}	Influent oxygen concentration
DO_{max}	Saturated oxygen concentration
K_{DO}	Oxygen saturation constant
K_La	Oxygen transfer rate
K_S	Substrate saturation constant
MLSS	Mixed Liquor Suspended Solids
PID	Proportional Integral Derivative
Q_{in}	Influent flowrate
Q_r	Recycle flowrate
Q_w	Wastage flowrate
RAS	Return Activated Sludge
S	Aeration tank substrate concentration
S_{in}	Influent substrate concentration
SRT	Solid Retention Time
SS	Suspended Solids
V_a	Aeration tank volume

V_S	Settling tank volume
W(t)	Air flowrate
WAS	Waste Activated Sludge
WWTP	Wastewater Treatment Process
X	Aeration tank biomass concentration
Y	Biomass yield factor
α	Oxygen transfer rate
μ	Biomass growth rate
μ_{mx}	Maximum specific growth rate

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The improper disposal of human excreta and sewage is one of the major factors threatening the health and comfort of individuals in areas where satisfactory municipal, on-site, or individual facilities are not available.

To guarantee clean wastewater discharge, extensive quality monitoring of the source and effluent of wastewater plants is performed. In case the wastewater quality does not meet the guidelines or Standards A and B as formulated by Department of Environment (Embas, 2009), the operation of the treatment is changed on basis of operator knowledge and experience. The quality of this effluent wastewater is influenced by day-to-day decisions of individual operators and operation is therefore sub-optimal.

The increase in population number puts pressure on the environment and threatens sources of fresh water, air and others. These environment disturbances by ‘human waste or action’ need proper management.

There has been a steady evolution of sewage (wastewater) treatment since early 1900s until modern day treatment plants producing high quality effluent which can be reused or discharged to the environment.

Recent developments in wastewater treatment systems have been improving the ability and efficiency of the system to comply with the effluent wastewater Standards A and B given by Environmental Quality Act 1974 and reducing the land occupied by treatment plants through accelerating natural treatment rates under controlled conditions (Embas, 2009).

In addition, the designs are based on the performance of individual processes with pre-set boundary conditions. It is assumed that an integral approach of the entire treatment plant can lead to more efficient operation.

The developments in sensor devices, automation and computation make the treatment system a challenge to improve quality and reliability of the treatment plants and to make maximal use of the installed infrastructure, postponing new investments.

Sewage comprises of various pollutants that enter the sewerage system from domestic, commercial and industrial premises. It is more than just what goes down a toilet as it also includes wastewater from kitchen, bathrooms and laundries.

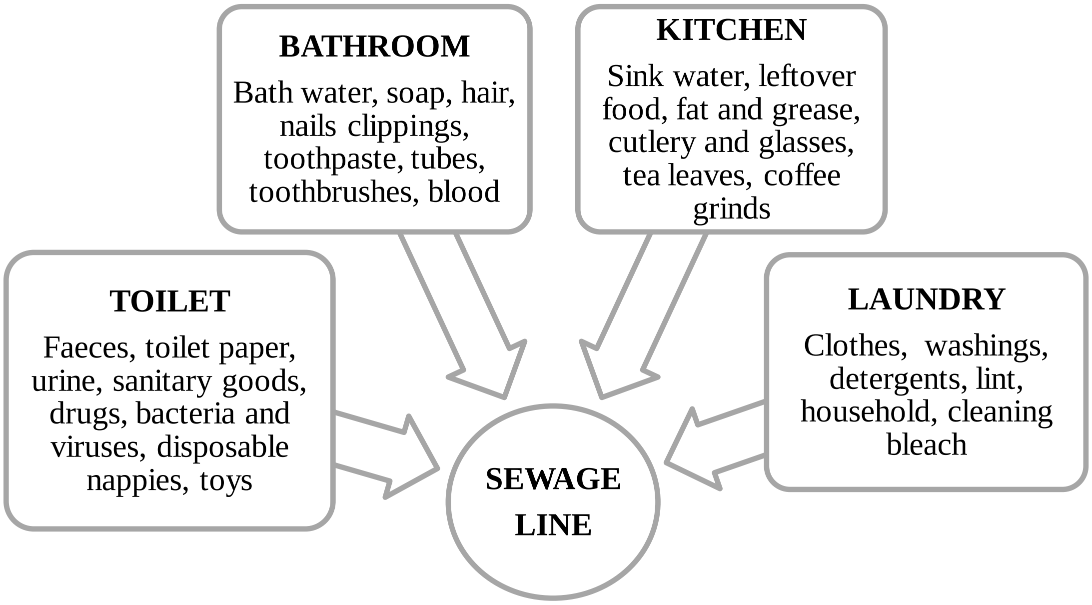

Figure 1: Waste materials entering sewerage from households (Indah Water Konsortium Sdn Bhd, 2010)

Indah Water Konsortium Sdn Bhd is Malaysia’s national sewerage company which has been entrusted with the task of developing and maintaining a modern and efficient sewerage system for all Malaysians. This project is partly depending on the wastewater treatment methods the company is following and partly on the system that simplify the operation of the treatment process.

The quality of the effluent product depends on the treatment method, chemical compound, and other nutrients we apply in our process. Wastewater treatment processes involves some chemical elements.

These chemical elements are shown on Table 1.

Table 1: Common elements in wastewater treatment process management

Name	**Symbol**	**Name**	**Symbol**
Arsenic	As	Nickel	Ni
Copper	Cu	Oxygen	O
Cadmium	Cd	Potassium	K
Cromium	Cr	Silicon	Si
Cobalt	Co	Mercury	Hg
Calcium	Ca	Sodium	Na
Carbon	C	Lead	Pb
Chlorine	Cl	Sulfur	S
Hydrogen	H	Zinc	Zn
Iron	Fe	Tungsten	W
Magnesium	Mg	Vanadium	V
Manganese	Mn	Selenium	Se
Nitrogen	N	Molybdenum	Mo
Phosphorus	P		

1.2 PROBLEM STATEMENT

The increase in population number puts pressure on the environment and threatens the sources of food, fresh air, and fresh water. These human wastes or actions need proper management. Statistics shows more than six billion people in the world today, over one billion have no access to improved drinking water—a basic necessity for human life and about 2.6 people do not have access to improved sanitation.

Most of the wastewater treatment plants that have been used involve human interferences. To overcome this automated control system is needed to be done.

1.3 OBJECTIVES AND SCOPE OF STUDY

1.3.1 Objectives

The objective of the project includes:

1. To model and design an automated control system for wastewater treatment plant.
2. To simulate and study on the automated control system for wastewater treatment plant

1.3.2 Scope of Study

The project is all about designing automated control system for wastewater treatment plant. The control system is designed for biological wastewater treatment process specifically for an Activates Sludge wastewater treatment system.

CHAPTER 2

LITERATURE REVIEW

2.1 WASTEWATER BACKGROUND

Sewage i.e., domestic wastewater is the water that has been used by a community and contains waste materials added during its use. Those wastes composed of human body wastes (urine) together with the water used for flushing toilets, and sullage, which is the wastewater resulting from personal washing, laundry, food preparation and the cleaning of kitchen utensils and many more. The wastewater can also be distinguished by its offensive odor.

The sewage is characterized by its physical, chemical and biological composition. The main constituents of these compositions are (Indah Water Konsortium Sdn Bhd, 2010):

1. Physical Properties: Color, Odor, Solids and Temperature,
2. Chemical Constituents :
   2.1 Organic - Carbohydrates, Fats, Oil, Grease, Proteins, and Surfactants
   2.2 Inorganic - pH, Chlorides, Nitrogen, Phosphorus, Sulfur
   2.3 Gases - Hydrogen Sulphide, Methane, Oxygen
3. Biological Constituents: Bacteria, Viruses, and Parasites

The urban sewages are characterized mainly by three parameters: the biochemical oxygen demand (BOD), the concentration of suspended solids (SS) and the bacteriological quality.

1. *Biochemical oxygen Demand (BOD*). This is the amount of oxygen uptake by bacteria of the organic content of the effluent for a set of standard incubation period conditions. Usually the incubation occurs over five days and at 20^0C; this gives the term five day BOD and hence the notationBOD_5^{20}.

   $$BOD_5{}^{20} = DO_0 - DO_5 \qquad (2.1)$$

   where DO_0 *and* DO_5 *are the initial and five days DO content. BOD is measured in [mg/litre].*

2. *Suspended Solids (SS).* The effluent wastewater contains material in suspension and divided into inorganic and organic components. The inorganic portion includes materials like grit and silt. The organic component has a much wider variety of sources but is likely to include bacteria, fats, grease, human waste, and food waste. The SS measured in [mg/litre].

According to **Environmental Quality Act 1974**, the effluent has to meet standards marked before discharging it to environment. The two most important parameters should meet the standards: Standard A (discharge to upstream) and Standard B (discharge to downstream), are Biochemical Oxygen Demand (BOD) and Suspended Solids (SS) as shown on Table 2(Embas, 2009):

Table 2: Common elements in wastewater treatment process management (Indah Water Konsortium Sdn Bhd, 2010).

Standard	BOD (mg/L)	SS (mg/L)
A	**20**	50
B	50	100

2.2 WASTEWATER TREATMENT PROCESSES

The wastewater treatment processes can be summarized as shown on Figure 2. These processes are adapted from (Eddy, 2004).

Preliminary Treatment Processes

- Screening - for removal of oversized solids, and
- Comminution - to screen and shred materials to sizes from 6 to 19 mm.
- Grinding - to tap and shear solids into a consistent size (6 to 9 mm).
- Sedimentation - for the removal of grit
- Flotation - for the removal of grease and oil

Primary Treatment Processes

- Flocculation - using flocculating agent to cause particles to coalesce to a large size then removed by gravity method.
- Removal of settled primary sludge
- Primary settling - to settle suspended particles heavier than water by gravity under quiescent conditions

Secondary Treatment Processes

- **Biological process** (aerobic and anaerobic) - for removal of biodegradable organic and suspended solids
- Secondary or final settling

Tertiary Treatment Processes

- Removal of solids and toxic substances including heavy metals
- Disinfection
- Nutrient removal
- Filtration

Solid Handling or Sludge Processing

- Physical: Thickening and dewatering
- Biological: Stabilization or digestion
- Disposal

Figure 2: Summary of wastewater treatment processes (Metcalf, 2004)

Figure 3 shows the wastewater treatment process steps. It shows the process from influent to the end products both effluent wastewater and sludge handling processes.

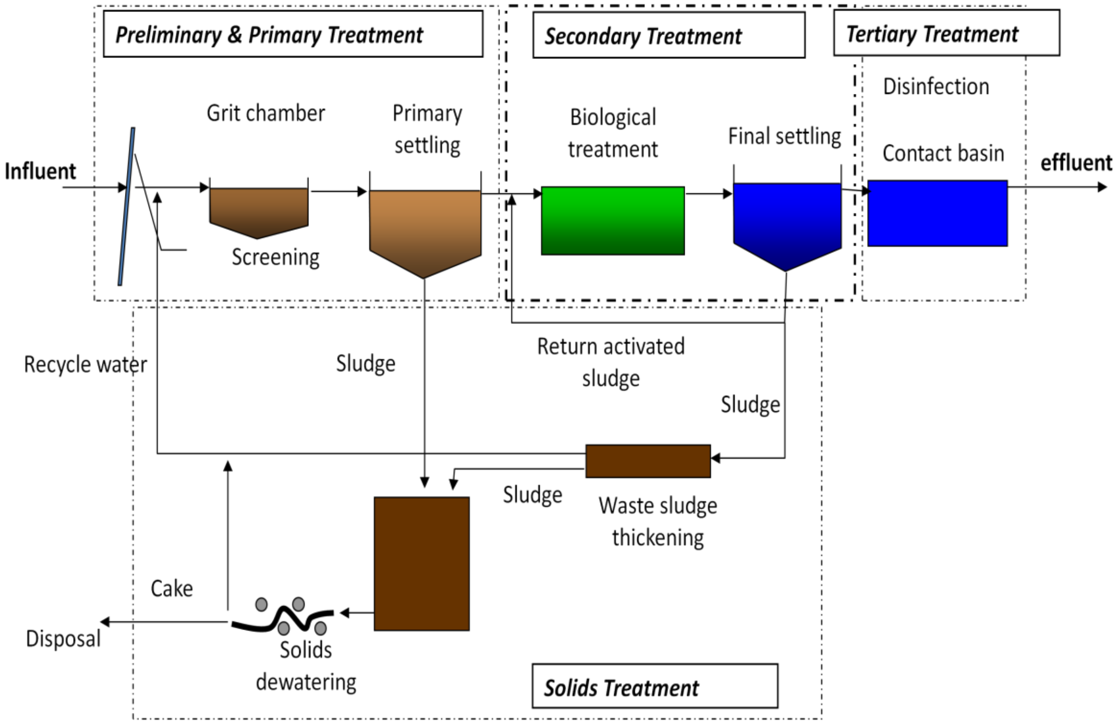

Figure 3: Typical wastewater treatment process flow (Eddy, 2004).

2.3 BIOLOGICAL WASTEWATER TREATMENT

Biological treatment of domestic wastewater is generally used to (Eddy, 2004):

1. Oxidize (convert) dissolved and particulate biodegradable constituents into acceptable end products
2. Capture and incorporate suspended and non-settleable colloidal solids into a biological floc or biofilm
3. Transform or remove nutrients, such as nitrogen and phosphorus, and
4. Remove specific trace organic constituents and compounds in some cases

In wastewater treatment processes, organic matters enter the process plant in different forms and converted from slowly biodegradable matter to readily biodegradable forms by biological process known as *hydrolysis*. The growth or microorganisms depends on factors like substrate concentration, temperature, pH, toxic and biomass (microorganisms) itself.

The basic biological renewal processes can be shown as follows on Figure 4.

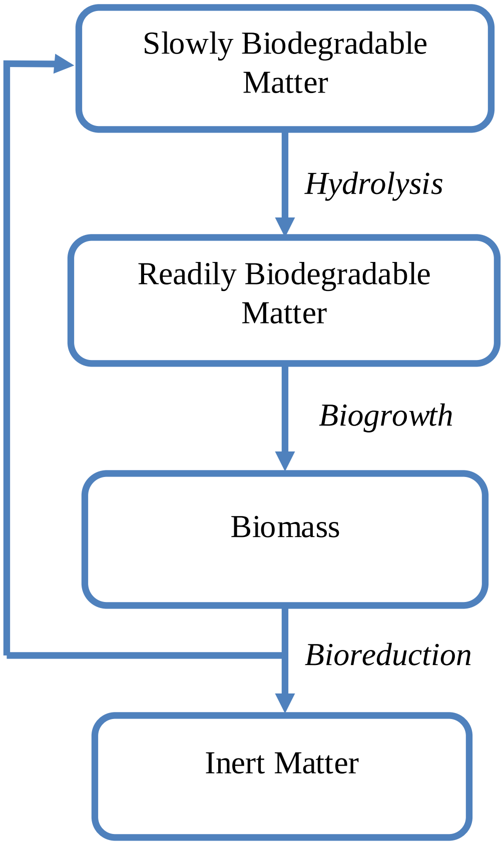

Figure 4: The biological renewal Process (Lindberg, 1997)

International Water Association (IWA) contributes a major part in biological processes in a WWTP. The Activated Sludge Models (ASM) family (ASM1, ASM2, ASM2d, ASM3) are used in most of the modeling and simulation studies, as well as in the commercial simulation platforms (Henze M., 2002). According to (Hauduc H., 2009), in an international ASM survey, 80% of the respondents used ASM models for various purposes. In today’s practice, Takács’ model is the most widely used mathematical representation of the clarifiers (Takács I., 1991).

2.3.1 Activated Sludge Process (ASP)

Wastewater and biological solids are first combined, mixed, and aerated in a reactor (aeration tank), see Figure 5.

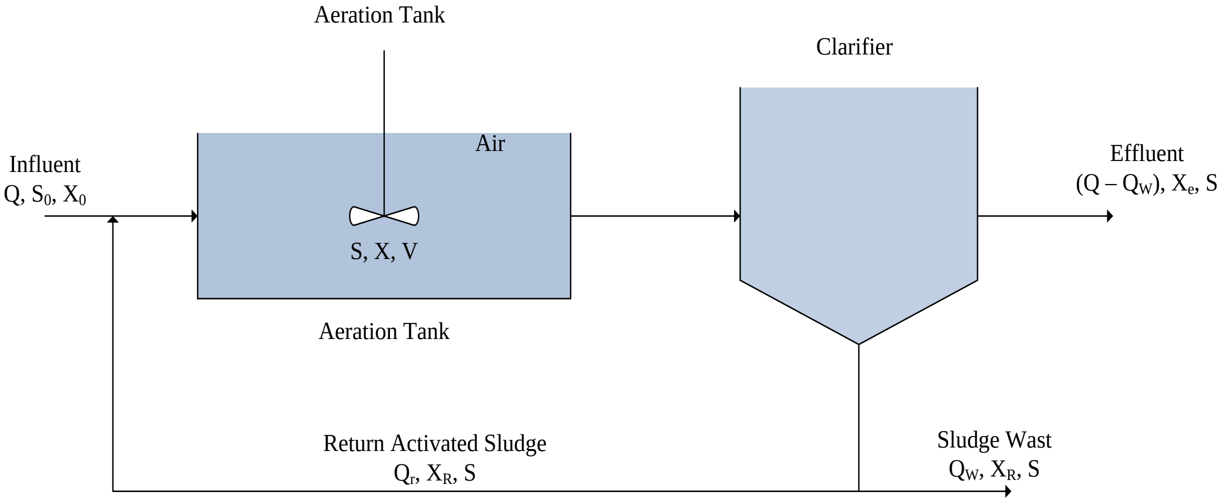

Figure 5: Activated sludge process control volume (Eddy, 2004)

2.3.2 Modeling Treatment Process Kinematics

Assumptions made during mass balance for the reactor system:

1. No active biomass in the present influent ($X_0 = 0$)
2. Biodegradation of organic wastes takes place only in aeration tank
3. No biological reactions in settling tank ($S=S_e=S_w$) hence biomass negligible

The following equations (2.2-2.8) are adapted from (Reza Katebi M. A., 1999).

Rate of Accumulation = Rate of inflow − Rate of outflow + Net growth within the Boundary

1. ***Wastewater Biomass Growth Law:*** Double Michaelis-Menten-Monod type of growth law that involves substrate and Dissolved Oxygen:

$$\mu(t) = \mu_{\max}\left[\frac{S(t)}{K_s + S(t)}\right]\left[\frac{DO(t)}{K_0 + DO(t)}\right] \tag{2.2}$$

where $\mu_{\max}$ = maximum specific growth rate $[h^{-1}]$
K_s = saturation constant $[mg/litre]$
K_0 = half - rate constant for oxygen $[mg/litre]$ and
$\mu(t)$ = the bacterial growth rate $[h^{-1}]$

2. ***Biomass Yield Relationships:***

$$Y = \frac{\text{mass of cells formed}(X)}{\text{mass of substrate consumed}(S)}$$

$$\frac{dS_{used}(t)}{dt} = \frac{\mu(t)X_v(t)}{Y} \tag{2.3}$$

3. ***Material Balance for Substrate (BOD):***

$$\frac{dS(t)}{dt} = \frac{Q(t)}{V}(S_{in}(t) - S(t)) - \frac{\mu(t)X_v(t)}{Y} \tag{2.4}$$

4. ***Material Balance for Viable (live/active) Biomass:***

$$V\frac{dX_v(t)}{dt} = Q(t)(X_v^{in}(t) - X_v(t)) + \mu(t)X_v(t)V - K_d X_v(t)V \tag{2.5}$$

Where K_d = death rate of viable biomass

5. ***Material Balance for Non-Viable (Dead) Biomass:***

$$V\frac{dX_{nv}(t)}{dt} = Q(t)(X_{nv}^{in}(t) - X_{nv}(t)) + K_d X_v(t)V \tag{2.6}$$

Where K_d = death rate of viable biomass

6. ***MLSS Concentration in Aeration Tank:***

$$M_T(t) = X_v(t) + X_{nv}(t) \tag{2.7}$$

7. ***Dissolved Oxygen (DO) Balance:***

$$\frac{dDO(t)}{dt} = \frac{Q(t)}{V}(DO_{in}(t) - DO(t)) - K_{DO}\frac{\mu(t)X_v(t)}{Y} + DO_c(t) \tag{2.8}$$

Where $DO_{in}(\mathrm{t})$ = influent *DO*

K_{DO} = coefficient of rate at which the substrate uses *DO(t)*

$DO_{\mathrm{c}}(t)$ = *DO(t)* supplied by the aeration system

2.4 AUTOMATED CONTROL SYSTEM

Control systems are needed to control a plant or any system that needs nearly perfection, and are very important for environments that are very dangerous for human to work.

The control systems are divided into: open loop and closed loop (feedback) control system. Open loop control systems are control systems without feedback while closed loop control systems are control systems with feedback response. Figure 6 shows an example of a closed loop system for wastewater treatment process.

Automated control systems are used to maintain the desired value of a measured or estimated process quantity (controlled variables) within prescribed limits (errors or deviation) without the direct action of the operator (J. B. Snape, 1995).

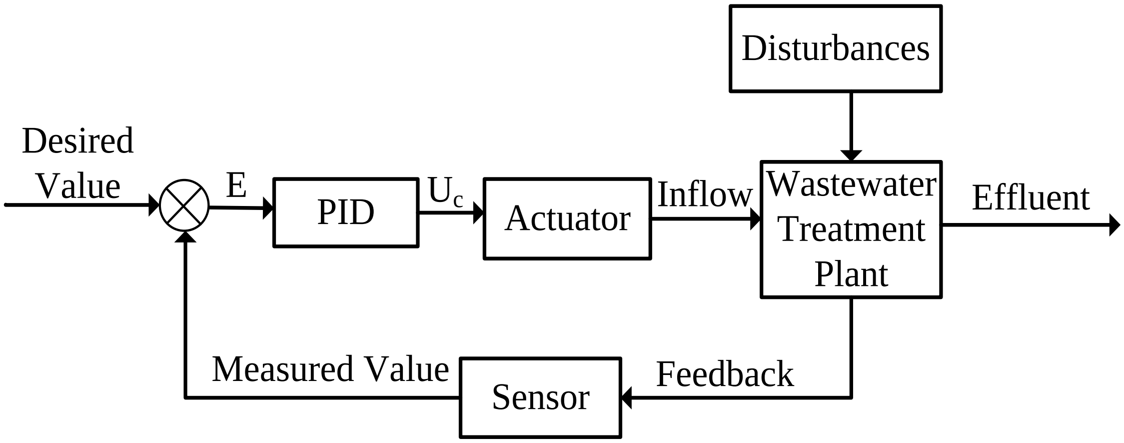

Figure 6: Automated control system for activated sludge process (Bolton, 2008)

2.4.1 PID Controller

The PID controller is a necessary controller in automated control systems. The PID represents three components: Proportional, Integral, and Derivative. The integral part of the controller is used to eliminate steady state errors while the derivative part is to make the controlled system more stable.

The PID controller looks like (Stenstrom, 1998):

$$u(t) = u_o + K\left[e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d \frac{de}{dt} \right] \tag{2.9}$$

Where, u_o *= bias value that gives proper signal amplitude,* $e(t)$ *= error signal between desired value and measured value,* K *= controller gain.*

Table 3: The three tem proportional, integral and derivative term and their properties(Reza Katebi M. A., 1999)

PID Term	Descriptions
Proportional (P)	✓ Increasing K_p speeds up the system response. ✓ Increasing K_p decreases any steady state offset if one exists. ✓ Increasing K_p too much may saturate actuators ✓ The dynamical order of the closed loop system is the same as that of the open loop system.
Integral (I)	✓ The integral term will almost exclusively be used in conjunction with P to give PI control ✓ Integral control eliminates steady state offsets; this is a guaranteed property. ✓ Measurement bias must not exist otherwise this destroys the use of I control to remove offsets. ✓ PI control increases the dynamic order of the closed loop system thereby introduce the potential for an unstable closed loop design. ✓ PI control can cause excessive overshoot in the system response.
Derivative (D)	✓ The derivative term will always be used in a structure, which includes P to give PD control at least. ✓ The derivative term can be used to reduce response peaks, and affect the equivalent damping of a system. Rate feedback in motor control is a special form of PD control. ✓ Derivative control has no effect on steady state error. ✓ Pure derivative control will amplify the high frequency noise in the measurement signal; hence it is usually implemented by a filtered form. ✓ Derivative control does not effect the dynamic order of the closed loop system.

The PID controller should be tuned before it is used in a system. But tuning it manually is difficult for slow dynamics processes. The classical Ziegler-Nichol's rules and auto-tuning are two of the ways to tune PID controller. The classical Zeigler-Nichol's method gives a fairly low damping. The auto-tuning method is based on a relay method and is a better choice. The process of auto-tuning is as follows: first, the controller is disconnected and replaced by a relay which induces a limit cycle oscillation. Then, the period and the amplitude of the oscillations give a point on the Nyquist curve which is used to choose the controller parameters (Lindberg, 1997).

There are three parameters that are adjusted to maintain efficient operation of an activated sludge process. They are dissolved oxygen levels, return activated sludge flows, and waste activated sludge flows. Among these, dissolved oxygen level (air flowrate) is the best choice because it can be optimized to control cost as well (Gustaf Olsson, 1999).

According to (Water Science and Technology, 1998), in order to keep activated sludge process stable and improve its performance, we have to apply a commonly used control system, conventional PI controller of the DO (dissolved oxygen) concentration which makes the DO concentration in aerator tank to be kept at desired level by manipulating air flow rate, W(t).

The PI controller provides the desired DO concentration by continuous aeration of activated sludge aeration tank with adjustable air flow rate, W(t).

Many publications have dealt with the control of effluent substrate concentration, S, which is still remain unresolved. Strong disturbances are among the factors which contribute to the problem of controlling the effluent quality. According to (Angelbeck D.J., 1978), because the influent follow rate, Q_{in}, cannot be used as control quantity, there are no quantities that influence the value of substrate concentration, S, to be considered as control quantities in classical continuous activated sludge process (Water Science and Technology, 1998).

During the last few years new water purification processes that provides effective control of substrate concentration, S, by manipulating output flow rate from aeration tank were published and applied in large scale wastewater treatment plants. Compared to conventional PI controller, model-based adaptive controller provides the ability to keep the value of substrate concentration equals to its set point, S^{sp} (Water Science and Technology, 1998).

Current control techniques for aeration systems are typically based on feedback signals provided by dissolved oxygen (DO) probes immersed in the aeration tanks. The dissolved oxygen concentration is an effect of oxygen transfer, and is an important indicator of proper process conditions. When the DO is too low, bacterial metabolism can be inhibited and the sludge composition may change, reducing the treatment efficiency or even causing process failures i.e., sludge bulking (Activated Sludge Process).

CHAPTER 3

METHODOLOGY

3.0 PROJECT FLOWCHART

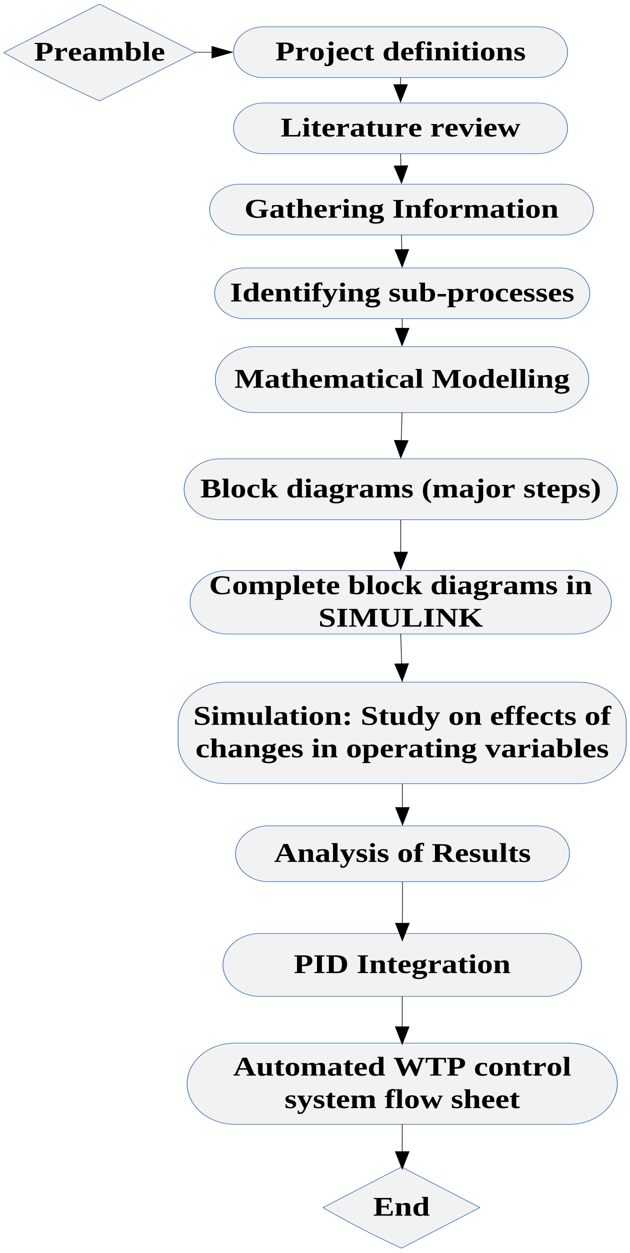

Figure 7: The basic flow process to complete the project

3.1 PREAMBLE

Real-time control system for Activated Sludge Process involves different kinds of instrumentations. These instrumentations include: pressure sensors, temperature sensors, Do sensors, pH sensors, flow meters, level measurement devices and vibration sensors.

Flow Meters. Flow meters measure the flow rate of concentrations of wastewater in general. Some of the most widely used flow meters includes: magnetic flow meters (“mag” meters), ultrasonic, flumes and weirs, differential-pressure, mechanical and mass-flow meters.

Level-measurement Devices. There are two types of level-measurement devices: continuous and point. The continuous level measurement devices includes: bubbler, capacitance and impedance, differential-pressure, sonic and ultrasonic, and microwave (radar). The point level measurement devices includes: ultrasonic gap, float, frequency-shift tuning fork, thermal dispersion, hydrostatic, conductivity, capacitance, and inductance.

Vibration Sensors. Vibration sensors monitor the mechanical conditions of pumps, motors, compressors, blowers, centrifuges, and other rotating and reciprocating devices. They also detect sudden mechanical failures and abnormal process conditions that stresses the machines.

Pressure Sensors. Pressure sensors monitor the pressure of those instruments involve in the wastewater processes pressure of pumps, pressure through pipes and the like. In general they monitor: compressed-air distribution systems, pump suction and discharges, and pressure-vessel pressures.

Temperature Sensors. Temperature sensors monitor the temperature of the wastewater in the vessels. The temperature sensors includes: thermocouples and thermalbulbs, resistance temperature detectors (RTDs), and thermisters.

DO Sensors. Do sensors or probes are used to monitor the oxygen content in the aeration tank. Two of the most widely used Do sensors in wastewater treatment plants are zullig sensors and luminescent dissolved oxygen sensor. Most continuous-measurement or on-line analysis of DO sensors use: galvanic (spontaneous voltage), polarographic, or amperometric electrolytic (applied voltage) means using cells.

pH Sensors. pH sensors are used in wastewater treatment plant mainly to monitor plant conditions, track biological treatment process conditions, and control acid base additions for pH adjustments. The pH values for different wastewater treatment processes are different. For instance, activated sludge systems can tolerate a pH variance of 5 to 9.

3.2 PROJECT DEFINITION

Automated control system is to be designed for domestic wastewater treatment using activated sludge process system. In order to design a control system we should:

1. Define our system of concern.
2. Proper schematic drawing of the system, (Figure 15),
3. Identifying the relevant variables in the system, (Figure 16) and classifying them into:
   3.1 Controlled output variables,
   3.2 Manipulated variables and
   3.3 Disturbances
4. Selecting control strategy i.e., feedback, feedforward, cascade and the like to achieve control objective
5. Dynamic model of the system and
6. Verification of the model

For complete system parameters and their respective units as well as their categories, see Appendix (A.2)

3.3 LITERATURE REVIEW AND GATHERING INFORMATION

In order to design wastewater treatment system, at least two important points should be considered: nature of the pollutants and quality of effluent system needed. Most pollutants in domestic wastewater are organic in nature and are best treated by biological treatment process (Indian Institute of Technology, 2007).

3.4 MATHEMATICAL MODELING

3.4.1 Wastewater Level Control Modeling

One of the main reasons of using control system is to control the level of the liquid in a given container so that the liquid does not flow over. At the same time the control system helps us to minimize cost. Instead of using control system we can use bigger tank for the process which is not cost effective.

To fully control the liquid level three components are considered: actuator (motorized valve), tank process, and level sensor (Bolton, 2008)(Jacqueline Wilkie, 2002)(Reza Katebi M. A., 1999). Figure 8 shows the block diagram for the wastewater level control system.

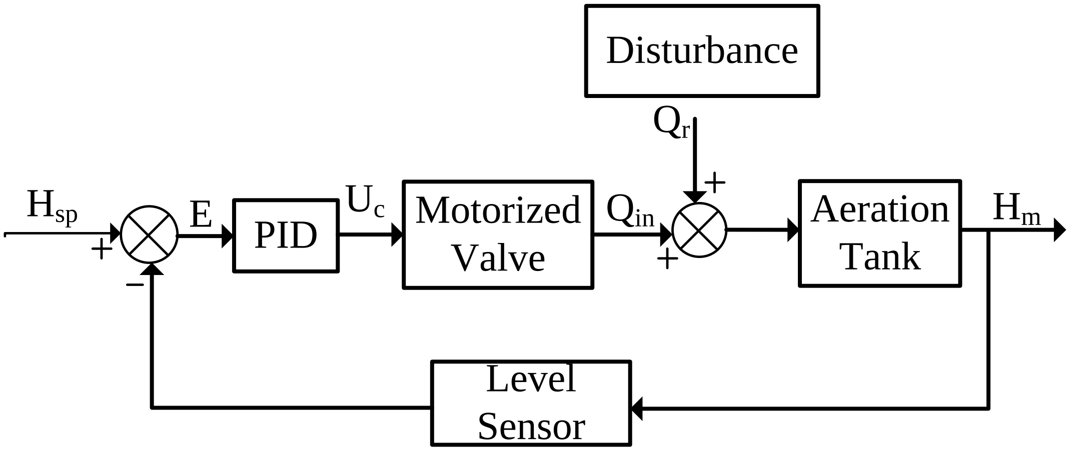

Figure 8: Block diagram for level control process

Figure 9 shows schematic diagram for level control process. Each of the components will be discussed individually.

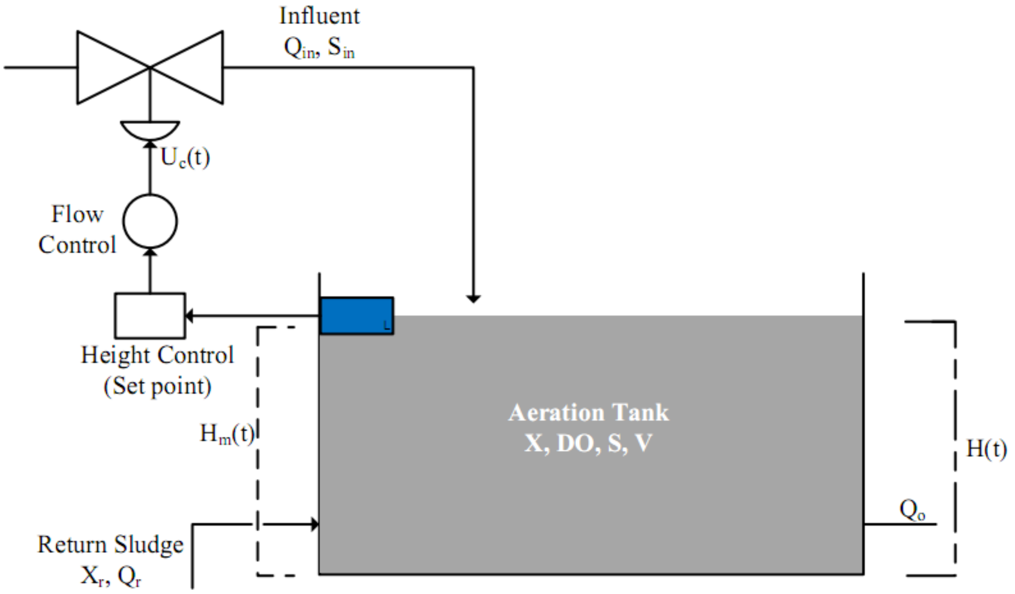

Figure 9: Schematic diagram for level control process

The State Equation:

$$\{\text{Rate of change of Liquid volume}\} = \{\text{Inflow}\} - \{\text{Outflow}\}$$

$$\frac{d}{dt}\{AH(t)\} = \{Q_{in} + Q_r\} - \{Q_o\}$$

$$A\frac{d}{dt}H(t) = \{Q_{in} + Q_r\} - \left\{\frac{H(t)}{R}\right\},\ Because\ \ Qo = \frac{H(t)}{R}$$

$$RA\frac{d}{dt}H(t) + H(t) = R\{Q_{in} + Q_r\} \tag{3.1}$$

Laplace Transformation:

From equation (3.1),

$$RA\{sH(s)\}+H(s)=R\{Q_{in}(s)+Q_r(s)\}$$

$$H(s)(\tau s+1)=k_h(Q_{in}(s)+Q_r(s))\text{, } \textit{Assuming } \tau = RA, k_h = R$$

$$H(s)=\frac{k_h}{\tau s+1}(Q_{in}(s)+Q_r(s)) \tag{3.2}$$

Figure 10 and Figure 11 shows transfer function for the tank level and SIMULINK representation of full level control system.

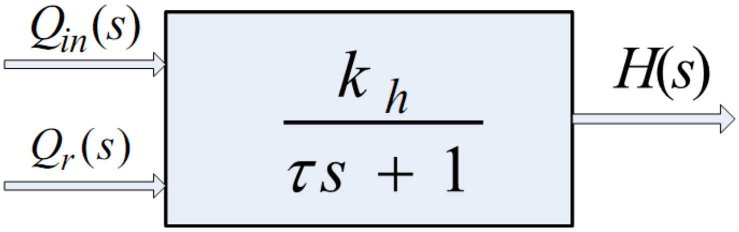

Figure 10: Transfer function of plant level model

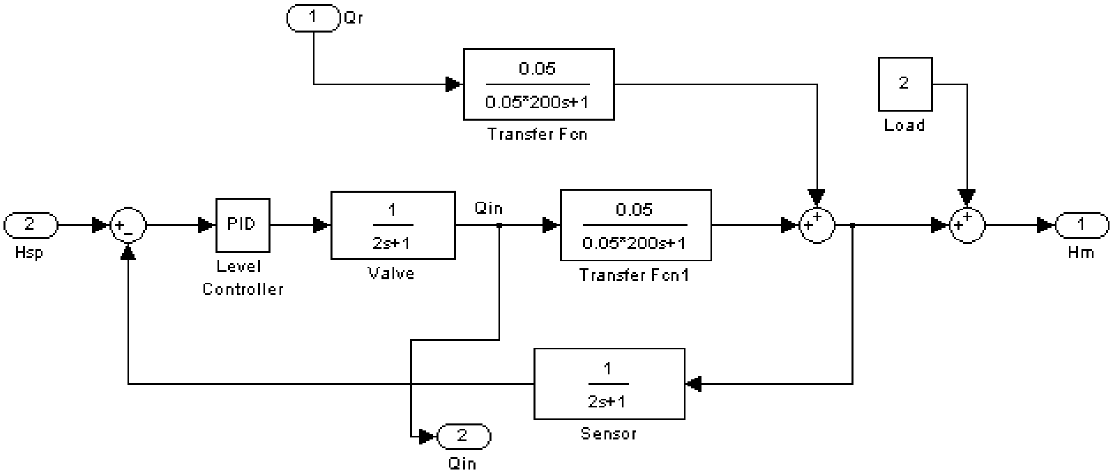

Figure 11: SIMULINK representation of complete level control system

3.4.2 Aeration System Modeling

Since the DO concentrations are highly responsible for the biodegradable reaction in activated sludge reactor aeration system, they are considered as the most important control parameters.

Aeration system is very complex, nonlinear, hybrid, time-varying and multivariable with strong interactions between the system components. The major objectives of aeration control are effective control of air delivery and oxygen transfer to minimize the associated cost and to create favorable conditions for microorganisms to grow (Piotrowski R., 2005). For aeration system modeling, refer to Appendix B.1 for more information.

The DO levels are established by controlling the amount of airflow to each basin of a diffuser type aerator. If DO levels are too high the flow can be throttled using valves on the air header pipes.

For multiple aeration tanks, the air system is branched to each tank. Throttling the flow to one tank will increase the flow to others. When the diffusers get clogged the airflow will drop dramatically. The diffusers can be "bumped" with a sudden burst of air to help clear them. Balancing the airflow between the basins, to maintain the proper DO levels, is an important part of maintaining an efficient operation (Activated Sludge Process).

The SIMULINK representation of the aeration system is shown on Figure 12 and its simulation result on Figure 13.

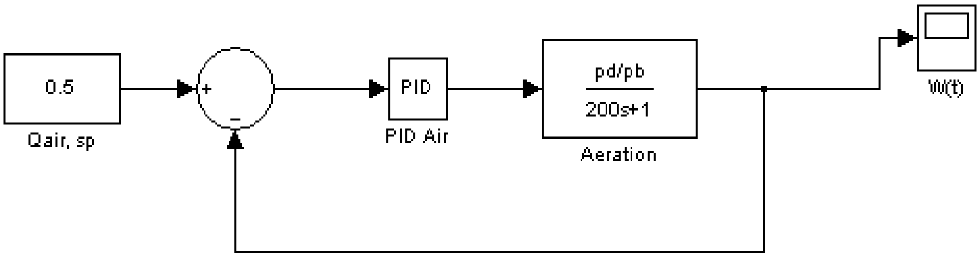

Figure 12: SIMULINK representation of aeration control system

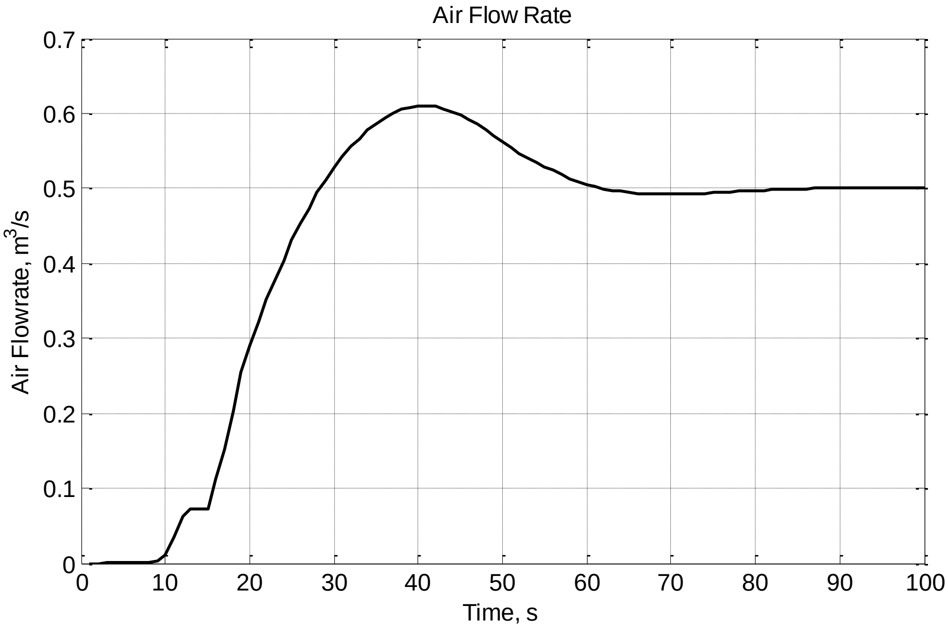

Figure 13: Simulation result of the aeration control system

3.4.3 Wastewater System Modeling

For mathematical modeling of the system, we first have to define our system. See section 2.4 for the steps to be followed. In this system the parameters considered includes: flow rate, Q, substrate (BOD), S, biomass (SS), X, oxygen uptake, DO, and actuators. Figure 14 shows the block diagram for DO and aeration system.

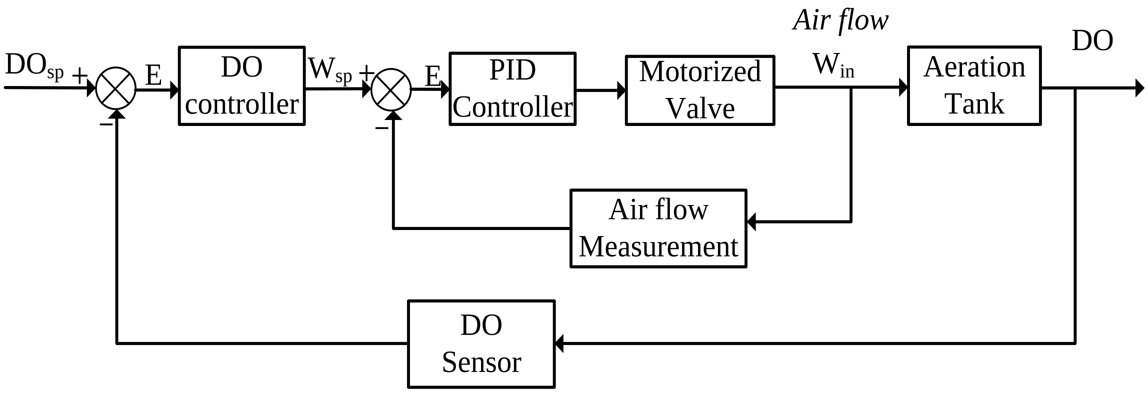

Figure 14: The block diagram for dissolved oxygen and aeration(Y. Han, 2008)

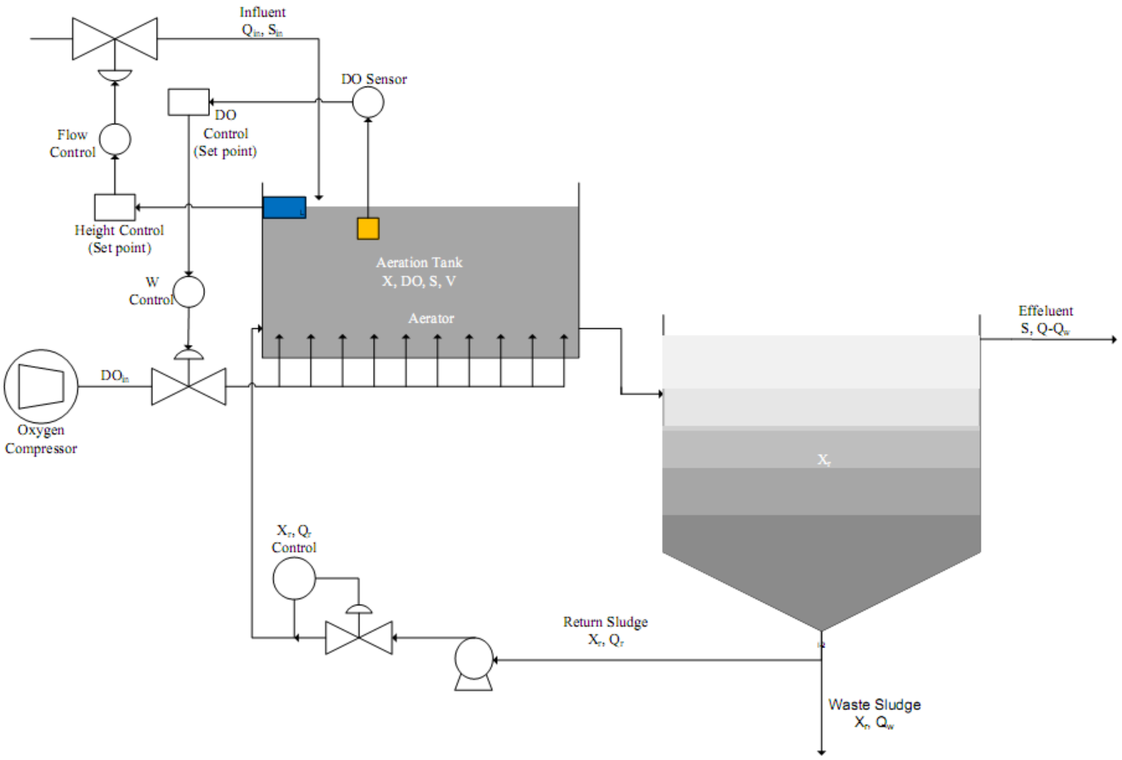

Figure 15: The schematic drawing of activated sludge system with related variables

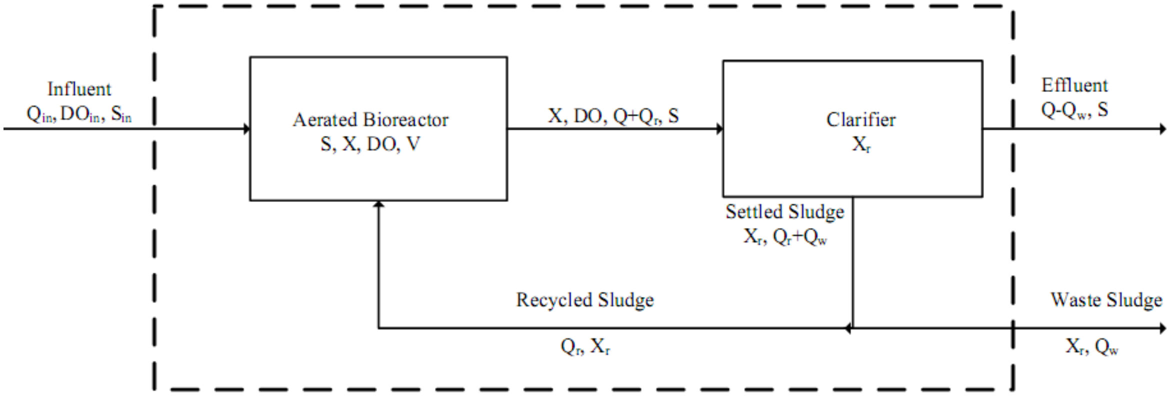

Figure 16: Schematic representation of activated sludge process of WWTP(F. Nejjari, 1999)

During the modeling process the biomass growth rate which is given by equation (2.2) is considered for the derivation of the mathematical equations.

1. Growth Rate and Substrate Conversion

According to Dochain D. and Vanrolleghem P.A (2001), and Reza K. (1999), the rate of substrate conversion to biomass and biomass growth is given as follows.

$$\text{Biomass Growth} = \mu(t)X(t) \tag{3.3}$$

$$\text{Rate of Conversion of Substrate to biomass} = \frac{\mu(t)}{Y}X(t) \tag{3.4}$$

2. Material Balance for Substrate (BOD) Concentration, S

Rate of Accumulation = Rate of inflow − Rate of outflow − Substrate loss due to Biomass Growth

$$\frac{d\{S(t)V\}}{dt} = Q(t)S_{in}(t) - [Q(t) + Q_r(t)]S(t) - \frac{\mu(t)}{Y}X(t)V$$

$$V\frac{dS(t)}{dt} = Q(t)S_{in}(t) - [Q(t) + Q_r(t)]S(t) - \frac{\mu(t)}{Y}X(t)V$$ *, dividing both sides by V*

$$\frac{dS(t)}{dt} = \frac{1}{V}Q(t)S_{in}(t) - \frac{1}{V}[Q(t) + Q_r(t)]S(t) - \frac{\mu(t)}{Y}X(t) \tag{3.5}$$

3. Material balance for Biomass Concentration, X

Rate of Accumulation = Rate of inflow − Rate of outflow + Growth of Biomass

$$\frac{d\{X(t)V\}}{dt} = [Q(t)X_{in}(t) + Q_r(t)X_r(t)] - [Q(t) + Q_r(t)]X(t) + \mu(t)X(t)V$$

$$V\frac{dX(t)}{dt} = [Q(t)X_{in}(t) + Q_r(t)X_r(t)] - [Q(t) + Q_r(t)]X(t) + \mu(t)X(t)V$$

, dividing both sides by V,

$$\frac{dX(t)}{dt} = \frac{1}{V}[Q(t)X_{in}(t) + Q_r(t)X_r(t)] - \frac{1}{V}[Q(t) + Q_r(t)]X(t) + \mu(t)X(t) \qquad (3.6)$$

4. Material Balance for Dissolved Oxygen Concentration, DO

Rate of Accumulation = Rate of inflow − Rate of outflow + DO supplied by aeration − DO loss to biomass growth

$$\frac{d\{DO(t)V\}}{dt} = Q(t)DO_{in}(t) - [Q(t) + Q_r(t)]DO(t) + K_{La}[DO_{\max} - DO(t)]V - K_O\frac{\mu(t)}{Y}X(t)V$$

$$V\frac{dDO(t)}{dt} = Q(t)DO_{in}(t) - [Q(t) + Q_r(t)]DO(t) + K_{La}[DO_{\max} - DO(t)]V - K_O\frac{\mu(t)}{Y}X(t)V$$

, dividing both sides by V

$$\frac{dDO(t)}{dt} = \frac{1}{V}Q(t)DO_{in}(t) - \frac{1}{V}[Q(t) + Q_r(t)]DO(t) + K_{La}[DO_{\max} - DO(t)] - K_O\frac{\mu(t)}{Y}X(t) \qquad (3.7)$$

5. Material Balance for Return Biomass Concentration, X_r

Rate of Accumulation = Rate of inflow − Rate of outflow

$$\frac{d\{X_r(t)V_s\}}{dt} = [Q(t) + Q_r(t)]X(t) - [Q_r(t) + Q_w(t)]X_r(t)$$

$$V_s\frac{dX_r(t)}{dt} = [Q(t) + Q_r(t)]X(t) - [Q_r(t) + Q_w(t)]X_r(t)$$

, dividing both sides by V_S

$$\frac{dX_r(t)}{dt} = \frac{1}{V_s}[Q(t) + Q_r(t)]X(t) - \frac{1}{V_s}[Q_r(t) + Q_w(t)]X_r(t) \tag{3.8}$$

Where

$X(t)$ - Biomass, $S(t)$ - Substrate, $DO(t)$ - Dissolved Oxygen, $DO_{max}(t)$ - Maximum Dissolved Oxygen, $X_r(t)$ - recycled biomass, S_{in} and DO_{in}- substrate and dissolved oxygen concentrations in the influent, Y – biomass yield factor, μ – biomass growth rate, μ_{max} – maximum specific growth rate, K_s and K_{DO} – saturation constants, α - oxygen transfer rate, $W(t)$ – aeration rate, K_0 – model constant.

Table 4: The model’s coefficients values (Sergiu Caraman, 2007)*:*

Parameters	**Y**	**K_{DO}**	**K_O**	**μ_{max}**	**K_s**	**DO_{max}**	**DO_{in}**	**S_{in}**
Values	0.65	2mg/l	0.5mg/l	0.15	100mg/l	10mg/l	0.5mg/l	200mg/l

3.4.4 SIMULINK Block Diagram of the System

The block diagram of each of the system parameter (DO, μ, S, X, and X_r) and the overall system's block diagram are shown respectively on the next figures.

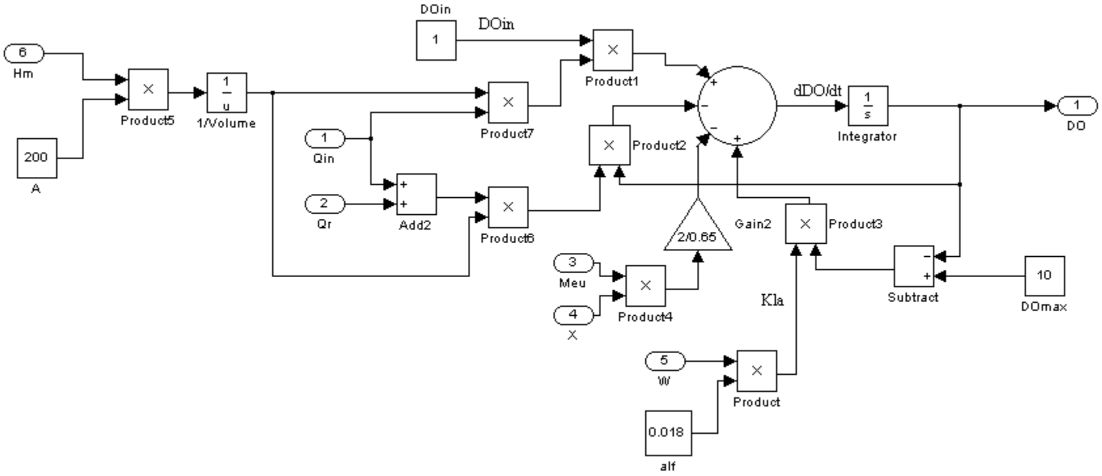

Figure 17: The SIMULINK representation of dissolved oxygen, DO, concentration system

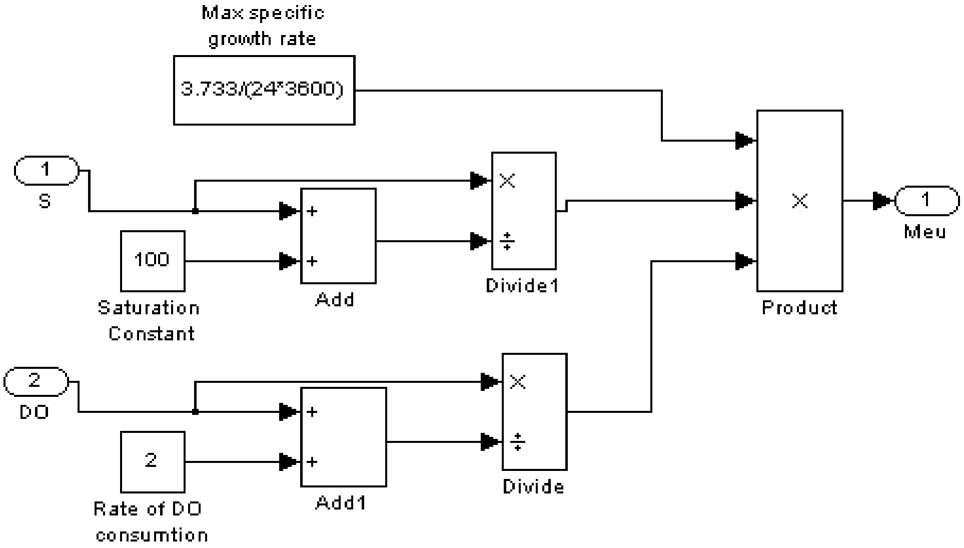

Figure 18: The SIMULINK representation of biomass growth rate, μ (Meu), system

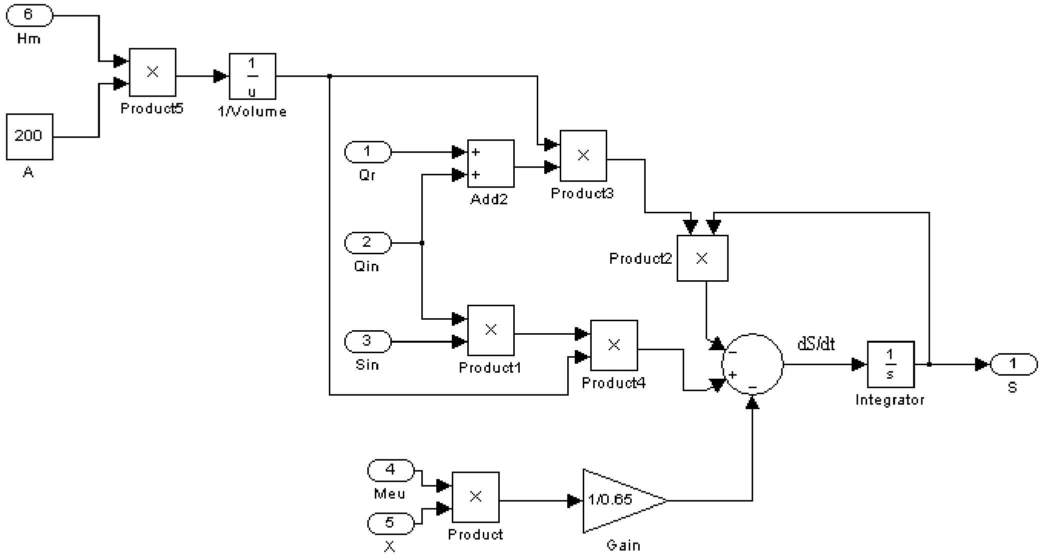

Figure 19: The SIMULINK representation of substrate, S, concentration system

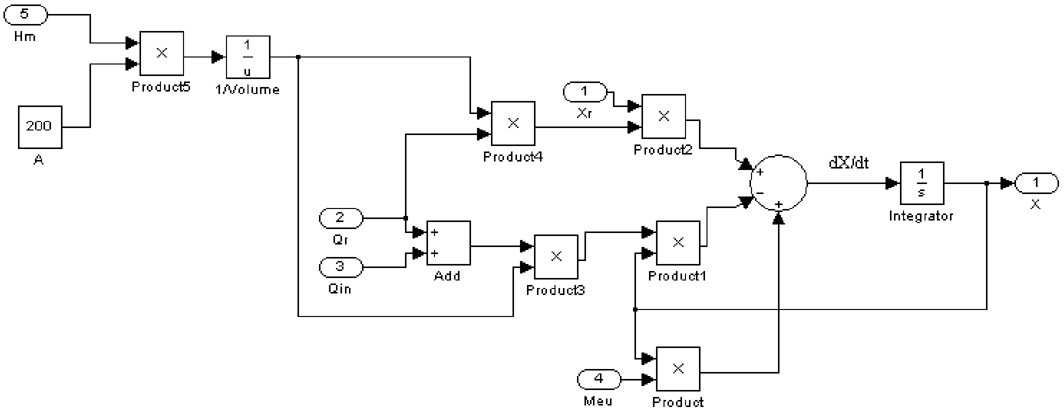

Figure 20: The SIMULINK representation of biomass concentration, X, system

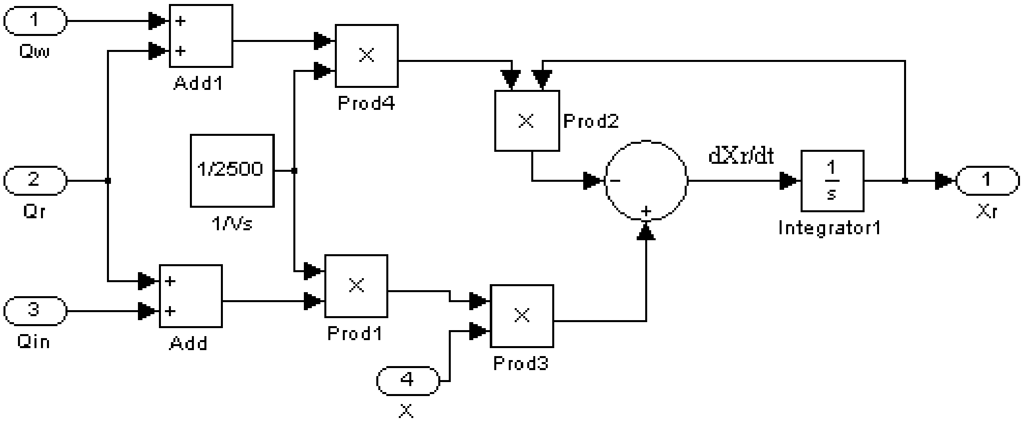

Figure 21: The SIMULINK representation of recycled biomass, X_r, concentration system

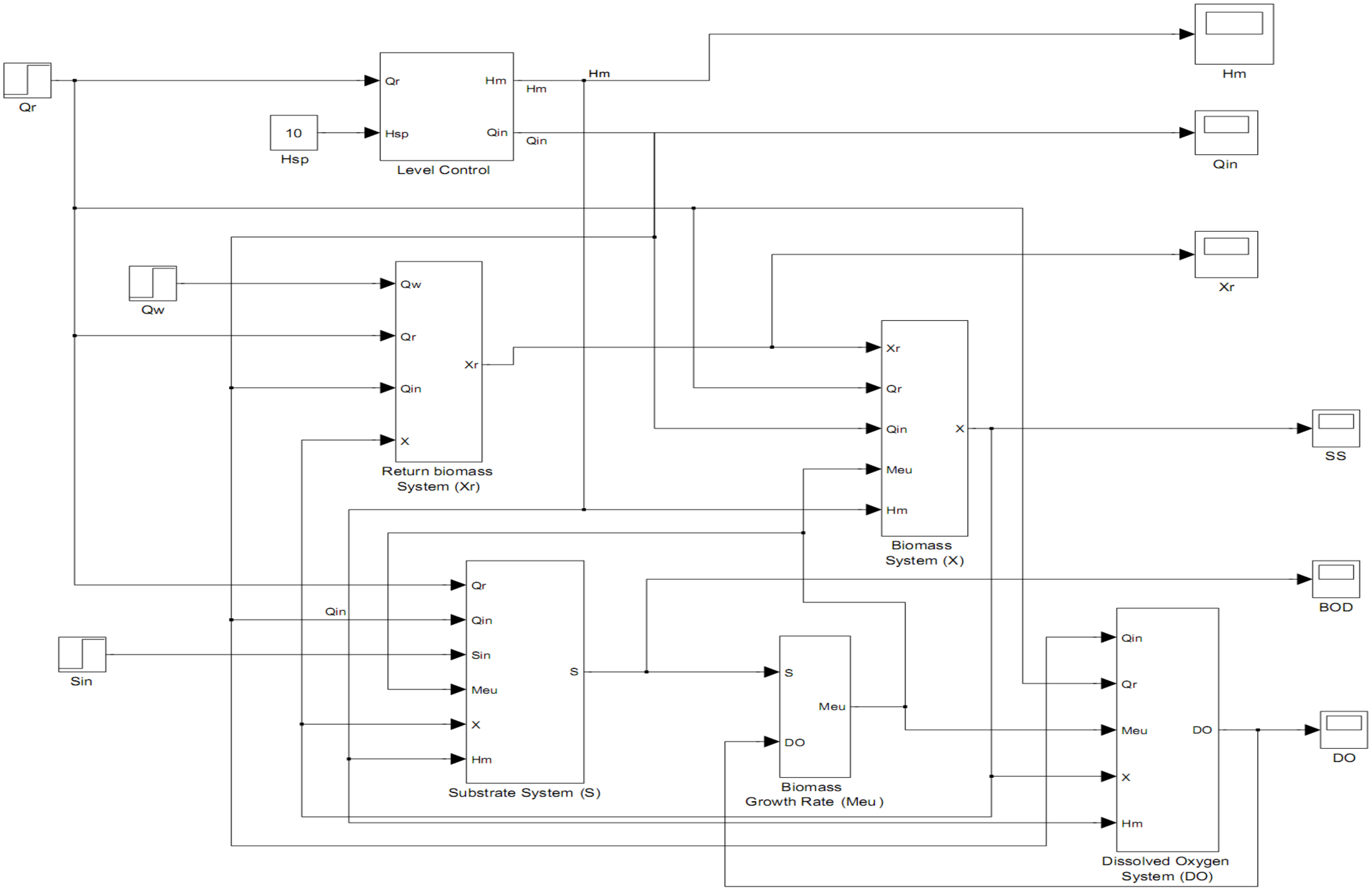

Figure 22: The SIMULINK representation of the activated sludge process of WWTP

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 RESULTS

The wastewater treatment processes system is discussed using activated sludge processes. The simulation of the system was done at steady state and unsteady state values of the system parameters.

During simulation, the integrator block calls for, among others, the initial value for the integration (the parameter **Initial condition**). This is especially important when we want to solve differential equations using SIMULINK, since the initial value must enter in to these equations (Beucher O., 2006).

4.1.1 Results of the Simulations

The results of the simulation of each sub-system at different values are shown on the following figures.

Figure 23 and 24 shows the results of the wastewater level measurement flow control. Figure 23 is the result without PID controller while Figure 24 is with PID controller applied to the system.

Since in reality the control system for level control doesn’t start directly from zero, this system is put at initial load of 5m level of liquid then the control system starts to apply the actions.

For figure 24 after PID is applied, the system become steady after nearly 70s and become equal with the setpoint.

Both figures show nearly zero or nearly no change for the first 10s because of the disturbance coming into the system.

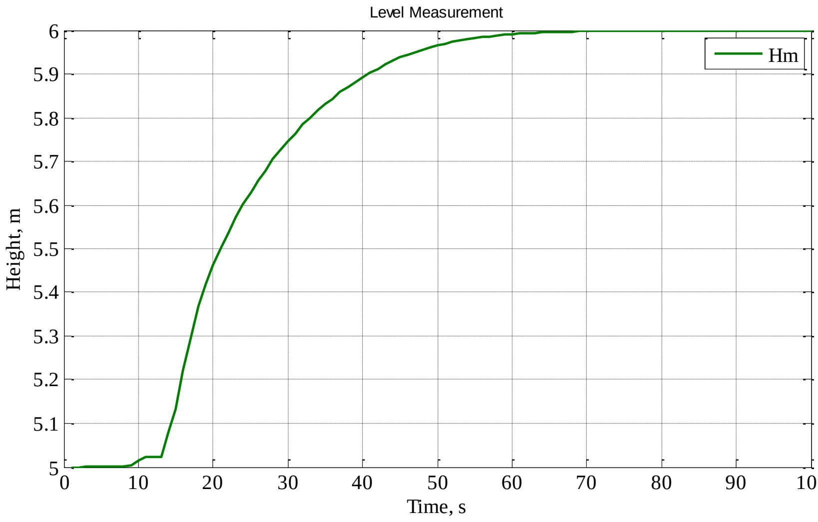

Figure 23: Level measurement without PID

Table 5: The PID parameters' values used in the level control

	Proportional	Integral	Derivative
1	18.46	3.856	2.415

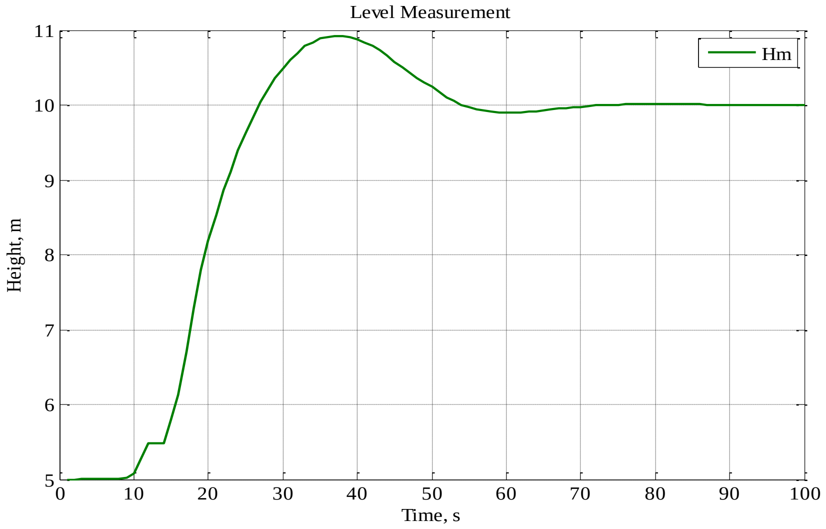

Figure 24: The wastewater level control process output with PID

Figure 25 shows, the BOD and the biomass results on the same graph. The substrate is used as a food for microorganisms or biomass. This picture show, the biomass, SS is increasing and the substrate, BOD is decreasing.

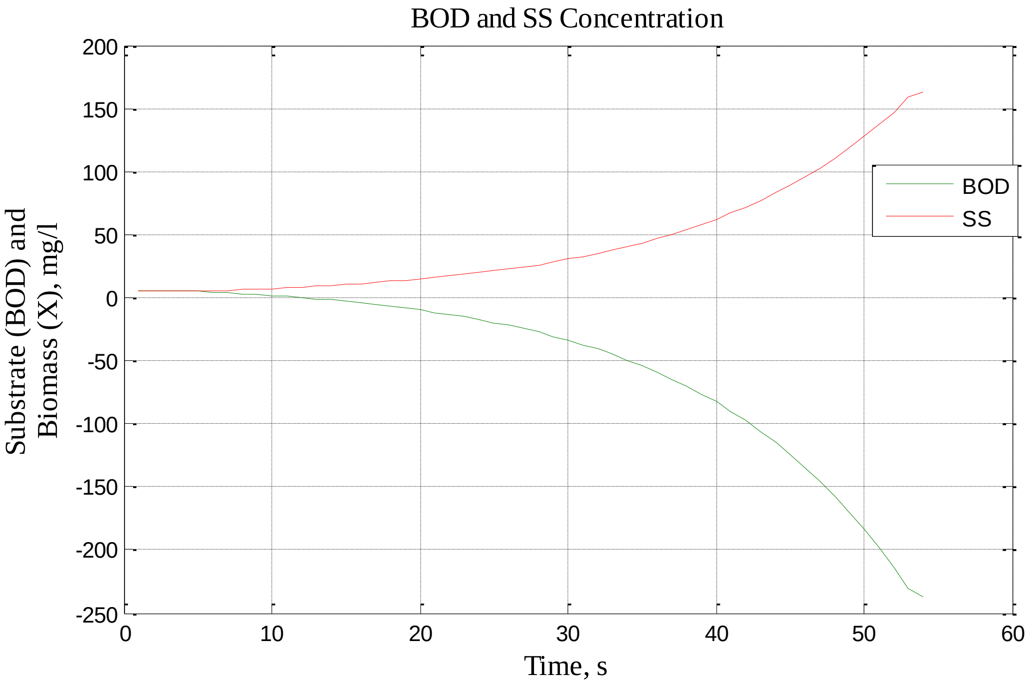

Figure 25: The simulation results for substrate, BOD and biomass, SS

On this figure, the upper line represents the biomass, SS and the bottom one represents the substrate, BOD.

Figure 26 shows, the same but on a different scale. And also this is result is after the control system is applied to the dissolved oxygen. It shows that the BOD value is decreasing as expected because they are used as a food for the biomass, SS to grow and utilize oxygen coming into the system.

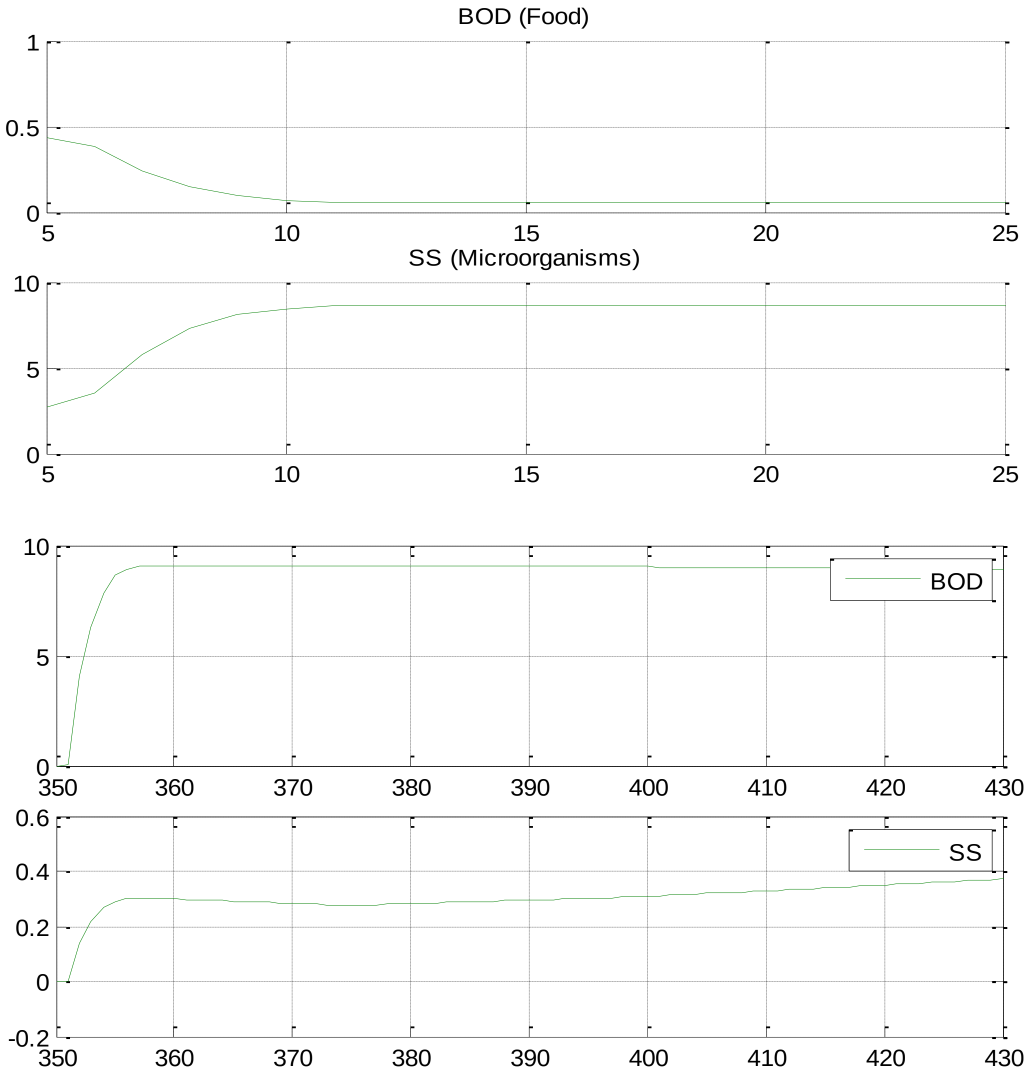

Figure 26: The simulation results for substrate, BOD and biomass, SS

Figure 27 shows, the biomass and the return sludge to the aeration tank. Due to disturbance rejection the values show a lot of changes at nearly 350s as shown on the figure. The diagram represents horizontal value is time while the vertical value is biomass and return sludge respectively on the following figure.

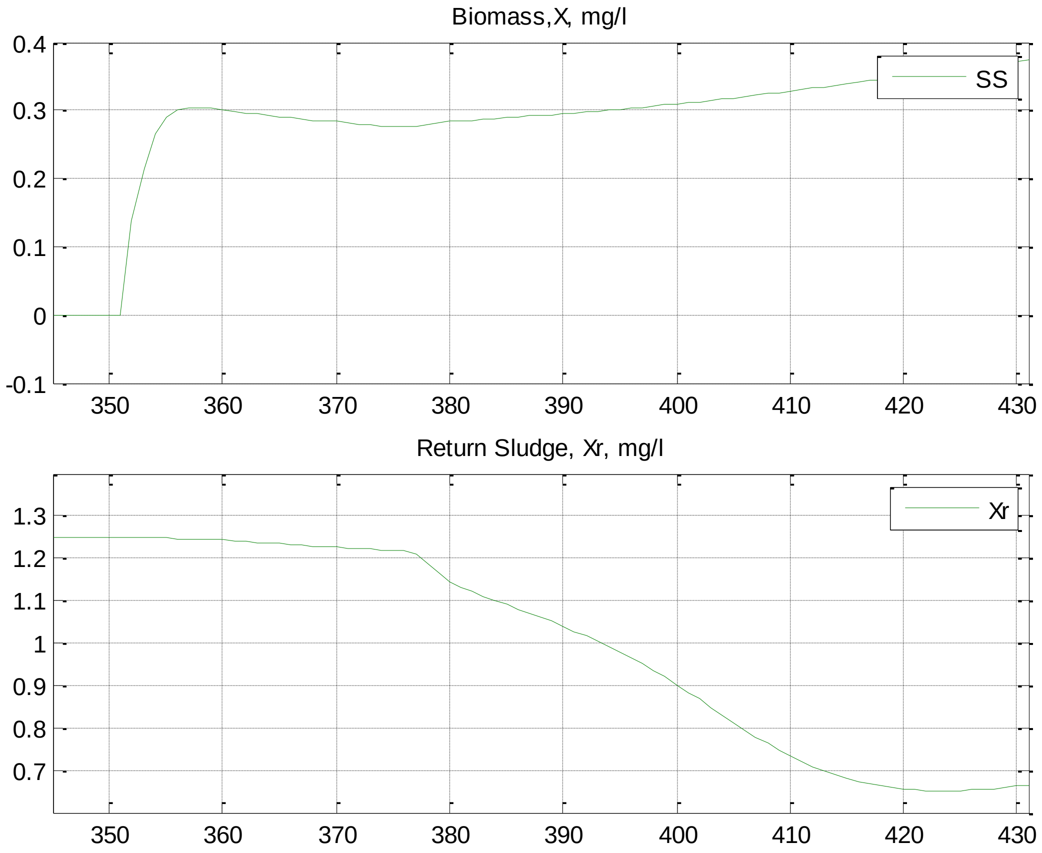

Figure 27: The simulation results for the biomass concentration, X, and return activated sludge, Xr

The simulations of non-linear DO dynamic system are taken at different PID control parameters' (P, I, D) values. The results at each value are shown on Figure 28 respectively.

Table 6: The PID parameters' values used in the DO simulations

PID	Proportional	Integral	Derivative
1	200	0.0025	0.00
2	125	0.4500	0.00
3	125	0.4500	3.45

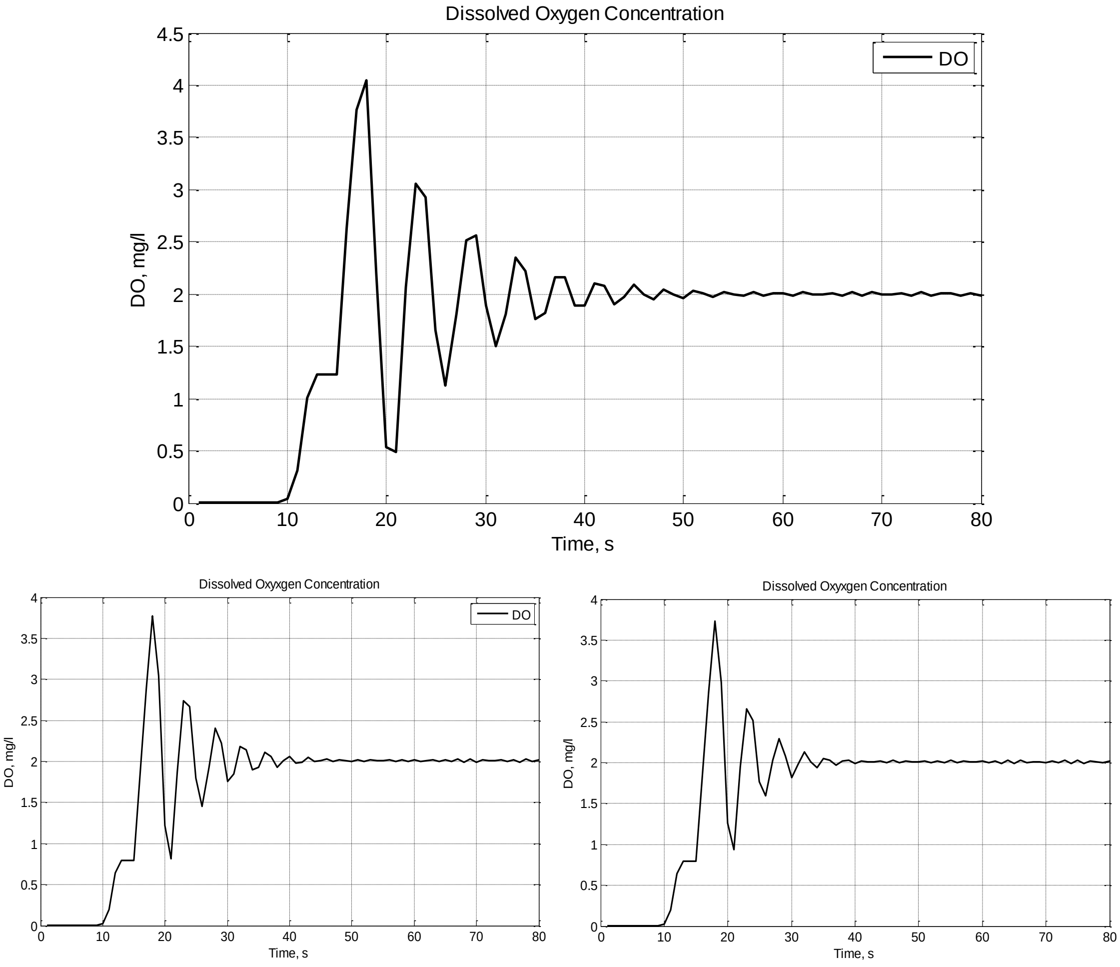

Figure 28: The WWTP simulation of dissolved oxygen, DO, concentration result

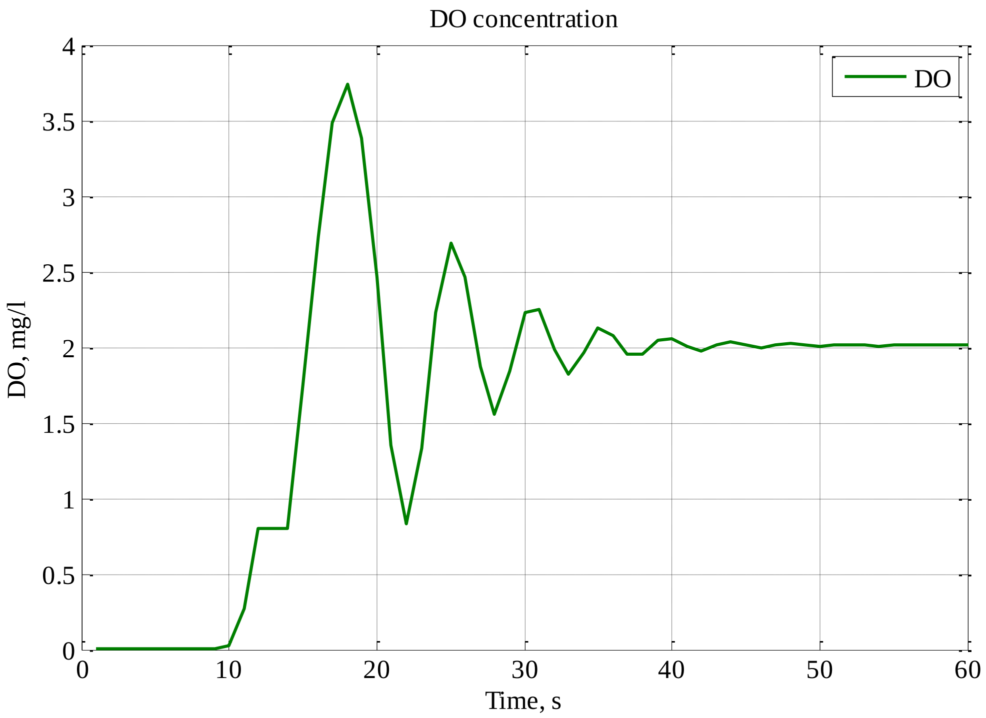

Figure 29: The WWTP simulation of dissolved oxygen, DO, concentration result

The results of figure 28 and 29 show the simulations of dissolved oxygen concentration after PI controllers are applied to it. As is has been explained previously in the literature part, PI is the control system that is used widely for DO.

To see the difference between PID and PI on this simulation, table 6 and figure 28 are shown in parallel.

Figure 29 shows that the system is nearly zero for the first 10s. It means the oxygen is not being utilized by the system. From 10s to nearly 50s, the system shows its unsteady state. After 50s the system become steady and equal to the setpoint.

4.2 DISCUSSIONS

The results of the simulations are shown under section 4.1 and are discussed here. As it is shown on Figure 24, the simulation was taken at some value of the PID parameters and other necessary values for the simulation. The result of the level control shows that the flow is unstable at first for about 60 seconds and become stable after 70 seconds. The overshot percent in not that much high compared to the set point, 10m.

From Figure 26 the substrate concentration (BOD) of the system is decreasing the time increases for the first 30 seconds. However, after 350 seconds it increased and become constant. The substrates, BODs, are foods for microorganisms to grow and should decrease until new substrate is added. The variations compared with biomass, X and dissolved oxygen, DO are also shown on the same figure as well.

Biomass concentration and return activated sludge are shown on Figure 27. As it is shown on the figure, the biomass concentration is the same as its initial value at the beginning of the process. After the process starts, it increased at high rate for nearly about 6 seconds and become dormant. The biomasses are created as a result of breakdown of organic compounds and they should increase until saturation stage. The return sludge, Xr is somehow decreasing continuously. The return sludge is always 60 to 70% of biomass concentration in activated sludge processes.

The dissolved oxygen concentration results are shown on Figure 28 and Figure 29. The figures show that the DO is highly unstable between 30 – 70 seconds. After 70 seconds is nearly stable and around the set-point, 2 mg/l. From Figure 28, it also shows that the value is fluctuating after 375 seconds and become stable again. Overall the system is not more than the saturated (maximum) dissolved oxygen concentration, 10 mg/l.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The wastewater treatment process, activated sludge process has been discussed from mathematical modeling for the control system to simulation results by considering necessary assumptions and values.

High level of treatment performance can be maintained by activated sludge process with automated control system. The main principal approaches to process control in wastewater treatment process is: maintaining dissolved oxygen (DO) levels in the aeration tanks, regulating the amount of return activated sludge (RAS), and controlling the waste activated sludge (WAS).

Only the dissolved oxygen level point was considered on this paper. Solids retention time, SRT is the most commonly used, and the mixed liquor suspended solids, MLSS may also used parameter for controlling activated sludge processing.

Return activated sludge is important in maintaining the mixed liquor suspended solids, MLSS concentration and controlling the sludge blanket level in the secondary clarifier. The waste activated sludge flow from the recycle line is selected usually to maintain the desired solids retention time.

5.2. RECOMMENDATION

There are many models that have been used for commercial purposes in industries to design wastewater treatment control systems. More than what was considered in this paper should be added for real case as I only considered activated sludge process for domestic wastewater treatment system. Also the system might not reflect the exact systems of the real system. Some assumptions are made during the modeling of the system and should be reconsidered for real applications.

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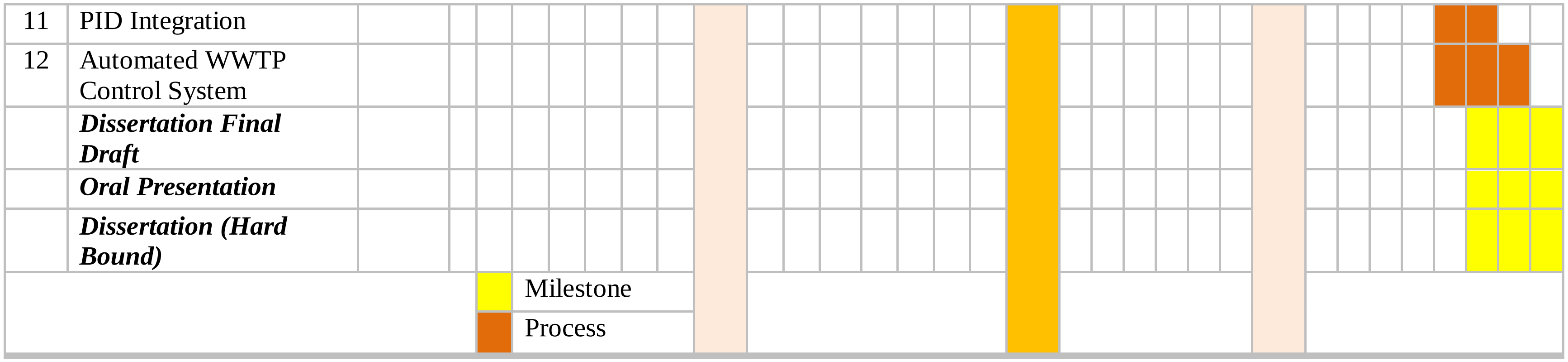
APPENDIX A

A.1 The Key Project milestone Gantt Chart

		Dura^n	FYP I: January 24, 2010 – May 07, 2010																FYP II: July 25, 2010 – November 05, 2010														
			Weeks																Weeks														
No.	Activity		1	2	3	4	5	6	7		8	9	10	11	12	13	14		1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Topic selection		🟧	🟧						**Mid-Semester Break**								**Semester Break**							**Mid-Semester Break**								
	Research Work																																
2	Project Definition				🟧																												
3	Literature Review					🟧	🟧	🟧	🟧		🟧																						
	Preliminary Report					🟨																											
4	Gathering Information					🟧	🟧	🟧	🟧		🟧																						
5	Process Identification					🟧	🟧	🟧	🟧		🟧																						
	Progress Report										🟨																						
	Seminar										🟨																						
6	Mathematical Modeling										🟧	🟧	🟧	🟧	🟧	🟧	🟧																
7	Block Diagrams										🟧	🟧	🟧	🟧	🟧	🟧	🟧																
	Interim Report Final																🟨																
	Oral Presentation																🟨																
	Simulation																																
8	Data Gathering																		🟧	🟧	🟧												
	Progress Report I																					🟨											
9	Block Diagrams in SIMULINK																					🟧	🟧	🟧		🟧							
	Progress Report II																										🟨						
	Seminar																										🟨						
10	Simulation & Analysis																										🟧	🟧	🟧	🟧	🟧		
	Poster Exhibition																													🟨			



11	PID Integration																												🟧	🟧		
12	Automated WWTP Control System																												🟧	🟧	🟧	
	Dissertation Final Draft																													🟨	🟨	🟨
	Oral Presentation																													🟨	🟨	🟨
	Dissertation (Hard Bound)																													🟨	🟨	🟨

🟨 Milestone

🟧 Process

Figure 30: The key project milestone Gantt chart

A.2 Wastewater treatment system process variables and their measurement (Gustaf Olsson, 1999)

System Variables	***Units***
Disturbances	
Influent flowrate, Q_{in}	*Ml/d*
Influent substrate concentration, S_{in}	*mg/l*
Influent oxygen concentration, DO_{in}	*mg/l*
Manipulated Variables	
Recycle flowrate, Q_r	*Ml/d*
Wastage flowrate, Q_w	*Ml/d*
Air flowrate, W(t)	m^3/min
Constant Variables	
Aeration tank volume, V_a	*Ml*
Settling tank volume, V_S	*Ml*
Saturated oxygen concentration, DO_{max}	*mg/l*
State Variables	
Aeration tank substrate concentration, S	*mg/l*
Aeration tank oxygen concentration, DO	*mg/l*
Aeration tank biomass concentration, X	*mg/l*
Unknown Parameters	
Biomass growth rate, μ	*1/d*
Maximum specific growth rate, μ_{mx}	*1/d*
Substrate saturation constant, K_S	*mg/l*
Oxygen saturation constant, K_{DO}	*mg/l*
Biomass yield factor, Y	-
Oxygen transfer rate, α	$1/m^3$
Oxygen transfer rate, K_La	*1/d*

A.3 Water Quality Parameters (Rietveld D. i., 2008)

Process	***Parameters***
Aeration	O_2, CO_2 ,CH_4, H_2S, $Fe^{2+,3+,T}$
Rapid sand filtration	SS, $Fe^{2+,3+,T}$, Mn, CH_4 *(T/DOC)*
Ozonation	*T/DOC, AOC, UV254, Pathogens (rotavirus, Giardia, E. coli), organic micro pollutants(pesticides),* BrO_3^-
Softening	CO_2 , HCO_3^-, *pH, EGV, temperature, Ca, Mg*
GAC/PAC	*Organic micro pollutants, T/DOC, AOC,* O_2
Coagulation/flocculation	*SS, T/DOC, pH, heavy metals, UV254, turbidity*
Sedimentation/ flotation	*SS, T/DOC, pH, heavy metals, UV254, turbidity*
Chlorine	*Residual* Cl_2 *(free/combined), THMs*
Conditioning	*pH*

A.4 Parameter limits of sewage effluent as of Standard A and B

Parameter	**Unit**	**Standard A**	**Standard B**
Temperature	°C	40.000	40.00
pH Value		6.0 - 9.000	5.50 - 9.00
BOD5 at 20°C	mg/L	20.000	50.00
COD	mg/L	120.000	200.00
Suspended Solids	mg/L	50.000	100.00
Mercury	mg/L	0.005	0.05
Cadmium	mg/L	0.010	0.02
Chromium, Hexavalent	mg/L	0.050	0.05
Arsenic	mg/L	0.050	0.10
Cyanide	mg/L	0.050	0.10
Lead	mg/L	0.100	0.50
Chromium, Trivalent	mg/L	0.200	1.00
Copper	mg/L	0.200	1.00
Manganese	mg/L	0.200	1.00
Nickel	mg/L	0.200	1.00
Tin	mg/L	0.200	1.00
Zinc	mg/L	1.000	1.00
Boron	mg/L	1.000	4.00
Iron (Fe)	mg/L	1.000	5.00
Phenol	mg/L	0.001	1.00
Free Chlorine	mg/L	1.000	2.00
Sulphide	mg/L	0.500	0.50
Ammoniacal Nitrogen (enclosed water body)	mg/L	5.000	5.00
Ammoniacal Nitrogen (River)	mg/L	10.000	20.00
Nitrate – Nitrogen (River)	mg/L	20.000	50.00
Nitrate – Nitrogen (enclosed water body)	mg/L	10.000	10.00
Phosphorous (enclosed water body)	mg/L	5.000	10.00
Oil and Grease	mg/L	5.000	10.00

APPENDIX B

B.1 Aeration system modeling process

The aeration model is done only for single blower and aeration tank system and the complete modeling of it is beyond this paper. Figure 31 shows the assumed schematic diagram of aeration system model.

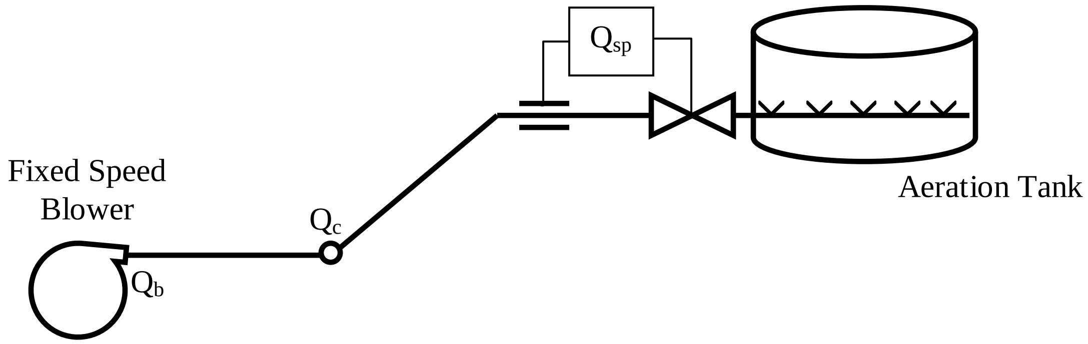


Figure 31: Schematic diagram of a single blower and single aeration tank system

The mathematical model for the aeration system is adapted from (Krawczyk, 2007)(Piotrowski R., 2005).

$$Q_b = f_b(x_b, \Delta p_b, n_b) \tag{B.1}$$

Where,

Q_b = *Air flow through the blower*

$f_b(.)$ = *nonlinear function available from manufacturer data*

$x_b = 1$ *if the blower is on and* $x_b = 0$ *if the blower is off*

n_b = *motor rotational speed*

$\Delta p_b = p_b - p_a$ *, pressure drop across blower,* p_b = *pressure at the blower node,* p_a = *atmospheric pressure*

$$Q_{air} = n\frac{(\Delta p_d - \Delta p_d^{open})}{R_d}, \text{for } \Delta p_d \geq \Delta p_d^{open} \quad \text{(B.2)}$$

$$0, \qquad , \text{otherwise}$$

$$R_d C_d \frac{dQ_{air}}{dt} + Q_{air} = \frac{T_d}{T_b}(p_b - p_d)\frac{1}{R(Q_b)} \quad \text{(B.3)}$$

$$R(Q_b) = \frac{p_b - p_d}{Q_b} \quad \text{(B.4)}$$

$$\frac{p_d}{p_b} = \frac{T_d}{T_b} \quad \text{(B.5)}$$

$$R_d C_d \frac{dQ_{air}}{dt} + Q_{air} = \frac{p_d}{p_b} Q_b \quad \text{(B.6)}$$

Parameters, $\mathrm{R_d} = 0.74[\frac{\mathrm{kPa.h}}{\mathrm{m^3}}], \Delta \mathrm{p_d^{open}} = 2\mathrm{kPa}$

GLOSSARY

Detention time - Detention time, or the length of time the MLSS are under aeration, differs with each type of activated sludge process. RAS flows can be used to manipulate the detention time in the aeration tanks. Increasing the RAS flow at night will help maintain the proper detention times as influent flows drop.

F:M Ratio - One of the process parameters used to control activated sludge solids inventory is known as the Food-to-Microorganism ratio or F:M ratio. It is a baseline established to determine how much food a single pound of organisms will eat every day. A pound of bugs will eat between 0.05-0.6 pounds of food per day depending on the process.

MCRT/Sludge Age - Another control parameter is the length of time the bugs stay in the process. If a system wastes 5% of the solids in the system every day, then MLSS would only remain in the system an average of about 20 days (100% / 5% per day = 20 days). This is known as the Mean Cell Residence Time or MCRT. Some operators also refer to this number as Sludge Age.

MLSS/MLVSS - The biomass of critters that is responsible for removing the BOD make up a large portion of the solids that are contained in the process. They are the "active" part of activated sludge. The solids under aeration are referred to as the Mixed Liquor Suspended Solids or MLSS. The portion of the MLSS that is actually eating the incoming food is referred to as the Mixed Liquor Volatile Suspended Solids or MLVSS. The inventory of the biomass is calculated as pounds of microorganisms based on the volume of the tanks and the concentration of the MLVSS.

RAS/WAS - As the mixed liquor moves to the secondary clarifier, the activated sludge settles to the bottom of the tank and is removed. This sludge is not a thick as primary sludge. The solids concentrations will normally be between 0.5-0.8% or 5,000-8,000 mg/L. One of two things will happen to the settled sludge. Most of it will be returned to the aeration basins to keep enough activated solids in the tanks to handle the incoming BOD. This is known as the Return Activated Sludge or RAS. A small portion of the sludge will be removed from the system as the MLSS inventory grows. It is referred to as Waste Activated Sludge or WAS.

SVI - The sludge volume index or SVI is a measurement of how well the activated sludge settles in the clarifier. Sludge settleability in a large part depends on the condition of the organisms. Good settling sludge will have an SVI between 80 and 120. As the sludge becomes lighter and the settled volume increases the SVI will also increase.