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MODELICA-BASED MODEL FOR ACTIVATED SLUDGE SYSTEM

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ خليل تيسير خليل مطر لنيل درجة الماجستير في كلية *الهندسة* قسم الهندسة الكهربائية – أنظمة التحكم وموضوعها:

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MODELICA-BASED MODEL FOR ACTIVATED SLUDGE SYSTEM

وبعد المناقشة التي تمت اليوم الثلاثاء 14 محرم 1437هـ، الموافق 2015/10/27م الساعة الحادية عشرة صباحاً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في كلية *الهندسة*/ قسم الهندسة الكهربائية – أنظمة التحكم.

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق،،،

نائب الرئيس لشئون البحث العلمي والدراسات العليا

أ.د. عبدالرؤوف علي المناعمة

ABSTRACT

Oxidation ditch (OD) is a common activated sludge method for wastewater treatment. The control of oxygen supply for this type of wastewater treatment is of great importance in controlling the treatment efficiency. The European Hospital (EH) in Gaza strip suffers from the same problem. Therefore, the main objective of this research is to produce a control model for the oxygen supply and treatment efficiency of this treatment plant. The methodology followed in this research comprised data collection on the wastewater treatment plant and building a control model using (MODELICA) object oriented programming language. The results from the model required are the oxygen concentration and organic matter concentration (BOD_5 concentration) proved to be responding to the control process induced on the aerator. For example, when the rotational speed of the aerator was increased from 0 to 1460 rpm the oxygen concentration increased from 0 to 2mg O_2/L and the organic matter was reduced from 290 to 20 mg BOD_5/L. Similar results were obtained when different aerator rotational speeds were used. It is concluded from this work that Modelica is a suitable Model for the oxidation ditch process control. In addition, it is concluded that controlling the aeration system in OD has a significant effect in improving the treatment process.

DEDICATION

To my family ...

ACKNOWLEDGEMENT

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Waste Water Treatment Plants	WWTPs
Oxidation ditch	OD
Biological Oxygen Demand	BOD
Sequencing Batch Reactor	SBR
Rotating Biological Contactors	RBC
International Association on Water Quality	IAWQ
Activated Sludge Model No 1	ASM1
Activated Sludge Process	ASP
Artificial Intelligence	AI
Kohonen Self Organizing Map	KSOM
Back Propagation Artificial Neural Networks	BPANN
Adaptive Network Based Fuzzy Inference System	ANFIS
Up flow Anaerobic Sludge Blanket	UASB
Complete Mixed Flow Reactor	CMFR
Plug Flow Reactor	PFR
Dissolved Oxygen	DO
Mixed Liquor Suspended Solids	MLSS
Hydraulic Detention Time	HDT
Hydraulic Retention Time	HRT
Modelica Standard Library	MSL
European Hospital	EH
Variable Frequency Drive	VFD

CHAPTER 1
INTRODUCTION

1.1 Background

Water is the basis of life for all creatures including humans, plants and animals; therefore no water means any life on earth planet. Because of the great importance of water, it must be protected and kept clean. One of the most important ways to keep water clean is treating wastewater before being discharged back to the nature.

Wastewater treatment plants (WWTPs) involve several different processes to treat it at different stages. Water is one of our most precious resources, and wastewater treatment is becoming more and more important in a highly populated, industrialized world. If these wastewaters are not efficiently treated, large amounts of organic matter and nutrients present in the effluent will lead to severe impacts on the aquatic ecosystem, such as Eutrophication and the release of toxic pollutants. The most frequent method to reduce organic matter in the effluents is by biological oxidation processes such as Oxidation ditches (ODs) process.

This method depends upon groups of microorganisms, mainly bacteria, along with protozoan, fungi and rotifers, being maintained in contact with the organic matter in the waste in an aerobic environment. This allows the reduction of the organic load with a minimum sludge production.

This thesis deals with mathematical modeling and process control of ODs at the wastewater treatment in European hospital in Khan Younis. The increased importance of biological purification processes has also resulted in increasing interest in their mathematical modeling, for understanding as well as for predictive and control purposes.

1.2 Problem Statement and Motivation

Gaza strip is subjected to ongoing wars, and being under siege for years. In addition, there is an obvious lack of interest in the field of wastewater treatment in Gaza; As a result, the crisis of wastewater has been aggravated in the Strip.

One of the environmental problems that Gaza strip faces is, being WWTP of EH in Khan Younis city not working properly. The control system of the WWTP is currently disabled. These force technicians to operate the plant manually every time, which in turns reduces the operation and overall efficiency of the plant. Results of the wastewater samples obtained from the European Hospital treatment plant in 15.6.2015 shown in table (1.1).

Table (1.1): Results of the wastewater samples obtained from the European Hospital treatment plant.

Date / Unit	15/6/2015		
	Tss	COD	BOD
Influent	450	800	400
Effluent	90	200	95

The table shows that there is an environmental problem in the wastewater treatment plant at the European hospital. The Biological Oxygen Demand (BOD) of wastewater that comes from the plant is 95 mg BOD_5/L. This BOD is considered higher than allowed, so there is a need to put a viable method to resolve this problem.

1.3 Research Objectives

1- Create a mathematical model for oxidation ditch operations.
2- Design a simulation tool that simulates oxidation ditch operations, particularly the concentration of organic matter that comes out of ditches.
3- Propose a methodology to solve the problem of the wastewater treatment plant at the European hospital using the designed simulation tool to reduce power consumption.

1.4 Literature Review

The activated sludge process was discovered in 1913 in the United Kingdom by two engineers, Edward Ardern and W.T. Lockett, who were conducting research for the Manchester Corporation Rivers Department at Davyhulme Sewage Works. This development led to arguably the single most significant improvement in public health and the environment during the course of the century. By the late 1930s, the activated sludge treatment was the

predominant process used around the world [1].

- In1983 The International Association on Water Quality (IAWQ, formerly IAWPRC)[12] Formed a task group, which was to promote development, and facilitate the application of, practical models for design and operation of biological wastewater treatment systems. The first goal was to review existing models and the second goal was to reach a consensus concerning the simplest mathematical model having the capability of realistically predicting the performance of single-sludge systems carrying out carbon oxidation, nitrification and denitrification. The final result was presented in 1987. Today the model is named Activated Sludge Model No 1, abbreviated ASM1.

- In 1996 Jeppssn [2] described a simplified modeling approach to include some possible effects of higher order organisms on nitrification, based on a proposed hypothesis of their oxygen consumption in the biofilm. Three different models are developed and investigated.

- In 1998Ranglaet al.[3] Used a simulation model to investigate control of an Activated Sludge Process (ASP). It is shown how the recycle and wastage flow rate variables can be employed to continually maintain plant operation in the presence wastewater load disturbances and plant changes. Considerations are also given as to how plant operation could be optimized in order to increase treatment capacity and reduce operating costs.

- In 1999Henzeet al. [4] presented the Activated Sludge Model No. 2d for biological phosphorus removal with simultaneous nitrification-denitrification in activated sludge systems.

- In 2000U.S. Environmental Protection Agency [5] Presented general information about the oxidation ditches, such as advantage, disadvantage, design criteria (construction, design parameter, solids retention time, BOD loading, Hydraulic retention time).

- In 2003Koet et al. [6] Discussed model for the model-based control of a wastewater treatment plant in terms of air flow-rate and aeration volume to development aspects of a Neural Network.

- In 2008Nelson et al. [7] analyzed a model for the activated sludge process occurring in a biological reactor without tricycle. The biochemical processes occurring within the reactor are represented by the activated sludge model number 1 (ASM1).

- In 2009Rustum [8] Presented the applications of Artificial Intelligence (AI) techniques for modeling the ASP. These include the Kohonen Self Organizing Map (KSOM), Back Propagation Artificial Neural Networks (BPANN), and Adaptive Network Based Fuzzy Inference System (ANFIS).

- In 2011Abdelati et al. [9] Derived a simple models and applied for the modeling and simulation of a real system. In this system, water for irrigation was collected by recovery wells around the wastewater treatment plant infiltration basins located in northern Gaza.

- In 2012Abdelati et al. [10] presented a method for modeling wastewater pumping stations using the component oriented modeling language Modelica. The model provides a valuable simulation tool to validate and judge on the different control schemes of these stations.

- In 2012Gary [11] Explored a potential relationships between dissolved organic matter and organic phosphorus and methods of removing organic phosphorus from waste water. Current limitations of pH simulation in the wastewater treatment process were investigated.

- In 2012Abdelati et al. [12] Derived easily manageable component-oriented models and applied to the modeling and simulation of a real wastewater pumping system. The model derived was implemented in Modelica.

- In 2013wei [13] Presented a modeling and optimizing the wastewater treatment process with a data-driven approach. The process model built then optimized with evolutionary computational algorithms to find the optimal solutions for improving process efficiency and reducing energy consumption.

- In 2014Pereia [14] Presented a modeling of the treatment process of the effluents, using the software GPS-X. This program has a clear-cut graphical interface and uses a specialized translator that converts the graphical process into material balance equations, based on dynamic models.

From previous work it is obvious that designing a mathematical model for the OD is needed to do simulation for the OD operation that will help in more understanding for these operation in addition to helping in implementing a control system which will lead to get wastewater treated as required, this contributes in time, money and efforts savings this is because it would become possible to build this control system on this software tool and try get the expected results via computer simulation, if the results of the simulation are identical of the expected results then the physical system will be implemented at the plant.

1.4 Contribution

This thesis, presents a mathematical model for ODs, and a simulation tool that is used to measure the performance of the OD control system based on object-oriented programming. The simulation tool was used in building a control system for the OD of the WWTP at EH to reduce BOD in the water that comes from the OD.

1.5 Thesis Outline

This section outlines the overall structure of the thesis and provides a brief description for each chapter. There are six chapters in this thesis; Chapter 2 includes background about wastewater treatment process, activated sludge, the derivation of the mathematical model of reactors, basic information about oxidation ditch and previous work, Chapter 3 includes research material and methodology. Chapter 4 includes control of oxidation ditch. Chapter 5 presents the implementation, simulation and results. Finally in chapter 6, conclusion and suggestion for future work are given.

CHAPTER 2
WASTE WATER BACKGROUND

2.1 Introduction

This section includes:

- Definition of Wastewater

- Solids in Wastewater

- Goals of Wastewater Treatment

2.1.1 Definition of Wastewater

Wastewater is any water that has been adversely affected in quality by anthropogenic influence. It comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture. Wastewater is simply that part of the water supply to the community or to the industry which has been used for different purposes and has been mixed with solids either suspended or dissolved. Wastewater is 99.9% water and 0.1% solids. The main task in treating the wastewater is simply to remove most or all of this 0.1% of solids [4].

There are many methods used to separate solids from water, including physical methods and chemical and biological, in our search we focused on biological method wastewater treatment.

2.1.2 Solids in Wastewater

There are many types of solids, first type is big floatable solids which separated physically by screens shown in Figure (2.1). Second type is grit and sand which separated physically by grit removal channels shown in Figure (2.2).Third type is suspended solids which separated physically by sedimentation tanks [16].

Suspended solids consist of two types, the first type is called a Settleable which separated physically by sedimentation tanks shown in Figure (2.3). The second type is called non-Settleable, which consists of two types also; the first type is called floatable which separated physically by floatation tanks, the second type is called colloidal which separated indirectly biologically or by chemical and physical methods coagulation followed by filtration tanks.

The last type of solids is dissolved solids which consists of two types, the first type is called organic which separated biologically by biological treatment tanks. The second type is called Inorganic which separated by chemical treatment tanks. The Typical wastewater treatment plant layout is shown in Figure (2.4).
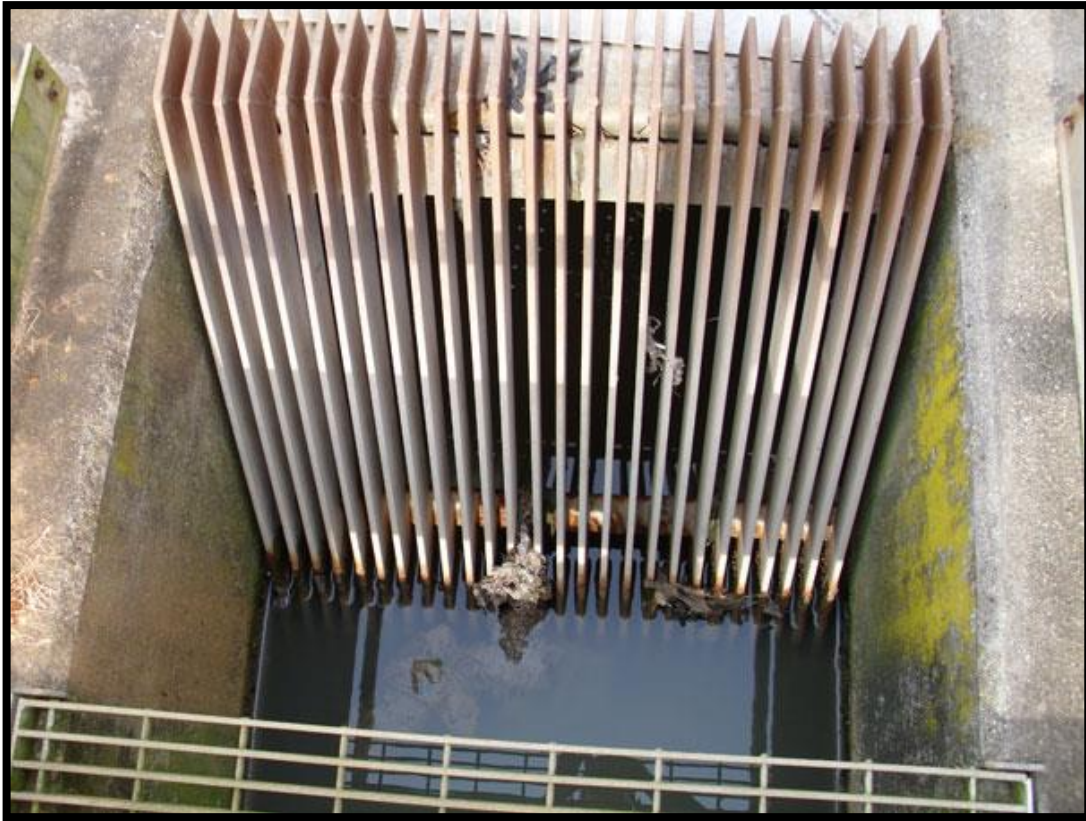
Figure (2.1): Bar screens.

Figure (2.2): Grit removal channel.

Figure (2.3): Sedimentation tanks.
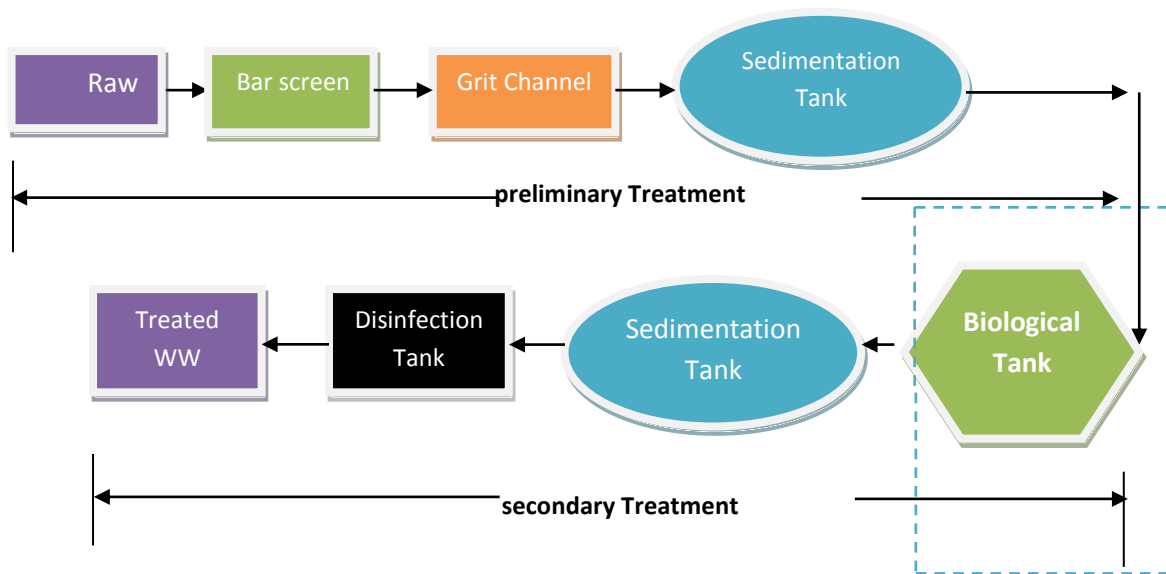
Figure (2.4): Typical wastewater treatment plant layout.

2.1.3 Goals of Wastewater Treatment

The main goals of wastewater treatment are three [17], the first goal is to protect people's health, since the waste water containing micro-organisms cause serious diseases to people and animals, in addition to containing hazardous substances such as heavy metals, which are often toxic and it produces odorous gases and bad smell.

The second goal is to protect an environmental. Wastewater untreated adversely affects the environment, where it is disrupt the Earth's surface and reduce the quality of groundwater and soil contamination. It is known that wastewater containing nitrogen and phosphorus, and this leads to the occurrence of the phenomenon of "Eutrophication", Eutrophication means the growth of a large amounts of algae and other aquatic plants leading to the deterioration of the water quality.

The waste water is rich in organic matter, which consumes oxygen in the water, leading to the killing of aquatic organisms such as fish. The third goal is reuse of the treated waste water and solids, where treated wastewater is used in all of agriculture, industry and water injection into the ground. The solids treated are used in agriculture, landfill and energy source.

2.2 Biological wastewater treatment

As previously mentioned, we focused in this thesis on the biological wastewater treatment. Biological wastewater treatment is the type of wastewater treatment in which a variety of microorganisms, principally bacteria, are used to remove dissolved and particulate matter. Biological treatment is an important part of any wastewater treatment plant.

Biological treatment using activated sludge aerobic processes for more than a century. It provides contact between the wastewater to be treated with bacteria that feed on organic matter in wastewater, this reduces the Biological Oxygen Demand (BOD) and this is the goal of treatment.

The objectives of biological wastewater treatment is transform dissolved and particulate organic biodegradable compounds into acceptable end products and remove nutrients, such as nitrogen and phosphorus. Microorganisms are used mainly for the removal of organic matter, nitrogen, and phosphorus. In this thesis we focused on the removal of organic matter.

2.2.1 Biological organic matter removal

This thesis briefly discusses the differences between aerobic and anaerobic biological treatment processes and subsequently focuses on select aerobic biological treatment processes/technologies. Aerobic, means in the presence of air (oxygen); while anaerobic means in the absence of air (oxygen) [18].

These two terms are directly related to the type of bacteria or microorganisms that are involved in the degradation of organic impurities in a given wastewater and the operating conditions of the bioreactor.

2.2.1.1 Aerobic biological organic matter removal

The first step is oxidation and synthesis [1].

$$COHNS + O_2 + \text{nutrients} \rightarrow CO_2 + NH_3 + C_5 H_7 N O_2 + \text{other end products}$$

The second step is endogenous decay or respiration.

$$C_5 H_7 N O_2 + O_2 \rightarrow 5CO_2 + 2H_2O + NH_3 + \text{energy}$$
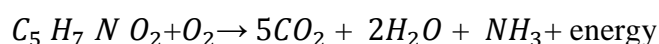
2.2.1.2 Anaerobic biological organic matter removal

Examples of removing of the organic material in the absence of air are in the next [1].

1. Removal of methanol.

$$4CH_3OH \rightarrow 3CH_4 + CO_2 + 2H_2O$$
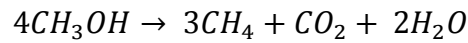
2. Removal of methylamine.

$$4(CH_3) \, 3(NH_2) + 2H_2O \rightarrow 3CH_4 + CO_2 + 6H_2O + 4NH_3$$
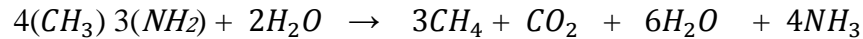
2.2.2 Types of biological process for wastewater treatment

The principal biological processes used for WWT can be divided into two main categories:

- Suspended growth processes.
- Attached growth processes.

The Suspended growth processes are a biological treatment process in which microorganisms are maintained in suspension while converting organic matter or other constituents in the wastewater to gases and cell tissue. Examples on this process are conventional activated sludge system, oxidation ditches, Sequencing Batch Reactor (SBR), aerated lagoons and up flow sludge blanket reactors. In this thesis we focused on oxidation ditches.

The attached growth processes are a biological treatment process in which microorganisms responsible for the conversion of organic matter or other constituents in wastewater to gases and cell tissue are attached to some inert material such as rocks, sand, or specially designed ceramic or plastic materials.

Attached growth treatment processes are also called fixed film process. Examples on this process are trickling filters, Rotating Biological Contactors (RBC), packed –bed reactors, fluidized bed biofilm reactors. In this thesis we did not work on this type, may be in the future work.

2.2.3 Bacterial growth kinetics (Monod equation)

The Monod equation is a mathematical model for the growth of microorganisms. It is named for Jacques Monod who proposed using an equation of this form to relate microbial growth rates in an aqueous environment to the concentration of a limiting nutrient. It is important to understand the way by which the bacterial growth can be quantified [19].

$$\mu = \mu_m \frac{S}{k_s + S} \tag{2.1}$$

Where, μ_m is maximum growth rate, t^{-1} S is a concentration of the limiting substrate, mg/L, and k_s is a half saturation constant, mg/L.

The above equation is a hyperbolic function as shown on the Figure (2.5).
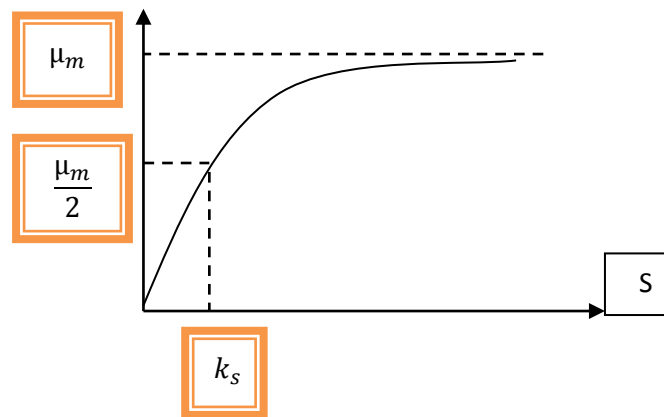
Figure (2.5): Bacterial growth kinetics function.

The rate of change of biomass (microorganisms) concentration is governed by the following expression:

$$\frac{dX}{dt} = \mu X \tag{2.2}$$

Where, $\frac{dX}{dt}$ is biomass growth rate, mg/L.t (it is also called rgrowth or rg), μ= growth rate constant, t^{-1}, X = concentration of biomass, mg Vss/L.

Substitute from equation (2.1) into (2.2)

$$\frac{dX}{dt} = \frac{\mu_m SX}{k_s + S} \tag{2.3}$$

Equation (2.3) accounts for growth only. To account for death or decay of biomass another term is subtracted as follows:

$$\frac{dX}{dt} = \frac{\mu_m SX}{k_s + S} - k_d X \tag{2.4}$$

Where, k_d is endogenous decay rate constant, t^{-1}.

The rate of substrate utilization by the biomass is expressed using the following relation:

$$-\frac{dS}{dt} = \frac{1}{Y}\frac{dX}{dt} \tag{2.5}$$

.Where, $Y=$ biomass yield $=\frac{\text{g biomass produced}}{\text{g substrate consumed}}$

By substitute equation (2.4) in to equation (2.5)

$$\frac{dS}{dt} = \frac{1}{Y}\left[\frac{\mu_m SX}{k_s + S} - k_d X\right] \tag{2.6}$$

Where, $\frac{dS}{dt}$ is also given the term: r_{su}(rate of substrate utilization).

$$r_{su} = \frac{1}{Y}\left[\frac{\mu_m SX}{k_s + S} - k_d X\right] \tag{2.7}$$

If the decay term is neglected, then

$$r_{su} = \frac{1}{Y}\left[\frac{\mu_m SX}{k_s + S}\right] = \frac{dS}{dt} \tag{2.8}$$

2.2.4 Types of reactors used for wastewater treatment

The following are the main types of reactors used for wastewater treatment [20]:

- **Batch reactor**

A batch of wastewater is added to the reactor and allowed to react. During reaction no flow is allowed in or out of the reactor. The contents of the reactor are mixed completely, so the concentration of microorganism and pollutants are the same everywhere.
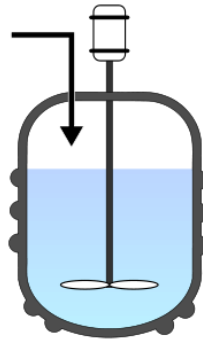
Figure (2.6): Batch reactor.

- **Completely mixed reactor**

Wastewater flows continuously in and out of the reactor. The content of the reactor is completely mixed and the concentration of microorganisms (biomass) and pollutants are the same everywhere inside the reactor.
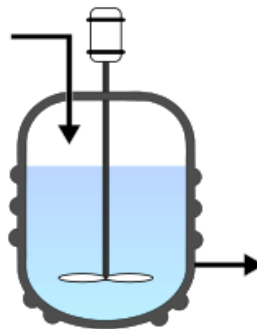
Figure (2.7): Completely mixed reactor.

- **Plug flow reactor**

Wastewater flows continuously in and out of the reactor. No mixing in the reactor, fluid particles pass through the tank and are discharged in the same sequence they inter. The concentration of biomass and pollutants is high at the inlet of the reactor and low at the outlet.
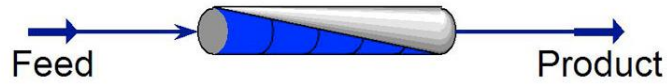
Figure (2.8): Plug flow reactor

In this thesis we focused on completely mixed reactor because it is the closest to oxidation ditch.

2.2.5 Modeling completely mixed reactors

There are two types of completely mixed reactors [21]:

- Completely mixed reactor without solids recycle
- Completely mixed reactor with solids recycle

2.2.5.1 Completely mixed reactor without solids recycles

Apply mass balance analysis on biomass, and on substrate.

- **Biomass mass balance.**

$$\frac{dX}{dt} * V = QX_0 - QX + Vr_g \qquad (2.9)$$

From equation (2.4)

$$r_g = \frac{\mu_m SX}{k_s + S} - k_d X$$

Thus,

$$\frac{dX}{dt} * V = QX_0 - QX + V\left[\frac{\mu_m SX}{k_s + S} - k_d X\right] \qquad (2.10)$$

Assume that $X_0 = 0.0$ and this equation is simplified to

$$\frac{Q}{V} = \frac{\mu_m S}{k_s + S} - k_d \qquad (2.11)$$

Where,

Q Wastewater flow rate (m^3/d).
θ Hydraulic detention time of the reactor $= V/Q$ (day).
S Concentration of the limiting substrate in the tank and in the effluent, mass/unit volume, such as (mg/L).
V Reactor volume (m^3).
X Concentration of biomass in the reactor, mass/volume (mg Vss/L).
S_0 Concentration of the limiting substrate in the influent, mass/unit volume, such as (mg/L).

Substrate mass balance

$$\frac{dS}{dt} * V = QS_0 - QS + Vr_{su} \qquad (2.12)$$

From equation (2.8)

$$r_{su} = \frac{1}{Y}\left[\frac{\mu_m SX}{k_s + S}\right] = \frac{dS}{dt}$$

Substitute r_{su} in equation (2.12) then;

$$\frac{dS}{dt} * V = QS_0 - QS + \frac{V}{Y}\left[\frac{\mu_m SX}{k_s + S}\right] \qquad (2.13)$$

At steady state $r_{su} = 0.0$, thus the above equation becomes

$$S_0 - S + \frac{V}{YQ}\left[\frac{\mu_m SX}{k_s + S}\right] = 0.0 \qquad (2.14)$$

Where,

$$\theta = \frac{V}{Q}$$

$$S_0 - S + \frac{\theta}{Y}\left[\frac{\mu_m SX}{k_s + S}\right] = 0.0 \qquad (2.15)$$

If equation (2.11) is rearranged in the following form,

$$\frac{1}{\mu_m}\left(\frac{1}{\theta} + k_d\right) = \frac{S}{k_s + S} \qquad (2.16)$$

and this term is substituted in equation(2.15)then equation(2.15) becomes,

$$S_0 - S + \frac{\theta}{Y}\left[\mu_m X\left[\frac{1}{\mu_m}\left(\frac{1}{\theta} + k_d\right)\right]\right] = 0.0$$

Rearranging the above equation becomes,

$$X = \frac{Y\,(S_0 - S)}{1 + k_d\theta} \qquad (2.17)$$

This is the concentration of biomass in the reactor.

2.2.5.2 Completely mixed reactor with solids recycles

This process is called the activated sludge system.
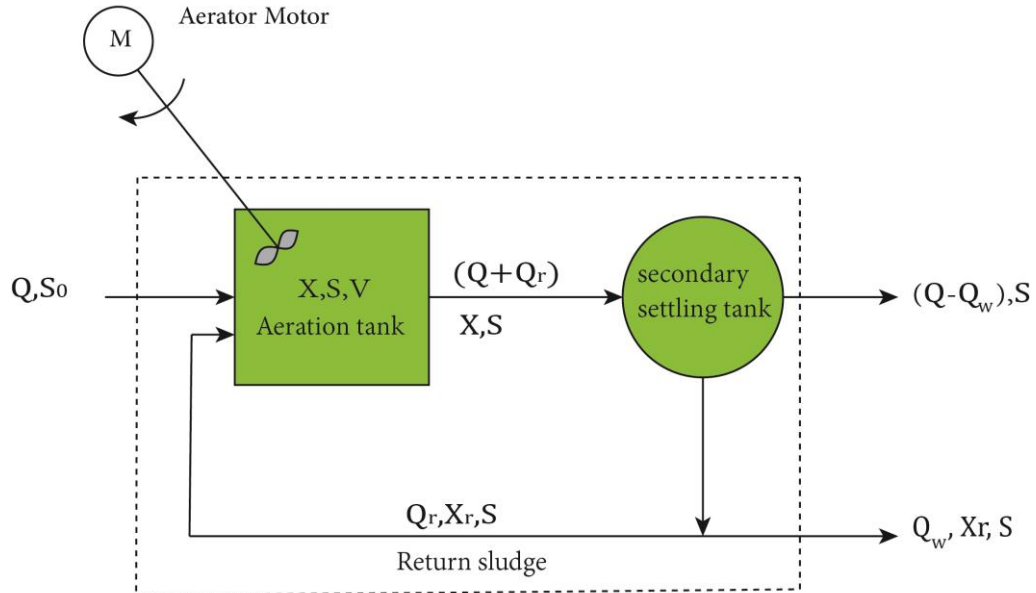
Figure (2.9): Completely mixed reactor with solids recycles.

- **Biomass mass balance**

$$\frac{dX}{dt} * V = QX_0 - (Q_w X_r + Q_e X_e) + V r_g \qquad (2.18)$$

Where,

Q_w waste flow rate

X_r concentration of biomass in the return line

Q_e effluent flow rate

X_e concentration of biomass in effluent

Assuming steady state conditions then $\frac{dX}{dt}$= 0.0, and assume X_0= 0.0, and substitute for r_g from equation (2.4), the above equation simplifies to

$$Q_w X_r + Q_e X_e = V\left[\frac{\mu_m SX}{k_s + S} - k_d\, X\right]$$

$$\frac{Q_w X_r + Q_e X_e}{VX} = \frac{\mu_m S}{k_s + S} - k_d \qquad (2.19)$$

The left hand side of equation (2.19) is the inverse of the mean cell residence time

$$\theta_c = \frac{VX}{Q_w X_r + Q_e X_e}$$

so equation (2.19) becomes,

$$\frac{1}{\theta_c} = \frac{\mu_m S}{k_s + S} - k_d \qquad (2.20)$$

➕ Substrate mass balance

$$\frac{dS}{dt} * V = QS_0 - (Q_w + Q_e) * S + V r_{su} \qquad (2.21)$$

Where,

$$r_{su} = \frac{1}{Y}\left[\frac{\mu_m SX}{k_s + S}\right]$$

At steady state $\frac{dS}{dt} = 0.0$

$$QS_0 - V\left[\frac{\mu_m SX}{Y(k_s + S)}\right] = Q_w S + Q_e S$$

Where,

$$Q_e = Q - Q_w$$

$$QS_0 - V\left[\frac{\mu_m SX}{Y(k_s + S)}\right] = QS$$

Rearrange the above equation

$$\frac{Q}{V}(S_0 - S) = \frac{\mu_m SX}{Y(k_s + S)}$$

Where,

$$\frac{Q}{V} = \frac{1}{\theta}$$

$$\frac{Y(S_0 - S)}{X\theta} = \frac{\mu_m S}{k_s + S} \tag{2.22}$$

Substitute from (2.22) into (2.20) and rearrange,

$$X = \frac{\theta_c}{\theta} * \frac{Y(S_0 - S)}{1 + k_d \theta_c} \tag{2.23}$$

Equation (2.23) is used for calculating and designing the steady state biomass concentration in completely mixed reactor with solids recycle.

Rearrange equation (2.20) and solve for S,

$$S = \frac{k_s(1 + k_d \theta_c)}{\theta_c(\mu_m - k_d) - 1} \tag{2.24}$$

Equation (2.24) is used to find the steady state substrate concentration in a completely mixed reactor with solids recycles.

2.3 Oxidation Ditches Treatment Systems

2.3.1 Introduction

Many treatment systems based on suspended microorganisms have been developed and still used until now. Some of these systems are aerobic and other is anaerobic. Some of the most commonly used activated sludge systems are [22]:

- Conventional activated sludge system.
- Oxidation ditches.
- Sequencing batch reactor (SBR)
- Aerated lagoons.
- Waste stabilization ponds.
- Up flow Anaerobic Sludge Blanket (UASB)

The following is a Glance for conventional activated sludge system and oxidation ditches, because they are related to the subject of thesis.

2.3.2 Conventional activated sludge system

The first version of activated sludge systems is called the conventional activated sludge system. This system is composed of two parts, the first part is aeration tank and the second part is final sedimentation tank. Activated sludge system can be designed through the design of each of the aeration tank and sedimentation tank.

This thesis focused on the aeration tank. The aeration tank in this system can be designed either as a Complete Mixed Flow Reactor (CMFR) or as a Plug Flow Reactor (PFR). This thesis focused on a complete mixed flow reactor because it is closest to the oxidation ditch. The aeration tank can be used to remove BOD only, nitrify only (convert NH_4^+ to NO_3^-) and remove BOD + nitrify.

2.3.3 Oxidation ditch

Some necessary information about the Oxidation ditches will be mentioned in the following [5]; Oxidation ditches are type of suspended growth systems. It is a modified of activated sludge biological treatment process that utilizes long hydraulic detention time to remove biodegradable organics. The oxidation process originated in the Netherlands, with the first full scale plant installed in Voorschoten, Holland, in 1954.

There are currently more than 9,200 municipal oxidation ditch installations in the United States. Nitrification to less than 1 mg/L ammonia nitrogen consistently occurs when ditches are designed and operated for nitrogen removal. Oxidation ditches are typically complete mix systems.

Typical oxidation ditch treatment systems consist of a single or multichannel configuration within a ring, oval, or horseshoe-shaped basin. As a result, oxidation ditches are called "racetrack type" reactors. Horizontally or vertically mounted aerators provide circulation, oxygen transfer, and aeration in the ditch.

Preliminary treatment, such as bar screens and grit removal, normally precedes the oxidation ditch. Primary settling prior to an oxidation ditch is sometimes practiced, but is not typical in this design. Tertiary filters may be required after clarification, depending on the effluent requirements.

Disinfection is required and reaeration may be necessary prior to final discharge. Flow to the oxidation ditch is aerated and mixed with return sludge from a secondary clarifier. Atypical process flow diagram for an activated sludge plant using an oxidation ditch is shown in Figure (2.1). Oxidation ditches are commonly constructed using reinforced concrete. Impervious materials are usually used to prevent erosion.
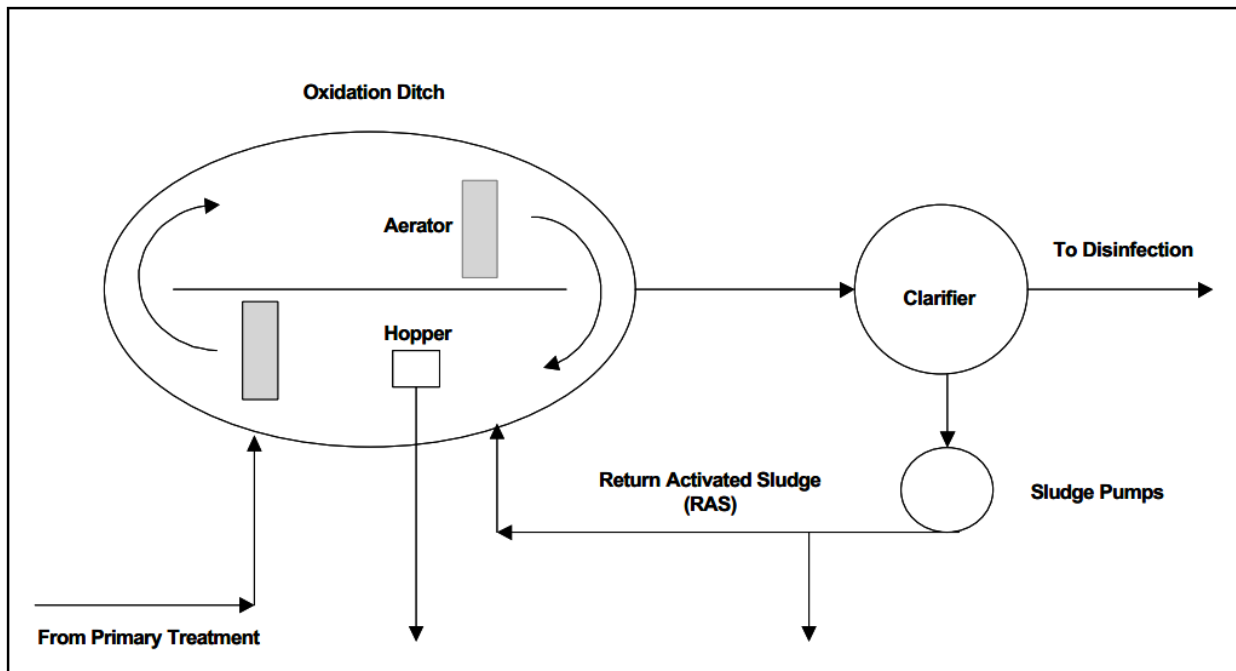
Figure (2.10): Typical process flow diagram for an activated sludge plant using an OD.

Surface aerators, such as brush rotors, disc aerators, draft tube aerators, or fine bubble diffusers are used to circulate the mixed liquor. The influent of raw sewage is introduced just upstream of the aerator (Rotor). The effluent weir is located just upstream of the influent pipe. The mixing process entrains oxygen into the mixed liquor to foster microbial growth and the motive velocity ensures contact of microorganisms with the incoming wastewater.

The aeration sharply increases the Dissolved Oxygen (DO) concentration but decreases as biomass uptake oxygen as the mixed liquor travels through the ditch. Solids are maintained in suspension as the mixed liquor circulates around the ditch. Oxidation ditch effluent is usually settled in a separate secondary clarifier.

In general the process consists of anoxic zone followed by aerobic one as illustrated in Figure 2.11(a). At the influent to the OD, there are organic matter and nitrate (NO_3^-) coming from the aerobic zone and the dissolved O_2 has low concentration (lower than 0.5 mgO_2 /L).

This is called anoxic condition where denitrification occurs. At the end of the anoxic zone and the beginning of the aerobic zone at the brush, we have the remaining organic matter that was not used for denitrification in addition to O_2 introduced by the aerator and ammonium (NH_4^+) that comes with influent and passes through the anoxic zone without any reduction in its concentration. In these conditions both BOD_5 removal and nitrification occurs. At the end of

the aerobic zone the dissolved oxygen becomes almost again zero. Oxidation ditches differ from conventional activated sludge system in terms of the ability to achieve the removal targets with high-performance, low-cost, operational, and maintenance needs, in addition to producing less sludge than other biological treatment processes.
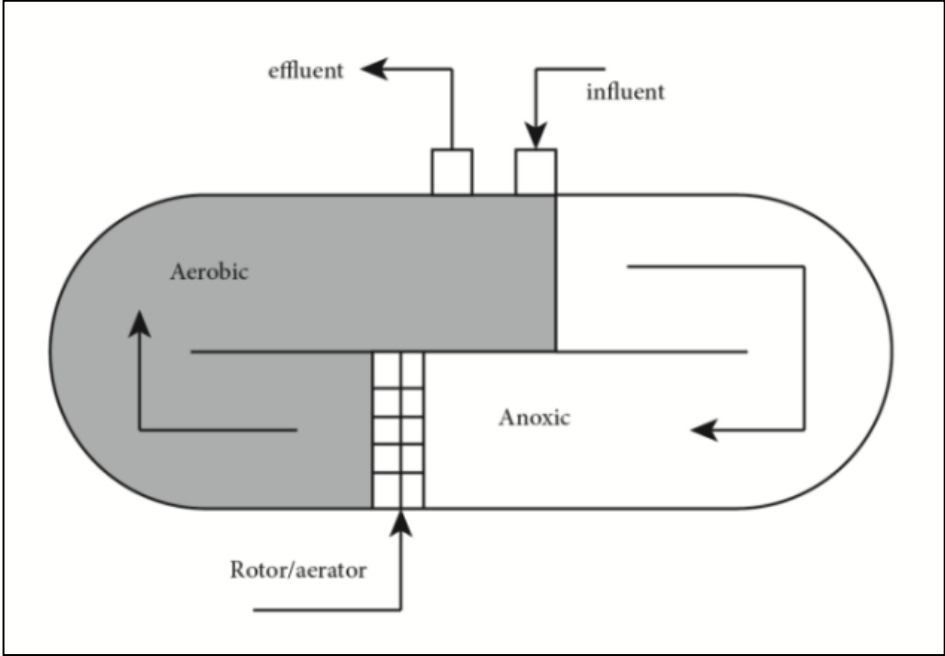
(a)

(b)

Figure (2.11): (a) Oxidation ditch process, (b) Oxidation ditch in European hospital.

Applicability

The oxidation ditch process is a fully demonstrated secondary wastewater treatment technology, applicable in any situation where activated sludge treatment (conventional or extended aeration) is appropriate. Oxidation ditches are applicable in plants that require nitrification because the basins can be sized using an appropriate hydraulic detention time to achieve nitrification at the mixed liquor minimum temperature.

This technology is very effective in small installations, small communities, and isolated institutions, because it requires more land than conventional treatment plants.

Advantages

The main advantage of the oxidation ditch is the ability to achieve removal performance objectives with low operational requirements and maintenance costs. Some specific advantages of oxidation ditches include:

- An added measure of reliability and performance over other biological processes owing to a constant water level and continuous discharge which lowers the weir overflow rate.

- Long hydraulic detention time and complete mixing minimize the impact of a shock load or hydraulic surge.

- Produces less sludge than other biological treatment processes owing to extended biological activity during the activated sludge process.

- Energy efficient operations result in reduced energy costs compared with other biological treatment processes.

- Ability to nitrify and denitrify in one tank.

- No need for primary sedimentation, because the high θ_c in the oxidation ditches is enough to digest the solids that is usually separated in the primary sedimentation tank.

Disadvantages

- Effluent suspended solids concentrations are relatively high compared to other modifications of the activated sludge process.

- Requires a larger land area than other activated sludge treatment options. This can prove costly, limiting the feasibility of oxidation ditches in urban, suburban, or other areas where land acquisition costs are relatively high.

Design Parameters

Screened wastewater enters the ditch, is aerated, and circulates at about 0.25 to 0.35 m/s to maintain the solids in suspension [23]. At this velocity, the mixed liquor completes a tank circulation in 5 − 15 min, leading to the dilution of the influent by 20-30 times. The recycle ratio is from 75 to150 percent, and the Mixed Liquor Suspended Solids (MLSS) concentration ranges from 1,500 to 5,000mg/L.

The design criteria are affected by the influent wastewater parameters and the required effluent characteristics, including the decision or requirement to achieve nitrification, denitrification, and/or biological phosphorus removal. Specific design parameters for oxidation ditches include:-

Hydraulic Detention Time (HDT): Oxidation ditch volume is sized based on the required HDT to meet effluent quality requirements. The HDT is selected as a function of nitrification requirements and the minimum mixed liquor temperature. Design HDT values vary from 4 to 48 or more days. Typical HDTs required for nitrification range from 12 to 24 days.

BOD Loading: BOD loading rates vary from less than 160,000 mg/1000 liters to more than $4x10^7$ mg/1000 liters. ABOD loading rate of 240,000 mg/1000 liters per day is commonly used as a design loading rate. However, the BOD loading rate is not typically used to determine whether or not nitrification occurs.

Hydraulic Retention Time (HRT): While rarely used as a basis for oxidation ditch design, HRTs within the oxidation ditch range from 6 to 30 hours for most municipal wastewater treatment plants.

Difference between oxidation ditches and conventional activated sludge

- Oxidation ditches were developed to minimize the net sludge production compared to the conventional activated sludge system.

- Net sludge production minimization is achieved by using law F/M ratio (0.02 − 0.15$\frac{mg\ BOD_5}{mgvss*d}$). In this case the active biomass is forced to feed on the decaying biomass due to the shortage of food. This leads to lower sludge production, and the sludge to be wasted will be less and has lower organic content.

- Oxidation ditches are operated at high θ_c (15-30 days) and at high θ (15-36 hrs).

- It is theoretically possible in OD to minimize the net sludge production to zero. This can be achieved by making the produced biomass equal to the degraded biomass by endogenous decay (i.e. biomass feeding on dead biomass). This is presented mathematically as follows [1]:

The sludge produced during wastewater treatment is

$$YQ(S_1 - S_2)$$

The sludge decaying during wastewater treatment is

$$k_d XV$$

So, the net production of sludge during wastewater treatment P_x is

$$YQ(S_1 - S_2) - k_d XV \tag{2.25}$$

Let the net production of sludge during wastewater treatment $P_x = 0.0$

So we can write the equation as follows;

$$YQ(S_1 - S_2) = k_d XV$$

After arranging the equation can be written as follows;

$$X * \theta = Y \frac{(S_1 - S_2)}{k_d} \tag{2.26}$$

This equation can be used to find X and V that can be used to a chive zero net sludge production.

Processes that can be achieved in oxidation ditches

Three processes can be achieved in oxidation ditches:-

- Organic matter removal (BOD_5 removal) in the aerobic zone.
- Nitrification (in the aerobic zone).
- Denitrification (in the anoxic zone).

At the influent to the oxidation ditch, we have organic matter in addition to nitrate (NO_3^-) coming from the aerobic zone and the dissolved O_2 is almost zero. This is called anoxic condition where denitrification occurs. At the end of the anoxic zone and the beginning of the aerobic zone, we have the remaining organic matter that was not used for denitrification in coming in the influent in addition to O_2 introduced by the aerator addition to ammonium NH_4^+. In this condition both BOD5 removal and nitrification occurs. At the end of the aerobic zone the dissolved oxygen becomes almost zero.

2.3.4 Wastewater treatment plant at European hospital

This research contributes to the rehabilitation of the wastewater treatment plant of the European Hospital located in the southern of Gaza Strip. This plant receives a daily average amount of 141 m^3 of untreated wastewater coming out of the European hospital. The average concentration of organic matter (BOD) entering the plant 317 mg /L [3], so this wastewater needs to be treated before it is injected into the aquifer or prior to use in irrigation, to prevent the pollution of the groundwater.

The plant utilizes an oxidation ditch for the biological treatment process and it is intended here to create a simulation model for the process using the component-oriented language *Modelica*

in order to better understand the process dynamics and investigate the efficiency of possible control schemes. The plant under study consists of 15 parts, as illustrated in the process flow diagram depicted in Figure (2.12).
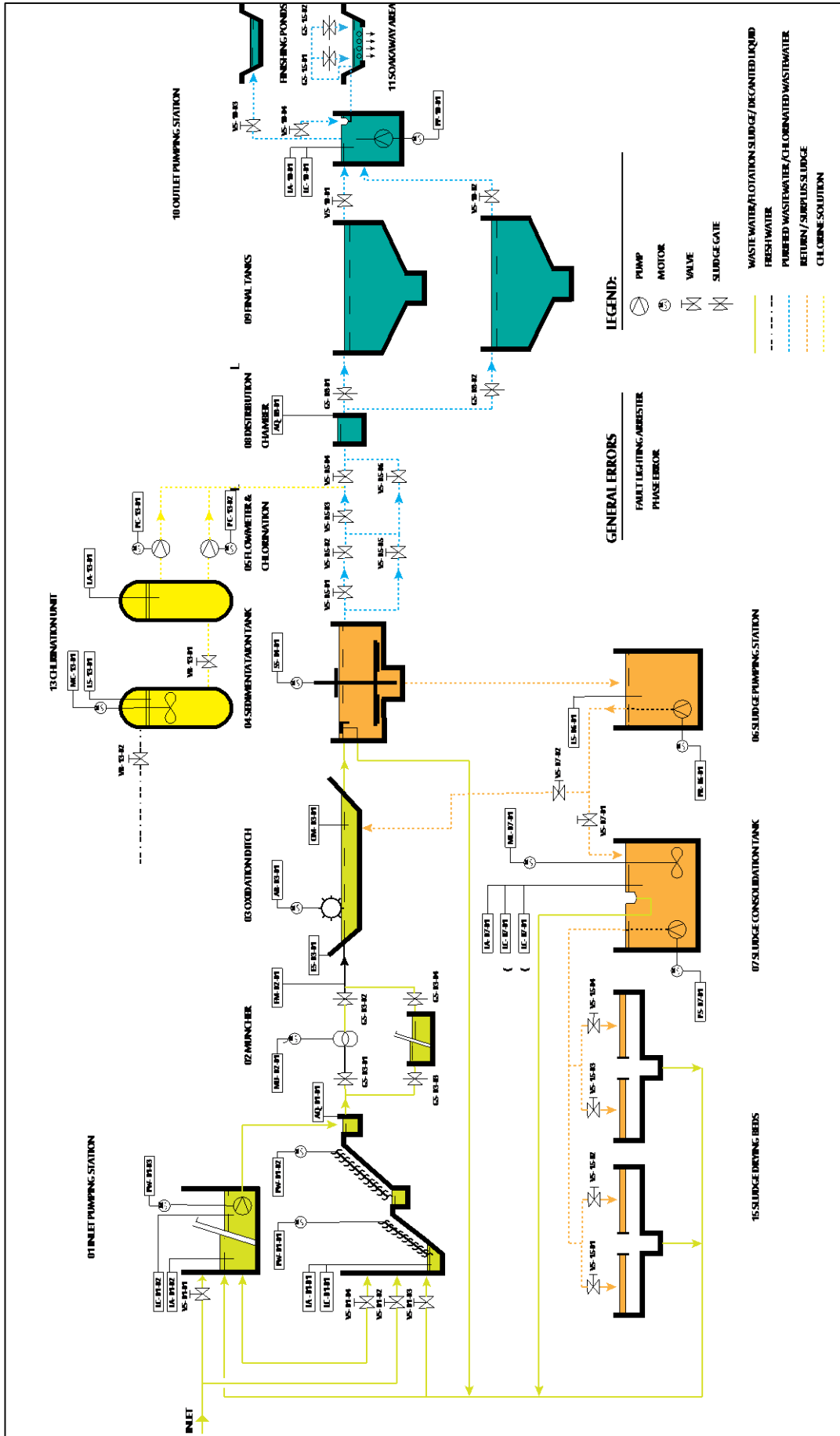
Figure (2.12): UNRWA hospital Gaza-sewage treatment plant

Part I: INLET PUMPING STATION consists of a tank for wastewater collection entering the wastewater to plant, in addition to the two screw pumps capacity of each is 10 L/S.

Part II: MUNCHER, which is used to remove solids.

Part III: OXIDATION DITCH is the most important part of the plant because the biological treatment process occurs in this part.

Part IV: SEDIMENTATAION TANK, which is used to separate and remove Settleable suspended solids.

Part V: FLOWMETER &CHLORINATION, which is used to control the sterilization process and to add chlorine.

Part VI: SLUDGE PUMPING STATION, which is a tank to collect the sludge for distribution either to oxidation ditch or to be sent for sludge treatment.

Part VII: SLUDGE CONSOLIDATION TANK is a tank that mixes the sludge to become homogeneous, so it is   transferred for drying.

Part VIII: DISTRIBUTION CHAMBER, which is the place where the treated water is being distributed to downstream units.

Part IX: FINAL COLLECTION TANKS, which are used to collect water that has been treated.

Part X: OUTLET PUMPING STATION, which is used to transfer the water that has been treated to Finishing Ponds and Soakaway Area.

Part XI: SOAKAWAY AREA, are ponds to inject treated water   into groundwater. Part XII: CHLRINATION UNIT, which is used for the disinfection of treated water using chlorine.

Part X III: SLUDGE DRYING BEDS, is the place, where the sludge is being dried for disposal or some industrial use.

As was mentioned previously the WWTP of the EH in Khan Younis city does not work properly, at the same time the control system for the WWTP is currently out of order. The aerator for the OD at plant is programmed to work in two speeds (high, low) which will lead to waste of power this is because the wastewater may need medium speed to be treated.

At this situation it's necessary to get the aerator working in the high speed which will mean the power is being wasted. In this research the speed of aerator would be variable depending on the concentration of the oxygen in the wastewater, this oxygen measures the organic matter in the wastewater as explained in the following chapters, this will decide the required speed to treat the wastewater in order to reach the acceptable concentration and accordingly will get the aerator working on that speed, which will lead to some saving in the power consumed.

CHAPTER 3
MATERIALS AND METHODOLGY

3.1 Materials

3.1.1 Introduction

Dymola is a tool for modeling and simulation. MATLAB is a sophisticated language and a technical computing environment. It provides core mathematics and advanced graphical tools for data analysis, visualization, and algorithm and application development. Simulink is a simulation and prototyping environment for modeling, simulating, and analyzing real-world, and dynamic systems. Simulink provides a block diagram interface that is built on the core MATLAB numeric, graphics, and programming functionality [24].

3.1.2 Comparison

Dymola and Simulink have their own advantages and disadvantages. Dymola and Simulink are compared. They are listed as follows [25]:

1. Platform

Both Dymola and Simulink can work on a platform such as Windows, UNIX and Linux. At least 150MB Disk space and 128MB RAM are needed for Dymola while 600MB Disk space and 256MB RAM are needed for MATLAB only.

2. Need for supporting software

Dymola provides self-contained environment for modeling and simulating. It doesn't need any other software to support it after installation. Simulink is built on the core MATLAB numeric, graphics, and programming functionality so it must run in the environment of MATLAB.

3. Modeling method

Dymola uses a modeling methodology based on object oriented modeling and equations. Users do not need to convert equations to block diagram. Simulink is based on many basic blocks. Users should convert equations to block diagram form manually.

4. Program language

Dymola uses Modelica language which is for modeling of large, complex and heterogeneous physical systems. Simulink uses M-file, which is based on MATLAB language and C-code for programming. It takes time to build complex physical systems.

5. Icons of components or blocks

In Dymola the icons of model components are defined either by drawing shapes, or by importing graphics from other tools in bitmap format could be both either 3-D and 2-D style. In Simulink users can only write commands to draw 2-D icons.

6. Algebraic loops

In Simulink the basic equations cannot be simulated directly due to algebraic loop, which only contains algebraic equations. It is necessary for users to transform the equations to the form required by Simulink. In Modelica it is possible to write balance and other equations in their natural form as a system of differential-algebraic equations.

Based on the previous comparison, modeling work was based on Dymola program because of the following features of the program [26]:

- Modelica is based on equations instead of assignment statements. This permits a causal modeling that gives better reuse of classes since equations do not specify a certain data flow direction. Thus a Modelica class can adapt to more than one data flow context.

- Modelica has a multi domain modeling capability, meaning that model components corresponding to physical objects from several different domains such as electrical, mechanical, thermodynamic, hydraulic, and biological and control applications can be described and connected.

- Modelica is an object oriented language with a general class concept that unifies classes. This facilitates reuse of components and evolution of models.

- Modelica has a strong software component model, with constructs for creating and connecting components. Thus the language is ideally suited as an architectural

description language for complex physical systems, and to some extent for software systems.

3.1.3 Modelica Standard Library (MSL)

In addition to define the specification for the Modelica language, the Modelica Association publishes a standard library of Modelica models. This library, called the Modelica Standard Library (MSL), is available free of charge. MSL was developed so that users of the Modelica language would not have to create their own basic models for the common modeling domains.

Note that the MSL is not a collection of black box model. Instead, Modelica representation of all the models can be viewed to help understanding exactly what behavior is modeled. The names of MSL's components begin with "Modelica.". For example, the physical type "Modelica.SIunits.Voltage" is a type defined in the "SI units" package nested inside the "Modelica" package.

In this thesis oxidation ditch model is not available in the library, so we created the oxidation ditch model from start to end.

3.2 Methodology

The procedure of this thesis is to achieve the desired goals as follows:

1. Several meetings were made with specialists in the field of wastewater treatment to understand the mechanism of wastewater treatment plants and to identify the efficiency determinants. Moreover, a detailed study shall be made to understand the design of treatment plants in order to highlight the most influential design factors on plant efficiency as well as learn to what extent the plant performance can be improved to obtain the best results. The most important research questions, which have been developed to better understand wastewater treatment process and to clarify some related points.

   ✓ What is the main component of a typical wastewater treatment plant and what is the key component of the treatment plant that would control the plant efficiency?
   ✓ What are the types of wastewater treatment systems and what is the most preferred and widely used system in Gaza Strip's treatment plants?

- ✓ What is an oxidation ditch, how does it work (Mechanism), and what are the key factors that would affect its efficiency?

- ✓ What is the possibility of using the European hospital wastewater plant as a pilot project to apply the theory of a developed wastewater treatment system?

- ✓ What are the most important references and previous studies that were conducted in this field and whether these studies were applied in other projects or not?

2. Reviewing and discussing what was published on modeling of wastewater treatment process by accredited scholars and researchers to transfer and share knowledge and ideas that have been established around this topic, and what strengths and weaknesses related to their work there are.

3. Conducting meetings with the director and field staff working at the European wastewater treatment plant, in addition to site visits to the European hospital (EH) to identify strengths and weaknesses of currently applied system. Moreover, identifying potential constrains that might be faced when applying the developed modeling system.

   In addition, identifying the type of environment at the European hospital and making sure that the developed modeling system will comply with the functional design of the plant. All aforementioned points relatively help in collecting required data. Collected data will be represented in a format that would assist in preparing the model and identifying the specific objectives, components, methodology, and outcomes.

4. Choosing suitable programming language, this through one can prepare or develop modeling and control system to enable the treatment plant of the hospital present high treatment efficiency and cost effective one. The most available modeling programs are Dymola and Simulink.

   The Dymola modeling program was favored for the program features, which were mentioned in this study. Based on modeling process of the oxidation ditch it was/is emphasized that the oxidation ditch represents an essential component in treatment plants because it controls the wastewater treatment efficiency.

5. Illustrating the mathematical equations used in the object-oriented programming. Determining the main format and clarifying the most important and influential input that can be used to build an automatic control system to achieve the highest benefit of energy consumption in line with fulfilling operating requirements.

CHAPTER 4
CONTROL OF OXIDATION DITCH

After describing the mathematical equations of the oxidation ditch system, the following is a description of the wastewater treatment control system. The main strategy followed is to control the treatment efficiency by controlling the oxygen concentration in the oxidation ditch.

4.1 The relationship between the amount of required oxygen and concentration of organic matter at effluent

The net production of sludge during wastewater treating Px, KgVss/d.

$$Px = \frac{Y}{1 + k_d \theta_c} Q(S1 - S2) \qquad (4.1)$$

The required of oxygen (R_o) kg O_2/d affects the change in organic matter as well as the net production of sludge. In [4, 23], it has been shown that these quantities are related as follows;

$$R_o = Q_1(S_1 - S_2) - 1.42 P_x \qquad (4.2)$$

Solve all of Equation (4. 1) and (4.2) results in the following equation;

$$S_2 = S_1 - K\frac{R_o}{Q_1} \qquad (4.3)$$

Where K is a coefficient that depends on Y, k_d and θ_c. In our example we used a value of $K=$ 290 gave reasonable results.

4.2 The relationship between the amount of required oxygen and rotational speed of the aerator

In the Oxidation ditches the amount of dissolved oxygen is controlled through adjusting the speed of the rotating brush. Let r represent the speed of aerator in (rpm). Then, for the sake of simplicity, a linear relationship is derived between r and R_o depending on the characteristics of the aerator brushof the wastewater treatment plant in EH(Manufacturer Name: krouger), model : am 160 mo4/16, the characteristics of the aerator as shown in the table (4.1).

Table (4.1): characteristics of the aerator brush of the wastewater treatment plant in European hospitals.

Data ⟍ Speed	Speed of rotor 980 (rpm)	Speed of rotor 1460 (rpm)
Oxygenation capacity of the rotor E, $\left(\frac{kgO_2}{h.Kw}\right)$	1	2
Power of Aerator (Kw)	6	9
Current (Ampere)	14	20
Voltage (Volt)	380	380
Frequency (hertz)	50	50

The linear relationship between Oxygenation capacity of the aerator(E) and the speed of Aerator (r) as follow:

$$E = \frac{r - 500}{480} \tag{4.4}$$

The linear relationship between the power of aerator (P) and the speed of Aerator (r) as follow:

$$P = \frac{r - 20}{160} \tag{4.5}$$

So we can calculate the required oxygen as following:

$$R_o = 24\ EP$$

Thus, the relationship between the amount of required oxygen and rotational speed of the aerator as follows;

$$R_o = \frac{1}{3200}r^2 - \frac{13}{80}r + \frac{25}{8} \qquad (4.6)$$

4.3 The relationship between the dissolved oxygen and rotational speed of the aerator

We measured the speed of waste water (v) in the oxidation ditch, when the speed of rotor is 980 rpm the speed of waste water equal 0.2 m/s, whilst the speed of rotor is 1460 rpm the speed of waste water equal 0.4 m/s. From this measurement we derived a liner relationship between the speed of waste water (v) and the speed of rotor (r) as follows;

$$v = \frac{r - 500}{2400} \qquad (4.7)$$

To get the oxygen concentration (O_2) mgO₂/L, from the following relationship;

$$O_2 = 0.0116\,\frac{R_o}{Q_d} = 0.0116\,\frac{R_o}{v.A_c} \qquad (4.8)$$

Where A_c is the cross section of the oxidation ditch. In the wastewater treatment plant in the European hospital $A_c = 6\ \text{m}^2$.

When substitute R_o from equation (4.6) in equation (4.8) produces the following;

$$O_2 = 0.0116\left[\frac{1250}{(r - 500)} + \frac{r^2}{8(r - 500)} - \frac{65r}{(r - 500)}\right] \qquad (4.9)$$

Through previous relationships we can control the oxidation ditch to reach the desired value of organic matter at the effluent.

CHAPTER 5
IMPLEMENTATION, SIMULATIONS, AND RESULTS

This chapter describes briefly how modeling is implemented in Modelica using the Dymola tool. It describes how to build models for Oxidation ditch. Connectors which are used in building Oxidation ditch system. Connectors represent input and output terminals of Oxidation ditch. It is a special class derived at modelica language.The first step is defining the wastewater connector (W). Its icon is represented by a small blue square and it is defined as follows:

```
connector W
      Real S(min=0.0);
flow Real Q;
end W;
```

5.1 The current situation of the WWTP

The plant works completely manually, where aerator is powered at constant speed at either 980 or 1460 rpm.

When setting the aerator speed at 1460 rpm, the motor consumes 9 KW. Figure (5.1) shows that at times when wastewater's flow is low; the concentration of BOD goes to zero, which implies that there is no need for such a speed to treat wastewater. Actually, the use of this speed affects the treatment process negatively and wastes energy uselessly.
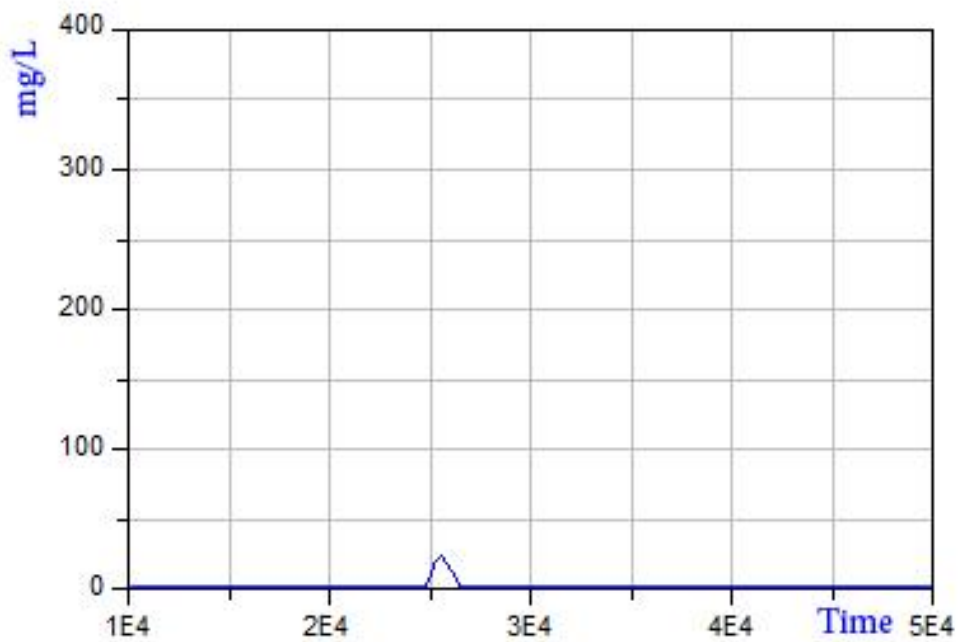
Figure (5.1): BOD of the effluent of OD when the speed of aerator is 1460 rpm.

When setting the aerator speed at 980 rpm, it consumes 6 KW. Figure (5.2) shows at times when wastewater's flow is high, the concentration of BOD tend to be high, ranging between 150-250 mg BOD_5/L. This means the treatment was not accomplished as required, because the amount of oxygen at these times is less than what is indeed required to complete the treatment process properly.
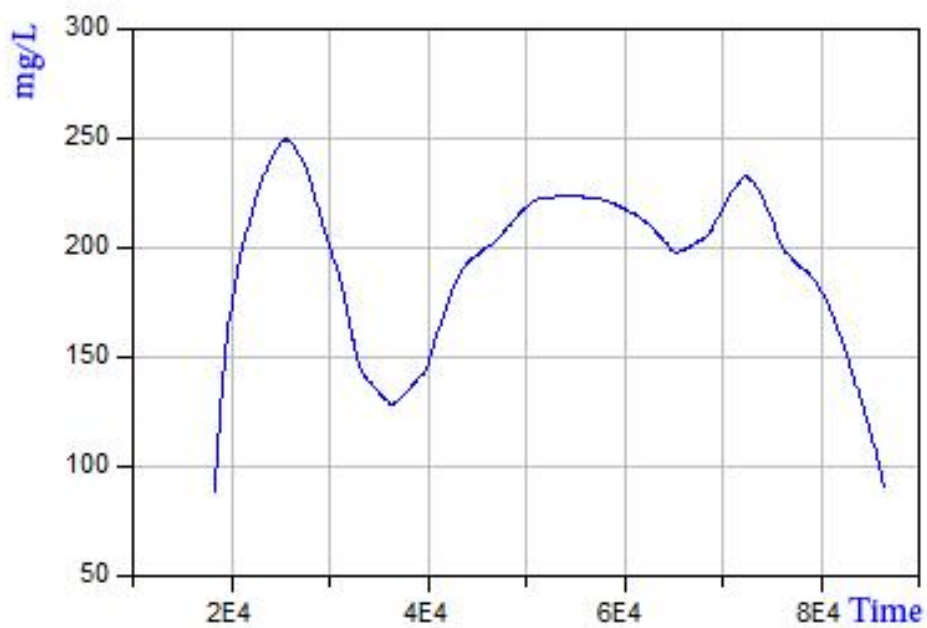

Figure (5.2): BOD of the effluent of OD when the speed of aerator is 980 rpm.

5.2 Using variable speeds

To build an oxidation ditch model, two wastewater connectors (w1 and w2) are needed, in addition to an output connector (O) of type real and input connector (r) of type real. Being governed by equations (4.3, 4.6, 4.9) its Modelica code is shown in Figure (5.3).

```
model OxiDitch
parameter Real Y= 0.5 "mgvss /mg BOD5";
parameter Real Kd=0.05 "d^-1";
parameter Real Ks= 30 "mgBOD5";
parameter Real mum= 2.5 "d^-1";
parameter Real thita= 1 "d";
parameter Real thita_c= 10 "d";
parameter Real Ac= 6 "m^2";
parameter Real a= 0.8;
parameter Real b= 0.115;
parameter Real Px=0;
parameter Real K=290;
Real RO;

equation

W2.S=W1.S-(K*RO/W1.Q);
RO=(r^2/3200) -(13*r/80)+(25/8);
Oxi=0.0116*((1250/(r-500))+
(r^2/(8*(r-500)))-(65*r/(r-500)));
M=W2.S;
W1.Q+W2.Q=0;
end OxiDitch;
```

Figure (5.3): Modelica code of the oxidation ditch.

The goal of the simulation is to verify the derived model and to see the progress of operations in the oxidation ditch. The control problem is a typical feedback control scenario in which the concentration of organic matter at the effluent is measured in correlation to the oxygen sensor reading, compared to a reference value, and then resultant error signal is used to derive the controller which adjusts the aerator speed. Consequently, the level of dissolved oxygen is adapted which the key factor of the microorganisms production that affects the organic matter consumption.

However, excess amounts of oxygen levels are undesired as it leads to growth of the filamentous bacteria which cause sludge bulking. It is recommended to keep the oxygen level

below 3mg O_2/l [27]. The top level module of such a system may be implemented in dymola as illustrated in Figure (5.4).

The proposed process controller is based on a PID controller with limited output, anti-windup compensation and set point weighting as illustrated in Figure (5.5), this PID controller is available in the Modelica standard library. The controller is tuned and its output is limited to the range from zero to 1460which is the maximum possible speed of our aerator.
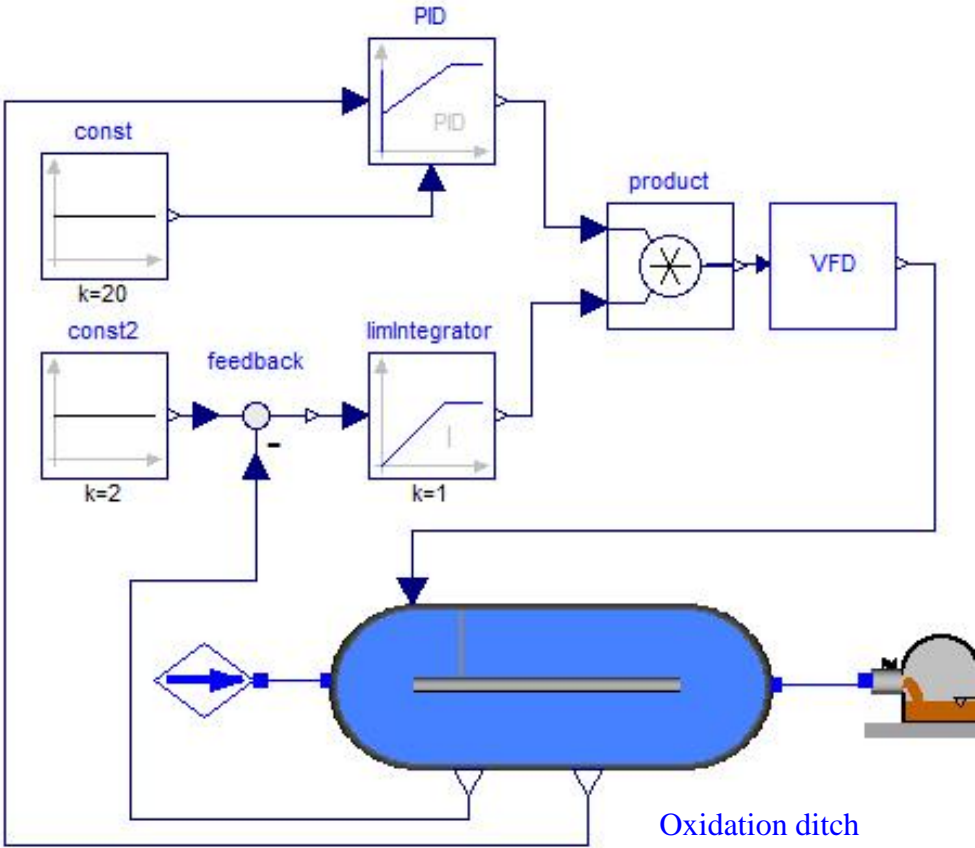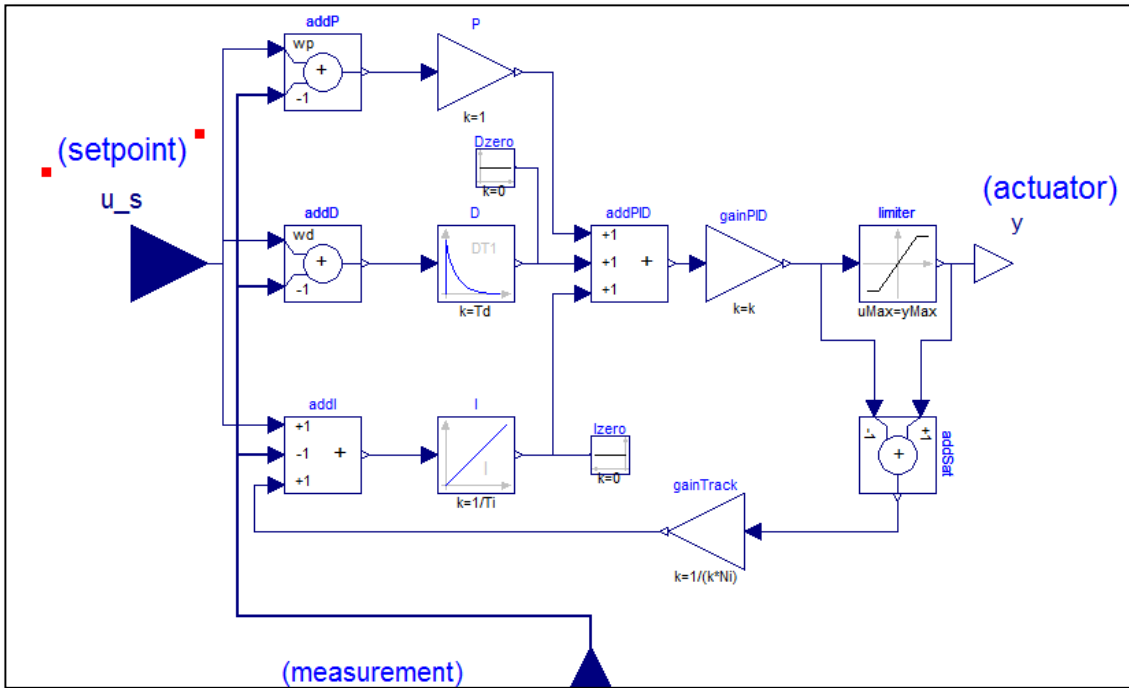

Figure (5.4): The system model.

Figure (5.5): PID controller with limited output.

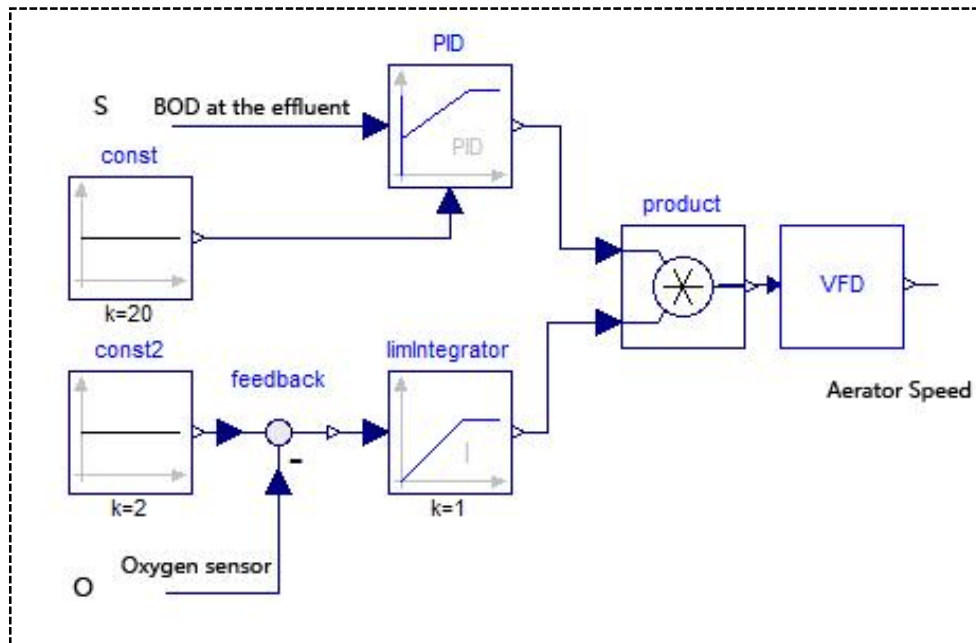The simulated controller of this process is shown in Figure (5.6).

Figure (5.6): Process controller.

Increasing oxygen leads to increase the efficiency of bacteria and thus less substrate for bacteria such as organic matter, it's better to keep oxygen around $2mgo_2/l$ to prevent the growth of the filamentous bacteria which cause sludge bulking. Control the amount of

dissolved oxygen in the wastewater through the rotor speed, when the rotor speed increases, it leads to an increase in the amount of dissolved oxygen in wastewater.

The upper part of the controller has a PID module with limited output, anti-windup compensation and set point weighting. Its output specifies the required speed of aerator. The lower part has an integrator with a limited output from zero to one.

In regular cases, the error signal is positive and the integrator saturates to unity value. Once the dissolve oxygen exceeds the specified threshold ($O \approx 2$ mg/l), the integrator output starts to decrease and eventually saturates to 0. This gives a measure for the persistence of the dissolved oxygen to exceed the threshold value. The result of this integrator is multiplied with the output of the Limited PID module to generate the recommended speed of aerator.

The Variable Frequency Drive (VFD) is modelled by a first-order block with a time constant of 5 s resulting in an acceleration time of about half a minute to move forward or backward between zero speed and rated speed states.

The wastewater flow pattern at the influent is illustrated in Figure (5.7).
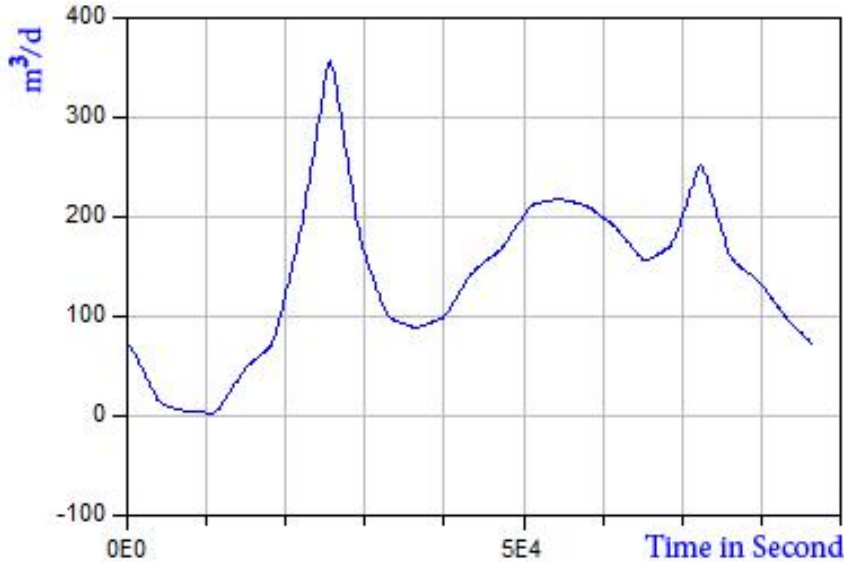

Figure (5.7): Wastewater flow Pattern of at influent of oxidation ditch.

The concentration of organic matter at influent and effluent of the oxidation ditch are illustrated in Figures (5.8). Since the concentration of organic matter at the influent is assumed to equal to

290 mg BOD$_5$/L, the concentration of organic matter at the effluent is reduced to 20mg/L as shown in Figure (5.8).
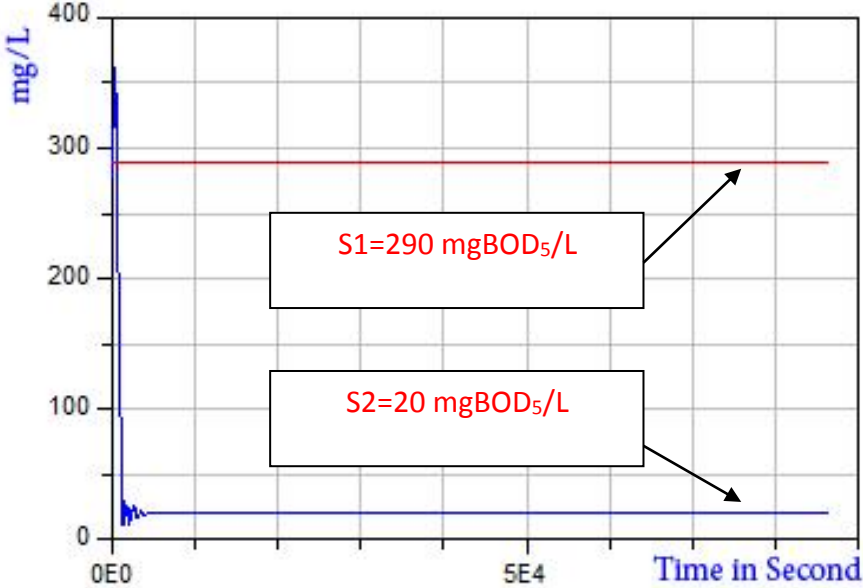

Figure (5.8): Concentration of organic matter at influent and effluent of OD.

The speed of aerator shown in figure (5.9), while the readings of the oxygen sensor shown in Figure (5.10). Both are reasonable and are within the acceptable range.
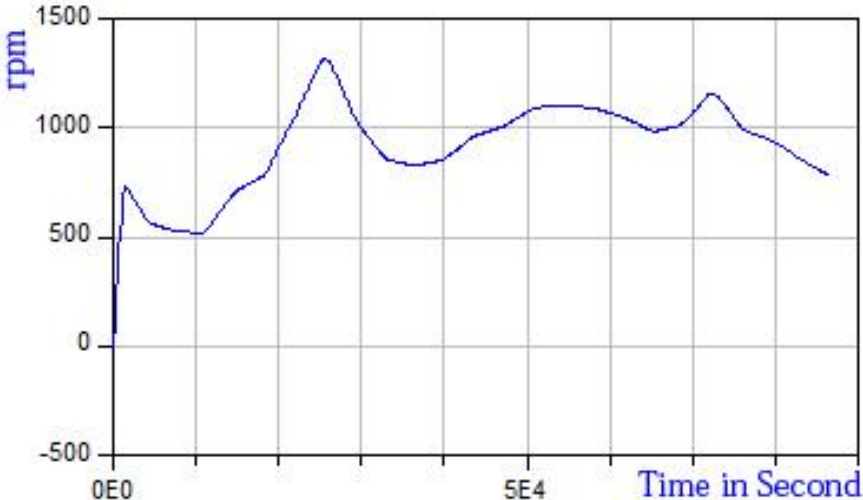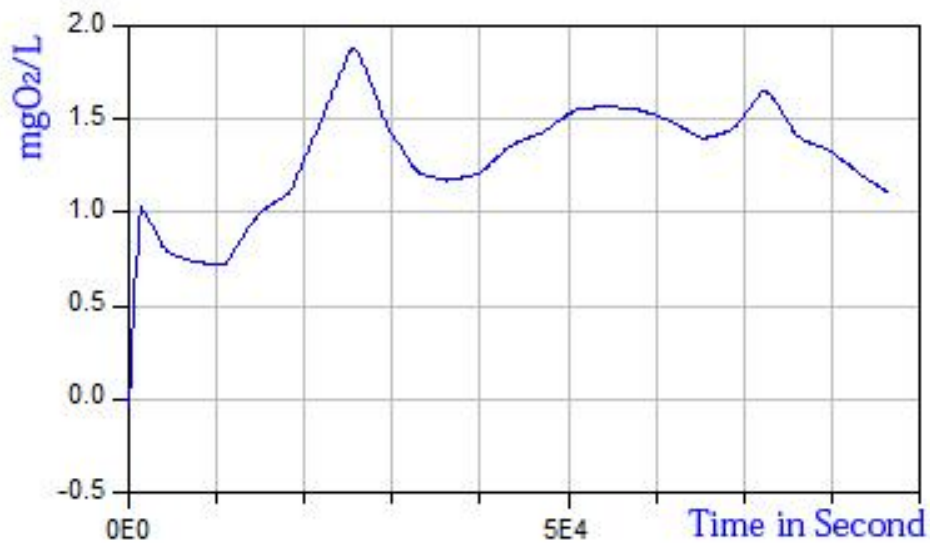

Figure (5.9): Speed of Aerator.

Figure (5.10): Concentration of oxygen.

The average of consumed power at variable speed is calculated using the following equation:

$$p_{av} = \frac{1}{b-a} \int_a^b p(r)\, dr$$

Where a=0, b=1460.

From equation (4.5)

$$p(r) = \frac{r - 20}{160}$$

$$p_{av} = 4.44\ KW$$

This means, when using variable speeds instead of the constant speed 1460 rpm, the power consumption is lowered to 50%. Similarly, the power consumption is lowered to 26% when variable speeds are used instead of the constant speed 980 rpm. In addition, running the aerator at variable speeds increase the overall quality of the treated wastewater coming from the oxidation ditch.

CHAPTER 6
CONCLUSION AND FUTURE WORK

6.1 Conclusion

This thesis targeted a small size hospital's plant, which depends on oxidation ditch to treat wastewater. This thesis presents an easily controlled and managed model for the oxidation ditch of the wastewater treatment plant of the European hospital. The model provides a tool for testing the system performance under different operation scenarios and control schemes. It also helps in understanding the dynamics of the system and allows designing a stable and robust controller unit for the system. The following conclusions were derived from this work:

1- The control system enabled the control of oxygen concentration from 0 to 2 mg O_2/L.
2- The control system enabled to reduce the concentration of organic matter. For example, form 290 to 20 mg BOD_5/L.
3- Using the control system reduced the power consumption. For example, from 9 KW to 4.44 KW when using the control system instead of the constant speed 1460 rpm and from 6 KW to 4.44 KW when using the control system instead of the constant speed 980 rpm.

6.2 Recommendation

Out of what was introduced in this thesis, Supervisors of the plant at EH are advised to change the speed of the aerator to variable speeds depending on the concentration of oxygen in wastewater, whereas oxygen measures the concentration of organic matter in wastewater as it was explained earlier. This will result in reducing consumed power.

6.3 Future Work

Future work will focus on the topic of oxidation ditch control. The work will study the development of the control system and will introduce new effective techniques in the control process.

In the future, mathematical models for wastewater treatment will be developed to cover wastewater purification process from phosphorous and nitrogen.

Finally, cost estimation for applying the proposed thesis on the wastewater treatment plant of the European hospital in real will be studied to determine the feasibility of this thesis.

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