Republic of Iraq Ministry of Higher Education & Scientific Research
University of Babylon
College of Engineering
Department of Environmental Engineering

Design a biological slaughterhouse wastewater treatment system (using an anaerobic baffle reactor - constructed wetland system)

By

HUDA MOHAMMED
GHUFRAN MAHMUD

Supervised

Prof. Dr. Alaa Hussein AL - Fatlawi

2021 2022

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

" اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ * خَلَقَ
الْإِنسَانَ مِنْ عَلَقٍ * اقْرَأْ وَرَبُّكَ
الْأَكْرَمُ * الَّذِي عَلَّمَ بِالْقَلَمِ * عَلَّمَ
الْإِنسَانَ مَا لَمْ يَعْلَمْ "
صدق الله العلي العظيم
«سورة العلق: الآيات 1-5»

الشكر

في البداية نحمد الله تعالى على أن وفقنا لإنجاز هذا البحث، له الحمد والشكر، ثم أود أن أشكر مشرفي

(الدكتور علاء الفتلاوي)

الذي كانت خبرته لا تقدر بثمن في صياغة أهم مواضيع البحث ومنهجيته. فقد دفعتني ملاحظاته الثاقبة إلى صقل تفكيري ورفع عملي إلى مستوى أعلى.

Supervisor Certification

We certify this project entitled “Design a biological slaughterhouse wastewater treatment system”(using an a anaerobic baffle rractor constructed wetland system)

presented by “Huda Mohammed” and “Ghufran Mahmud was perpaeed under supervision as partial fulfillment for the degree of Bachelor of Science in Environmental Engineering College of Engineering University of Babylon.

Signature:

Name:Prof.Dr.Alaa Hussein AL-Fatlawi

CERTIFICATION

We certify that we have read this project entiled ‘Desing a biological slaughterhouse wastewater treatment system’ (using an anaerobic baffle reactor-constructed wetland system) in ist content and in what is connected with it ,and that in our opinion it meets the standard of a graduated project for the degree of Bachelor of Science in Environmental Engineering

Signature: **Signature:**

Pro.Dr.Amal H.Kaleel **Pro.Dr.Nisreen J.ALmansori**

Signature: **Signature:**

Pro.Dr.Rasha Salah AL-Kizwiui **Pro.Dr.Isra’a Sadi Samaka**

Signature:

Asst.Pro.Dr.Suad Mahdi Ghaliwa AL-Fatlawi

Approval of Enironmental Engineering Department

Signature

Asst.Pro.Dr.Hussien A.Mahdi AL-Zubaidi

Head of the Environmental Engineering Department

Table Of Content

Chapter1

Chapter2

Chapter Three

Chapter four

Chapter five

Table Of Figures

Abbreuiations table

MPPs	**meat peocessing plants slaughtering**
SWW	**slaughterhouse wast water**
USEPA	**United states environmental protection agency**
MPP	**meat processing plant**
AOPS	**advanced oxidation processes**
BOD	**biochemical oxygen demand**
COD	**chemical oxygen demand**
TOC	**total organic demand**

TN	**Total nitrogen**
TP	**Toral phosphorus**
TSS	**Totai suspended solids**
EV	**European vnion**
USA	**New Zealand**
BAT	**Best available technology**
DO	**Dissolved oxygen**
UPBR	**Vp fiow packed-bad reactors**

ST	**Septic tanks**
UST	**Ultra sound technology**
VSS	**Volatile suspended solids**
COS	**Reversr osmosis**
MF	**Micro filtration**
HRT	**Hydraulic retention time**
GMP	**Good manufacturing practies**
AS	**Active sludge**

Slaughterhouse Wastewater: Treatment, Management and Resource Recovery

Abstract

The meat processing industry is one of the largest consumers of total freshwater used in the agricultural and livestock industry worldwide. Meat processing plants (MPPs) produce large amounts of slaughterhouse wastewater (SWW) because of the slaughtering process and cleaning of facilities. SWWs need significant treatment for a sustainable and safe discharge to the environment due to the high content of organics and nutrients. Therefore, the treatment and final disposal of SWW are a public health necessity. Although physical, chemical, and biological treatment can be used for SWW degradation, each treatment process has different advantages and drawbacks depending on the SWW characteristics, best available technology, jurisdictions, and regulations. SWWs are typically assessed using bulk parameters because of the various pollutant loads derived from the type and the number of animals slaughtered that fluctuate amid the meat industry. Thus, an on-site treatment using combined processes would be the best option to treat and disinfect the slaughterhouse effluents to be safely discharged into receiving waters

CHAPTER ONE

INTRODUCTION

CHAPTER ONE
INTRODUCTION

1.1 Introduction

The meat processing industry consumes 29% of the total freshwater used by the agricultural sector worldwide . Moreover, the global production of beef, pork, and poultry meat has been doubled in the past decade and is projected to grow steadily until 2050. Thus, the number of slaughterhouse facilities is increasing, which results in an expected higher volume of slaughterhouse wastewater (SWW) to be treated SWWs are classified as one of the most detrimental industrial wastewaters to the environment by the United States Environmental Protection Agency (US EPA) because the inadequate disposal of SWW is one of the reasons for river deoxygenation and groundwater pollution [4]. Thus, SWWs require significant treatment for a safe and sustainable release to the environment, and the treatment and disposal of wastewater from slaughterhouses are an economic and public health necessity [5, 6].

The organic matter concentration in meat processing plant (MPP) effluents is usually high, and the residues are moderately solubilized, leading to a polluting effect due to the high levels of organics and pathogens present in SWW along with detergents used for cleaning purposes. SWWs are typically assessed using bulk parameters because of the various pollutant loads derived from the type and the number of animals slaughtered that fluctuate amid the meat industry [7].

Therefore, aerobic anaerobic treatment is the preferred biological treatment because of its effectiveness in treating high-strength wastewater such as SWW with less complex equipment requirements [8]. Although anaerobic treatment is efficient, anaerobically treated effluents require post treatment to comply with required discharge limits where the complete stabilization of the organic matter is not possible by anaerobic treatment alone. Anaerobically treated effluents treatment systems are more frequently used in wastewater treatment systems since they operate at higher rates than conventional anaerobic treatment methods. Taking into account that oxygen requirements and treatment time are directly proportional to an increase in wastewater strength, aerobic treatment is frequently applied as post treatment of anaerobic effluents as well as for nutrient removal [9].

Nevertheless, biological processes alone do not produce effluents that comply with current effluent discharge limits when treating high-organic-strength wastewaters. The use of combined anaerobic and aerobic processes is beneficial for its potential resource recovery and high treatment efficiency [10].

On the other hand, some slaughterhouse effluents contain toxic, bioresistant, recalcitrant, and nonbiodegradable substances. Thus, advanced oxidation processes (AOPs) could be used to improve the biodegradability of SWW and inactivate pathogenic microorganisms and viruses, left after biological treatment of the wastewater. Consequently, AOPs are an attractive alternative and a complementary treatment method to biological processes for the treatment of slaughterhouse effluents, especially as a posttreatment method [5–7]. Adopting combined biological treatment and AOPs for the treatment of slaughterhouse effluents is considered operationally and economically advantageous. Combined processes incorporate advantages of diverse technologies to achieve high-quality effluents from industrial and high-strength wastewaters for water reuse and resource recovery purposes [9, 10].

The overall treatment efficiency of organics and nutrients, the potential energy recovery from CH_4 production, and the H_2O_2 residual are discussed. A cost-effectiveness analysis is used to minimize the treatment time as well as the overall incurred treatment costs required for the efficient treatment of slaughterhouse effluents.

1.2 Characteristics of Slaughterhouse Wastewater

Meat processing effluents are considered harmful worldwide due to the SWW complex composition of fats, proteins, fibers, high organic content, pathogens, and pharmaceuticals for veterinary purposes. Slaughterhouse effluents are typically evaluated using bulk parameters because of the broad range of SWW and pollutant loads. SWW contains large amounts of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) [7].

As a result, due to the diverse characteristics of the SWW, it is appropriate to classify and minimize wastewater production at its source. Meat processing effluents are becoming one of the major agribusiness concerns due to the vast amount of water used during slaughtering, processing, and cleaning of the slaughtering facilities.

1.3 Regulations for slaughterhouse wastewater management

Regulations are necessary to mitigate the environmental impact of slaughterhouses, and the treatment methods are used as the main regulatory requirement [11]. The compliance with current environmental legislation and the state-of-the-art technologies may also provide some economic relief via resource recovery from biogas generation using high-rate anaerobic treatment.

Although it can be seen that Canadian standards are stricter than other international regulations such as those in the European Union (EU), Australia and New Zealand, or the USA, Canada does not have a specific regulation for the meat processing industry. Moreover, Australia and New Zealand and the USA have been incorporating an integrated approach to the regulation of the MPPs, where industry and regulatory sectors are working together to achieve a common goal of reducing the threats caused by the hazardous and high-strength wastewaters produced in slaughterhouses. Finally, emerging economies such as India, China, and Colombia have less strict standards, but their legislation is focused on specific industries to attain certain levels of treatment depending on the wastewater strength. Therefore, the selection of a specific treatment method depends on the characteristics of the SWW being treated, the best available technology economically achievable (BAT), and the compliance with regulations in different political jurisdictions.

1.4 Environmental impact and health effects of slaughter-house wastewater

The commercialization of animal products for consumption leads to the production of a large volume of SWW. Although the environment can handle a certain amount of pollutants through natural degradation processes, as the SWW concentration increases, these mechanisms come to be overburdened, where contamination problems commence [22].

The discharge of raw SWW to water bodies affects the quality of water particularly by causing a reduction of dissolved oxygen (DO), which may lead to the death of aquatic life [23]. Moreover, macronutrients, such as nitrogen and phosphorus, may cause eutrophication events. The discharge of these nutrients triggers an excessive algae growth and subsequent decay. Thus, the mineralization of the algae may lead to the deterioration of aquatic life due to depletion of DO levels. Finally, SWW may contain compounds, such as chromium and unionized ammonia, which are directly toxic to aquatic life [24].

Another source of contamination of the meat processing industry is the addition of surfactants as a result of the cleaning process. Surfactants, major components in detergents, may enter the aquatic environment due to an inadequate SWW treatment, causing short-term and long-term changes in the ecosystem that affect humans, fish, and vegetation [25].

The environmental impact of SWW is not only characterized by pollution via surfactants, nitrate, and chloric anions but also pathogens, which persist in the soil and reproduce continuously. Pathogens from SWW can also be transmitted to humans who are exposed to the water body, making those areas nonsuitable for drinking, swimming, or irrigation purposes [5, 26].

The general public health effects of the meat processing industry are related to the direct interaction of human communities with the slaughterhouse activities and indirect interactions with the environment, which can be previously affected by the inadequate management of the liquid effluents, solid waste, and obnoxious odors [27]. According to Um et al. [28], conventional treatment processes have no major impact on the reduction of antibiotic-resistant *Escherichia coli* strains present in SWW, highlighting the public health risks associated with inadequately treated slaughterhouse effluents concerning the propagation of antibiotic resistant and pathogenic bacteria into the environment.

The unsanitary conditions in some slaughterhouses allow the proliferation of pathogens to the final meat product to be consumed. People from developing countries in Africa, Asia, and South America have experienced serious gastrointestinal diseases, bloody diarrhea, liver malfunctions, and, in some cases, death associated with the presence of viruses, protozoa, helminthic eggs, and bacteria in SWW [5, 27]. Furthermore, the presence of hepatitis A and E viruses has been reported in the sewage of animal origin in Spain. Therefore, SWW must be treated efficiently before discharge into water bodies to avoid environmental pollution and human health effects [29].

1.5 Objectives

1.5.1 Overall Objectives

The overall objective is to design a biological slaughterhouse wastewater treatment system for effective treatment of the slaughterhouse effluent for disposal into the environment.

1.5.2 Specific Objectives

i. To analyze the quantity and composition of the slaughterhouse wastewater. (I.e. BOD_5, COD, SS, and Oil and Grease content etc.)

ii. To establish pertinent parameters for design of a biological slaughterhouse waste water treatment system. iii. To use the parameters from (ii) above to size the baffle reactor and the constructed wetland.

1.6 Statement of the scope

The scope of the project is in the structural design a biological wastwater treatment system for a house required in the area to reduce water pollution of rivers and the Kiserian dam due to the disposal of waste water containing high BOD_5, nitrates, phosphate and chloride to level permitted by NEMA. The project will involve carrying out geotechical surveys inorder to determine the optimal location of the waste water treatment plant. It will also involve carrying out test and studies to determine the average content and amount of waste water generated daily from the slaughter house. The determined paraments will help in providing design specification of anaerobic baffle reactor as a means of pretreatment of the waste water and finally a constructed wetland as secondary treatment method. Eventually, the project will involve coming up with detailed engineering drawings for each system and combined engineering drawing for the system.

1.7 Literature review

1.7.1 Treatment

Slaughterhouse waste water collection and treatment is typically subject to NEMA regulations and standards. The treatment generally involves three stages, called primary, secondary and tertiary treatment.

- Primary treatment consists of temporarily holding the waste water in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid subjected to secondary treatment.
- Secondary treatment removes dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro-organisms from the treated water prior to discharge or tertiary treatment.
- Tertiary treatment is sometimes defined as anything more than primary and secondary treatment in order to allow rejection into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers, coral reefs...). Treated water is sometimes disinfected chemically or physically (for example, by lagoons and microfiltration) prior to discharge into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes. In Kenya, various slaughterhouse wastewater systems have been adopted. These include; anaerobic lagoons, dissolved air flotation (DAF), anaerobic contact reactor (ACR), anaerobic sequencing batch reactor (ASBR), and upflow anaerobic sludge blanket (UASB). Some of the slaughterhouses

integrate two of the above systems as their waste water management system. For example, at Keekonyokie slaughterhouse in Kiserian, a system that integrates anaerobic (fixed dome) and aerobic systems (open lagoons) have been used.

1.7.2 Anaerobic digestion

Anaerobic digestion is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen. The digestion process begins with bacterial hydrolysis of the input materials. Insoluble organic polymers, such as carbohydrates, are broken down to soluble derivatives that become available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. These bacteria convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide. Anaerobic digestion is widely used as a source of renewable energy. The process produces a biogas, consisting of methane, carbon dioxide and traces of other 'contaminant' gases. This biogas can be used directly as fuel, in combined heat and power gas engine or upgraded to natural gas-quality biomethane. The nutrient-rich digestate also produced can be used as fertilizer. When the digesters first are installed, it may take some time until the specific biogas producing bacterial community has installed. It can help to seed the reactor with anaerobic sludge form a septic tank or another anaerobic digester. Once the process is set up, the hydraulic retention time (HRT i.e. the time the sludge should be kept in the reactor until it is completely digested strongly depends on temperature and can vary from some days up to several months. In the optimum temperature range (20 to 30°C daily mean temperature, FAO 1996; ISAT/GTZ 1999, Vol. I), a HRT of 30 to 60 days is required. Due to the sensibility of the microorganisms, temperature fluctuation should be as low as possible (ISAT/GTZ 1999, Vol. I). If the temperature of the biomass is below 15°C, gas production will be so low that the biogas plant is no longer interesting from an economic point of view (ISAT/GTZ 1999, Vol. I).

At higher temperature, not only methane production can be increased but also free ammonia, which can have an inhibitory effect on the digestion performance (ISAT/GTZ 1999, Vol. I). The design size of the reactor depends on the HRT (depending on the temperature) and the volume of fermentation slurry (i.e. the feed material). The required volume is calculated by multiplying the daily amount of fermentation slurry by the HRT. To predict how much biogas will be produced with the wastes added to the reactor, one needs to know the chemical oxygen demand (COD) of the sludge or the biodegradability constant (total methane produced during a retention time of at least 50 days MES et al. 2003)

ANAEROBIC	AEROBIC
Organic loading rate: High loading rates:10-40 kg COD/m3-day Biomass yield: Low biomass yield: 0.05-0.15 kg VSS/kg COD (biomass yield is not constant but Depends on types of substrates metabolized). Specific substrate utilization rate: High rate: 0.75-1.5 kg COD/kg VSS-day Microbiology: Anaerobic process is multi-step process and diverse group of microorganisms degrade the organic matter in a sequential order. Environmental factors: The process is highly susceptible to changes in environmental conditions.	**Organic loading rate:** Low loading rates: 0.5-1.5 kg COD/m3-day (for high rate reactors, e.g. AF, UASB, E/FBR) (for activated sludge process). High biomass yield: 0.35-0.45 kg VSS/kg COD(biomass yield is fairly constant irrespective of types of substrates metabolized Low rate: 0.15-0.75 kg COD/kg VSS-day Aerobic process is mainly a one-species phenomenon. The process is less susceptible to changes in environmental conditions.

Table 2.1: Comparison between Anaerobic and Aerobic reaction

(Lettingaet al., 1997; Seghezzoet al., 1998)

1.7.3 Anaerobic Baffle reactor (improved septic tank)

There are several types of anaerobic digesters such as the continuous stirred tank reactor (CSTR), the anaerobic contact process digester, the conventional mixed anaerobic digester, the anaerobic filters (AF), the upflow anaerobic sludge bed (UASB), the expanded granular sludge bed reactor (EGSB) and the anaerobic sequencing batch reactor (ASBR).

The choice of the reactor depends on the type of wastewater to be treated.

The ABR is a reactor made up of a succession of baffles forcing raw wastewater to flow under and over (or through) vertical baffles as it passes from the inlet to the outlet (McCarthy and Bachmann, 1985). There is a gentle rise and settling of bacteria in the reactor due to the characteristics of flow and production of gas. However, the movement of bacteria within the reactor is low (Boopathy and Sievers, 1991). It There are several types of anaerobic digesters such as the continuous stirred tank reactor (CSTR), the allows the wastewater to be in contact with a high quantity of active biomass as it flows through the reactor (Grobicki and Stuckey, 1991). Jianlonget al., (2004) reported that the most important advantage of this reactor is its ability to separate acidogenesis and methanogenesis phases longitudinally down the reactor. This is explained by the fact that different conditions develop at different points during digestion relating to pH, temperature and substrate concentration. Different zones result in the development of different microbial populations that are adapted to the prevailing conditions, specifically, acidogenesis in front and methanogenesis at the end. Therefore, bacteria grow under most favorable conditions defined by the pH and the temperature. Furthermore, the ABR can be cost-effective at large-scale operation (Orozco, 1997). The reactor can be operated without electricity as wastewater could be channeled to the reactor by gravity (Foxonet al., 2004). The ABR can be compared to a modified septic tank divided in compartments by vertical hanging and standing baffles. The design with baffles presents an advantage by limiting biomass washout as solids cannot bypass from the first to last compartment (Polprasertet al., 1992; Barber and Stuckey, 1999). Also, it has the potential to allow high treatment rates compared to the traditional septic tank at similar hydraulic loadings (Foxonet al., 2006). In this reactor, the interactive association of microorganisms confers great protection against toxic substances (Barber and Stuckey, 1999). Furthermore, it may improve the hydrolysis of particulate organics in the front of the reactor due to a low pH. In addition, previous studies have indicated that the baffled design of an ABR results in a residence time distribution that can be approximated by a number N of completely mixed tanks in series, where N is the number of real compartments of the ABR (Foxon, 2009). The design objective is to maximize the contact between the biomass and the wastewater made up of dissolved and suspended substances. This is achieved both by maximizing the hydraulic retention time (which is the treatment time) and solids retention within the constraints of space and capital cost (Foxonet al., 2006) has identified the following key parameters in the design of an efficient ABR:

1. Mean hydraulic retention time: it affects the contact time for the treatment of wastewater Number of compartments: it affects the internal velocity of the liquid within the reactor, therefore, the solids retention capacity of each compartment can be affected if the
2. Number of compartments is high. Also, it affects the capital cost of the reactor.
3. Design upflow velocity: it affects the sludge retention characteristics such as settling velocity.
4. Upflow-to-downflow area ratio: it affects the fluid dynamics in the sludge bed.

5. Compartment length-to-width ratio: the length –to- width ratio between 1:3 and 1:4 can be used depending on the space available at the installation site. 6.Hanging baffle clearance: this must be adequately large to prevent the occurrence of blockages by the sludge bed.

7.Reserve Capacity: The total volume of the reactor should be double the working volume for a 36 h retention time design. Since the development of the ABR in the early 1980s, several modifications have been made to improve the reactor performance. The main driving force behind these modifications has been to enhance the solids retention capacity. However, other design modifications were developed in order to treat difficult wastewater (e.g. with high solids content) and to reduce capital costs.

1.7.4 Constructed wetlands

A constructed wetland is a shallow basin filled with some sort of filter material (substrate), usually sand or gravel, and planted with vegetation tolerant of saturated conditions. They are constructed to recreate the structure and function of natural wetlands. Wastewater is introduced into the basin and flows over the surface or through the substrate, and is discharged out of the basin through a structure which controls the depth of the wastewater in the wetland. A constructed wetland comprises of the following five major components:

- Basin
- Substrate
- Vegetation
- Liner
- Inlet/Outlet arrangement system.

The excavated basin is filled with a permeable substrate (rock, gravel, sand and soil have all been used), and the water level is maintained below the top of the substrate so that all flow is supposed to be subsurface. This substrate supports the roots system of the same types of emergent vegetation, which are planted in the top surface of the substrate. The equal distribution and collection of wastewater is achieved by inlet and outlet arrangement systems. A liner is used, if the protection of the groundwater is important. Since the 1950s, CWs have been used effectively to treat different wastewaters with different configurations, scales and designs throughout the world. Existing systems of this type range from those serving single-family dwellings to large-scale municipal systems. Nowadays, constructed wetlands are common alternative treatment systems in Europe in rural areas and over 95% of these wetlands are subsurface flow wetlands. In the following years, the number of these systems is expected to be over 10,000 only in Europe (Platzer, 2000). Advantages of constructed wetlands

- Wetlands can be less expensive to build than other treatment options
- Utilization of natural processes,
- Simple construction (can be constructed with local materials).
- Simple operation and maintenance,
- Cost effectiveness (low construction and operation costs)
- Process stability

Limitations of constructed wetlands

- Large area requirement
- Wetland treatment may be economical relative to other options only where land is available and affordable.
- Design criteria have yet to be developed for diff erent types of wastewater and climates.

Although these systems do not rely upon complicated and sophisticated technology, constructed wetlands need a proper design and a careful construction. Natural wetlands act as a biofilter, removing sediments and pollutants such as heavy metals from the water, and constructed wetlands can be designed to emulate these features. Vegetation in a wetland provides a substrate (roots, stems, and leaves) upon which microorganisms can grow as they break down organic materials. The periphyton (community of microorganisms) and natural chemical processes are responsible for approximately 90 percent of pollutant removal and waste breakdown. Constructed wetlands are of two basic types: subsurface-flow and surface-flow wetlands. Subsurface-flow wetlands can be further classified as horizontal flow and vertical flow constructed wetlands depending on the flow direction used in the wetland.

Horizontal Flow (HF)

In HF, wastewater is fed in at the inlet and flow slowly through the porous substrate under the surface of the bed in a more or less horizontal path until it reaches the outlet zone. During this passage the wastewater will come into contact with a network of aerobic, anoxic and anaerobic zones. The aerobic zones will be around the roots and rhizomes of the wetland vegetation that leak oxygen into the substrate. During the passage of wastewater through the rhizosphere, the wastewater is cleaned by microbiological degradation and by physical and chemical processes (Cooper et al. 1996). HF wetland can effectively remove the organic pollutants (TSS, BOD_5 and COD) from the wastewater.

Due to the limited oxygen transfer inside the wetland, the removal of nutrients (especially nitrogen) is limited, however, HF wetlands remove the nitrates in the wastewater.

Vertical flow (VF)

VF constructed wetland comprises a flat bed of sand/gravel topped with sand/gravel and vegetation. Wastewater is fed from the top and then gradually percolates down through the bed and is collected by a drainage network at the base.(Diener, 2006)

VF wetlands are fed intermittently in a large batch flooding the surface. The liquid gradually drains down through the bed and is collected by a drainage network at the base. The bed drains completely free and it allows air to refill the bed. The next dose of liquid traps this air and this together with aeration caused by the rapid dosing onto the bed leads to good oxygen transfer and hence the ability to nitrify. The oxygen diffusion from the air created by the intermittent dosing system contributes much more to the filtration bed oxygenation as compared to oxygen transfer through plant. Platzer (1998) showed that the intermittent dosing system has a potential oxygen transfer of 23 to 64 g $O_2.m^2$ $.d^{-1}$whereas Brix (1997) showed that the oxygen transfer through plant (common reed species) has a potential oxygen transfer of 2 g $O_2.m^{-2}.d^{-1}$ to the root zone, which mainly is utilized by the roots and rhizomes themselves. The latest generation of constructed wetlands has been developed as vertical flow system with intermittent loading. The reason for growing interest in using vertical flow systems are:

- They have much greater oxygen transfer capacity resulting in good nitrification.
- They are considerably smaller than HF system.
- They can efficiently remove BOD_5, COD and pathogens.

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

CHAPTER TWO
THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

The management of slaughterhouses waste and wastewaters is a very significant problem under the environmental and economic point of view. In particular, slaughterhouse wastewaters have a high organic content, with a chemical oxygen demand (COD) which spans between 1100 and 20,000mgL^{-1}.[1] Anaerobic digestion is a widely used solution for wet residues treatment [2,3] with the aim of water pollution reduction and energy recovery. The process converts a large part of COD into biogas (composed by methane) or biohydrogen, thanks to its high removal efficiency. The anaerobic process has been studied over the years from many points of view. As a result, both the conventional and unconventional aspects of such a process are adequately known. In order to obtain a good removal of organic matter during anaerobic digestion, it is necessary to properly select the system to be implemented. In this frame, the attached growth reactors are systems where bacteria are attached to an inert support, developing a biofilm.[11] This kind of reactor is widely used for the food industry wastewaters treatment.[12–14]There are many configuration of attached growth reactors [11]: fluidized bed reactors, anaerobic expanded bed reactors and upflow packed-bed reactors (UPBR) or filters (UPBF).[15–18].

Saravanan and Sreekrishnan [19] argued that to optimize the design and scale break, mathematical models are needed. In anaerobic reactors, performances are affected by the hydrodynamics of the reactor (i.e. pattern flow), the mass transfer in the biofilm and the kinetic effects, which are also influenced by the high loading rates and the presence of toxic compounds.[20,21] The methods for analysing the models that describe the studied systems are mainly based on the process phenomenology and the concentration gradient. The determination of the parameters describing the behaviour of a system can be accomplished using empirical facts or applying mathematical models. For model application, empirical data provided by operating plants, laboratory and pilot-plant experiences, collected using effluents of similar characteristics to those presently under study, are necessary. However, the assay conditions, the technology used and the loading rate cannot always be identical, adding a degree of uncertainty in the evaluation of alternatives.[22] Moreover, if the purpose is the process control, the use of focused models is desirable (i.e. models that take into account only the methanogenic stage or at most two of the process stages, the acidogenic and the methanogenic ones).

The present paper shows the experimental results of a laboratory-scale UPBF fed with typical slaughterhouse residuals. Two types of packing materials were considered. Experiments, carried out under mesophilic conditions, allowed to (i) compare the filters performances (in terms of methane production), (ii) study reactors behavior during feedstock overloading conditions and (iii) determine the parameters governing the process kinetics for biomass growth and methane production yield, useful for real-scale UPBF design

2.2. Treatment methods for slaughterhouse wastewater

The freshwater consumption substantially varies in the meat processing sector, and a typical MPP generates a large amount of wastewater from the slaughtering process and cleaning of the facilities. Therefore, the water reuse and the recovery of valuable by-products from the meat processing effluents are the main focus in the agribusiness toward a cleaner production focused on high-quality effluents, biogas production and exploitation, and recovery of nutrients and fertilizers [7].

Treatment methods for SWW are comparable to those used in municipal wastewater treatment and include primary, secondary, and tertiary treatment. However, this does not eliminate the need for primary treatment. There are numerous SWW treatment methods after preliminary treatment, which can be divided into four main categories: physicochemical treatment, biological treatment, AOPs, and combined processes [2, 7]. Each method has advantages and disadvantages, which are discussed below

2.3 Preliminary treatment

The purpose of the preliminary treatment is to separate solids and large particles from the liquid portion in SWW and remove up to 30% of the BOD_5. The most common unit operations for preliminary treatment of SWW include screeners, sieves, and strainers. Thus, large solids with a 10–30 mm diameter are retained while the SWW passes through. Other preliminary treatment methods include homogenization and equalization and flotation, among other systems such as catch basins and settlers [30].

2.4. Physicochemical treatment

After preliminary treatment, the effluent should be further treated using primary and secondary treatment. One of the most practical methods of primary treatment for SWW is dissolved air floatation (DAF) for the reduction of fat, oil, grease, TSS and BOD_5 [31]. The most commonly used physicochemical treatment methods are presented below.

2.4.1. Coagulation-flocculation and sedimentation

In the coagulation process, colloidal particles in the SWW are grouped into larger particles, called flocs. The colloidal particles in SWW are nearly negatively charged which make them stable and resistant to aggregation. For this reason, coagulants with positively charged ions are added to destabilize the colloidal particles to form flocs and facilitate the sedimentation process. Various coagulant types can be found in the market, and the most widely used are inorganic metal based-coagulants such as aluminum sulfate, aluminum chlorohydrate, ferric chloride, ferric sulfate, and poly-aluminum chloride with removal efficiencies of up to 80% for BOD_5, COD, and TSS [32].

2.4.2. Dissolved air flotation

The DAF technology refers to the method of liquid-solid separation by air introduction. The fat and grease along with light solids are moved to the surface creating a sludge blanket. Thus, it can be continuously removed via scum scraping. Furthermore, flocculants and blood coagulants can be added to enhance the effectiveness of the DAF treatment for COD and BOD_5 removals of up to 75%. Nevertheless, common DAF disadvantages include occasional malfunctioning, poor TSS elimination, and moderate nutrient removal [33].

2.4.3. Electrocoagulation

The electrocoagulation (EC) process has been employed as a cost-effective technology for the removal of organics, heavy metals, and pathogens from slaughterhouse effluents by inducing an electric current without chemical addition. The EC process generates M^{3+} ions, mainly Fe^{3+} and Al^{3+}, using different electrode materials. Other electrode types including Pt, SnO_2, and TiO_2 can interact with H^+ or OH^- ions in acidic or alkaline conditions, respectively. Thus, removal efficiencies of up to 80, 81, 84, 85, and 96% can be achieved for BOD_5, TSS, TN, COD, and color, respectively [34, 35].

2.4.4. Membrane processes

Membrane processes are becoming an alternative treatment method for meat processing effluents. Different membrane processes, including microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO), have been used for SWW treatment to remove particulates, colloids, macromolecules, organic matter, and pathogens with overall efficiencies of up to 90%. However, membrane processes are required to be coupled with conventional processes for nutrient removal in SWW. Another drawback of membrane processes refers to the membrane fouling when treating high-strength wastewater because of the formation of biofouling layers on the membranes, restricting the permeation rate [36].

2.5. Biological treatment

Primary treatment and physicochemical processes typically do not treat SWW completely, to a degree of satisfaction set by regulations. Thus, secondary treatment is used for the removal of the remaining soluble organic compounds from primary treatment. Biological processes include lagoons with anaerobic, aerobic, or facultative microorganisms, trickling filters, activated sludge (AS) bioreactors, and constructed wetlands (CWs) for organic and nutrient removal efficiencies of up to 90% [7].

2.5.1. Anaerobic treatment

Anaerobic digestion is the preferred method for SWW treatment due to its effectiveness in treating highly concentrated industrial effluents since organic compounds are degraded by anaerobic bacteria in the absence of oxygen into CO_2 and CH_4. Anaerobic systems have the advantage of achieving low sludge production, minimum energy requirements with potential resource recovery, and high COD removal. Typical anaerobic processes for the treatment of meat processing effluents comprise anaerobic baffled reactor (ABR), anaerobic digester (AD), anaerobic filter (AF), anaerobic lagoon (AL), septic tanks (ST), and up-flow anaerobic sludge blanket (UASB) [30].

Nevertheless, anaerobic treatment barely complies with current discharge limits. Complete stabilization of the organic compounds is difficult due to the high organic strength of SWW. Therefore, an additional treatment stage is recommended to remove the organics, nutrients, and pathogens that remain after anaerobic treatment. On the other hand, anaerobic treatment requires a higher space and a higher residence time to achieve high overall treatment efficiency, affecting the economic viability of anaerobic treatment alone. Accordingly, the combination of anaerobic and aerobic processes is necessary to achieve a maximum efficiency for the treatment of SWW [37].

2.5.2. Aerobic treatment

Aerobic processes are frequently employed for nutrient removal and further treatment after primary treatment. The required oxygen and treatment time are directly related to the strength of the SWW, which makes it inadequate as primary treatment of SWW but adequate after anaerobic treatment [38].

There are many advantages of using aerobic wastewater treatment processes, including low odor production, fast biological growth rate, and rapid adjustments to the temperature and loading rate changes. Conversely, the operating costs of aerobic systems are higher than those for anaerobic systems due to the maintenance and energy requirements for artificial oxygenation. There are different aerobic unit operations for SWW treatment, such as aerobic AS, rotating biological contactors (RBCs), and sequencing batch reactors (SBRs) [39].

2.5.3. Constructed wetlands

Constructed wetlands (CWs) emulate the degradation mechanisms of natural wetlands for water decontamination, integrating biological and physicochemical processes from the interaction of vegetation, soil, microorganisms, and atmosphere for the adsorption, biodegradation, filtration, photooxidation, and sedimentation of organics and nutrients.

The performance of CW systems for the treatment of SWW has been evaluated using both horizontal and vertical subsurface flow CWs. Results have shown a wide range of organic and nutrient removal for different vegetation with encouraging maximum removals of 99, 97, 85, and 78% for BOD_5, COD, TSS, and TN, respectively [40]. As a result, CWs are simple methods with low operation and maintenance costs and few negative impacts on the environment, which make them an attractive alternative to conventional treatment [41].

2.6. Advanced oxidation processes

AOPs are an interesting complementary treatment option for primary or secondary treatment of SWW, showing excellent overall treatment efficiencies for water reuse. AOPs are diverse and include gamma radiation, ozonation, ultrasound technology (UST), UV/H_2O_2, UV/O_3, and photocatalysis, among others, for the oxidation and degradation of organic matter. The disinfection is another benefit of AOPs, which can inactivate pathogens without adding additional chemicals in comparison to other disinfection methods, such as chlorination, preventing the formation of hazardous by-products [5]. Another main advantage of the AOPs is the high reaction rates as well as very low treatment time.

Photocatalysis using Photo-Fenton–based processes and photooxidation using UV/H_2O_2 are the most commonly used AOPs for SWW treatment. Although these processes are usually expensive if applied alone, removal efficiencies of over 90% can be achieved for SWW secondary effluents in terms of TOC and COD as a post treatment method. Thus, the combination of biological processes and AOPs is recommended for SWW treatment [42, 43].

2.7. Combined processes

The implementation of combined processes is operationally and economically beneficial for SWW treatment since it couples the advantages of different technologies to treat high-strength industrial wastewaters. The combined ABR-AS-UV/H_2O_2 system is recognized as a costeffective solution for SWW treatment with removal efficiencies of over 95% for organics and nutrients at optimum operating conditions [6, 9, 10].

2.8. Slaughterhouse wastewater management and resource recovery

The meat processing industry needs to incorporate both waste minimization and resource recovery into SWW management strategies considering the portion of the industry's waste and by-products that have a potential of recovery for direct reuse, including nutrients and methane as biofuel. presents a schematic illustration of the ideal operation of a meat processing plant and supply chain from the animal farming and raw materials to the final product, waste disposal, and recoverable resources [27, 63].

A cleaner production should be the focus of meat processing plants due to the increasing interest in environmental initiatives and demands for green practices. Thus, it is appropriate to classify and minimize waste generation at the source, and on-site treatment is the preferred option for water reuse and potential energy recovery. As a result, there are some considerations to be made for the adequate treatment of SWW effluents. presents a proposed layout of the pretreatment, treatment, and disinfection of slaughterhouse wastes for a typical meat processing plant, as well as the potential resource recovery for water reuse and products recycling [63, 64].

2.9. Physicochemical Treatment

Physicochemical treatment methods usually involve solid separation from the fluid. It is recommended that the effluent be sent for primary or secondary treatment after the preliminary treatment depending on the intensity of the SWW [4]. Dissolved air floatation (DAF), coagulation–flocculation and sedimentation, electrocoagulation process and membrane technology are usually employed as primary treatment technologies for the treatment of SWW [5,6]. In the analysis of samples, the standard methods for the examination of water and wastewater of the American Public Health Association [7] are commonly applied, to achieve chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total suspended solid (TSS), volatile suspended solids (VSS), ammonia nitrogen (NH_3-N), fats, oil and grease (FOG), colour and turbidity removals.

2.9.1. Dissolved Air Floatation (DAF)

Dissolved air floatation is simply the introduction of air from the bottom of the system for liquid–solid separation. During operation, the FOG light solid materials are transported to the surface, creating a sludge blanket. Thus, the scum formed is continuously removed by scrapping. Polymers and other flocculants are usually applied to enhance the efficiency of DAF. In treating SWW, ferric chloride and aluminium sulphate are usually added to facilitate the aggregation and precipitation of protein in addition to fat and grease floatation. Moreover, 30 to 90% COD, as well as 70 to 80% BOD_5 removal efficiency can be achieved using the DAF process. Furthermore, Mittal. [9] and De Nardi et al. [5] have shown that the DAF system is capable of achieving moderate to high nutrient removal. Floatation can also be used as an alternative method of handling pulp and paper mill effluent in addition to firm

settling. These devices inject a pressurized flow of air-saturated water at the base of a deep chest that holds the paper mill process steam.
The injected waters released into the chest, and tiny air bubbles come out of the solution and start to rise. The rising bubbles tend to carry any other fairly solid binding particles and can easily be skimmed from the water’s surface. DAF’s main drawback, however, is commonly associated with relatively frequent system failure and inefficient TSS separation [10]. Therefore, an alternative treatment system like the upflow anaerobic sludge blanket reactor is required, due to its lesser energy demand, smaller ecological foot print production as well as its overall operation and maintenance cost.

2.9.2. Coagulation–Flocculation and Sedimentation

The addition of coagulant into a reactor vessel containing SWW promotes the formation of large colloidal particles, which are called flocs. The colloidal particles produced in SWW, however, are negatively charged, making them stable and aggregation resistant. Coagulants with positively charged ions are therefore added into the vessel for proper floc formation in order to destabilize the colloidal particles to form flocs and ease the sedimentation process. Chemicals such as ferric chloride, ferric sulphate, aluminium sulphate, aluminium chlorohydrate, and poly-aluminium chloride were used as coagulants for the SWW treatment. The use of poly-aluminium chloride as reagent showed a total phosphorus (TP), total nitrogen (TN), and COD removals efficiencies of up to 99.9%, 88.8%, and 75.0%, respectively. On the other hand, the sludge volume can be reduced by 41.6% using inorganic coagulants [9,11]
Satyanarayan et al. [13] have reported the use of anionic polyelectrolyte, ferrous sulphate, lime, and alum as coagulants in the treatment of SWW. The results revealed BOD_5, COD, and TSS removal efficiencies of 38.9, 36.1, and 41.9% using only lime as a coagulant. A significant

improvement in COD removal up to 56.8% was realized in the combination of ferrous sulphate with lime. Likewise, an increase in COD removal to 42.6% was recorded in the combination of alum and lime. Tariq et al. [14] investigated the use of alum and lime individually in the treatment of SWW. It was revealed that with the increasing dose of alum, the COD removal reached a maximum of 92% along with high sludge volume, and this rendered the process inefficient. Conversely, 74% COD reduction was realized with an increasing dosage of lime as a single coagulant. Comparatively, the sludge volume generated using lime was quite low compared to that of alum. However, the combination of the two coagulants revealed a maximum COD removal of 85% with a small quantity of sludge volume.

Different contaminants can be removed from the wastewater through coagulation/ flocculation which would otherwise be difficult without the application of these chemicals. Limited investment is required for these tanks and dosing units. Nevertheless, the operating costs are a major disadvantage of this strategy. In some situations, significant amounts of coagulant and flocculent are needed to achieve the required level of flocculation. A certain amount of physico–chemical sludge is also produced, which is usually handled externally. These costs may escalate, especially with large volumes of wastewater. The correct dosage of chemicals is also very important for the proper functioning of the process. Therefore, this is not simple for sewage with widely varying composition.

2.9.3. Electrocoagulation (EC) Process

Electrocoagulation requires the production of in situ coagulants by electrically dissolving aluminium or iron from aluminium or iron electrodes, respectively. Figure 3 shows the schematic diagram of electrocoagulation processes. Metal ions are produced at the anode and hydrogen gas is emitted from the cathode. Hydrogen gas would also help lift the flocculated particles out of the air. The electrodes can be set in a monopoly or bipolar mode. The products may be made of aluminium or iron in the form of plates or the form of scraps, such as steel turning and milling. The EC process is an advanced treatment technology recently applied to the treatment of SWW. According to Emamjomeh and Sivakumar [15] and Bayar et al. [16], the system is capable of removing pathogens, organics, nutrients, and even heavy metals from SWW by introducing an electric current without the addition of any chemical. Electrodes such as Al, Fe, Pt, SnO_2, and TiO_2 are commonly utilized for the EC process, however, Al and Fe are the most widely applied. In the EC process, M^{3+} ions are usually generated on-site with the help of sacrificial anodes. Moreover, studies have shown that these sacrificial electrodes might interact with hydrogen ions in an acidic medium or with an OH- ion in an alkaline medium [17–20]. For instance, the research of Kobya et al. [18] into the EC process treating SWW demonstrated that Al, as an electrode material in the EC process, was responsible for removing up to 93% COD, whereas Fe as an electrode material was able to achieve a maximum of 98% oil and grease removal efficiency. During this process, the influential parameters that lead to the high COD, oil, and grease removal included the pH, operating time, electrode material, and the current density.

(An evaluation of the chemical reactions that occur in the process of electrocoagulation reveals aluminium electrodes) are:

Anode: $Al \rightarrow Al^{3+}(aq) + 3e$ (1)

Cathode: $3H_2O + 3e \rightarrow 3/2H_2 + 3O^-$

The cathode may also be chemically attacked by HO^- ions generated during H2 evolution at high pH [22]:

$2Al + 6H_2O + 2HO^- \rightarrow 2Al\,(HO)_4^- + 3H2$

Al^{3+} (aq) and OH^{-} ions generated by electrode reactions (1) react to form various monomeric species such as Al $(OH)^{2+}$, Al $(HO)_2^{+}$, Al_2 $(HO)_2^{4+}$ and Al $(HO)_4^{-}$, and polymeric species such as Al_6 $(HO)_{15}^{3+}$, Al_7 $(HO)_{17}^{4+}$, Al_8 $(HO)_{20}^{4+}$, and Al_{13} O_4 $(HO)_{24}^{7+}$, Al_{13} $(HO)_{34}^{5+}$, which finally transform into Al $(OH)_3$ according to complex precipitation kinetics [23].

Al^{3+} (aq) and OH^{-} ions generated by electrode reactions (1) react to form various monomeric species such as Al $(OH)^{2+}$, Al $(HO)_2^{+}$, Al_2 $(HO)_2^{4+}$ and Al $(HO)_4^{-}$, and polymeric species such as Al_6 $(HO)_{15}^{3+}$, Al_7 $(HO)_{17}^{4+}$, Al_8 $(HO)_{20}^{4+}$, and Al_{13} O_4 $(HO)_{24}^{7+}$, Al_{13} $(HO)_{34}^{5+}$, which finally transform into Al $(OH)_3$ according to complex precipitation kinetics [23].

2.9.4. Membrane Technology

Membrane technology is becoming more popular in the treatment of water and wastewater due to regulatory issues towards meeting the stringent water quality requirements. Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (OS) are the common membrane technologies used for water purification. Figure 4 depicts the different membrane sizes for the treatment of water and wastewater. Depending on the pore size, membranes can remove colloids, particles, and macromolecules. This technology is increasingly applied in the treatment of SWW to remove organic matter and bacteria [24]. The performance of RO in the treatment of secondary effluent of SWW (activated sludge as pre-treatment) was reported by Bohdziewicz and Sroka [25]. The result of parameters like BOD_5, COD, TN, and TP were found as 50.0, 85.8, 90.0, and 97.5%, respectively. It was concluded that RO was a suitable technique for the post-treatment of SWW effluent. The study of Yordanov [26] on the performance of the UF membrane treating SWW showed BOD_5 and COD removal efficiencies of around 97.8–97.89 to 94.52–94.74%, whereas TSS and FOG removal were 98 and 99%, respectively.

The investigation of Gürel and Büyükgüngör [28] indicated that a membrane bioreactors could significantly remove nutrients and other organics from SWW. A pilot-scale experiment of anaerobic submerged bioreactor membrane (SAMBR) treating high-strength wastewater (raw tannery wastewater) achieved a higher COD removal efficiency of up to 90% at 6 g/L·day organic loading rate (OLR) and biogas production (0.160 L g COD removed) [29]. The process worked efficiently but was strongly characterized by a high hydraulic retention time (HRT) of 40 h, and as such high energy was spent, although the permeate flux remained at (6.8 LMH) well below the critical flux (17.5 LMH) as established in the earlier work of Hu and Stuckey [30]. Most recently, the filtration performance of an anaerobic membrane bioreactor (AnMBR) treating high strength lipid-rich wastewater and corn-to-ethanol thin stillage was conducted by Dereli et al. [31]. The reactors delivered a high COD removal efficiency of up to 99% under stable operating conditions with an average OLR of 8.3, 7.8 and 6.1 kg COD/m^3·day. However, the permeate turned out to be inferior in quality with an increased solid retention time (SRT). Generally, membrane lifetime remains the main concern of investors in the water treatment and wastewater industries. The efficiency of reversing fouling on the membrane surface is being exploited by physical, chemical, and biological methods. Although there were enough physical and chemical methods, the disadvantages are enormous. During aeration, much energy is expended, and sometimes chemicals are used for membrane cleaning, and this activity does not benefit the players in this field in terms of cost and environment.

2.9.5. Summary of Physicochemical Treatment Methods

Table 1 summarizes the advantages and disadvantages of the different physicochemical treatment methods of slaughterhouse wastewater.

Table 1. Advantages and disadvantages of physicochemical methods.

Methods	Advantage	Disadvantage
Dissolved air floatation	It can achieve 30–90% COD and 70–80% BOD_5 removal efficiencies. Moderate to high nutrient removal. Tends to carry fairly solid binding particles and can easily be skimmed from the water's surface.	High energy demand due to aeration. Chemical addition which renders the sludge unsuitable as fertilizer. Inefficient total suspended solid separation. Lacks energy recovery facilities. Frequent system failure. High cost of operation and maintenance.
Coagulation–flocculation and sedimentation	Promotes large colloid formation which can easily sediment. TP, TN, and COD removals efficiencies of up to 99.9%, 88.8%, and 75.0% can be achieved.	Huge quantity of chemical is applied. Large volume of sludge is generated causing an additional cost of treatment. Difficult to handle or reuse. Landfill disposal or incineration is usually the only option available to handle the sludge. Lacks energy generating facilities.

Electrocoagulation (EC) process	The system is capable of removing pathogens, organics and other nutrients by Introducing electric current. High COD and FOG removal efficiency (>90%).	High energy demand and not cost effective. Lack energy generation facilities especially in the treatment of organic wastewater to high energy potentials.
Membrane technology	Depending on the type of membrane, the technology is capable of achieving 97.8–97.89% and 94.52–94.74% BOD_5 and COD removal efficiencies in the treatmentof slaughterhouse wastewater.	Depending on the type of membrane, the technology is capable of achieving 97.8–97.89% and 94.52–94.74% BOD_5 and COD removal efficiencies in the treatmentof slaughterhouse wastewater.

2.10. Biological Treatment

In the treatment of SWW, biological treatment is applied as a secondary treatment to reduce the concentration of BOD_5 and other soluble compounds after primary treatment [32]. Depending on the characteristics of SWW, the biological process is applied when aerobic and anaerobic digestion are operating individually or as combined systems with packing material [33]. Unlike the physicochemical process, the biological treatment process employs the use of microorganisms to remove organics from SWW effluent. Mittal [9] demonstrated that the biological method that properly applies the aerobic or anaerobic process could remove about 90% BOD_5 from SWW effluent. There exist different biological systems, which include anaerobic, aerobic, facultative lagoons, the activated sludge process and trickling filters [34]. Generally, the mechanisms of biological treatment are a function of bacterial consortium to break down organic waste.

2.10.1. Anaerobic Treatment

Anaerobic treatment technology has proven to be a vital area of research in the management of organic waste. This is because the technology tends to offset the setbacks exhibited by aerobic and physicochemical methods [35]. Considering the portion of the industry's waste and its by-products that have recovery potential for direct reuse, including nutrients and methane gas, anaerobic systems are a suitable technology for handling high-strength industrial wastewater such as swine and SWW. It is seen in the discharged effluent consistency, material recovery, energy generation, and sludge output, handling, and storage [36]. The biogas composition consists of methane (55–70%) and carbon dioxide (30–45%) under strictly anaerobic conditions. Other contaminants are nitrogen (0–15%), oxygen (0–3%), water (1–5%), hydrocarbons (0–200 mg m^{-3}), ammonia (0–100 ppmv) and siloxane (0–41 mg Si m^{-3}) [37]. Typical anaerobic digestion systems include anaerobic lagoon (AL), anaerobic filter (AF), anaerobic baffled reactor (ABR), and upflow anaerobic sludge blanket reactor (UASB).

2.10.2. Anaerobic Lagoon

Anaerobic lagoons (ALs) have been widely applied in the degradation of wastewater, especially in developing countries with hot weather. The method used largely depends on the climate, location, availability of land, and proximity to urban areas [9]. The influent usually introduced through the bottom of the system and is not mechanical mixed. A layer of scum frequently forms on the surface of the lagoon, ensuring the system is confined to anaerobic conditions with low heat loss. According to the literature [38,39], the COD, BOD_5, and TSS removal efficiency of a typical AL with a depth of 3–5 m and a hydraulic retention time of 5–10 days were found as 96%, 97% and 95%, respectively.

However, this system's pitfalls include odour generation and weather dependency, coupled with a long HRT and requiring a large area of land to operate. Thus, to reduce odour and smell, the synthetic floating cover is normally employed to collect biogas and trap the odour.

Moreover, the synthetic cover must be durable and able to resist change in temperature, or ice and snow accumulation [9]. ALs are frequently the preferred method of treating SWW due to their simplicity as well as their low operational and maintenance costs, especially in developing countries [39].

2.10.3. Anaerobic Filters

Anaerobic filters are usually run in upflow mode, as the system has a lower risk of washing out the fixed biomass. In order to ensure an even flow regime, the water level must cover the filter media by at least 0.3 m. Hydraulic retention time (HRT) is the most important design parameter to influence filter efficiency. For bacteria to grow, the ideal filter should have a large area, with pores small enough to avoid clogging. The surface area ensures increased contact which ultimately degrades it between the organic matter and the attached biomass. Ideally, the material must occupy a surface area of 90 to 300 m^2 per m^3 of the volume of the reactor. The typical filter content sizes vary from 12 to 55 mm in diameter. Widely used products include dirt, crushed stones or bricks, cinder, pumice, and specially shaped plastic parts, depending on local availability. The systems are used for the secondary treatment of SWW to achieve high solids removal and biogas production. These systems usually work in series and have a fixed bed biological reactor coupled with a filtration chamber. When the SWW flows through the filtration chambers, large and medium suspended particles are confined within; then, the active biomass attached to the surface of the filter degrades the particulate organic matter [9]. Gannoun et al. [43] examined the performance of upflow anaerobic filters (UAFs) treating SWW at mesophilic and thermophilic temperatures. The results showed that at an organic loading rate (OLR) of 9 g/L/d, the COD removal efficiency was 90% at mesophilic, and only 72% was achieved at the thermophilic condition. On the other hand, the mesophilic (35°C) treatment of SWW at a high organic loading rate of OLR 10.05 kg/m^3day and HRT of 12 h was evaluated by Rajakumar et al. [44]. The system recorded a COD removal rate of 79% with a varied methane production between 46 and 56% on the average. The experiment of Stets et al. [45] evaluated the influence of substrate characteristics, microorganisms present in the sludge, and the supporting media in AF. The results showed a maximum COD and TN removal efficiency of 80 and 90% at an HRT of 1 day. The major drawback of anaerobic baffle reactor is the need for relatively higher temperatures for optimum service, but this is not an obstacle in tropical countries.

2.10.4. Anaerobic Baffled Reactor

Anaerobic baffled reactors (ABRs) consist of a series of compartments with inlet and outlet, in which SWW flows in from beneath and above. The reactor is commonly referred to as an optimized version of a septic tank, and the diagrammatic representation of the reactor design and its characteristic dimensions is shown .

The purpose of using the anaerobic baffled reactor is to provide the enhanced removal and digestion of organic matter as well as of microorganisms present in the influent. The design objective was to increase the contact time between the suspended or dissolved contaminants and biomass and to minimize the amount of sludge washout in the ABR effluent. This can be achieved by maximizing the hydraulic retention time, the number of passes through the sludge bed (i.e., the number of compartments), and the upflow rate to reduce the transport of solids within processing and capital cost constraints as determined by solid retention. Two six-compartment anaerobic baffled reactors to be installed in series are usually designed to achieve maximum treatment rates. This engineered two six-compartment ABR offers 96 h (48 h for each ABR) hydraulic retention period which by far was higher than the 48–92 h ranges for high peak-flow output levels and the 20–60 h, which allowed high-performance treatment for domestic wastewater. The peak up-flow rate of 0.54 m/h was proposed by Foxon and Buckley [47], and peak flow factor of 1.8 resulted in an upflow rate of 0.30 m/h. This value corresponds to the one suggested by Tilley et al. [42], which is <0.6 m/h. The study of Kus¸çu and Sponza [48] revealed that a significant improvement in COD and BOD_5 removals up to 90% was achieved in the upflow compartment. A laboratory-scale study of the performance of combine ABR and UV/H_2O_2 treating SWW with a total organic carbon (TOC) concentration of 973 mg/L exhibited high organic carbon removal efficiency up to 95% [49]. One major drawback of this type of reactor is that the system does not have auxiliary mechanisms for the retention of biomass, in the case of large variations and extreme peaks of the influential flow.

2.10.5. Up flow Anaerobic Sludge Blanket Reactor

The development of the UASB technology dated back to the late 1970s, and was initially developed for the anaerobic treatment of liquid waste streams with a high concentration of COD (1.0 to 200 g COD L^{-1}) and low solid content [50,51]. The upflow anaerobic sludge blanket (UASB) reactor is a tank with a sludge bed occupying half or less the volume of the total tank from the bottom of the tank. UASB reactor consists of three zones: the sludge zone containing the biomass, substrate-like SWW, and the gas zone above the substrate [52,53]. As the name implies, upflow, the SWW enters from the bottom and flows upward with a high or low velocity through the sludge blanket, which then exits from the top as an effluent . Depending on the prevailing parameters, literature have reported a satisfactory performance of the UASB reactor in degrading SWW.

The many advantages of UASB reactors include less sludge production, energy recovery, and the overall low cost of application [55]. Moreover, the bacteria can withstand a long period of starvation without dying, and only one discharge of sludge is required per year for a UASB reactor with around 4 m high. Tropical countries stand to benefit more in the use of the UASB reactor because they work better at mesophilic conditions. The research of Caldera et al. [56] demonstrated that a high COD removal efficiency of up to 94.31% from a UASB reactor treating SWW under mesophilic condition. The substrate concentration varied from 1820 to 12,790 mg/L, and the experiment lasted for 90 days at HRT of 24 h. In another development, Chávez et al. [57] reported the 95% BOD_5 removal efficiency of UASB treating slaughterhouse waste at an optimum OLR 31,000 mg/L under mesophilic conditions at HRT 3.5 and 4.5 h. The work of Miranda on the 800 m^3 full-scale UASB reactor treating SWW with an influent of COD concentration in the range of 1400–3600 mg/L and oil and grease content between 413 and 645 mg/L, respectively. The results of their experiment revealed that around 70–92% COD and 27–58% oil and grease removal efficiencies. Moreover, an optimum COD removal efficiency of 90% was also revealed in the study of Rajakumar and Meenambal, [58] at an HRT of 10 h, varying the COD concentration from 3000 to 4800 mg/L in the UASB reactor. Mijalova et al. [59] analysed the output of a UASB reactor treating SWW after solid separation under the ambient condition. It was reported that the efficiencies of COD removal improved in relation to OLRs. With an influent COD concentration of 3437 mg/L, the system recorded a high COD removal efficiency of 90%. While UASB reactors are found to be effective for SWW treatment, compliance with current water quality standards for water body discharge requires a post-treatment process. Table 2 shows the review of the performance of previous works on UASB reactors treating SWW and other wastewater. However, the system shortfall of sludge washout at elevated upflow velocity and the slow-growing methanogenic bacteria. The performance of various UASB reactors treating slaughterhouse and other wastewaters

CHAPTER THREE
BACKGROUND INFORMATION

CHAPTEE THREE

INTRODUCTION

3.1Background Information

The world population is ever growing and today it is estimated to be 7.122 billion by the United States Census Bureau (USCB, 2012). This has a direct effect on the demand for protein and therefore increase demand on meat products. Annual meat production is projected to increase from 218 million tonnes in 1997-1999 to 376 million tonnes by 2030 (WHO, 2010). Kenyans consume an average of 15-16 kg of red meat (meat and offal from cattle, sheep, goats and camels) per capita annually, for a national total of approximately 600,000 MT of red meat per year. Cattle are the most important source of red meat, accounting for 77 percent of Kenya's ruminant off-take for slaughter. Approximately 80 to 90 percent of the red meat consumed in Kenya comes from livestock that are raised by pastoralists, with the remainder coming from highland cattle (USAID, 2010). This high demand for meat production has a very harmful effect on the environment due to production of waste from the slaughterhouses. Environmental Protection Agency (EPA) has classified slaughterhouse wastewater as one of the most harmful to the environment. Pollution arises from activities in meat production as a result of failure in adhering to Good Manufacturing Practices (GMP) and Good Hygiene Practices (GHP). About 200 liters of water is used in processing operations (slaughtering and cleaning) per cattle, which produces large amount of wastewater. The main pollutant in slaughterhouse effluents is organic matter i.e. paunch, feces, fat and lard, grease, undigested food, blood, suspended material, urine, loose meat, soluble proteins, excrement, manure, grit and colloidal particles. The waste from slaughterhouse is estimated to contain; BOD_5 approximately 1,000 to

4,000 mg/L, COD approximately 2,000 to 10,000 mg/L, SS approximately 200 to 1,500 mg/L, High Oil and Grease content, possible high chloride content from salting skins (Lawrence, 2006). There are four different processes which are often used for treating wastewater from slaughterhouses (Johns et al., 1995; Manjunath et al., 2000):

- Anaerobic treatment + activated sludge
- Anaerobic treatment + contact aeration
- Activated sludge + chemical coagulation
- Contact aeration + chemical coagulation.

The disadvantages of the first two systems are that they require a relatively large area for the construction of the anaerobic processing unit. The last two systems involving chemical coagulation have the disadvantage of a large requirement for chemical usage, and would also produce a greater quantity of sludge. NEMA regulations on waste water disposal to the environment are; Biochemical Oxygen Demand (BOD_5days at 20 oC) 30 mg/l, Chemical Oxygen Demand (COD) 50 mg/l, Oil and grease Nil, Total Suspended Solids, 30 mg/l, Total Nitrogen 100mg/l.

3.2 Statement of the problem and problem analysis

Kiserian slaughterhouse drains its wastswater direct to the waterways and eventually this waste water flows into Kiserian Dam though river Kiserian. Wastewater from slaughterhouse contains large amounts of blood, fat, and hair. Waste from slaughterhouse causes air, water and soil pollution. Air pollution is caused by the generation of carbon (IV) oxide, methane and odor from decomposing slaughterhouse waste. Wastewater from the slaughterhouse is among the largest contributors to toxic pollution in waterways – primarily BOD_5, COD, nitrate, phosphates, and potassium pollutant. The presence of high BOD_5 may indicate fecal contamination or increases in particulate and dissolved organic carbon from animal sources that can restrict water use and that the community around has access to safe and clean water. The project will concentrate with development of a modular slaughterhouse waste water treatment.development. Increased oxygen consumption poses a potential threat to a variety of aquatic organisms, including fish. Organic pollution can occur when inorganic pollutants such as nitrogen and phosphates accumulate in aquatic ecosystems. High levels of these nutrients cause an overgrowth of plants and algae and this eventually leads to eutrophication and anoxia. This organic pollution alters the aquatic ecosystem and makes the water from the dam unfit for consumption which was mainly the intended purpose of the dam. It is therefore important to come up with a proper waste water treatment mechanism that will help in reducing the pollution this ecosystem and ensure

3.3 Site analysis and inventory

3.3.1 Location

Kiserian is a settlement in Kenya's Kajiado county, latitude1° 26' 52" S, longitude: 36° 40' 57" E, population range is under 1000 people. Kiserian town boarders Ongata Rongai, Ngong town, Enoomatasiani town, Kisamis town and lies at the foot of the Ngong Hills. It is found along Magadi Road. There is a famous Maasai community around Kiserian town, and small Maasai villages called Olteyani and Olooseos

3.3.2 Climate

In Kiserian, the climate is warm and temperate. The average annual temperature in Kiserian is 17.8 °C. About 833 mm of precipitation falls annually.

3.3.3 Geology

The Kiserian area is prone to subsequent tectonic movements which are related to the formation of the Great Rift Valley. The area is underlain by volcanic rocks estimated to be of Tertiary age. The fractured and weathered trachytes and basalts, the sands and sediments comprise the aquifer formations in the area.

3.3.4 Land Use

The community habiting this region is mainly pastoralist community and therefore meat and other animal products (raw meat, raw milk, and raw blood) forms part of their main diet. Currently, Kiserian slaughterhouse does not have any wastewater management system and the waste water gets to the water ways and finally ends up in Kiserian dam causing aquatic pollution. This situation was caused by the failure of the wastewater treatment system installed a few years ago. The failure was due to presence of high slurry wastewater in the constructed wetland leading caused by lack of settling and filtering mechanisms of the wastewater. This eventually led to the clogging of the constructed wetland and eventually failure of the whole system.

3.4 Theoretical framework

3.4.1 Chemical oxygen demand

Chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in wastewater, making COD a useful measure of water quality. It is expressed in milligrams per liter (mg/L) also referred to as ppm (parts per million), which indicates the mass of oxygen consumed per liter of solution. When ferrous ammonium sulfate (FAS) is used as the reagent in the test, the following formula is used to calculate COD

Where;

b = volume of FAS used in the blank sample,

s = volume of FAS in the original sample,

n = normality of FAS.

COD=8000(b-s)/sample volume ……………………….(3.1)

The COD can also be estimated from the concentration of oxidizable compound in the sample, based on its stoichiometric reaction with oxygen to yield CO_2 (assume all C goes to CO_2), H_2O (assume all H goes to H_2O), and NH_3 (assume all N goes to NH_3), using the following formula:

COD=(C/FW)x(ROM)x(32)………………………………………(3.2)

Where;

C = Concentration of oxidizable compound in the sample.

FW = Formula weight of the oxidizable compound in the sample.

RMO = Ratio of the number of moles of oxygen to number of moles of oxidizable compound in their reaction to CO_2, water, and ammonia.

3.4.2 Biochemical Oxygen Demand

The Biochemical Oxygen Demand, or BOD_5, is the amount of dissolved oxygen which is used up by these microorganisms and is roughly equivalent to the amount of organic matter found in the wastewater. The more organic matter that is present in the water, the more DO will be used up by the bacteria and the greater the BOD_5 reading will be. . Wastewater treatment plants use BOD_5 as an estimate of the waste load in the influent water.They can also test BOD_5 of the effluent to determine the plant's efficiency, to control plant processes, and to determine the effects of discharges on receiving waters.BOD_5 is determined through determination of initial and final dissolve oxygen of the wastewater in the laboratory. From these parameters, BOD_5 is calculated as follows; When dilution water is not seeded:

BOD_5,mg/L=D1D2/P………………………………………………..(3.3)

When dilution water is seeded:

BOD_5,mg/L=(D1-D2)-(B1-B2)f/p……………………………….(3.4)

Where:

D1 = DO of diluted sample immediately after preparation, mg/L.

D2 = DO of diluted sample after 5 d incubation at 20oC, mg/L.

P = decimal volumetric fraction of sample used.

B1 = DO of seed control before incubation, mg/L.

B2 = DO of seed control after incubation mg/L

f = ratio of seed in diluted sample to seed in seed control

f=%seed in diluted sample/%seed in seed controi…………………(3.4a)

f=%seed in diluted sample/%seed in seed control…………………..(3.4b)

3.4.3 Total Suspended Solids

Concentration of total suspended solids in the sample can be calculated using the following

formula:

Total suspended Solids, mg/L=(A-B)X1000/(Sample Volume, ml)..(3.5)

Where;

A=Sample And Filter Weight ,mg

B=Filter Weight, mg

If two samples were used, then the average total suspended solids can be calculated as follows;

Average total suspended solids, mg/l=(C+B)/2…………………….(3.6)

Where

C=Total suspended Solids Of Sample 1,mg\l

D=Total Suspended Solids Of Sample 2,mg\l

3.4.4 Design of the anaerobic baffle reactor

Flow rate (Q)/ daily wastewater generation:

The flow for the wastewater treatment plants are based on the effluent production from the slaughterhouse. The flow estimates for a location should show peak, minimum and average flow rates.

Q(Nc x Vc)+(Ng x Vg)……………………………………………..(3.7)

Q = flow rate, litres/day .

Nc = number of cattle slaughtered daily .

Vc = volume of water used in slaughtering each cattle, litres

Ng = number of goats and sheep slaughtered daily.

Vg = volume of water used in slaughtering each goat/sheep, litres

Volume of the reactor

Baffle Reactor Working Volume

Active digester volume (Vs.) is the volume occupied by the slurry in the digester and

Vs (m^3)=Q x HRT(days)…………………………………………..(3.8)

Where

is given as;

Vs = active digester volume.

Q = daily slurry feed/ flow rate, m3 /day

HRT = Hydraulic Retention Time.

Volume of input slurry depends on the dilution of the waste and therefore the waste should be less diluted to ensure that a smaller digester is used. Total volume of gas storage is equal to the volume of gas generated in 24 hours under normal operating conditions. (Nijaguna 2002)

Gas Storage Volume (Vg): The methane produced in an anaerobic process is proportional to the amount of substrate removed. The rate of methane production is given by the following equation.

Qm=QM(So –Se)=Q x Ex M xSo……………………………..(3.9)

Qm = Gas production rate.

S0 = Total influent COD

Se = Total effluent COD

M = volume of CH_4 produced per unit of COD removed

Q = Influent Flow Rate

E = Efficiency factor

Peak up-flow velocity, Vp

Peak up-flow velocity is the maximum permitted up-flow in the reactor that does not cause an unacceptable washout of sludge. The peak up-flow velocity is the design velocity increased by a peak flow factor. For this design case, Peak Upflow Velocity is taken to be 0.54m/hr

Design up-flow velocity, Vd

Design up-flow velocity is the ratio of the peak up-flow velocity expected to peak flow factor.

Studies have found a peak flow factor of 1.8 to be adequate for design purposes.

Therefore,Vd=Vp/1.8……………………………………………(3.10)

Where ;Vp=peak up-flow velocity

Compartment Upflow Area, Au

Compartment Upflow Area ,Au

Au=Q/Vd.24…………………………………………………(3.11)

Where ;daily flow rate

Vd= Design up-flow velocity

Total Compartment Area, Ac

Ac= Au x (1+Rud/Rud)

Where; Au= Compartment Upflow area

Rud= Upflow to Down flow Area Ration (i.e.2)

Reactor Depth, Rd

The reactor depth will largely be governed by the cost of excavation. For this case, reactor depth is taken to be 3m.

Reactor Width, Rw

Rw=$\sqrt{Vs \times Cwl \div N \times Rd}$……………………………(3.13)

Where;

Vs = Reactor working volume

Cwl = Compartment width to length ration (i.e. 3)

N = number of compartments (i.e. 5)

Rd = reactor depth

Reactor Length, Rl

R1=N x Rw/Cwl……………………………………………………(3.14)

Where; Rw=width the reactor

Solid Retention Time (SRT or Θx):

The solids retention time can be described by the mass of sludge in the reactor divided by the mass removal rate of sludge from the reactor

Qx=Vxv/QwXw……………………………………………………..(3.15)

Where

Qw = Volumetric flow rate of waste solids from system

Xw = VSS concentration in Qw

V = Volume of reactor

Xv = Average concentration of VSS in reactor

Substrate Removal Se: The effect of temperature on substrate removal can be determined by the following e

Rst1=Rst2℃ $* (T2 - T1)$…………………………………………(3.16)

Where

Rst1 = Substrate removal rate at temperature 1

Rst2 = Substrate removal rate at temperature 2

θ = Constant (equals 1.06 for $10°C<T<30°C$)

T1 = Temperature 1

T2 = Temperature

3.4.5 Sizing of the wetland

Hydrology Factors

For lined wetland

Qi= Qo + P- ET=dv/dt…………………………………………..(3.17)

Where

Qi = Influent wastewater flow

Qo = effluent wastewater flow

P = precipitation

ET = evapotranspiration

V = volume of water

t = time

For unlined wetland;

S(dv/dt)=Qi- Qo +P+I-ET…………………………………………..(3.18)

Where

I=net infiltration

Hydraulic Retention Time, HRT

This is the time taken by the wastewater to pass through the treatment system.

HRT(Days)=Lwnd/Q……………………………………………(3.19)

Where

L = length of system parallel to flow

W = width of the system

n = Porosity of the bed

d = depth of submergence

Q = averae flow through the system

Porosity of bed, n = Vv/V

Sizing based on equation

The wetland might be sized based on the equation proposed by Kickuth:

$Ah=Qd\ (\ln ci-\ln ce)/KBOD_5$……………………………………..(3.20)

Where

Ah = Surface area of bed (m^2)

Qd = average daily flow rate of sewage (m^3/d)

Ci = influent BOD_5 concentration (mg/l)

Ce = effluent BOD_5 concentration (mg/l)

$KBOD_5$ = rate constant (m/d)

$KBOD_5$ is determined from the expression KTdn, where,

$KT=K201.06^{T-20}$……………………………………………(3.21)

K20=rate constant at 20 ℃(d^{-1})

T = operational temperature of system (°C)

d = depth of water column (m)

n = porosity of the substrate medium (percentage expressed as fraction)

$KBOD_5$ is temperature dependent and the BOD_5 degradation rate generally increases about 10 % per °C. Thus, the reaction rate constant for BOD degradation is expected to be higher during summer than winter. It has also been reported that the $KBOD_5$ increases with the age of the system.

Sizing based on specific area requirement per Population Equivalent (PE)

The specific area requirement per PE holds true where there is uniformity in the specific wastewater quantity and quality. In general, the rules of thumb suggested by several works can be served as a safe bed (depending on the climatic conditions). However the investment costs tend to be higher due to conservative aspects of this approach. Specific area requirement for HF and VF constructed wetland has been calculated for various specific wastewater discharges for a certain population. The BOD contribution has been taken as 40 g BOD_5/pe.d, 30% BOD_5 load is reduced in the primary treatment and the effluent concentration of BOD_5 is taken as 30 mg/l. The $KBOD_5$ for HF and VF wetlands are taken as 0.15 and 0.20 respectively. It is seen that a specific area requirement of 1 – 2 m^2 /pe would be required of HF constructed wetlands where as a specific area of 0.8 – 1.5 m^2 /pe for the VF wetland.

Depth

In general, the depth of substrate in a subsurface flow constructed wetland is restricted to approximately the rooting depth of plants so that the plants are in contact with the flowing water and have an effect on treatment. However, Hydraulic Retention Time – HRT (time the wastewater is retained in the wetland) is to be considered in the selection of the depth of the wetland.

Bed cross section area (only for HF wetland)

Dimensioning of the bed is derived from Darcy's law and should provide subsurface flow through the gravel under average flow conditions. Two important assumptions have been made in applying the formula:

Hydraulic gradient can be used in place of slope, and

The hydraulic conductivity will stabilize at 10-3 m/s in the established wetland.

The equation is

Ac= Qs/Kf(dH/dS)…………………………………………………(3.22)

Where;

Ac = Cross sectional area of the bed (m^2)

Qs = average flow (m^3/s)

Kf= hydraulic conductivity of the fully developed bed (m/s)

dh/ds= slope of bottom of the bed (m/m)

For graded gravels a value of Kf of 1 x $10^{-3}$to 3 x 10^{-3} m/s is normally chosen. In most cases, of 1% is used.

Media selection

The media perform several functions. They:

- are rooting material for vegetation,
- help to evenly distribute/collect flow at inlet/outlet,
- provide surface area for microbial growth, and
- Filter and trap particles.

Very small particles have very low hydraulic conductivity and create surface flow. Very large particles have high conductivity, but have little wetted surface area per unit volume of microbial habitat. Large and angular medium is inimical to root propagation. The compromise is for intermediate-sized materials generally characterized as gravels. It is recommended that the gravels are washed because this removes fines that could block the void spaces.

VF wetland

The substrate properties, d10 (effective grain size), d60 and the uniformity coefficient (the quotient between d60 and d10) are the important characteristics in the selection of the substrate. The rate of decrease in permeability for similar SS influent characteristics is highest for porous media with smaller pore sizes. Compared to the gravel, the sands show a relatively more rapid reduction in their permeability due to effects of sediment accumulation at the surface of the sands. However, the depth of clogging is higher for larger particle sizes (Walker, 2006). It is recommended to use sand (0 – 4 mm) as main substrate with d10 > 0.3 mm, d60/d10 < 4 and having permeability.

Bed slope

The top surface of the media should be level or nearly level for easier planting and routine maintenance. Theoretically, the bottom slope should match the slope of the water level to maintain a uniform water depth throughout the bed. A practical approach is to uniformly slope the bottom along the direction of flow from inlet to outlet to allow for easy draining when maintenance in required. A slope of 0.5 to 1% is recommended for ease of construction and proper draining.

BOD_5 Removal

$$ {}^{ce}/_{co} = e^{-kt} \qquad \text{......(3.23)} $$

Where

Ce = effluent BOD_5, mg/l

Co = influent BOD_5, mg/l

K = temperature dependent, d^{-1}

t = detention time, days

As= Qava (ln co-ln ce)/Kt X dw X η……………………………..(3.24)

Where

As = wetland surface area

Q ave =Average flow rate

dw = water depth

n= wetland Porosity

Temperature correct removal rates

KT=K20$(1.06)^{(T-20)}$……………………………………………..(3.25)

Where

K20=reaction constant at 20℃

T=Average temperature

TSS Removal

TSSe=TSSo{0.1058 + 0.0011(HLR)}…………………………….(3.26)

Where

TSSe=effluent TSS

TSSo=influent TSS

HLR=hydraulic loading rate

Hydraulic Loading Rate

HLR=Q/As

Where

Q=flow rate

As=Surface area of the wetland

Nitrification

Ne\No=e^{-kt}……………………………………………….(3.27)

Where

Ne=effluent Nitrogen

No=influent Nitrogen

Total Phosphorous removal

Ce/Co=$e^{-kp/HLR}$……………………………………………..(3.28)

Where

Kp=1^{st} order phosphorous reaction rate (2.73cm\day)

Hydraulic Loading Rate

HLR=ln flow rate,Qi/Wetland Surface Arae,As…………………..(3.29)

Pathogen Removal

Ce=[Ci/$(1 + TKT)^{n}$…………………………………………(3.30)

Where

Ce=effluent fecal coliform concentration

Ci=influent fecal coliform concentration

n=porosity of substrate

T=hydraulic residence time

Sealing of the bed

Subsurface flow wetlands providing secondary treatment should be lined to prevent direct contact between the wastewater and groundwater. Liners used for wetlands are the same as those typically used for ponds. Synthetic liners include:

- Polyvinyl chloride (PVC)
- Polyethylene (PE)
- Polypropylene

Liners should be selected based on its availability and cost effectiveness. Preparation of the subgrade under the liner is crucial for successful liner installation. The finished subgrade should be free from materials that might puncture the liner.

Inlets

In VF wetlands, it is essential to get an even distribution over the whole bed area. Inlet structures for VF wetland comprises of an intermittent feeding tank with distribution network. Some wetlands have used a network of pipes with downward pointing holes. The pipe ends should be raised so that air can pass through during flushing as well as to achieve equal distribution of the wastewater. Others have used troughs or gutters with overflow from each side.

Outlet

Outlet structures help to control uniform flow through the wetland as well as the operating depth. The design of subsurface flow wetlands should allow controlled flooding to 15 cm to foster desirable plant growth and to control weeds. The use of an adjustable outlet, which is recommended to maintain an adequate hydraulic gradient in the bed, can also have significant benefits in operating and maintaining the wetland. A perforated subsurface manifold connected to an adjustable outlet offers the maximum flexibility and reliability as the outlet devices for subsurface flow wetlands. This can be an adjustable weir or gate, a series of stop logs, or a swiveling elbow.

Vegetation

Vegetation and its litter are necessary for successful performance of constructed wetlands and contribute aesthetically to the appearance. The vegetation to be planted in constructed wetlands should fulfill the following criteria:

- application of locally dominating macrophyte species;
- deep root penetration, strong rhizomes and massive fibrous root;
- considerable biomass or stem densities to achieve maximum translocation of water and assimilation of nutrients;
- maximum surface area for microbial populations;
- Efficient oxygen transport into root zone to facilitate oxidation of reduced toxic metals and support a large rhizosphere.

Phragmites karka and P. australis (Common Reed) is one of the most productive, wide spread and variable wetland species in the world. Due to its climatic tolerance and rapid growth, it is the predominant species used in constructed wetlands.

3.5 Assesment of current waste management situation

Desk reviews and intervies Study of the existing wastewater management systems and their efficiencies and determining the modification viable to improve the efficiency of slaughterhouse wastewater treatment. Observation Observation technique was used to determine the wastewater disposal and management being used at the Kiserian slaughterhouse.

3.6 Acqusition of data

Information on the quantity of daily wastewater production also forms an important component of the data required for design. This information was obtained through flow measurement and interviewing the slaughterhouse officials on the estimate of the amount of water they use every day. Wastewater content determined through lab tests, (i.e.BOD_5, COD, SS, Oil and Grease content).. Soil bearing capacity was determined by find the values of soil cohesion an angle of internal friction form triaxial test.

3.7 Location of the project

Geotechnical survey was carried out to determine the optimum location of the treatment plant in the proposed site and whether the available space/land is sufficient for the proposed wastewater management system.

3.8 Determination of the system parameters.

Desk study . Indepth analysis of engineering principles governing wastewater treatment and structural design inorder to identify parameters that will require consideration in the entire course of the project Relevant standards and conditions of waste water disposal as stipulated by NEMA were also considered. Study of literature of works done in the past in this area of study inorder to form a basis of my design Analysis of collected data Amount of waste produced, load on the system, sizes of the structures required, constructed wetland grades of beds and the appropriate plant to be used. These paremeters were used to determine the volume of the ABR and the surface area of the CW. Inlet and outlet flowrates were also be analysed inorder to determine the design specifications..

3.9 Modelling the system/making design drawings

After determination of the relevant design specifications, the information was used to come up with detailed engineering drawings of the proposed project.

3.10 Inventory control and management

To ensure an efficient and effective management and operation of the system, recommendation to improve the system were made. Also, basic operation and maintenance procedures were aalso stipulated to ensure the system wastewater treatment capability is not compromised.

CHPTER FOUR

Design a biological slaughterhouse wastewater treatment system (Using an anaerobic baffle reactor – constructed wetland system)

CHAPTER FOUR

Design a biological slaughterhouse wastewater treatment system (Using an anaerobic baffle reactor – constructed wetland system)

The slaughter house shall have the essential facilities for the following activities:

1. Receiving the animal
2. ante-mortem inspection
3. isolation of sick/diseased animals
4 Resting place for animals before slaughter
5. Carrying out humane slaughter – stunning box
6. Flaying, dressing and washing of the carcasses
7. Hanging carcasses and edible offal
8. Handling by-products
9. Handling solid and liquid wastes
10. Inspection of meat
11. Chilling and Freezing facilities
12. Emergency slaughter
13. Staff welfare
14. provision of hot and cold of potable water
15. Toilets and changing rooms

4.1 Food Animal

any mammal or bird declared to be an animal for slaughter.

4.2 Carcass

the body of any slaughtered animal after bleeding and dressing**.**

4.3 Evisceration

to disembowel and remove entrails of a carcass

4.4 Lairage-

means holding pens for livestock at a slaughterhouse prior to slaughtering.

4.5 Meat

means any portion of an animal which is intended for human consumption, whether fresh, chilled or frozen or otherwise processed by any means whatsoever or included in any article of food for human consumption.

4.6 Red offal

include heart, liver, kidney, spleen, tongue, lungs, pancrease.

4.7 Green offal

include the rumen, reticulum, omasum, abomasum, small intestines, large intestines, colon, and gizzards.

4.8 White offal

include the brain, spine, bone marrow, testicles and teats.

4.9 Slaughterhouse

means any place kept for the purpose of the slaughter of animals for human consumption.

4.10 Stunning

is any mechanical, electrical, chemical or other procedure which causes immediate loss of consciousness; when used before slaughter, the loss of consciousness lasts until death from the slaughter process; in the absence of slaughter, the procedure would allow the animal to recover consciousness.

4.11 fractious animals

animal that would not submit to the harness. readily angered; peevish; irritable; quarrelsome

4.12 clean area

area designated for slaughter operations after evisceration to dispatch

Figure 1— flow diagram for basic operation of a slaughter house

4.13 unclean/dirty area

area designated for slaughter operations from stunning to evisceration

4.14 Unclean operation

In animal slaughter, unclean(dirty)operations entail animal handling in lairages, stunning, bleeding, flaying or scalding (in pigs or poultry),remove of trotters, head, hide or skin/hair or feathers (in pigs or poultry).

4.15 Clean operations

evisceration, carcass splitting; diaphragm, fat, tail trim; carcass washing and dispatch to the cold room.

4.16 LOCATION

4.16.1 A slaughterhouse shall be located in an area which is reasonably free from objectionable odors, smoke and dust. Adequate dust-proof access-ways connecting the slaughterhouse with public roads shall be available. The slaughterhouse must be completely separated from any other buildings used for industrial, commercial, agricultural, residential or other purposes other than connected building used for the processing of the meat

4.16.2 The plan for construction of slaughter house shall follow the relevant provisions of EMCA Act, Physical Planning Act, Meat Control Act, Food Drugs and Public Health Act, Public Health Act and County physical Development Plans.

4.16.3 The slaughter house site shall be guided by the Part Development Plan (PDP) of the area.

4.16.4 General Provision.

Slaughter house shall be hygienically managed and under the supervision of a competent authority.

A slaughterhouse shall have—

(a) Properly built and drained lairage erected not less than ten meters from the slaughterhouse and equipped with adequate facilities for ante-mortem inspection and Isolation pens for suspect animals.

dressing rails if necessary together with drainage valleys, not less than seven decimal five centimeters wide, with a slope of the floor towards drainage valleys or inlets of at least two decimal five centimeters per meter.

(p) Drains for paunch and stomach contents at least twenty centimeters in diameter.

(q) Waste disposal system of adequate size and must comply with Environmental Management and Coordination Act (EMCA1999) and local regulations.

4.17 SLAUGHTER HOUSE LAYOUT PLAN

The slaughter house shall have the essential facilities for the following activities:

I. Receiving the animal

II. ante-mortem inspection

III. isolation of sick/diseased animals

IV. Resting place for animals before slaughter

V. Carrying out humane slaughter – stunning box

VI. Flaying, dressing and washing of the carcasses

VII. Hanging carcasses and edible offal

VIII. Handling by-products

IX. Handling solid and liquid wastes

X. Inspection of meat

XI. Chilling and Freezing facilities

XII. Emergency slaughter

XIII. Staff welfare

XIV. provision of hot and cold of potable water

XV. Toilets and changing rooms

4.17.1 A flow diagram for basic operation of a slaughter house is shown in Fig. 1 for information and guidance only. The layout of entire slaughter house, as far as possible, shall follow forward flow principle. Figures 2 and 3 show a typical layout plan for slaughter house and a sample planning outline

4.17.2 The slaughter house design shall provide for the separate gates for the entry of slaughter animals and exit of the products.

4.17.3 Should the retail or wholesale market for finished products be required to be included within the complex itself, the same should be physically excluded from the rest of the establishment in such a manner that the customers have an access only to these sections where such business is transacted.

4.17.4 Slaughter houses shall have an adequate separation between clean and dirty sections, which shall be arranged in such a way that from the introduction of a live animal into the slaughter house up to the emergence of meat and offal classed as fit for human consumption, there shall be a continuous process, without any possibility of reversal, inter-section or over lapping between the live animals and meat, and between meat and by-products or waste.

4.18 SECTIONS OF A SLAUGHTER HOUSE

4.18.1 In view of the facilities to be provided (5.1), the slaughter house shall have the following units:

4.18.2 Reception(a) The slaughter house shall have reception area of adequate size and shall have adequate artificial lighting if animals are offloaded at night(b)Offloading ramps shall be movable or stationary and shall:–

i. be so constructed to avoid injury of animals during offloading and provide a stable area to facilitate the free movement of animals.

ii. not have open spaces between the offloading ramp and the vehicle.

iii. be at the same height of the vehicle for which it is used.

iv. have guide rails.

v. have permanent non-slip floor at a slope of not more than 20o.

vi. not have sharp protruding edges or any other features that may cause injury.

4.18.3 Lairage

Cattle, goats, sheep and pigs shall be penned separately. In the case of pigs, pigs from different origins should be penned separately, in accordance with their origins. Depending on the size of the animals and the duration of time that the animals will be penned, the penning space shall not be less than:

a) For each adult cow – 1.74 square metres floor area.

b) For each bacon type pigs and small porkers, sheep and goats – 0.56 square metres floor space.

c) For each heavy pigs and young calves – 0.74 squared metres floor area. In the case of pigs, water sprays or hoses shall be used for cleaning and cooling hot, dirty or fractious pigs.

d) For poultry- 10 to 15 birds per square metre

Fractious animals shall not be penned with other animals. Provision shall be made in pens for -

i. Facilities such as racks, mangers or other suitable feed containers which are easy to clean and will allow the feeding of the animal away from the floor.

ii. Facilities for the safe and humane keeping and handling of animals.

iii. A water trough with an adequate and accessible supply of clean, portable water at all times.

iv. Sufficient facilities for the adequate and regular cleaning of pens.

v. Adequate facilities for isolation of sick or suspect animals.

vi. The pens shall always be maintained in a good state of repair and sharp points such as jagged ends or protruding nuts and bolts which could cause injury to animals shall be removed or suitably dealt with. Protection from weather elements shall be provided.

vii. Animals shall not be penned in overcrowded conditions and the floor of the entire pen, including the off-loading banks, passages, races and pens shall be so constructed as to provide acceptable non – slip surfaces that can be regularly cleaned and kept suitably dry and in a condition fit for the holding of livestock.

4.18.4 Slaughter hall

The slaughter halls and ancillary accommodation thus provided shall be separated, keeping in view the economic and local requirements, by solid walls depending upon the site. The slaughter hall shall have the following facilities:-

4.18.5 Stunning area

There shall be a separate area designated for stunning the animals depending on the species.

4.18.6 Bleeding area

A curbed-in bleeding area of adequate size shall be provided. It shall be so located that the blood shall not be splashed on other animals being slaughtered or on the carcass being skinned. A floor wash point should be provided for intermittent cleaning.

4.18.7 Hoisting area

A suitable means of hoisting the slaughtered animal shall be provided. The bleeding rail shall be of sufficient height for the animal carcass to hang above the floor. The height and length of rails provided for bleeding and dressing shall be as provided as shown in Table 1.

No	Carcass	Height(metres)	Length per carcass(metres)
1	Bleeding rail for sheep, goats and pigs	3.0-2.2	0.45
2	Bleeding rail for cattle, camel, donkey	4.5- 5.0	0.60
3	Dressing rail for sheep, goats and pigs	2.0- 2.2	0.90
4	Dressing rail for cattle, camel, donkey	3.2	1.8 for legging, dehiding and 2.4 for evisceration.
5	Poultry		Leg to leg 10" Shackle to shackle 15" Big birds shackle to shackle 30-45"

Flaying section

Flaying of carcasses shall not be done on floor. Adequate means and tools for dehiding or belting of the animals shall be provided. Means for immediate disposal of hides or skins shall be provided. Hides or skins shall be immediately transported either in a closed and appropriate carriage or by a chute provided with self-closing door to a room where they shall be held before moving to the preservation area. Means for immediate disposal of legs, horns,hooves, etc, should be provided. Floor wash point and adequate number of hand wash basins with sanitizer and cutting equipment sterilizer shall be provided in this section.

Evisceration area

For cattle either a mechanical evisceration table or individual paunch/gut holders can be used for the reception and inspection of these products. Facilities shall be provided for the eviscerator to do the job hygienically. In the case of a mechanical conveyor belt, boot washing, apron washing and other washing/sterilising facilities shall be made available. The evisceration platform used at smaller slaughter house shall be provided with a hand basin/steriliser. In all cases there shall be facilities for the sterilisation of the evisceration platform or offal containers. Racks and/or facilities for handling red and green/rough offals shall be provided.

Carcass splitting

Appropriate carcass splitting equipment shall be provided in the slaughter house. Carcasses shall be split straight down the middle as appropriate so as not to damage to the meat applicable for beef and pork carcasses.

Carcass washing area

Potable water at sufficient pressure shall be provided to remove all blood, slight blood marks, bone, dust and marrow.

Inspection facilities

The following facilities, conditions and such others as may be essential to efficient conduct of inspection and maintenance of sanitary conditions shall be provided by each slaughterhouse:-

a) Adequate space, suitable and properly located facilities shall be provided for inspection of

the various types of animals slaughtered. This section shall have adequate facilities for hand washing, equipment sterilization and floor washing and for immediate separation and disposal of condemned material.

b) Sufficient natural and/or abundant artificial light at all places and such times of day when natural light may not be adequate for proper conduct of inspection.

c) Rooms shall be kept sufficiently free from vapours and steam for inspection to be properly made.

d) Racks, receptacles, or other suitable devices for retaining such parts as the head, tongue, tail, thymus gland and viscera, and other parts and blood to be in the preparation of meat until after the post-mortem is completed, in order that they may be accurately identified in case of condemnation of the carcass.

e) Watertight metal carriers or receptacles for holding and handling diseased carcasses and parts, so constructed as to be easily cleaned; such trucks or receptacles shall be suitably marked in a conspicuous manner with the word— CONDEMNED‖ in letters not less than five centimetres high, and when required by the inspecting officer, to be equipped with facilities for locking or sealing.

Carcass chilling area

Facilities that shall ensure chilling of the meat at temperature range -2 to 4 oc shall be

provided. The space required per carcass and the distance between the rails in hanging or chill room, shall be in accordance with Table 2.

Table 2: Requirement of space per carcass and distance between rails in hanging or chilling room

NO	Carcass	Space carcass (metres)	Distance between rails (metres)	Height of raiis (metres)
1	Sheep and goats	0.3-0.4	0.3-0.4	2.0-2.2 minimum(single changing)
2	Pigs a. Mass of pig >70kg b. Mass of pig >70kg	0.45-0.6 0.3-0.4	0.45-0.6	
3	Cattle.camel and donkey		0.8-1.0	3.2(for halves)2.0-2.2 For quarters
4	Pouitry	10-15 birds $1m^2$ per crate		

Carcass freezing area

Facilities that shall ensure freezing of the meat at a temperature of -12 oc and below shall be provided.

419. ANCILLIARY/AUXILIARY FACILITIES

1.DISTRIBUTION ROOM

A separate area /room set aside for various functions i.e. sales or collection of products and or by products to avoid customers or outsiders from accessing prohibited areas in the slaughterhouse.

2. HIDES/SKINS ROOM

A separate room outside the slaughter house shall be provided for temporarily storage of the hides/skins.

3. OFFAL ROOM

A separate room and hanging space shall be provided for emptying and cleaning of stomachs and intestines. This room shall be provided with sufficient potable running water work tops. This room shall have a separate exit and sufficiently drained.

4. RETENTION ROOM

Suitable and sufficient room shall be provided for the retention of all meat condemned as unfit for human consumption and shall be locked up separately. Suitable and sufficient facilities shall be provided for the isolation of meat requiring further examination by the veterinary inspector within the premises of the slaughter house

5. LABORATORY

A laboratory within the premises of the slaughter house may be provided

6. DISPOSAL OF CONDEMNED MEAT

Suitable and sufficient facilities shall be provided for the disposal of condemned meat. This shall be through an appropriately designed condemnation pit or appropriately designed incineration facilities or other approved means of disposal.

7. SANITATION FACILITIES

Appropriately located toilet and changing rooms should be provided in the slaughter house building sufficiently away from slaughter walls for the dirty and clean areas. A separate hall with lockers and shower facilities should be provided. Solid and liquid wastes from the sanitation facility shall be handled separately from slaughter house waste. Adequate drinking water and washing facilities shall be provided at convenient locations.

8. SUPPLY OF WATER

Adequate supply of potable water shall be available at appropriate pressure throughout the premises. sufficient supply of potable hot water above 820 C for sterilizing of equipment shall be available in the slaughter hall and workrooms during working hours. Suitable facilities for washing of hands (including adequate supplies of hot and cold running water, and soap or other detergent) shall be provided for persons working in an Slaughter house. Where non-potable water is used for fire control, it shall be carried in completely separate lines preferablyidentified by colour and with no cross-connection or back siphonage with lines carrying potable water.

9. SLAUGHTER HOUSE WASTE WATER DISPOSAL

An efficient method of disposing of slaughter house wastes shall be provided in accordance with EMCA Act.

10. GREASE TRAP

Catch basin for the recovery of grease shall be suitably located and not placed in or near edible products department or area where edible products are unloaded from or loaded on to vehicles, to facilitate ready cleaning, such basins shall have inclined bottoms and shall be without covers. They shall be so constructed that they may be completely emptied of their contents for cleaning. The area surrounding an outside catch basin should be paved with impervious material, such as concrete, and shall be provided with suitable drainage facilities. Suitable facilities shall be provided for the transfer of grease to the point of disposal after it is skimmed from the basins by mechanical or other means.

11. MANURE DISPOSAL

A suitably designed facility for disposal of manure shall be provided. A separate drain line for water containing manure shall be provided. This waste water may be pumped by wet pit or dry pit non-clog pumps and manure screened out and disposed off by mechanical or the other suitable means. Some consideration as in catch basin shall be given for location of this plant.

An access path for easy and convenient removal of the manure shall be provided.

12. EMERGENCY SLAUGHTER HOUSE

Appropriate facility shall be provided for the emergency slaughter of animals. The facility shall have all the necessary equipments for hygienic meat preparation.

13. POST MORTEM ROOM

Appropriate facilities shall be provided for conducting post mortem of animal arriving dead at the slaughter house or dies at the lairage.

14. VETERINARY OFFICES

There shall be suitable and sufficient offices facilities for the veterinary/inspecting officer equipped with adequate sanitary and hygiene facilities. The offices shall be located in the slaughter house to enable the officers have effective control of all activities within the slaughter house.

15. SAFETY REQUIREMENT

Adequate firefighting equipment and appliances shall be fixed in accordance with Occupation Safety and Health Act (OSHA). Adequate facilities for first-aid shall also be provided.

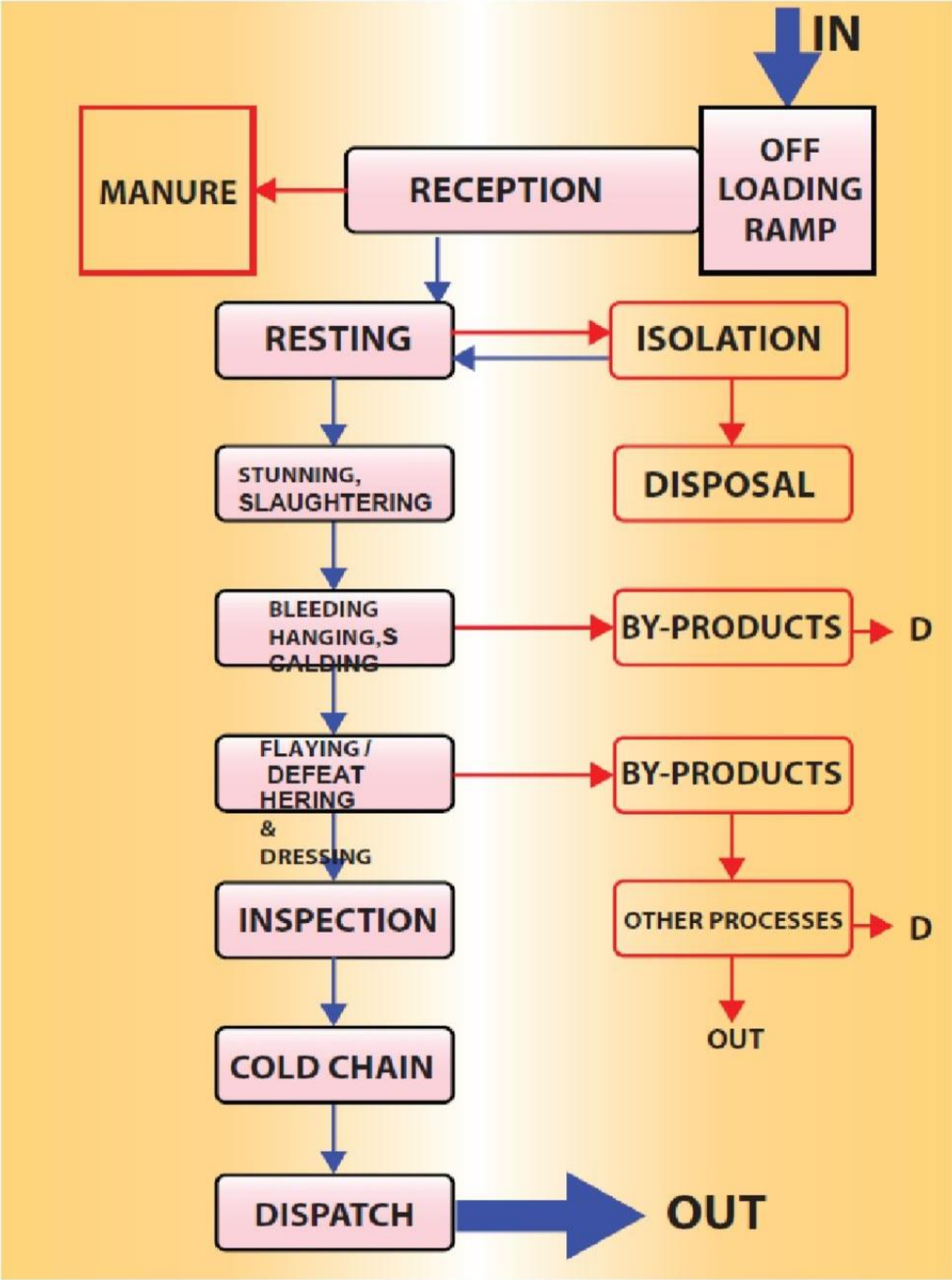

Figure 1. Requirement of height and length of bleeding and dressing rail

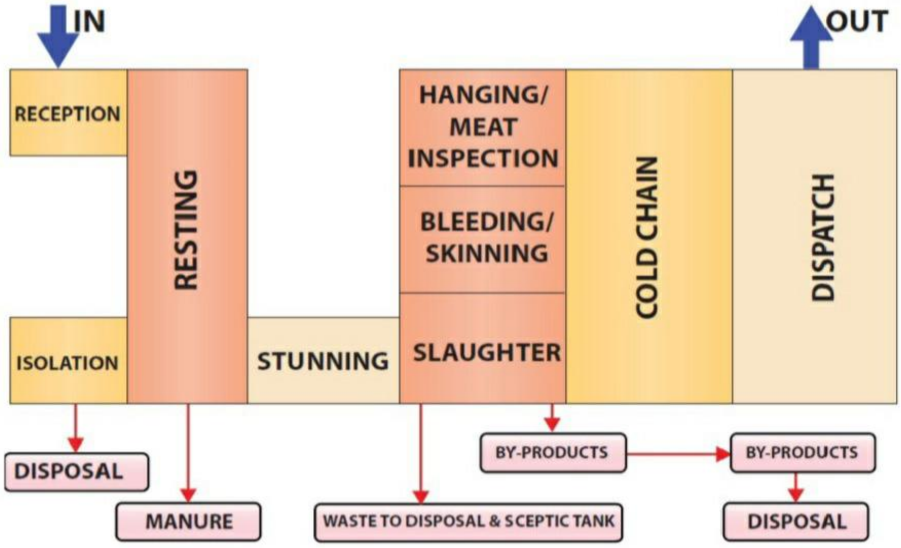

Figure2-A typical planning outling for a slaughter house

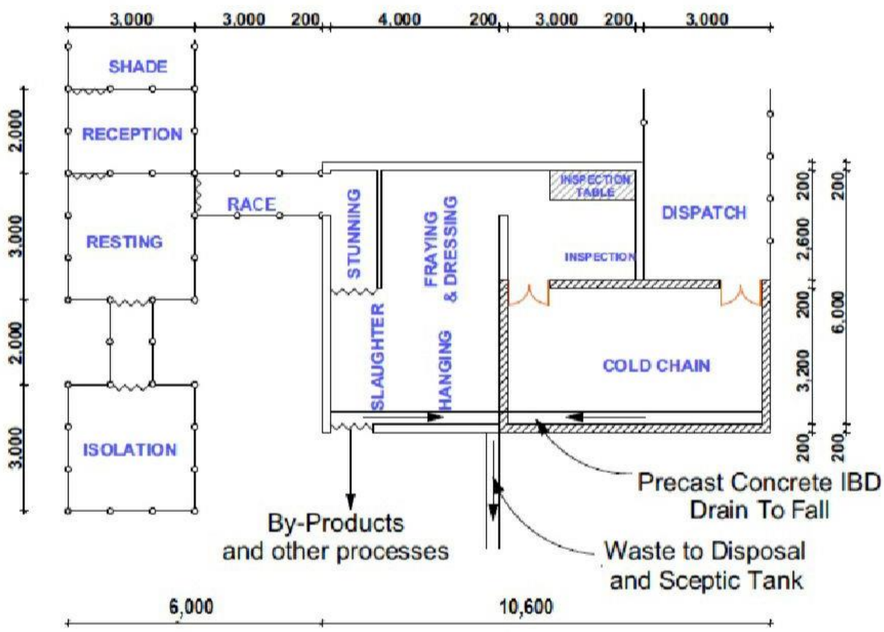

Figure 3-A typical layout plant for a slaughter house

CHAP FIVE

REFERENCES

References

[1] Gerbens-Leenes P.W., Mekonnen M.M., Hoekstra A.Y. The water footprint of poultry, pork and beef: A comparative study in different countries and production systems. Water Resources and Industry. 2013;1–2:25–36. DOI: 10.1016/j.wri.2013.03.001

[2] Mekonnen M.M., Hoekstra A.Y. A global assessment of the water footprint of farm animal products. Ecosystems. 2012;15(3):401–415. DOI: 10.1007/s10021-011-9517-8

[3] Valta K., Kosanovic T., Malamis D., Moustakas K., Loizidou M. Overview of water usage and wastewater management in the food and beverage industry. Desalination and Water Treatment. 2015;53(12):3347. DOI: 10.1080/19443994.2014.934100

[4] United States Environmental Protection Agency (US EPA). Effluent limitations guidelines and new source performance standards for the meat and poultry products point source category [Internet]. 2004 [Updated: 2004-10-08]. Available from: https:// federalregister.gov/a/04-12017 [Accessed: 2016-06-22]

[5] Barrera M., Mehrvar M., Gilbride K., McCarthy L., Laursen A., Bostan V., et al. Photolytic treatment of organic constituents and bacterial pathogens in secondary effluent of synthetic slaughterhouse wastewater. Chemical Engineering Research and Design. 2012;90(9):1335–1350. DOI: 10.1016/j.cherd.2011.11.018

[6] Bustillo-Lecompte C., Mehrvar M., Quiñones-Bolaños E. Slaughterhouse wastewater characterization and treatment: an economic and public health necessity of the meat processing industry in Ontario,

Canada. Journal of Geoscience and Environment Protection. 2016; 4:175–186. DOI: 10.4236/gep.2016.44021

[7] Bustillo-Lecompte C.F., Mehrvar M. Slaughterhouse wastewater characteristics, treatment, and management in the meat processing industry: a review on trends and advances. Journal of Environmental Management. 2015; 161:287–302. DOI: 10.1016/ j. jenvman.2015.07.008

[8] Jensen P.D., Yap S.D., Boyle-Gotla A., Janoschka J., Carney C., Pidou M., et al. Anaerobic membrane bioreactors enable high rate treatment of slaughterhouse wastewater. Biochemical Engineering Journal. 2015; 97:132–141. DOI: 10.1016/j.bej.2015.02.009

[9] Bustillo-Lecompte C.F., Mehrvar M., Quiñones-Bolaños E. Combined anaerobicaerobic and UV/H2O2 processes for the treatment of synthetic slaughterhouse wastewater. Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering. 2013;48(9):1122–1135. DOI: 10.1080/1093 4529.2013.774662

[10] Bustillo-Lecompte C.F., Mehrvar M., Quiñones-Bolaños E. Cost-effectiveness analysis of TOC removal from slaughterhouse wastewater using combined anaerobic-aerobic and UV/H2O2 processes. Journal of Environmental Management. 2014; 134:145–152. DOI: 10.1016/j.jenvman.2013.12.035

[11] Sneeringer S.E. Effects of environmental regulation on economic activity and pollution in commercial agriculture. The B.E. Journal of Economic Analysis and Policy. 2009;9(1): 1935–1682. DOI: 10.1016/S1642-3593(07)70117-9

[12] World Bank Group. Environmental, Health and Safety (EHS) Guidelines for Meat Processing. General EHS Guidelines: Environmental Wastewater and Ambient Water Quality. [Internet]. 2007 [Updated: 2013-11-15]. Available from: http://www.ifc.org/ ehsguidelines [Accessed: 2016-06-24]

[13] Council of the European Communities (CEC). Urban Wastewater Treatment Directive 91/271/EEC. Official Journal of the European Communities. 1991; L 135(30.5):40–52.

[14] US Environmental Protection Agency (US EPA). Effluent limitations guidelines and new source performance standards for the meat and poultry products point source category; Final Rule; Federal Register. 2004;69(173):54476–54555.

[15] Environment Canada. Framework and recommendations concerning effluent quality of wastewater disposed by federal institutions, Final Report, Federal Committee on Environmental Management Systems (FCEMS)/Wastewater Working Group [Internet]. 2000 [Updated: 2003-06-11]. Available from: http://www.csc-scc.gc.ca/politiques-etlois/318-6-gl-eng.shtml [Accessed: 2016-06-24]

[16] Environment Canada. Wastewater Systems Effluent Regulations. Fisheries Act. SOR/ 2012-139 [Internet]. 2012 [Updated: 2016-06-17]. Available from: http://laws-lois.justice.gc.ca/eng/regulations/sor-2012-139/FullText.html [Accessed: 2016-06-24]

[17] Colombian Ministry of Environment and Sustainable Development. Resolution 631 of 2015 Whereby the parameters and maximum permissible exposure limits in specific discharges to surface water and public sewer systems and other provisions are established [Internet]. 2015. Available from: https://www.minambiente.gov.co/

images/normativa/app/resoluciones/d1-res_631_marz_2015.pdf [Accessed: 2016-0624]

[18] Chinese Ministry of Environmental Protection. Discharge standard of water pollutants for meat packing industry GB 13457-92 [Internet]. 1992 [Updated: 1998?01?01]. Available from: http://english.mep.gov.cn/standards_reports/standards/water_environment/Discharge_standard/200710/t20071024_111799.htm [Accessed: 2016-06-24]

[19] Indian Central Pollution Control Board. General standards for discharge of environmental pollutants Part A: Effluents [Internet]. 1986 [Updated: 1993-12-31]. Available from: http://cpcb.nic.in/GeneralStandards.pdf [Accessed: 2016-06-24]

[20] Australian and New Zealand Environment and Conservation Council. Australian Guidelines for Sewerage Systems: Effluent Management [Internet]. 1997. Available from: https://www.environment.gov.au/system/files/resources/e52e452b-a821-4abe9987-0e353/files/sewerage-systems-effluent-man-paper11.pdf [Accessed: 2016-06-24]

[21] Australian and New Zealand Environment and Conservation Council. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy. 2000;1(1–7):4.

[22] Amorim A. K. B., De Nardi I. R., Del Nery V. Water conservation and effluent minimization: case study of a poultry slaughterhouse. Resources, Conservation and Recycling. 2007;51(1):93–100. DOI: 10.1016/j.resconrec.2006.08.005

[23 Torkian A., Eqbali A., Hashemian, S.J. The effect of organic loading rate on the performance of UASB reactor treating slaughterhouse effluent. Resources, Conservation and Recycling. 2003;40(1):1–11. DOI: 10.1016/S0921-3449(03)00021-1

[24] Belsky A.J., Matzke A., Uselman S. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation. 1999;54(1): 419–431.

[25] Verheijen L.A.H.M., Wiersema D., Hulshoff Pol L.W. Management of Waste from Animal Product Processing [Internet]. 1996. Available from: http://www.fao.org/ WAIRDOCS/LEAD/X6114E/X6114E00.HTM [Accessed: 2016-06-24]

[26] Cao W., Mehrvar M. Slaughterhouse wastewater treatment by combined anaerobic baffled reactor and UV/H2O2 processes. Chemical Engineering Research and Design. 2011;89(7):1136–1143. DOI: 10.1016/j.cherd.2010.12.001

[27] Mbuligwe S.E. Waste management and resource recovery in the food processing industry: the livestock industry. In: Bellinghouse V.C., editor. Food Processing: Methods, Techniques and Trends. New York, NY: Nova Science Publishers, Inc.; 2009. p. 77– 113.

[28] Um M.M., Barraud O., Kérourédan M., Gaschet M., Stalder T., Oswald E., et al. Comparison of the incidence of pathogenic and antibiotic-resistant Escherichia coli strains in adult cattle and veal calf slaughterhouse effluents highlighted different risks for public health. Water Research. 2016; 88:30–38. DOI: 10.1016/j.watres.2015.09.029

[29] Pina S., Buti M., Cotrina M., Piella J., Girones R. HEV identified in serum from human with acute hepatitis and sewage of animal origin in

Spain. Journal of Hepatology. 2000;33(5):826–833. DOI: 10.1016/S0168-8278(00)80316-5

[30] Mittal G.S. Treatment of wastewater from abattoirs before land application—a review. Bioresource Technology. 2006;97(9):1119–1135. DOI: 10.1016/j.biortech.2004.11.021

[31] Al-Mutairi N.Z., Al-Sharifi F.A., Al-Shammari S.B. Evaluation study of a slaughterhouse wastewater treatment plant including contact-assisted activated sludge and DAF. Desalination. 2008;225(1–3):167–175. DOI: 10.1016/j.desal.2007.04.094

[32] De Sena R.F., Moreira R.F.P.M., José H.J. Comparison of coagulants and coagulation aids for treatment of meat processing wastewater by column flotation. Bioresource Technology. 2008;99(17):8221–8225. DOI: 10.1016/j.biortech.2008.03.014

[33] De Nardi I.R., Fuzi T.P., Del Nery V. Performance evaluation and operating strategies of dissolved-air flotation system treating poultry slaughterhouse wastewater. Resources, Conservation and Recycling. 2008;52(3):533–544. DOI: 10.1016/j.resconrec. 2007.06.005

[34] Kobya M., Senturk E., Bayramoglu M. Treatment of poultry slaughterhouse wastewaters by electrocoagulation. Journal of Hazardous Materials. 2006;133(1–3):172–176. DOI: 10.1016/j.jhazmat.2005.10.007

[35] Bayramoglu M., Kobya M., Eyvaz M., Senturk E. Technical and economic analysis of electrocoagulation for the treatment of poultry slaughterhouse wastewater. Separation and Purification Technology. 2006;51(3):404–408. DOI: 10.1016/j.seppur.2006.03.003

[36] Gürel L., Büyükgüngör H. Treatment of slaughterhouse plant wastewater by using a membrane bioreactor. Water Science and Technology. 2011;64(1):214–219. DOI: 10.2166/ wst.2011.677

[37]Chan Y. J., Chong M. F., Law C. L., Hassell D. A review on anaerobic-aerobic treatment of industrial and municipal wastewater. Chemical Engineering Journal. 2009;155(1–2): 1–18. DOI: 10.1016/j.cej.2009.06.041

[38] Al-Mutairi N.Z. Aerobic selectors in slaughterhouse activated sludge systems: a preliminary investigation. Bioresource Technology. 2009;100(1):50–58. DOI: 10.1016/ j. biortech.2007.12.030

[39] Keskes S., Hmaied F., Gannoun H., Bouallagui H., Godon J.J., Hamdi M. Performance of a submerged membrane bioreactor for the aerobic treatment of abattoir wastewater. Bioresource Technology. 2012;103(1):28–34. DOI: 10.1016/j.biortech.2011.09.063

[40] Vymazal J. Constructed wetlands for treatment of industrial wastewaters: a review. Ecological Engineering. 2014; 73:724–751. DOI: 10.1016/j.ecoleng.2014.09.034

[41] Gutiérrez-Sarabia A., Fernández-Villagómez G., Martínez-Pereda P., RinderknechtSeijas N., Poggi-Varaldo H.M. Slaughterhouse wastewater treatment in a fullscale system with constructed wetlands. Water Environment Research. 2004;76(4): 334–343. DOI: 10.2175/106143004X141924

[42]Bustillo-Lecompte C.F., Ghafoori S., Mehrvar M. Photochemical degradation of an actual slaughterhouse wastewater by continuous UV/H2O2 photoreactor with recycle. Journal of Environmental Chemical Engineering. 2016;4(1):719–732. DOI: 10.1016/j.jece.2015.12.009

[43] Vidal J., Huiliñir C., Salazar R. Removal of organic matter contained in slaughterhouse wastewater using a combination of anaerobic digestion and solar photoelectro-Fenton processes. Electrochimica Acta. 2016; 210:163–170. DOI: 10.1016/ j. electacta.2016.05.064

[44] Bayar S., Yildiz Y.S., Yilmaz A.E., Koparal A.S. The effect of initial pH on treatment of poultry slaughterhouse wastewater by electrocoagulation method. Desalination and Water Treatment. 2014;52(16–18):3047–3053. DOI: 10.1080/19443994. 2013.800268

[45] Kundu P., Debsarkar A., Mukherjee S. Kinetic modeling for simultaneous organic carbon oxidation, nitrification, and denitrification of abattoir wastewater in sequencing batch reactor. Bioremediation Journal. 2014;18(4):267–286. DOI: 10.1080/10889868.2014.939134

[46] Martinez S.L., Torretta V., Minguela J.V., Siñeriz F., Raboni M., Copelli S., et al. Treatment of slaughterhouse wastewaters using anaerobic filters. Environmental Technology. 2014;35(3):322–332. DOI: 10.1080/09593330.2013.827729

[47] McCabe B.K., Hamawand I., Harris P., Baillie C., Yusaf T. A case study for biogas generation from covered anaerobic ponds treating abattoir wastewater: Investigation of pond performance and potential biogas production. Applied Energy. 2014; 114:798– 808. DOI: 10.1016/j.apenergy.2013.10.020

[48] Mees J.B.R., Gomes S.D., Hasan S.D.M., Gomes B.M., Vilas Boas M.A. Nitrogen removal in a SBR operated with and without pre-denitrification: Effect of the carbon: nitrogen ratio and the cycle time. Environmental Technology. 2014;35(1):115–123. DOI: 10.1080/09593330.2013.816373

[49] Ozyonar F., Karagozoglu B. Investigation of technical and economic analysis of electrocoagulation process for the treatment of great and small cattle slaughterhouse wastewater. Desalination and Water Treatment. 2014;52(1–3):74–87. DOI: 10.1080/194 43994.2013.787373

[50] Pan M., Henry L.G., Liu R., Huang X., Zhan X. Nitrogen removal from slaughterhouse wastewater through partial nitrification followed by denitrification in intermittently aerated sequencing batch reactors at 11°C. Environmental Technology. 2014;35(4):470– 477. DOI: 10.1080/09593330.2013.832336

[51] Stets M.I., Etto R.M., Galvão C.W., Ayub R.A., Cruz L.M., Steffens M.B.R., et al. Microbial community and performance of slaughterhouse wastewater treatment filters. Genetics and Molecular Research. 2014;13(2):4444–4455. DOI: 10.4238/2014.June.16.3

[52] Yoon Y.M., Kim S.H., Oh S.Y., Kim C.H. Potential of anaerobic digestion for material recovery and energy production in waste biomass from a poultry slaughterhouse. Waste Management. 2014;34(1):204–209. DOI: 10.1016/j.wasman.2013.09.020

[53] Almandoz M.C., Pagliero C.L., Ochoa N.A., Marchese J. Composite ceramic membranes from natural aluminosilicates for microfiltration applications. Ceramics International. 2015;41(4):5621–5633. DOI: 10.1016/j.ceramint.2014.12.144

[54] Abdurahman N.H., Rosli Y.M., Azhari N.H., Bari H.A. The potential of ultrasonic membrane anaerobic systems in treating slaughterhouse wastewater. Journal of Water Reuse and Desalination. 2015;5(3):293–300. DOI: 10.2166/wrd.2015.107

[55] Odong R., Kansiime F., Omara J., Kyambadde J. Tertiary treatment of abattoir wastewater in a horizontal subsurface flow-constructed wetland under tropical conditions. International Journal of Environment and Waste Management. 2015;15(3):257–270. DOI: 10.1504/IJEWM.2015.069160

[56 Pan M., Hu Z., Liu R., Zhan X. Effects of loading rate and aeration on nitrogen removal and N2O emissions in intermittently aerated sequencing batch reactors treating slaughterhouse wastewater at 11°C. Bioprocess and Biosystems Engineering. 2015;38(4):681–689. DOI: 10.1007/s00449-014-1307-1

[57] Paramo-Vargas J., Camargo A.M.E., Gutierrez-Granados S., Godinez L.A., PeraltaHernandez J.M. Applying electro-Fenton process as an alternative to a slaughterhouse effluent treatment. Journal of Electroanalytical Chemistry. 2015;754(2169):80–86. DOI:

10.1016/j.jelechem.2015.07.002

[58] Wosiack P.A., Lopes D.D., Rissato Zamariolli Damianovic M.H., Foresti E., Granato D., Barana A.C. Removal of COD and nitrogen from animal food plant wastewater in an intermittently-aerated structured-bed reactor. Journal of Environmental Management. 2015; 154:145–150. DOI: 10.1016/j.jenvman.2015.02.026

[59] Abdurahman N.H., Rosli Y.M., Azhari N.H. The potential of ultrasonic membrane anaerobic system (UMAS) in treating slaughterhouse wastewater. ARPN Journal of Engineering and Applied Sciences. 2016;11(4):2653–2659.

[60] Coskun T., Debik E., Kabuk H.A., Manav Demir N., Basturk I., Yildirim B., et al. Treatment of poultry slaughterhouse wastewater using

a membrane process, water reuse, and economic analysis. Desalination and Water Treatment. 2016;57(11):4944– 4951. DOI: 10.1080/19443994.2014.999715

[61] Bustillo-Lecompte C.F., Mehrvar M Treatment of an actual slaughterhouse wastewater by integration of biological and advanced oxidation processes: Modeling, optimization, and cost-effectiveness analysis. Journal of Environmental Management. 2016;182: 651-666. DOI: 10.1016/j.jenvman.2016.07.044

[62] Ontario Ministry of Agricultural and Rural Affairs (OMAFRA). Provincially Licensed Meat Plants in Ontario [Internet]. 2016. Available from: http://www.omafra.gov.on.ca/ english/food/inspection/maps/TblAllAbattoirs.htm [Accessed: 2016-06-24]

[63] Sgarbossa F., Russo I. A proactive model in sustainable food supply chain: insight from a case study. International Journal of Production Economics. 2016;1–11. DOI: 10.1016/ j. ijpe.2016.07.022 (in press).

[64] Manios T., Gaki E., Banou S., Klimathianou A., Abramakis N., Sakkas N. Closed wastewater cycle in a meat producing and processing industry. Resources, Conservation and Recycling. 2003;38(4):335–345. DOI: 10.1016/S0921-3449(02)00169-6