UNIVERSITI PUTRA MALAYSIA

ADSORPTION AND BIODEGRADATION OF POLLUTANTS FROM LIVESTOCK WASTEWATER BY AGED REFUSE BIOREACTOR

ANIJIOFOR SANDRA CHINENYENWA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

September 2018

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DEDICATION

Dedicated to God Almighty,
my darling husband and precious children,
my loving mother and lovely sister Amaka,
for undying love and support throughout the period of my study

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

ADSORPTION AND BIODEGRADATION OF POLLUTANTS FROM LIVESTOCK WASTEWATER BY AGED REFUSE BIOREACTOR

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ANIJIOFOR SANDRA CHINENYENWA

September 2018

Chairman : Nik Norsyahariati Nik Daud, PhD
Faculty : Engineering

This study investigated the characteristics of landfilled solid wastes, "aged refuse", for adsorption and biodegradation processes, as an affordable livestock wastewater treatment option. Presently, the UPM dairy farm discharges about 2000-2200 L/day of untreated wastewater into a nearby river, raising serious environmental concerns, especially regarding water pollution. The parameters studied were pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), turbidity, total nitrogen (TN), ammonia nitrogen (NH_3-N), total phosphorous (TP) and total coliform. Three sources of livestock wastewater (Dairy farm, chicken slaughter house and fishpond), were examined, while the aged refuse was collected from Air Hitam sanitary landfill, Selangor, Malaysia.

The results revealed aged refuse characteristics such as pH 7.14, moisture content 29.5%, organic content 9.90%, total coliform 7.1 x 10^6 CFU/100 mL, which are suitable conditions for biodegradation. Hydraulic conductivity 0.31 cm/s, porosity (*n)* 51%, and bulk density (ρ) 1.23 g/cm^3, are suitable conditions for free water flow and air diffusion. The available exchangeable cations (Ca, Mg, K, Na), will promote ion exchange while low metal concentrations of (Pb = 0.858, Cr = 14.0, Cu = 1.10 and Zn = 12.16 mg/kg), will reduce interference. The scanning electron microscopy (SEM), showed available pore spaces, and BET surface area 3.376 m^2/g, which are suitable for adsorption, while the Fourier Transform Infra-red (FTIR), revealed functional groups of carbonyl, carboxyl and hydroxyl groups, with strong adsorption capacity.

The batch adsorption study indicated the effects of pH, dosage and contact time on removal efficiency, and optimum conditions were; pH 6, dosage 2-4 g/100 mL, adsorbent size $\leq$ 2 mm, contact time 10-180 minutes, agitation speed 250 rpm and ambient temperature conditions. The maximum removal efficiency were about 94%

(COD, BOD), 91% (TSS, TDS), 97% colour and 88% NH_3-N. The correlation coefficient R^2 (0.9026 to 0.9999) for Langmuir, and (0.9422 to 0.9999) for Freundlich isotherms, fitted well to experimental data.

Furthermore, an aged refuse bioreactor (15 cm diameter and 80 cm height), was developed and used for livestock wastewater treatment at a loading rate of 4 L m^3/day and flow rate of 0.1 L/min. The reactor was very effective after over 10 hours retention time which resulted in high removal rates > 90% for COD, BOD_5, TSS, Turbidity, Colour, TP and total coliform, TDS = 62%, NH_3-N = 60% and TN = 46%. The effluent quality for most of the parameters meet the Malaysian effluent discharge standard B, while alternating aerobic and anaerobic systems were recommended in future development for enhanced nitrogen removal.

The Malaysian aged refuse has very significant characteristics such as adequate pore structure and surface characteristics, huge bacteria population, high porosity, high moisture and organic content, and has shown efficient adsorption and biodegradation processes in different livestock wastewater treatment. Moreover, it is a simple and affordable wastewater treatment technology, and therefore proposed for UPM dairy farm to experiment on a larger scale, for future development and application.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENJERAPAN DAN BIODEGRADASI BAHAN PENCEMAR DARI AIR SISA TERNAKAN MENGGUNAKAN BIOREAKTOR SISA BERUMUR

Oleh

ANIJIOFOR SANDRA CHINENYENWA

September 2018

Pengerusi : Nik Norsyahariati Nik Daud, PhD
Fakulti : Kejuruteraan

Kajian ini menyiasat ciri-ciri sisa pepejal yang ditanam, "sampah berumur", untuk proses penjerapan dan biodegradasi, sebagai pilihan rawatan air sisa ternakan yang mampu. Terkini, ladang tenusu UPM melepaskan kira-kira 2000-2200 L/hari air sisa yang tidak dirawat ke dalam sungai berdekatan. Ini menimbulkan kebimbangan yang serius terhadap alam sekitar, terutamanya dalam pencemaran air. Parameter yang dikaji ialah pH, permintaan oksigen kimia (COD), permintaan oksigen biologi (BOD), jumlah pepejal terampai (TSS), jumlah pepejal terlarut (TDS), kekeruhan, jumlah nitrogen (TN), ammonia nitrogen (NH_3-N) jumlah fosforus (TP) dan jumlah koliform. Tiga sumber air kumbahan ternakan (ladang tenusu, rumah penyembelihan ayam dan kolam ikan) telah dikaji, sementara sisa berumur telah diambil dari Tapak Pelupusan Sanitari Air Hitam, Selangor, Malaysia.

Keputusan menunjukkan ciri-ciri sisa berumur seperti pH 7.14, kandungan lembapan 29.5%, kandungan organik 9.90%, jumlah koliform 7.1 x 10^6 CFU/100 mL, yang merupakan keadaan yang sesuai untuk biodegradasi. Keberaliran hidraulik 0.31 cm/s, keliangan (n) 51%, dan ketumpatan pukal (ρ) 1.23 g/cm^3, adalah keadaan yang sesuai untuk aliran air bebas dan penyebaran udara. Kation tersedia yang boleh ditukar (Ca, Mg, K, Na), akan menggalakkan pertukaran ion manakala kepekatan logam rendah (Pb = 0.858, Cr = 14.0, Cu = 1.10 dan Zn = 12.16 mg/kg) akan mengurangkan gangguan. Mikroskop elektron pengimbasan (SEM), menunjukkan ruang liang sedia ada dan kawasan permukaan BET 3.376 m^2/g, yang sesuai untuk penjerapan, manakala Penjelmaan Fourier Inframerah (FTIR), menunjukkan kumpulan fungsian karbonil, karboksil, hidroksil dengan kapasiti penjerapan yang kuat.

Kajian penjerapan kumpulan menunjukkan kesan pH, dos dan masa sentuhan terhadap kecekapan penyingkiran, dan keadaan yang optimum adalah; pH 6, dos 2-4 g/100 mL, saiz penjerap ≤ 2 mm, masa sentuhan 10-180 minit, kelajuan goncang 250 rpm dan

pada suhu ambien. Kecekapan penyingkiran maksimum adalah sekitar 94% (COD, BOD), 91% (TSS, TDS), 97% warna dan 88% NH_3-N. Pekali korelasi R^2 (0.9026 hingga 0.9999) bagi Langmuir, dan (0.9422 hingga 0.9999) bagi isoterm Freundlich, sesuai dengan data eksperimen.

Seterusnya, bioreaktor sisa berumur (diameter 15 cm dan ketinggian 80 cm), telah dibina dan digunakan untuk merawat air sisa ternakan pada kadar pemuatan 4 L m^3/hari dan kadar aliran 0.1 L/min. Reaktor sangat berkesan selepas penahanan masa selama 10 jam dan menghasilkan kadar penyingkiran yang tinggi, iaitu > 90% untuk COD, BOD_5, TSS, kekeruhan, warna, TP dan jumlah koliform, TDS = 62%, NH_3-N = 60% dan TN = 46%. Kualiti efluen bagi kebanyakan parameter memenuhi piawaian pelepasan efluen Malaysia B, sementara itu, sistem aerobik dan anaerobik adalah disyorkan untuk pembangunan di masa hadapan bagi mempertingkatkan penyingkiran nitrogen.

Sisa berumur Malaysia mempunyai ciri-ciri yang sangat signifikan seperti struktur liang dan ciri-ciri permukaan yang mencukupi, populasi bakteria yang banyak, keliangan yang tinggi serta kelembapan dan kandungan organik yang tinggi telah menunjukkan proses penjerapan dan biodegradasi yang efisien dalam rawatan air sisa ternakan yang berbeza. Dan lagi, ia merupakan teknologi rawatan air sisa yang mudah dan mampu milik. Oleh kerana itu, kaedah ini dicadangkan untuk ladang ternakan UPM dalam skala yang besar untuk pembangunan dan aplikasi di masa hadapan.

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My family is my greatest source of strength and I thank you all for the bond of friendship we share. I love you all. Words cannot explain how indebted I am, may God reward you all abundantly for making this dream come true.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
AR	Aged Refuse
ARB	Aged Refuse Biofilter/Bioreactor
AHSL	Air Hitam Sanitary Landfill
FPW	Fishpond wastewater
SHW	Slaughterhouse wastewater
DFW	Dairy farm wastewater
TSS	Total suspended solids
LOI	Loss On Ignition
OM	Organic Matter
ADMI	American Dye Manufacturers Institute
TDS	Total dissolved solids
COD	Chemical oxygen demand
BOD	Biochemical oxygen demand
DO	Dissolved oxygen
TN	Total Nitrogen
TP	Total Phosphorous
NH_3-N	Ammonia Nitrogen
BET	Brunauer-Emmett-Teller
CEC	Cation Exchange Capacity
FTIR	Fourier transform infrared
ATR	Attenuated total reflectance
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NSWMD	National Solid Waste Management Department
MHLG	Ministry of Housing and Local Government
SEM	Scanning Electron Microscopy
EDX	Electron Dispersive X-ray
MEQR	Malaysian Environmental Quality Regulation
NWQS	National Water Quality Standards
APHA	American Public Health Association
ASTM	American Society for testing of Materials
ISO	International Standards Organization
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometry

ICP MS	Inductively Coupled Plasma Mass Spectrometry
GHG	Green House Gas
OECD	Organization for Economic Development
FAO	Food and Agricultural Organization
HLR	Hydraulic Loading Rate
NLR	Nitrogen Loading Rate
WWTP	Wastewater treatment plant
UNDP	United Nations Development Programme
GPS	Global Positioning System
CFU	Coliform Forming Unit

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background of Study

Due to the rising population rates in developing countries, numerous challenges are being faced to contain the threat in increased solid waste generation. As a fast-developing country, average solid waste generation rates for Malaysia ranges between 0.5-1.9 kg/cap/day, depending on the province, (United Nations Development Programme, 2008; Manaf et al., 2009). Meanwhile, landfilling is the cheapest form of solid waste disposal in Malaysia, and accounts for over 80% of municipal solid wastes disposal. However, the National Solid Waste Management Department, stated that 131 out of 296 existing landfills in Malaysia have been closed due to congestions and construction of new landfills is practically impossible due to large land required and high cost (MHLG, 2014). These problems have necessitated the on-going search for reuse of landfilled materials, which has benefitted the exploration of "Aged Refuse" (AR). Aged refuse are solid wastes deposited in the landfill, which decomposes and become stabilized over a period of placement, mainly after 8-10 years of placement, (Zhao et al., 2002; Wang and Zhao, 2004).

On the other hand, the 2011 annual report of the Organisation for Economic Cooperation and Development (OECD), in partnership with the Food and Agricultural Organisation (FAO) of the United Nations, stated that livestock prices will increase by 30% between 2011 and 2020 (OECD-FAO, 2011). As a result, Malaysia has experienced significant growth in the livestock industry due to the increasing demand for meat and other livestock products. However, such activities produce large volumes of highly polluted wastewater mostly organic, inorganic and nutrients. According to Mukhopadhyay et al., (2003) and Sarkar et al., (2006), livestock wastewater consists of faeces, urine and water used in washing animals and livestock farming. Thus, depending on the type of feed, the degree of processing and many other factors, livestock wastewater has high concentrations of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Oil and Grease, Total Phosphorous (TP), Total Nitrogen (TN), Ammonia Nitrogen (NH_3-N), Total Suspended Solids(TSS), Total Dissolved Solids (TDS), Colour and Microbial Population (MP).

Consequently, disposal of such highly polluted wastewater into the environment has become a fundamental environmental issue of enormous concern. Most chicken slaughterhouses are located within residential areas, and wastewater from such activities are disposed into sewerages without pre-treatment. Also, most farmhouses are in rural areas without adequate facilities to control wastewater produced from such activities. Therefore, water pollution from animal sources has continued to generate global concern, calling for stringent measures for livestock wastewater disposal, as most rural populations depend on groundwater sources for domestic use.

Furthermore, livestock wastewater treatment has been a growing challenge over the years because of the varying influent concentrations coupled with high discharge conditions for effluent. There are variety of options for wastewater treatment such as: chemical precipitation, coagulation/flocculation, aeration, filtration, ion exchange, electrochemical treatment, adsorption and biodegradation (Al-Shamrani et al., 2002; Rivas et al., 2003; Wang and Shao, 2004; Kurniawan et al., 2006; Babarinde et al., 2006; Gupta and Suhas, 2009; Bashir et al., 2013). Nonetheless, due to high operational and maintenance costs, excessive use of chemicals, reduced efficiency with time, large sludge production and complexity in the use of some of the methods, adsorption and biodegradation processes have become more efficient and preferred wastewater treatment methods.

Adsorption is a physiochemical process which occur at an interface between two phases (liquid-liquid, gas-liquid or liquid-solid), (Barakat, 2011). The main components of adsorption are surface characteristics and pore structure and adsorption equilibrium is a fundamental factor in designing adsorption operations (Ushakumary 2013). Moreover, the advantages of adsorption are numerous and include; low capital, simple design and operation, limited sludge, high effluent quality, favourable at wide range of pH and effective in removal of metals even at low concentrations (Devi et al., 2008; Ali et al., 2012, Gupta and Nayak, 2012; Ideriah et al., 2012; Foo et al., 2013). However, the efficiency in adsorption also lies on the development of cheap, affordable, abundant and environmentally friendly adsorbents.

Biodegradation is the process by which organic substances are broken down into smaller compounds by living microbial organisms (Marinescu et al., 2009). Numerous microorganisms, comprising fungi, bacteria and yeasts are involved in biodegradation process, which can be aerobically (with oxygen), or anaerobically (without oxygen). Some microorganisms have natural ability to degrade several organic pollutants due to their formation and can also adapt to unfavourable environments. However, their efficiency depends on many factors such as; chemical nature and the concentration of pollutants, their availability to microorganisms, and the physicochemical characteristics of the environment (El Fantroussi and Agathos, 2005).

Filtration on the other hand, is one of the oldest forms of water purification, which involves a solid-liquid separation process in which the liquid passes through a porous medium to remove suspended solids in the water. This removal of particles within a filter bed involves; transport of the suspended particles to the filter and attachment of particles to the surface (Yao et al., 1971). There are several filtration methods, however, the selection of the appropriate method is based on design.

The Aged Refuse Bioreactor (ARB) has the configuration of a trickling filter which supports bacterial growth, and allows the wastewater to seep down by the force of gravity. The ARBs developed earlier were rectangular or square shaped however, modern ARB's are cylindrical for easy water distribution which has been a major drawback of the former, and has a filter attached at the bottom so that the suspended

solids not trapped at the top of the column as the wastewater trickles down are further removed at the bottom by filtration.

Indeed, ARB advantages include; low investment and maintenance costs, simple construction and operational processes, low sludge production, high efficiency in pollutants removal, availability and environmentally safe. The effectiveness of the AR from regions within China have been reported (Zhao and Shao, 2004, Zhao et al., 2007; Sun et al., 2011; Xie et al., 2013; Wang et al., 2012), for leachate treatment, however, its application in livestock wastewater treatment is yet to be maximized.

1.2 Statement of Research Problems

The alarming rate of disposal of untreated livestock wastewater into community sewerages and flowing water, has become an enormous environmental issue. Slaughterhouses and dairy farms generate large volumes of highly concentrated wastewater which are discharged into water bodies or sewerage systems without pre-treatment, and results in blockages of wastewater pipes and reduced lifespan of such materials. Such practices are harmful to aquatic life, poses environmental problems and present challenges for the relevant authorities in sustaining the quality of surface water used for domestic activities as well as for recreational activities (WHO 2012).

Malaysia, does not practice a centralised livestock farming system and is faced with many challenges regarding livestock wastewater treatment. The Minister for Agriculture and Agro-based Industry, Datuk Seri Ismail Sabri Yaakob, noted that 80% of the 2,000 poultry slaughterhouses in Malaysia are not licensed with the Veterinary Services Department (VSD). The 1998/1999 outbreak of Nipah disease originating from pig farms, placed numerous restrictions on pig farming in certain areas, regulated by Veterinary Services (Mohd-Nor et al., 2000). Most disease outbreaks and epidemics experienced in developing countries result from the effects of surface and groundwater pollution, especially from livestock wastewater sources. The principal inorganic compounds found in livestock wastewater are nitrates, nitrogen and ammonium nitrogen which are incredibly harmful to human health. Therefore, strategies for economically viable and affordable treatment processes for such wastewaters must be developed and put into practice.

Conventional livestock treatment methods are becoming obsolete due to variations in composition and volume of different livestock wastewater, coupled with high operational and maintenance costs, complexity in application which has limited their usage. Interestingly, the use of the ARB could be a better alternative as notably been focussed on landfill leachate treatment as shown in the extensive data available in literature (Zhao et al., 2002; Wang and Zhao 2004; Xie et al., 2012; Sun et al., 2011) but, its application in livestock wastewater treatment is insufficient and limited. Moreover, due to the varying characteristics of solid waste generated from region to

region, there is a need to investigate the Malaysian AR for adsorption and biodegradation characteristics for application in livestock wastewater treatment.

Previous lab scale investigations on the applicability of the aged refuse bioreactor for leachate treatment in Malaysia faced numerous challenges. Abu Mansor (2013) used a square shaped aged refuse bioreactor of dimensions (40cm x 40 cm x 60 cm) for landfill leachate treatment and recorded low pollutant removal rates of only 33-49% COD, 25-48% BOD, 31-48% TSS and 39-67% TDS. Also, Nik Daud and Misban (2015), recorded only 45% NH_3-N removal from landfill leachate and the reactor experienced clogging and fouling problems which deteriorated effluent quality as a result of the size of the AR used. The following drawbacks were summarized from previous studies involving the use of ARB in Malaysia; (i) parameters investigated were insufficient to adequately assess its efficiency (ii) no attached filtration device at the bottom (iii) poor water distribution due to square shape in (Abu Mansor 2013) (iv) insufficient retention times due to low AR height (v) clogging and fouling problems (vi) inadequate characterization of the AR to streamline its applicability.

Therefore, this study focuses on addressing some of the drawbacks and development of a modified AR bioreactor for enhanced pollutants removal. Therefore, a novel material characterization of Malaysian AR is intended in this study, for detailed characteristics such as pH, porosity, density, hydraulic conductivity, organic content, moisture content, bacteria population (total coliform), functional groups FTIR, cation exchange capacity CEC, exchangeable cations, carbon content, heavy metals presence, surface morphology SEM and EDX and surface characteristics, which are ideal requirements for adsorption and biodegradation. Furthermore, a modified lab-scale AR reactor would be developed and constructed taking into consideration suggestions for improvement and further works by Abu Mansor, (2013). The ARB will be investigated for effectiveness in livestock wastewater treatment as a novel study, and is intended to cover a wider range of pollutants such as organic pollutants (COD, BOD), inorganic pollutants (TSS, TDS, Turbidity, Color), nutrients (NH_3-N, TN, TP) and microbes. Also, this wide range of pollutants covered in the treatment design will comprise three different livestock farms (Fish farm, Dairy farm and Chicken Slaughterhouse), for effective exploration of variations in different livestock wastewater.

Consequently, this study differs from previous studies particularly explored in China using different AR biofilters, and mostly centred on landfill leachate treatment. No investigations on batch adsorption study to determine adsorption effects of the AR, or AR bioreactor experiments on livestock wastewater, notably the fishpond and chicken slaughterhouse wastewater has been previously studied anywhere to my knowledge. Moreover, it is important to consider variations in different livestock wastewater in the design of such treatment plants for enhanced efficiency. Secondly, the material characterization aspect of this study, with regards to the Malaysian landfilled AR is a novel study which covers extensive research properties of the material. No detailed research work on AR characterization has been categorically carried out in Malaysia.

This characterization is very important in promoting potentials for future development of the AR bioreactor and also to initiate possibilities for bioreactor landfills.

In addition, the specific research problem in this study is the discharge of large volumes of untreated livestock wastewater from the UPM livestock farm (Ladang 16), of the Faculty of Agriculture, Universiti Putra Malaysia into a flowing river source close to the farm. The study will also carry out investigations on the level of contamination of the river. Consequently, the development of this technology will provide an alternative and affordable wastewater treatment option for the farm and ensure safe wastewater discharge into the environment.

1.3 Aim and Objectives

This research is aimed at providing economic and affordable treatment alternative for livestock wastewater through the development of an aged refuse bioreactor. The study involved two major technological practices in wastewater treatment; adsorption and biodegradation. The first step involved batch adsorption study to determine the correlation between adsorption isotherms using aged refuse as adsorbents, while the second step involved the use of a laboratory scale aged refuse bioreactor for livestock wastewater treatment.

The specific objectives are;

1) To determine the varying influent composition of different livestock wastewater from three selected sources (dairy farm, fish farm and chicken slaughterhouse), over a period of time in terms of pH, TSS, TDS, colour, turbidity, BOD, COD, TN, NH_3-N, TP and total coliform.
2) To evaluate AR characteristics such as physical (moisture content, bulk density and porosity), chemical (pH, organic content, CNS, CEC, heavy metals, BET, FTIR, zeta potential), biological (total coliform), mechanical (hydraulic conductivity) and structural (SEM and EDX).
3) To carry out batch sorption studies, determine the effects of pH, AR dosage and contact time on pollutants removal efficiency and model experimental data into Freundlich and Langmuir isotherm models.
4) To develop a lab-scale aged refuse bioreactor for livestock wastewater treatment and assess the quality of effluent in terms of pH, TSS, TDS, colour, turbidity, BOD, COD, TN, NH_3-N, TP and total coliform.

1.4 Scope of the Study

This work focused on adsorption and biodegradation techniques for livestock wastewater treatment using AR as media. This involved a sorption study using the AR as media for the adsorption of pollutants, and also, the use of a laboratory scale modified AR bioreactor for column treatment.

The livestock wastewater was sampled from three livestock sources; the UPM livestock farm (Ladang 16), the UPM Fish farm (Ladang 10), both located within the UPM, and a chicken slaughter house located at Bukit Serdang, a suburb close to the university. The AR was obtained from the Air Hitam Sanitary Landfill in Selangor which has been closed for 10 years.

The investigations carried out for the wastewater were; Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Hydrogen ion concentration (pH), Temperature, Colour, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Turbidity, Total Nitrogen (TN), Total Phosphorus (TP), Ammonia Nitrogen (NH_3-N), and microbial population, while oil and grease was analysed for chicken slaughterhouse wastewater only.

For the AR, investigations carried out were; moisture content, pH, bulk density (ρ), porosity (n), organic content, Cation Exchange Capacity (CEC) and exchangeable cations, Brunauer-Emmett-Teller (BET) specific surface area (SSA), hydraulic conductivity, Carbon-Nitrogen-Sulphur (CNS), elemental analysis (Zn, Cu, Cd, Pb, and Cr), microbial population, as well as surface morphology (SEM/EDX), functional groups (FTIR) and zeta potential.

For the adsorption studies, the influence of various parameters such as; pH, adsorbent dosage and contact time were investigated at different time intervals. The river source point of discharge for the dairy farm was also investigated for pollutant load concentration. Graphical analysis using Excel workbook, linear regression analysis, adsorption isotherms and models (Freundlich and Langmuir) only, were used to analyse, compare and validate experimental data.

1.5 Thesis Structure

This thesis is structured in five chapters.

The First chapter covers general introduction which includes major issues in areas of solid waste management, landfill management, wastewater treatment and management. It highlights the need for the study through an in-depth problem

statement which justifies the study. Furthermore, the aim and the specific objectives were clearly defined while the scope and limitations were also precisely stated.

Chapter Two covers a comprehensive analysis of solid waste generation, collection, disposal and management issues as a bedrock for the future of the AR technology. Secondly, landfill issues and concerns as it affects landfill congestions and closure were highlighted in the light of available literature. Also, livestock wastewater generation and subsequent disposal in relation to available technologies for treatment was extensively discussed. Although available literature for the treatment of livestock wastewater using the AR is very limited, appraisal of a lot of successful studies on its usage for leachate treatment provided the literature for discussions on the subject.

Chapter Three covers the methods, materials, sampling procedure which formed the investigational techniques. The sampling procedure for both AR and livestock wastewater and also all experimental procedure for AR characterization, livestock wastewater composition, adsorption and bio-filtration processes are all discussed in this chapter.

Chapter Four presents a detailed analysis of the results of the experiments and investigations carried out as detailed in Chapter Three. This includes the results of livestock wastewater composition and AR characterization, results on the effect of operating parameters on removal efficiencies, graphical representations of the isotherms for Langmuir and Freundlich models and a presentation of the results from the bio-filtration experiment. It also covers results from sampling of the river source for the dairy farm wastewater discharge.

Chapter Five summarizes all the results obtained with very detailed conclusions and gives apt recommendations for actual practice and specific areas for further research.

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