# Domestic Bio-digester Feedstock Water-Content Optimization

# Table of Contents





# CHAPTER I: INTRODUCTION

## 1.1 Background

The world population will be likely to increase by 2.5 billion over the next 40 years, passing from the current 6.7 billion to 9.2 billion in 2050 (United Nations, 2007). Energy is one of the most important factors to global prosperity. The global mix of fuels comes from fossil (78%), renewable (18%) and nuclear (4%) energy sources. The dependence on fossil fuels as primary energy source has led to global climate change, environmental degradation, and human health problems. Moreover, the recent rise in oil and natural gas prices may derive the current economy toward alternative energy sources such as biogas (Sunarso et al., 2012).

The municipal solid waste (MSW) is treated differently in different parts of the world. The waste is naturally degraded in unstandardized landfills, burnt the waste in dump sites and through controlled aerobic and anaerobic digestion process. The first two processes are widely in operation in developing countries and large volume of methane and carbon dioxide is released into the atmosphere. The release of these gases into the atmosphere becomes very harmful for the environment (Jingura & Matengaifa, 2009). The natural degradation of the organic matter is causing smell and spreading of diseases in the surroundings. Natural biodegradation of organic matters contributes approximately 590-800 million tons of methane in the atmosphere. Waste water and landfills constitute 90% of waste sector emissions and about 18% of global anthropogenic methane (CH4) emissions (Bogner et al., 2008). The methane (CH4) which has high potential of global warming either can be taped or freely released into the atmosphere. The latter situation take place when the organic matters are illegal disposed of or thrown away in the vacant places. The taped methane (Biogas) is used as a source of energy while un-taped methane is very harmful for the environment. Dheenbandhu and Nepali design (GCC 2047) design was introduced and being practiced in Pakistan. These designs are also widely used and are successful because of less leakage and high gas yield (Ghimire, 2007b). The installed biogas plants are small in scale with varying capacity of 5-15 m3 biogas production per day (Ghimire, 2007a). Organic waste which is a good substrate for biogas production is absent in Pakistan. The installed biogas plants in Pakistan are fed by animal dung with the same amount of water. These small-scale biogas plants are designed to meet the energy demand at household level. Beside these small-scale plants, only 2 medium size 20 and 35 m3 plants Nepali design GCC 2047 have been installed in Dera-Ismail Khan by the Rural Support Programme Network with the financial help of Foundation for Integrated Development Action (Ghimire, 2007b). Theoretically all organic matters can be used for biogas production (Bond & Templeton, 2011). But practically animal manure, municipal solid waste, industrial waste water, crop residues and energy crops are the substrates which are normally used for biogas production across the world. These substrates can be solid, slurry, and the mixture of both. However, some of the organic materials are preferred more than others because of their easy degradability, economical suitability, high gas yield and technological (FAO, 1997). Animal manure is the most common substrate used for biogas production. Manure is a combination of animal faeces, urine, feed waste and bedding in the yards. So, the composition of manure is different depending on yard management (AgSTAR, 2012). Municipal Solid Waste (MSW) is a potential substrate for anaerobic digestion mainly consists on household waste, restaurants and hotel waste, fruits and vegetable market waste etc. Due to increase biogas yield and resource efficiency of biogas plant, in Europe there is also a growing interest to cultivate energy crops like sugar, beet and barley (Bond & Templeton, 2011).



## 1.2 Energy conservation in developed and developing nations

Energy conservation and security has become a global concern these days in both the developing and developed nations  (Sorrell, 2015). With the exploding global population in most parts of the world, the major focus has been to first provide a sustainable means of meeting the growing energy demand of any society, and then devising technologies that are cleaner, cheaper, and more socially acceptable from a novel or existing list of energy alternatives. This development in the energy technology of any nation is greatly linked to its economic status and social standing (Howley et al., 2015, p. 4).

It is estimated that some 60 percent of the world's population live in rural areas of developing countries and rely on agriculture for their livelihood. About one billion people rely on residue as their principal cooking fuel. In many areas, particularly in Asia, the commercialization of bio-residues is a source of modest income but at the same time it is a burden for poor people. Very often the utilization of bio-residue is associated with a very low efficiency and therefore a higher level of smoke emissions and a negative impact on health.

In remote areas of the developing countries, petroleum products are not easily available and even when they are available, they are not affordable to poor people who are the main users of wood-fuels. On the other hand, wood burning in an in-efficient traditional stove built by the households themselves emits harmful gas like carbon monoxide (CO) which is hazardous for health of estate women. It leads to Acute Respiratory Infections (ARI) and Chronic Obstructive Lung Diseases (COLD). Women, not only do they suffer physically, but their expenditure on health increases due to illness. The conversion of bio-waste to more dense form such as briquettes increases the efficiency and, if the process is well managed, it can lead to the introduction of technical change and the development of small enterprises in low-income areas.

Another aspect of various global sustainability plans and policies that has raised a lot of concerns in recent years has is the energy conservation and security. With the exploding global population in most parts of the world; the major focus has been to first provide a sustainable means of meeting the growing energy demand of any society, and then devising technologies that are cleaner, cheaper, and more socially acceptable from a novel or existing list of energy alternatives. This development in the energy technology of any nation is greatly linked to its economic status and social standing (Howley et al., 2015, p. 4).



With petroleum-based fuel prices at record highs and growing public interest in environmentally conscious products, alternative fuel sources are receiving more attention than ever. Universities, private and public corporations, and government agencies are spending millions of dollars each year to further research towards production of effective and feasible alternative fuels that are renewable, clean burning, and more economical to produce compared to the long-established fossil fuels. One alternative fuel that has been received with great success in Europe and Asia, and is showing increased interest in the United States, is biomethane (biogas). Biogas has been evaluated as one of the most energy-efficient and environmentally beneficial technologies for bio energy production (Fehrenbach, 2007).
However, its applicability in the developed and developing nations vary which is examined as follows:

### 1.2.1 Developed country scenario- Ireland

The population of Ireland by 2011 was 4.593 million persons, while the gross domestic product of Ireland by 2014 was €189,046 million, growing by 5.2% in 2014.

Primary energy demand for that period fell by 0.5% to 13.3 Mtoe, while energy-related $CO_2$ emissions decreased by 1.2% to 37 Mt. The consumption of all forms of fossil fuels fell in 2014, except for peat, renewables, and non-renewable wastes. Ireland's import dependency decreased to 85% in 2014 (from 89% in 2013) (Howley et al., 2015, p. 4). The cost of all energy imports to Ireland was approximately €5.7 billion, down from €6.5 billion (revised) in 2013 due mainly to falling oil and, to a lesser extent, gas import prices. Final consumption of electricity was almost static at 24 TWh with a 0.7% reduction in the fuel inputs, after taking a peak in 2008 to return to the 2004 level (Howley et al., 2015, p. 4). Renewable electricity generation, consisting of wind, hydro, landfill gas, biomass and biogas, accounted for 22.7% of gross electricity consumption. The use of renewables in electricity generation in 2014 reduced $CO_2$ emissions by 2.6 Mt and avoided €255 million in fossil fuel imports. Overall primary energy use fell by 0.5% in 2014 (Howley et al., 2015, p. 5).

Consumption of all fuels fell in 2014 except for peat, renewables, and non-renewable wastes. Coal use fell by 4.6% and its share fell back to 9.5% in 2014 from 9.9% in 2013. Oil continues to be the dominant energy source and had a 47% share in 2014 – the same as in 1990. Natural gas use fell in 2014 by 3.1% to 3,721 ktoe and its share of TPER was 28% (Howley et al., 2015, p. 8). Total renewable energy increased by 13.3% during 2014 to 1,021 ktoe. All forms of renewable energy experienced growth, with hydro, wind, and biomass growing by 18.2%, 13.2%, and 13.9% respectively. The overall share of renewable in primary energy stood at 7.7% in 2014.



Over the period 1990 to 2014 primary energy per capita increased by 6.3% to 33 MWh, while energy-related $CO_2$ emissions per capita fell by 10.7% to 8.0 tons. This reflects the switch from the use of solid fuels to oil, gas, and renewable energy (Howley et al., 2015, p. 9). This advancement in the sustainability and capacity in Ireland's energy generation, however commendable is still short on the projected rise in demand that would occur in the next three decades. As the energy demand continues in a steady, however minute, increment; there would be a great need to develop an energy strategy that would support a greater contribution from the renewable energies, and policies that support research and development geared at the optimization of the existing technology (Kamat, 2007, p. 2834-2860).

## 1.2.2 Developing country scenario- Pakistan

Pakistan is one of those many countries in the world where biogas technology was initiated many years ago, but has not yet been widely and successfully adopted. Biogas plant development history goes back 54 years ago when the first biogas plant was initiated. The conventional use of animal dung in the form of dung cake as a source of energy for cooking and lighting has been practiced for a long time in the villages of Pakistan. This mode of energy was not limited only in rural areas, but it was the major source in the urban areas until the natural gas was discover in Pakistan. Based on biomass resource availability from livestock and crop residues for biogas production, the country has a potential to install 5 million biogas digesters. Until 2006, only six thousand small scale biogas plants are being installed (Ghimire, 2007b). The use of biomass resource in Pakistan is not very efficient for energy purposes and potential is wasted because of non-scientific conventional technologies (Sahir & Qureshi, 2008). Contrary to this, in China and India 6.8 million household and 1000 medium and big size biogas plants were installed by the end of 2007 (Amjid et al., 2011). Compared to these 1000 biogas plants in China and India, Pakistan Council for Renewable Energy Technology installed only 3 community based and one big thermophilic plant, but none of them is working (Amjid et al., 2011).



Rural Support Programme Network (RSPN) success story in Pakistan in the biogas plant field is due to appropriate policies and practical knowledge of biogas technology. More than 250 technically trained masons were used to build biogas plants. RSPN has as a future policy to achieve carbon credits under CDM by installing 300,000 biogas plants in the country. Biogas plants help to reduce the use of firewood for cooking, which further assists to reduce CO2 emission and deforestation. Rural Support Programme Network (RSPN) vision is highly appreciable in the reduction of GHG emissions and to fulfil the energy demand through renewable energy source. But probably this will get very low positive assistance from carbon credit scheme because the prices of per ton CO2 emissions are gradually going down and especially in the future when RSPN will achieve it Pakistan Dairy Development Company (PDDC) installed some biogas plants in 2009 and received very overwhelming public response. Due to this positive public response PDDC increased their number of biogas units from 450 to 556 (Amjid et al., 2011). The aim of PDDC is to provide low cost energy to the rural people by providing 50% subsidies to each unit. Similarly, with the help of New Zealand Aid the Alternative Energy Development Board (AEDB), installed biogas units in

Karachi with the aim to produce 250KW electricity by using the manure of 400,000 cattle of the area (Sheikh, 2010).

So far, Lahore compost plant is the only one plant in Pakistan which recycles only 20% of the total Lahore collected municipal solid waste into organic rich fertilizer without recovering the energy.

## 1.3 Problem statement

The bio-digester technology, as applied on a household scale, is a sustainable alternative renewable energy form, which has relatively high sustainability and profitability ratings, as well as a growing potential market; considering all the advantages it presents with respect to energy recovery, high-grade fertilizer production for agricultural application and nutrient cycle locking, and very importantly wastes management. However, a critical examination of the technology involved, and its economic and environmental impact, with respect to the cost of installation and maintenance, and the bio digester water consumption and $CO_2$ generation would reveal the subtle truth that even this renewable energy technology as viable as it might appear has set backs in its present design that must be addressed, through research based optimization of the various components and parameters involved (Hu & Wang, 2010, p. 247-252). In the developed nation scenario, there are lot of researches which examined the potential of biogas and have even used several techniques to optimise the production of biogas. In Ireland, it is deemed that there are several techniques used at biodigester plants to improve the production of biogas. However, the case of developing nations is quite different. Pakistan which is a developing nation is striving to achieve advantage through the recycling of animal dung and other livestock manure to produce biogas but the generated amount is not utilised properly. Furthermore, with the growing population in the nation, there is a need to improve the potentials of the biodigester plants in the nation to satiate the energy needs of the nation.



It is deemed that the production of biomethane in biogas plants can be improved through the optimisation of feedstock water content. According to Demirbas et al. (2009), Nizami et al. (2009) and (Rafique et al., 2010), it is discerned that slurries that develop due to excess content of water in the digester tend to lower the methanogenic capacities of the digester which makes the biogas plants less economically viable. Furthermore, large watery wastes also require huge reactors ; furthermore, the parasitic demand increases due to the necessity to increase the temperature of this water. In this regard, it has become common that feedstock were imported and used (Tsegaye, 2016). As the potential of feedstock water optimisation is identified to have better benefits on the performance of the biodigesters, biodigester plants in Ireland have been utilising the methods of feedstock water optimisation to reduce water and improve the performance. However, no studies till date have recorded the benefits of feedstock water optimisation in Ireland which became the premise for the present research. However, understanding the benefits in the Irish scenario does not provide ample benefits for the developing nation. In this regard, the research also attempts to examine the ways of improving biodigester performance in the developing nation context (Pakistan selected for the research) wherein the benefits of Domestic Bio-digester Feedstock Water-Content Optimization will be elucidated.

## 1.4 Research questions

In this research, the following research questions are examined:

- What is the relationship between the water content of the bio digester feedstock and the energy and volumetric efficiency of the domestic bio digesters for application in Ireland?
- What is the optimal bio-digester feedstock water content that would result the optimal domestic biogas production for a specific feedstock?
- Can a framework be developed from the results of Domestic Bio-digester Feedstock Water-Content Optimization in Ireland to a developing nation (Pakistan)?



## 1.5 Research aim and objectives

The present research aims at examining the benefits of domestic bio-digester feedstock water content optimisation for biodigester plants in Ireland wherein the findings of the research will be used to provide technical benchmarks towards enhancing the performance of biodigester plants in Pakistan. In this regard, the following objectives are framed

- To determine the relationship between the water content of the bio digester feedstock and the energy and volumetric efficiency of the domestic bio digesters for application in Ireland

- To determine the optimal bio-digester feedstock water content that would result the optimal domestic biogas production for a specific feedstock.
- To develop a framework for optimal domestic biogas production in a developing nation considering the findings in the Irish context

## 1.6 Scope and significance

The scope of this investigation is that it has been confined to the collection and analysis of data on biogas production from small-scale bio-digester plants in Ireland, which might not have been designed and constructed with the optimal experimental requirements. This limitation produces a tendency for analytic and systematic error. There is also the challenge of disparity in the feedstock composition across bio-digester facilities. Although this challenge is outside the focus of this study, it is significant to the study of the optimal feedstock water contents of an anaerobic bio digester. The significance of this research lies in upgrading the existing knowledge and improvement of this energy technology for the domestic purposes because this alternative source of energy offers environmental, economic, energy conservation, and provides sustainable development. Though the study is limited within the Irish context, the findings of the study are applied to recommend strategies for the optimal operation of biodigester plants in developing nation context (Pakistan). Such strategies will have a broad scope of applicability in other developing nations as well.



## 1.7 Chapters scheme

The chapter structure of this research is as follows:

**Chapter I-** Introduction is the first chapter in which elaborate details on the present topic are covered. In this chapter, background, problem statement, research questions, research aim and objectives, and scope and significance of the study are explained.

**Chapter II-** Literature Review is the second chapter in which the previous studies that are pertinent to the present research are described in detail. In this chapter, description of concepts and definitions pertaining to the present research, microbiology of AD, solid content, number of stages, current technology, types of anaerobic reactor, energy management policy compliance in Ireland, Greenhouse gas emission in Ireland, potential of AD cooperative in Ireland, and process improvement are explained. This chapter ends with research gap.

**Chapter III-** Research Methodology is the third chapter. The type of research methodology employed in the present research is described.

**Chapter IV-** Analysis is the fourth chapter. This chapter displays the analysed data wherein interpretations for the analysed data are provided.

**Chapter V-** Discussion and conclusion is the fourth chapter. A discussion on the outcomes of the present study is performed. Moreover, the conclusion is drawn out of the discussion. Further, this chapter also elucidates the prospect of the future research.

# CHAPTER II: LITERATURE REVIEW

## 2.1 Introduction

Biofuel is now identified to be the renewable energy's perfect alternative source (Energy.Gov, 2017). The production of biofuels of 1st generation is with several edible products like soybean and corn. Such variants of feedstock of biomass have now led to the debate about fuel vs. food and, as the inference; biofuels of 2nd generation are developed. The biomass feedstock of 2nd generation will show much variability upon the physical properties it has (example, moisture contents and more ash) than biomass of 1st generation. The variation of such physical properties have highly significant effect upon the expenses for delivering biomass feedstock towards reactor throat that is referred as the delivered cost (Langholtz et al., 2016). The delivered cost consists of the transportation cost, production expense, operations, storage, preprocessing, handling, and harvest. Specifically, the expenses of production has the feedstock expense that accounts to 40% to 60% of total operating cost inside the conversion facilities (Caputo et al., 2005; Leistritz et al., 2007).



Feedstock conditioning provides important potential towards process optimization, and improves the rates of digestion and yields from biogas (Mezes et al., 2017). Within such context, the current chapter aims at exploring the earlier literature and its output which were connected with the Domestic Bio-digester Feedstock Optimization for increasing the biogas yield. For such purpose, definitions and concepts which were connected the current were briefed during the 1st section which has the anaerobic digester process that follows will also be briefed. In addition, this research makes an analysis of the kinds of AD and bio- digester's significant parameters would be briefed. The AD technology's current condition and its importance in Ireland region were found through the literature reviews. The research connected with AD optimization would be reviewed through the classification of thermal, chemical and physical optimization. Through such studies the gap can be found out.

## 2.2 Concepts and definition

### 2.2.1 Bio gas

Biogas is a renewable source of energy which is produced in the bioreactor through anaerobic digestion process by using waste as feedstock. The waste includes municipal solid waste, industrial waste water, animal excreta and agricultural waste used for biogas production. Bond and Templeton (2011) illustrate that biogas is a comprehensive approach to get rid of from organic waste and producing energy through anaerobic digestion process which makes it a sustainable source of energy. Even though, in some cases biogas is preferred because of resource efficiency over other renewable energy sources like bioethanol and biodiesel as mitigation of GHG emissions (Borjesson & Mattiasson, 2008). Typically, biogas contains 50-70% methane and 30-50% carbon dioxide and small amount of other gases. It has a calorific value of 21-24 MJ/m3 Bond and Templeton (2011).

Biogas actually implies to the production of methane rich gas produced through organic matter's fermentation within the anaerobic environment. CH4 or Methane through biomass can be very popular for the greenhouse effect when it naturally comes through the wetlands, swaps and forest fires, and guts of ruminant animals, rice paddies and landfills (Jaber & Noguchi, 2007). Biogas that generally refers to the gas through the units of anaerobic digestion, will be the assuring ways of addressing the energy demands of the world and offers several environmental merits (Cuellar & Webber, 2008; Tambone et al., 2010; Rehl & Müller, 2011; Qi et al., 2005; Jiang et al., 2011). Its instances is the estimation of EU policy, which at least is deriving 25% of entire bio-energy through biogas (Holm-Nielsen et al., 2009); in Italy, the electric current of 3405 GWh will be produced through biogas during 2011 (Bacenetti et al., 2013); in Germany, almost 4000 agricultural units for biogas production worked in their farms during the last of 2008 that can be beneficial for the environment of the farmer living (Weiland, 2010); in China, biogas plants worth 26.5 million was constructed during 2007 having the 10.5 billion m3 output, and this further grew up to 248 billion m3 (per year) during 2010 (Deng et al., 2014). In addition, at the view of socio-economic point, biogas will not just important lowers the expenses to treat its waste (Holm-Nielsen et al., 2009) while having a very less feedstock expenses. Based on biogas having higher sale cost when compared to petrol and diesel. Such instances show that utilization of biogas will be broader like renewable source (Mao et al., 2015).



Biogas is a biologically-produced, renewable fuel that can be used for any combustion process that utilizes methane as a fuel source, such as heat, transportation, electricity, and Combined Heat and Power (CHP) generation (Den, 2016). Biogas can also be scrubbed and upgraded to meet pipeline gas quality standards for transmission. Biogas is comprised of methane, carbon dioxide, hydrogen sulphide and other trace gases, and is generated by biological anaerobic digestion of organic compounds and materials, such as agricultural wastes, including animal and crop wastes, food wastes, energy crops, industrial wastes, and municipal wastes. With the success of biogas as a fuel source in Europe and Asia, and the prospective future of biogas as a fuel source in the United States, research studies were performed to evaluate anaerobic digester operations from an alternative fuels production standpoint (Achinas et al., 2017). The scope of these research studies was to operate suspended growth, Continuous Stirred Tank Reactor (CSTR) anaerobic digesters at the bench-scale level to evaluate improved operation techniques/methods and develop biokinetic relationships (Stover, 2011). Multiple digester reactors were operated simultaneously for approximately fourteen months to obtain data that were used to develop improved operational processes and biokinetic relationships, along with evaluation of treatment performance under various operating conditions (Stover, 2011).

### 2.2.2 Anaerobic Digestion

Anaerobic digestion is the process and technique of decomposition of organic matter by a microbial process in an oxygen-free environment (FAO, 1997). Controlled anaerobic digestion of organic wastes has multiple benefits. On one hand, it provides a renewable source of clean energy, while on the other side the digestates can be used as organic fertilizers in the agriculture sector. The electricity and fuel production from the biogas might strengthen the national energy supply, as well as reduce Greenhouse Gases (GHG) emissions (Yadvika et al., 2004). AD is a biological process which involves the organic matter's decomposition that is microorganisms triggered when there is no oxygen and is highly suitable for treating the biodegradable food waste, C&I waste and MSW (Appels et al., 2011). This attractive approach that the biodegradable waste treatment has owing to the renewable energy or biogas generation (Mata-Alvarez et al., 2000) and the solid outputs / digestate or marketable liquid production actually utilized like the fertilizer for crop and agricultural production (Rigby & Smith, 2014; Angelonidi & Smith, 2015a)



AD or Anaerobic digestion processes would help in the usage of organic wastes like farm and food waste through the bio fertilizer and energy generation (Angelidaki et al., 2009). AD or Anaerobic digestion comprises of various processes that are microbiologically mediated (Kjerstadius, 2017). During Anaerobic digestion processes, breaking down of metabolic bacteria as the organic matter as very simple chemical compounds like H2S, NH3, CO2, and CH4 sans the oxygen (Batstone et al., 2001). Prior to digestion, the organic matter goes through the pretreatment that has undesirable materials' removal, the water addition, and mixture for forming slurry. The AD's byproducts were digestate and biogas (Drosg et al., 2015; Oreggioni et al., 2017). AD or Anaerobic digestion is performed like the batch or continuous process based on the digestion of biomass and configuration of the digester (Schnurer & Jarvis, 2010). For this process of continuous digestion, constant additions of biomass in phases of the digester at an interval when there is constant removal of the end products. It helps in the constant production of biogas (Matheri et al., 2017a).

**2.2.3 Feedstock**

Feedstocks for the production of biogas might be slurries, solid, and both dilute and concentrated liquids. Also, biogas can also be prepared through the organic material's left by the production of biodiesel and ethanol. An array of feed stocks that are a potential waste would be very wider such as: sugar production, municipal wastewater, breweries, dairy manure, residual sludge, potato processing, food waste, seafood processing wastewater, yard wastes, and municipal solid wastes. Food processing wastewaters may come from citrus processing, dairy processing, vegetable canning, food processing wastewater, aquaculture wastewater and poultry manure (IFAS, 2017).

**2.2.4 Bio- digester/ Anaerobic Digester (AD)**

Anaerobic Digester is the highly utilized method to treat the organic sludges that would result from the wastewaters through the biological treatment using the processes of activated sludge. For such process, the treatment of the organic sludge during the oxygen's absence for lowering both the sludge's odor and the amount that breaks down its organic matter. The residual sludge is loaded with organic matter and nutrients that can enhance the applications of soil conditions like the soil supplements (Oilgae, 2017). The conversion of Anaerobic digesters as the energy that are stored within the organic materials found in manure as biogas. It is possible to feed biogas directly inside the combustion turbine that is gas-fired. The turbine type usually utilized for the electricity production at a small scale will be the micro turbine. Combusting the biogas changes the storage of energy stored within the molecular bonds in methane that has the biogas as the mechanical energy while it is spinning the turbine. The production of mechanical energy through biogas combustion inside the micro turbine or engine that is spinning the turbine for producing the electricity or electrons' stream (Oilgae, 2017).

### 2.2.5 Domestic Bio-digester

The conversion of domestic biodigesters using biomass is through various sources (agricultural residue, pig manure, cattle) as combustible bio-slurry and biogas that might be utilized like organic fertilizer (E-MFP, 2014). DBDs or Domestic biogas digesters were effectively implemented across the globe, and institutions and governments became much involved using construction, maintenance, operation, design, planning, and subsidy schemes inside the biogas plants (Bond & Templeton, 2011). Various nations inside Africa and Asia, specifically Tanzania, Rwanda, Vietnam, Bangladesh, Nepal, India, Kenya, Cambodia, and China, also held huge campaigns for promoting biogas technology (Kossmann et al., 1999; Cheng et al., 2014).

## 2.3 Bio- digester: Technical overview

Several definitions of sustainable development have been put forth but the following is very common one 'the development that meets present generation needs without compromising on future generation needs' (Dincer, 2000). Environmental compatibility is a crucial asset of renewable energy. In line with other renewable resources waste to energy technology like biogas will become an attractive alternative of energy in near future (Kothari et al., 2010).



### 2.3.1 Digester Types

Generally solid waste's anaerobic reactors might be divided as varied types, usually based on the feeding mode (batch mode and continuous mode: two stages and single stage) and the content's moisture or complete substrate's solid (dry or wet digestion). Based on the temperature of digestion process (thermophilic or mesophilic) and the reactors' shape (horizontal or vertical). The array of systems was developed for treating anaerobic MSW. It will be split as varied categories given by:

### A. Wet and Dry anaerobic digestion

During wet AD processes, slurried feedstock for adding of water, the concentration of solid matter is mid to low (generally, TS: <15%), and fully digesters with mixing tank were utilized (WCEAD 2015). During dry AD processes, higher is the solid matter concentration (TS 20– 40%) and fully batch reactors, plug-flow and mixed were used (Tchobanoglous et al., 1993; Abbassi-Guendouz et al., 2012). Every system has their own specific constraints and benefits.

The 2 AD technologies systems having dry digestion towards the biomass' solid digestion; the content of DM is its substrate having higher than 15% (generally from 20% - 40%). The liquid digestion's wet digestion; the DM content's average about the substrate is lower than 15%. The application of wet digestion with biomass such as liquid animal manure and sewage sludge when application of dry digestion towards restaurant organic waste, household, agriculture waste, and municipal organic waste (Al Seadi et al., 2008; Rapport et al., 2008; Matheri et al., 2017b).

The research by Angelonidi and Smith (2015) reveals that wet AD plants have highly positive economic performance and energy balance when comparison with dry AD plants. But, providing dry AD plants about varied significant benefits, like better flexibility of feedstock type that is accepted, times with lesser retention, lower water usage and management of highly flexible, and marketing chances, and end-product. Totally, wet AD plants are highly cost effective for the waste treated and its specific capital cost and biogas produced per m3; they will have higher biogas productivity when compared dry AD plants. Adversely, there were specific economic merits offered through the dry AD processes which might not be considered for such assessment, related to the expenses based on the collection system, restricting the for extra infrastructure with treatment and the end-product's marketing. The approach of the UK towards the MSW's AD and usage of food waste with wet AD systems on the basis of stirred reactor technologies continuously looks justified, on the basis on the energy performance and direct merits for such technologies during biodegradable MSW's treatment.



**B. Mesophilic and thermophilic digestion**

Anaerobic digestion takes place during psychrophilic temperature with 20 degree C, while it is generally operational during 2 temperature ranges: at thermophilic temperature range from 50 degree C to 60 degree C and at mesophilic temperature at 35 degree C. Mesophilic bacteria will be very active with broader temperature range when compared to thermophilic bacteria and will be tolerating higher changes within the parameters of environment (Shanthi & Natarajan, 2016).

### C. Batch and continuous feeding systems

Generally, 2 feeding modes can be utilized for solid waste's anaerobic digestion: the continuous system and the batch system. Within batch system, filling up of digesters is done using fresh feedstock without or with inocula's addition, and sealing it for full retention period, after which the removal of effluent happens after opening it. However, during the continuing process, the fresh feedstock goes inside the digester continuously and similar quantity of the digested material will also be removed (Shanthi & Natarajan, 2016).

### D. Single stage and multi stage digestion

The digestion systems that are continuous will be categorized as multi-stage and single stage processes. Such operations of digester have withdrawal and feeding, gas collection, heating and mixing. The one stage system comprises of a single reactor, where every biochemical reactions will happen. The involvement of varied microbial groups for the biogas production and anaerobic digestion having varied rates of growth and tolerating the operational conditions' fluctuations. It can lead to the imbalance among the production rate of volatile fatty acid and rate of methane production. So, the stage system that is single can be very sensitive for disturbances when compared with multistage systems. The multi-stage system has a minimum of two reactors. At several multi-stage systems, the production of volatile fatty acid occurs inside the aceto genesis and reactor, and methanogenesis happens within the $2^{nd}$ reactor. The optimization of multistage system and its conditions for every phase to offer distinct reactors. The single stage systems in praxi were preferred as they possess low investment expenses and needs easy technical support. For instance the Linde BRV, Kompogas and Dranco processes were actually one stage DAD systems. The WAD systems with single stage were actually referred like CSTR or continuous stirred tank reactors (Shanthi & Natarajan, 2016). Multi- Instances (Doelle K, 2015). Study shows that the reactor with 2-stage connecting with better methane and biogas yields when compared with the reactors of single stage. But, dual reactors promote the materials expenses and construction when the common single-stage system prevails owing to fewer amounts of capital costs. On the basis of research, it will be elaborated that food waste's anaerobic digestion for the recovering energy based on optimized methodology, temperature and conditions and feedstock loading. Several researches might be performed for improving the content of methane inside lowering the operational expenses and biogas.



### 2.3.2 Digester Parameters

#### A. pH value and Alkalinity

Methane gives out bacteria during the anaerobic digestion's process will be highly sensitive in acid conditions, which is why their growth is stopped. The maximum pH must be within the 6.2 - 8.5 range for accelerating growth of granular sludge and stimulating the response activities of bacteria that generates methane. Lot of growth or less within the pH amount is loaded with toxic effects upon the reactor's performance which is owing to the methane generator bacteria's inhibitory property (Majd et al., 2017).

#### B. Temperature

Temperature within the digester has more effect upon the process of biogas production. It has different temperature ranges where the anaerobic fermentation will occur (Choorit & Wisarnwan, 2007); a) Thermophilic (50 – 60o C) b) Mesophilic (30 – 40o C) c) Psychrophilic ( < 30oC) But, anaerobes were very active within range of thermophilic and mesophilic temperature (Kigozi et al., 2014). The methanogens remain inactive at very low and high temperatures. The maximum temperature at 35 degree C. Moderate levels of gas production occurs at the mesophilic range, from 25° to 30° C. (Ward et al., 2008b; FAO, 1996).



But, research show anaerobic digestion's successful performance during mesophilic temperature at 37°C and 55°C as thermophilic temperature (Majd et al., 2017).

#### C. Carbon to Nitrogen Ratio (C/N)

Biogas production has a direct relation with the material's type that enters the reactor; a major parameter for the case will be the carbon to nitrogen ratio. Accoridng to Gripentrog et al. a higher ratio containing carbon to nitrogen will lead to large mutagens population growth, when meeting the protein demands, which will not eat carbon than the required level and the problem causes gas production's lower (Gripentrog et al., 2009). For the research during 2012 about co-digestion of wheat bran, poultry, and livestock manures, the report by C/N ratio within the 25 – 30 range having the stable pH and might be inhibitory for methane production. Plus, the suggestion was 27.2 as the optimum ratio (Wang et al., 2012). Such less levels of the ratio limit activation of methanogenic bacteria and lowers the production of gas (Majd et al., 2017).

**D. Volatile Solids (VS)**

Volatile Solids (VS) shows the way the dry sample mass will be oxidized while it has combustion at 550 degree C temperature. The toleration of dry digesters will be very high OLR during the process of wet anaerobic digestion. It has the rate of optimum feeding for a specific reactor which will produce maximum gas, and beyond which further increases in the quantity of substrate that would proportionately have several gas production (Yadvika et al., 2004). The wastes will not be treated through Anaerobic Digestion that might have biodegradable organic fraction, the inert and combustible fraction. This biodegradable organic fraction consists of food residue, tree cuttings, and grass and kitchen scraps. The inclusion of combustible fraction is less lingo cellulosic organic matter that is degrading has paper, cardboard and coarser wood. The VS or volatile solids inside the organic wastes will be measured like total solids sans its ash content, when achieved through the feed wastes and full combustion (Shanthi & Natarajan, 2016).



**E. Total solids content (TS)/Organic Loading Rate (OLR)**

OLR or Organic loading rate will be measured on the basis of the anaerobic digestion system's biological conversion capacity. The definition of OLR as the organic matter's amount (known to be volatile solids or the feeding substrate's COD) which should be treated using anaerobic digester with specific volume for a specific time period. For calculation, OLR can be expressed with equation (2.10). VS or Volatile solids the way the dry sample mass which when oxidized while it has combustion during the temperature at 550°C. V QS OLR = 2.10) While, S = substrate concentration (kg like VS substration) organic loading rate or OLR (kg day/ substrate digester x m3) Dry digesters will be able to tolerate very higher OLR when compared with the process of wet anaerobic digestion (Beevi, 2015). The maximum rate of feed for the specific reactor that would have optimum gas, and will be further improved the substrate's quantity might not give out a lot of gas proportionately (Yadvika et al., 2004). For the system feed, upon the sustainable OLR, inferences of less biogas yield owing to collection of the inhibiting substances like the fatty acids within digester slurry. For this case, the system's feeding rate should be lowered. During continuous systems, OLR has a crucial control parameter. The reports about System failures by several plants owing to overloading (RISE-AT, 1998). The reports by Chaudhary (2008) is that the anaerobic digestion reactor with dry continuous stabilization of OFMSW that are source-sorted revealed balanced performance having top biogas yield (278.4 LCH4/kg VS) and reduction of VS at 59.21% for 2.5 kg VS/m3 /d as the loading rate within thermophilic condition within 3 varied OLRs of 2.5, 3.3 and VS/m3 /d of 3.9 kg for 25 days with constant retention period.

**F. Volatile Fatty Acids Concentration (VFA)**

VFA or Volatile Fatty Acids were significant intermediate compounds within metabolic pathway through the methane fermentation and leads to microbial stress when found inside higher concentrations. The production of intermediates in the anaerobic bio-degradation of the organic compound were mostly valeric acid, butyric acid, propionic acid, and acetic acid (Nayono, 2010). Within these, propionic and acetic acids were the crucial VFAs found within anaerobic bio-degradation as well as its concentrations offer very useful measurement for digester performance. The improvement of acetate yield will be slightly improving pH, when there is an improved butyrate yield with low level of pH. The identification of propionate yield will not be related to pH (Guendouz et al., 2010). Better VFAs concentrations within digester might lessen pH; methanogenic activity will be inhibits and leads to the anaerobic digestion process' failure. Vieitez et al. (2000) showed the way fermentative reactions stops during VFAs concentration of 13 g/l along with lesser pH of 5. The anaerobic digestion's limiting step will be hydrolysis, that generally has higher propionate concentrations inhibited within (Juanga, 2005).



**G. Hydraulic Retention Time (HRT)**

The single parameter that affects biogas production will be time of hydraulic detention that is wide and different based on the process type. As the hydraulic detention time relies upon the reactor type and reactor starts this process, thereby the type of reactor identifies the time of hydraulic detention (Sakar et al., 2009). The wide range of reactors like two-step system, fixed-film reactor, anaerobic hybrid reactor, attached-film bioreactor, temperature-phased anaerobic digestion, anaerobic rotating biological reactor, up-flow anaerobic filter, up flow anaerobic sludge blanket, down flow anaerobic filter, fixed dome plant, batch reactors, continuously stirred tank reactor for optimizing the biogas production, and organic anaerobic biodegradation were used, that would be discussed below. During

2015, the livestock manure's anaerobic digestion inside AHR reactor type having 14.5 liters as the effective size of recycled biogas was examined. The reactor was measured at seven different time periods. The authors reported that mean value of produced methane was higher than earlier time. It showed the AHR reactor having floating media with higher output towards biomass fixation and to biogas recycle within the livestock manure's anaerobic digestion with higher loading and concentration (Demirer & Chen, 2005). The research about TPAD or anaerobic digestion basic temperature system, 2 cylindrical reactors that are made using Plexiglas having mesophilic (58°C) and one-stop thermophilic (38°C) temperatures having volumes of Boske et al. (2015) and Garfí et al. (2011) liter within time of hydraulic detention Sakar et al. (2009) and Foreest (2012) were studied. Seeding the reactors have the thermophilic laboratory reactor's activated sludge as well as mesophilic high scale reactor. The TPAD system contains 6 substrates having varied traits. For the study, optimum removal value is at 42.6 VS % and achieving methane having maximum organic matters load were 0.54 – 0.61 L CH4 g –1VS 49. The reactors effectiveness having extra film psychrophilic digesters should also be studied. For the research, 8 digesters of 5-liters having 10 - 37 °C as temperature range having a range of testing the media with lime and polyester. The report by type of polyester media using high surface and high porosity with high volume ratio achieves top performance for methane production at 37 °C50 temperature.



**H. Mixing**

The anaerobic digestion process mixing helps in improving the process through the exposure of substrate material using bacteria and with distribution of homogeneous temperature. Mixing will be performed mechanically or through the produced biogas recycling. During 2007, the research for conducting an investigation the mixing effect of 3 conditions with intermittent, minimum, and continuous inside the methane production's laboratory scale. The study showed a methane increase by 12% for lowest mixing conditions (Kaparaju et al., 2008). During 2015 a a research was held for investigating the impact of mixing upon livestock manure's digestion and helps in biogas production with closed reactors of 1 liter. For the study it showed that mixing restricts biogas production and the inference revealed a lag in acid formation phase transferring to phase of methane generation. Lastly, it showed that mixing of parameters relies upon biochemical and physical parameters within substrate. There is also variation about varied manures and types of reactor and should be identified based on local conditions (Ward et al., 2008c).

**I. Nutrients**

The processes of anaerobic digestion had the ability to use a vast number of organic materials like crop waste, human waste, feedstock, and animal manure. Even though, for helping it grow, bacteria require a lot of organic substances supply such as source of nutrients and carbon, while needing specific mineral nutrients. Apart from hydrogen, oxygen and carbon, the biomass' generation needs enough supply of magnesium, sulphur, calcium, potassium, nitrogen phosphorus, etc. Agricultural wastes and residues will generally have enough amounts of such elements (Kigozi et al., 2014).

**J. Moisture content**

The excretion of microorganisms and extra essential metabolic processes need water for performance so the feedstock must possess maximum moisture content towards bacterium performance. The maximum value that moisture content has must be 90% out of total volume in the feedstock. Too much water inside feedstock causes a decline in the production rate per unit based on feedstock's volume and having not adequate water on the other hand causes the acetic acids to accumulate a lot by inhibiting the digestion process and also its production. In addition, the thick scum develops over the substrate's surface. The scum will hinder with the effective mixing within the digester to initiate a charge (Kigozi et al., 2014).



The biogas is generally completely soaked with water vapour. This entails chilling the gas, example: by crushing it through a subway duct, so that the surplus water vapour reduces at lower heating. When the gas is heated further, its proportionate vapour content reduces. The "drying" of biogas is particularly helpful with respect to the usage of dry gas meters, that on the contrary would ultimately fill up with compressed water (Energypedia, 2015). Moisture was stated (Potts & Martin, 2009) to support digestion by (i) commanding cell turgidity; (ii) shipping nutrients, intermediates, items, enzymes and microorganisms; (iii) reacting in hydrolysis of intricate organic substances; and (iv) changing the form of enzymes and other macromolecules (Khalid et al., 2011). Lofty moisture contents generally assist the anaerobic digestion because of the truth that water contents are probably to influence the procedure execution by dissolving promptly degradable organic substance.

Grounded on the whole solids content of the slurry in the digester reactor, anaerobic digestion procedures are categorized into low solids or moist digestion ( below 10% TS ), average solids or semidry ( 10 – 20% TS ) and lofty solids ( above 20% TS ). Majority of the researches on degradation of organic fraction of municipal hard waste were done employing dry anaerobic digestion procedure because of the lofty-hard content of OMSW (Fernández-Rodríguez et al., 2013; Alvarez-Gallego, 2005; Fdez.-Güelfo et al., 2011; Fernández et al., 2008). Nevertheless, adding water or codigesting with low-hard wastes like sewage slime and dung can escalate the moisture content of OMSW and make it appropriate for semidry anaerobic digestion procedure (Fernández et al., 2010; Hartmann & Ahring, 2005).

Lay et al. (1997) announced that escalating preliminary moisture content of mesophilic anaerobic digesters from 90 to 96 per cent escalated the methanogenic action in lofty-hard slime digestion. In some other research (Fernández et al., 2008), digesters functioned at loftier preliminary moisture content acquired loftier methane making pace, along with superior dissolved organic carbon ( DOC ) elimination capability in mesophilic anaerobic digestion of OMSW. Nevertheless, it was announced (Hernández-Berriel et al., 2008) that escalating the moisture content of OMSW reduced methane making pace of anaerobic digester with recurrent pattern of leachate drainage and adding water. The bioreactors functioning at 80 per cent moisture content submitted a second-rate volatile solids (VS) content equated with the ones functioning at 70 per cent moisture content because of the truth that water refillings into the bioreactors could lead to cleaning out of nutrients and microorganisms.



### 2.3.3 Factors affecting AD

As stated by Cioabla et al. (2012), because of the intricacy of the bioconversion procedures, several components influencing the actions of an anaerobic digester were examined and portrayed (Ward et al., 2008a; Surroop & Mohee, 2011). These can be separated into 3 chief groups: (i) feedstock features, (ii) reactor structure, and (iii) functional terms. Amongst the functional terms, temperature and pH are the supremely significant confines; thereby the survey was guided particularly to these.

Nevertheless, Manyi-Loh et al. (2013) described elements influencing the act of an anaerobic digester as functional components [ pH, temperature, organic loading rate ( OLR ) / hydraulic retention time ( HRT ), free ammonia concentration ], substrate features / biodegradability and biodigester design (Cioabla et al., 2012b). Nevertheless, Wilkie (2005) announced that temperature, biodegradability, OLR, and HRT have immense effect on the anaerobic digestion of animal dung.

**Varieties of feedstock:** Means of biomass feedstock for power creation comprise agriculture crops, agricultural and forest remains, agroforestry remains and other organic waste means. These different means of biomass inlets can be categorized under the below-mentioned wide classes:

**Energy crops:** These are agricultural crops that are appropriate to generate bioenergy. These comprise food crops from starch crops like corn, sugar-centric crops like sugar cane and oilseed crops like soya bean. Non-food crops solely raised to generate bioenergy are in addition comprised in this group, example: grass and woody crops.

**Primary residues from agriculture and forestry:** These remains are organic by-products from forestry and agricultural reaping actions. These normally comprise of lignocellulosic substance, example: tiny twigs, leaves, corn stove, than can be employed to generate power.

**Organic wastes:** Organic waste like organic municipal hard waste, demolition wood or used cooking oils consists of an extremely dissimilar flow of biomass which can be employed to generate power.



**Forest growth:** This comprises possible obtainable woody biomass from endurable forest administration. Employing woody Biomass for power objectives on the other hand perhaps cause rivalry with the industry of forest items like lumber, boards, pulp and paper, etc.



**Secondary residues from processing industry:** These remains are generated throughout the industrial treatment of wood and food crops. There is a wide extent of remains generated from different industrial procedures each one possessing diverse features. For instance, the wood treatment industry creates sawmill and black liquor that can be employed as feedstock to generate power. Note that the usage of remains from the food treatment industry like treacle or press cake for power generation is just one of its many advantageous uses (Food and Agriculture Organization of the United Nations, 2010).

**Trace Elements:** Trace elements like iron, nickel, cobalt, selenium, molybdenum, and tungsten are important for the growth rate of microorganisms and often must be added for biogas production if single feedstocks such as energy crops are used (Abdoun & Weiland, 2009; Jarvis et al., 1997).

## 2.4 Biodegradable Waste management technologies

Waste water and landfills constitute 90% of waste sector emissions and about 18% of global anthropogenic methane (CH4) emissions (Bogner et al., 2008). The methane (CH4) which has high potential of global warming either can be taped or freely released into the atmosphere. The latter situation take place when the organic matters are illegal disposed of or thrown away in the vacant places. The taped methane (Biogas) used as a source of energy while un-taped methane is very harmful for the environment (Bond & Templeton, 2011). Several researches have been conducted in the world to solve local, regional, and global problems due to the improper disposal of MSW. Most of these researches showed their reliance on renewable energy for sustainable development to meet their daily energy needs through waste to energy routes that cause less negative environmental and social impacts (Rao et al., 2010) as well as energy is recovered during the process.

The municipal Solid Waste (MSW) is treated differently in different parts of the world. The waste is naturally degraded in unstandardized landfills, burnt the waste in dump sites and through controlled aerobic and anaerobic digestion process. The first two processes are widely in operation in developing countries and large volume of methane and carbon dioxide is released into the atmosphere. The release of these gases into the atmosphere becomes very harmful for the environment (Jingura & Matengaifa, 2009). The natural degradation of the organic matter is causing smell and spreading of diseases in the surroundings. Natural biodegradation of organic matters contributes approximately 590-800 million tons of methane in the atmosphere (Bond & Templeton, 2011). Following are some of the Biodegradable Waste management technologies used;



### 2.4.1 Anaerobic digestion

Production of methane by means of anaerobic procedure is a suitable solution for food waste administration. Anaerobic digestion is the process and technique of decomposition of organic matter by a microbial process in an oxygen-free environment (FAO, 1997). Controlled anaerobic digestion of organic wastes has multiple benefits. On one hand, it provides a renewable source of clean energy, while on the other side the digestates can be used as organic fertilizers in the agriculture sector. The electricity and fuel production from the biogas might strengthen the national energy supply, as well as reduce Greenhouse Gases (GHG) emissions (Yadvika et al., 2004). The process has lower expenses and less residuary waste generation and usage of food waste as renewable means of power (Nasir et al., 2012; Morita & Sasaki, 2012).

### 2.4.2 Biodegradation

Biodegradation of organic substance is a critical and natural eco-friendly procedure that takes place in both terrestrial and aquatic surroundings. The treatment undergoes a series of microbial catalyzed reactions like oxidation, hydroxylation, hydrolysis, reduction, dehalogenation, and dealkylation. The oxidation procedure of organic substance perhaps occur by various oxidizing agents like oxygen, nitrate, and sulphate (Bobeck, 2010). Given that oxygen is available, it is the preferable oxidizing agent and biodegradation of organic substance; nevertheless, if oxygen becomes scarce, decay persists by the decrease of oxidizing agents like sulphate, $SO_4$ ($2^-$), that ensues in generation of the poisonous gas, hydrogen sulphide, $H_2S$. Degradation of organic substance ensues in creation of carbondioxide and methane, where anaerobic decay ensues in wide creation of methane (Manahan, 2005).

### 2.4.3 Composting



Composting is the treatment of aerobic decay of biodegradable organic substance in a warm, wet surroundings by the activity of bacteria, yeasts, fungi, and other organisms. In India, MSW has a preliminary C/N proportion of approximately 30:1, perfect for decay. The organisms entailed in stabilization of organic substance use around 30 sections of carbon for each section of nitrogen. Composting needs around $25m^2$ area per ton of MSW (just for windrow creation for 21 days composting and maturity yard for 30 days stabilization). The extra space needed is for hardware, packing, and storage. Conveniences are also needed for recycling and process of liquid waste (leachate) and hygienic dumping ground for rubbish ( inert substances, slime from ETP ) (CPCB, n.d.).

### 2.4.4 Garden waste dumping

The most general way of waste disposal is getting rid of it on land, as it is the most inexpensive way. Nevertheless, this needs huge area and correct drainage (Pillai et al., 2014). The possible reason for adulterated groundwater is because of the waste disposal on land by the municipality and the industrial hard waste. Irrationally handled landfills are liable to adulterated groundwater due to the creation of leachate. Leachate is the fluid that trickles from hard wastes or other channel and have extracts with disintegrated or hanging substances from it (Goswami & Sarma, 2007). The quantity of leachate relies primarily on the area of the dumping ground, the meteorological and hydro-geological components and capability of limiting. It is necessary that the quantity of leachate produced be held to the least and in addition makes sure that the entry of groundwater and the top layer of water is reduced and restrained. The quantity of leachate produced is hence anticipated to be extremely lofty in moist areas with more downpour, or run-off and shallow water table (Chapman, 1992). This portrays the truth that Garden waste disposal or plainly disposal is a method where significant drawbacks constitute danger to the surroundings.

### 2.4.5 Illegal dumping

Garbage dumping acts comprise unlawful concealing in regions not legitimately allotted as poisonous waste disposal spots like cultivable regions, roads and buildings and construction yards (Ferrara et al., 2013). Certain writers like Senior and Mazza (2004), summarized that the lofty stage of cancer death in the region can be associated with the stage of contamination due to insufficient waste-restriction ways and by unlawful disposal.



### 2.4.6 Landfill mining



Landfill mining (LFM) develops the pic, shift, and treatment of concealed substance taken from an active or shut (usually unlined) dumping ground. The objectives of LFM have been: (1) preservation of dumping ground area; (2) decrease in dumping ground region; (3) removal of a possible means of adulteration; (4) alleviation of a present adulteration means; (5) power restoration; (6) recycling of restored substances; (7) decrease in administration arrangement funds; (8) spot redevelopment. LFM has been conducted in the universe for the past 50 years.

### 2.4.7 Evolution of AD- short history

A Frenchman, Mouras, initially used anaerobic digestion to process wastewater, in his innovation of a coarse version of a septic tank in 1881 and christened it "automatic scavenger". Later, in 1895, an Englishman, Cameron, built a tank that was much like Mouras' "automatic scavenger" but had superior processing capability. He named it "septic tank". Due to the effective outcomes attained in employing these tanks, in 1897, the regional government of Exeter sanctioned the processing of the whole city's wastewater by these septic tanks. In addition, the benefit of the methane gas that was produced in the process of slime decay in the septic tanks was identified by Cameron and some amount of the gas was employed for warming and illumination objectives at the dumping works. Throughout major part of the ensuing century, the growth of anaerobic digestion technology stayed solely connected to the stabilization of the putrescible solids from national wastewaters. This directed to the structure of heated, wholly combined, reactors of the kind broadly employed even today for the digestion of sewage slimes and animal dung. Utilization of anaerobic digestion arrangements to industrial wastewater depollution was aroused by the steep upturn in fossil fuel costs in the early 1970s and by the escalatingly rigorous adulteration command rules. The inappropriateness of the traditional combined digester for the process of industrial wastewaters of mean-strength and of hugely dissolvable organic combination, directed to the idea of biological solids recycling and to the holding of active biomass inside the digester (Chawla, 1986).

## 2.5 Benefits of Domestic Bio-digester



Weather transformation is one of the most eco-friendly difficulties confronting the universe nowadays. Unjustifiable usage of power in earlier times has led to global warming that requires to be dealt with. Household digesters could decrease the stress on the surroundings by lessening deforestation and greenhouse gas discharges, soil corrosion, and loss of cultivable land. A main factor to global warming is greenhouse gases (GHG), discharged to the surroundings chiefly from burning fossil fuels like coal, oil, and organic gas. Rural biogas creation can partly decrease global warming. By using biogas for rural households, eco-friendly, financial, and social advantages were acquired. Although both methane and carbondioxide are main elements to the greenhouse impact, the global warming possibility of methane is 21 times greater than that of carbondioxide. Nevertheless, the contrast of the houses furnished with and without biogas arrangements, comprising the leakage of gases in the biogas arrangements disclosed that the households with biogas plant have 48 per cent less discharges equated to households without biogas arrangements (Krich, 2005).

Besides eco-friendly advantages, there are a number of social and health advantages in employing biogas as a fuel. Enhanced health environment and shift in lifestyle for ladies in the households were monitored following installation of a biogas digester. They could satisfy their power requirements in a endurable method by employing the regionally accessible substances. Biogas is one of the potential option to create power for rural India. The fundamental 7 objectives are: price reduction, capability increase, job creation, arrangement dependability, reduction of petroleum items, increased use of regional assets, and reduction of discharges. If connected to a public toilet where waste is not stored, biogas can enhance hygiene significantly.

## 2.6 Research gap

As recommended in the previous literature review, the bio-digester optimization procedure, as an instrument for endurable power has turned into a significant study concentrate in the light of the existing power and garbage administration difficulties in Ireland. It is nevertheless significant to observe that the latest events that have been reported in the enhancement of the bio-digester technology have consistently motivated by the growing currents of these difficulties in Ireland, and to make sure a endurable future for the Irish economy; it is significant to create cost-effective arrangements for the optimization of the bio-digester machinery. A review of literature discloses a shortage in probing reports on the optimization of the bio-digester feedstock water-content, as an instrument for enhancing the power capability of the bio-digester machinery. Hence, the current research targeted to establish the association between the bio-digester feedstock water-content and the power capability of volumetric output and power capability of the biogas item, for the achievement of ideal biogas power restoration from bio-digester factory in Ireland, with respect to the heat of combustion. Furthermore, the research also contends to propose a feasible framework for the optimisation of biodigesters in Pakistan, a developing nation which has better prospects for establishing biodigester plants that could have better energy output.



# CHAPTER III- MATERIALS AND METHODS

## 3.1 Introduction

The present research attempts to examine the impact of feedstock water content optimisation on the performance of domestic biodigester plants. In this regard, the researcher has collected data from a small scale bio-digester plant in Ireland. Since Ireland is known for its keen vision for low carbon energy system that could reduce greenhouse gas emissions and the initiatives taken by the government to support the use of eco-friendly biogas (Seai, 2017), the researcher had ease in collecting data required for the research. In the present chapter, the collection of bio-gas production data from Ireland is elaborated and the analysis techniques used for the examination of performance of domestic biogas were also elucidated. The ethical considerations for the research are described and the chapter ends with a chapter summary.

## 3.2 Collection of bio gas production data



For the collection of bio-gas production data, the researcher has approached a small scale domestic biodigester plant in Ireland. Feedstocks used by these plant consisted of combined agricultural waste feedstocks, such as laying hen litter, swine manure, corn husk age, thin stillage from fuel alcohol production, and sweet corn silage juice. Feedstocks were chosen based on availability and reasonable trucking distance within a specific region of Ireland based on the concept of regional waste biogas production facilities. Individual feedstocks were characterized for Chemical Oxygen Demand (COD), nutrient value, and pH and alkalinity. Individual feedstocks were blended together to provide a co-digestion process based on individual feedstock characterization to control COD to nutrient ratios, pH and alkalinity demands in the digesters, manage ammonia inhibition/toxicity, and provide macronutrients (nitrogen and phosphorus) and micronutrients without requiring additional nutrient supplementation. Three different tanks were examined for the pH value as well as water content.

## 3.3 Data collection

The data collected from the three biodigester tanks include the pH values of each tank for a designated time frame (03-07-2017 to 21-07-2017), the TAC and FOS values for each tank, and the amount of dry matter in the digesters. For the analysis of the collected data, the following analysis techniques are used:

### 3.3.1 Nordmann test

The researcher has adopted the Nordmann- Methode for the analysis of FOS/ TAC ration which is used to determine the acid concentration quotient and buffer capacity in the fermentation substrate (Hach Company, 2015). FOS and TAC are german terms which stand for ‘Flüchtige Organische Säuren (volatile organic acids)’ and ‘Totales Anorganisches Carbonate (total inorganic carbonate)’ respectively. FOS is measured in mg HAceq/l (acetic acid equivalent) and TAC is measured in mg CaCO3/l (Calcium Carbonate equivalent) (Lossie & Putz, 2009).

**Measurement of FOS/TAC ratio:**

The following steps need to be followed to measure the FOS/TAC ratio which is utilised by the biodigester plants.

**Step1:** A representative sample of the fermentation substrate needs to be taken

**Step 2:** Any coarse components present in the sample needs to be removed



**Step 3:** Sample preparation should be performed using a filter, centrifuge or a tea strainer to screen any coarse components

**Step 4:** 20 mL sample substrate should be filled with distilled water if required

**Step 5:** the sample should be placed on a magnetic stirrer to homogenise it during the process of titration

**Step 6:** Titration with 0.1 N H2SO4 to pH 5; the volume (ml) of acid added needs to be noted

**Step 7:** Titration with 0.1 N H2SO4 to pH 4.4; the volume (ml) of acid added needs to be noted

**Step 8:** FOS- TAC ratio should be calculated using the following formula in Table 1

**Table 1: Empirical calculation**

| |
|---|
| ***FAL specifications:*** |
| Quantity of substrate: 20 ml |
| Sulphuric acid: 0.1 N (0.05 mol/l) |
| TAC = H2SO4-Volume added from start to pH 5 in ml × 250 |
| FOS = (H2SO4-Volume added from pH 5 to pH 4.4 in ml × 1.66 – 0.15) × 500 |

**Source: Adopted From** Lossie and Putz (2009)

**Significance of the FOS/ TAC ration:**

The FOS/ TAC ratio is used to arrive at a conclusion that a biodigester plant is producing an optimal amount of biogas or not. In general, if the ratio is found to be within 0.3 to 0.4, the production of biogas in the biodigester plant is deemed optimal; however such an observation can be made only through long term observations and frequent checks. It is also deemed that the FOS- TAC ratio has strong dependence with the substrate. For a stable operation of the bio-digester plant FOS/TAC should be around 0.4 to 0.6 for a stable operation (Lossie & Putz, 2009).



**3.3.2 Determination of Total Solids/ Dry Matter content**

The total solids (TS) content in a biodigester is a parameter used to indicate the viscosity of the reactor's fermentation broth. In a biodigester tank, the viscosity should not rise to a specific level which will lead to lowered efficiency of pumping. Predominant bio-digesters operate as wet fermentations systems wherein the concentration of the TS/ Dry matter should not exceed more than 10 per cent. When the dry matter content is within 10 per cent, pumping and mixing of contents in the digester will be performed with ease. In cases of fibrous feedstock used, then the concentration of the TS will ultimately lead to problems in stirring in the tank. In such cases, digestate, fresh water or process water are used (Resch et al., 2008).

## 3.4 Ethical considerations

For the present research, the researcher has collected realtime data from three bio-digester plants; however to maintain anonymity, the researcher has not disclosed the names of the plant elsewhere in the document.

## 3.5 Summary

In the present chapter, the researcher has elaborated on the collection of data from bio-digester plants and has also elucidated the various data analysis techniques used in the research. Furthermore, the ethical considerations that are inherent in the research are also depicted in the chapter wherein the results of the research is provided in the next chapter.

# CHAPTER IV- RESULTS

## 4.1 Introduction

The present chapter comprise of the results and findings acquired from the analysis of collected data. Data collected from the select small scale biodigester plant is analysed and the results are interpreted in this chapter. The chapter begins with the analysis of pH values in the different tanks

## 4.2 Determination of pH in the tanks

The researcher at first examined the values for PH of the three different tanks which are provided in Table 1, 2 and 3. It is deemed that in all the tanks, the pH values are found to be around 8.09 to 8.45. According to Lay et al. (1997a), the appropriate pH values in a completely mixed digester tank should be around 6.8-7.2; however, (Tudelft, 2017) ascertained that the pH value should lie between 7- 8.5 in the tank where stabilisations have been made under anaerobic conditions. If the pH values reached higher than 10, then obliteration of the anaerobic digestion process occurs (Li et al., 2012). The values for PH of three different tanks are given in the tables below.



**Table 2: pH values in Tank1**

| Tank 1 | PH |
|---|---|
| 03-07-2017 | 8.16 |
| 04-07-2017 | 8.23 |
| 05-07-2017 | 8.26 |
| 06-07-2017 | 8.10 |
| 07-07-2017 | 8.14 |
| 10-07-2017 | 8.12 |
| 11-07-2017 | 8.09 |
| 12-07-2017 | 8.22 |
| 13-07-2017 | 8.21 |
| 14-07-2017 | 8.15 |
| 15-07-2017 | 8.19 |
| 18-07-2017 | 8.21 |
| 19-07-2017 | 8.14 |
| 20-07-2017 | 8.13 |
| 21-07-2017 | 8.16 |

**Table 3: pH values in Tank 2**

| Tank 2 | PH |
|---|---|
| 03-07-2017 | 8.20 |
| 04-07-2017 | 8.20 |
| 05-07-2017 | 8.12 |
| 06-07-2017 | 8.10 |
| 07-07-2017 | 8.13 |
| 10-07-2017 | 8.15 |
| 11-07-2017 | 8.16 |
| 12-07-2017 | 8.31 |
| 13-07-2017 | 8.20 |
| 14-07-2017 | 8.26 |
| 15-07-2017 | 8.23 |
| 18-07-2017 | 8.26 |
| 19-07-2017 | 8.23 |
| 20-07-2017 | 8.31 |
| 21-07-2017 | 8.22 |

**Table 4: pH values in Tank 3**

| Tank 3 | PH |
|---|---|
| 03-07-2017 | 8.38 |
| 04-07-2017 | 8.36 |
| 05-07-2017 | 8.29 |
| 06-07-2017 | 8.25 |
| 07-07-2017 | 8.39 |
| 10-07-2017 | 8.30 |
| 11-07-2017 | 8.36 |
| 12-07-2017 | 8.40 |
| 13-07-2017 | 8.32 |
| 14-07-2017 | 8.36 |
| 15-07-2017 | 8.38 |
| 18-07-2017 | 8.45 |
| 19-07-2017 | 8.43 |
| 20-07-2017 | 8.40 |
| 21-07-2017 | 8.42 |

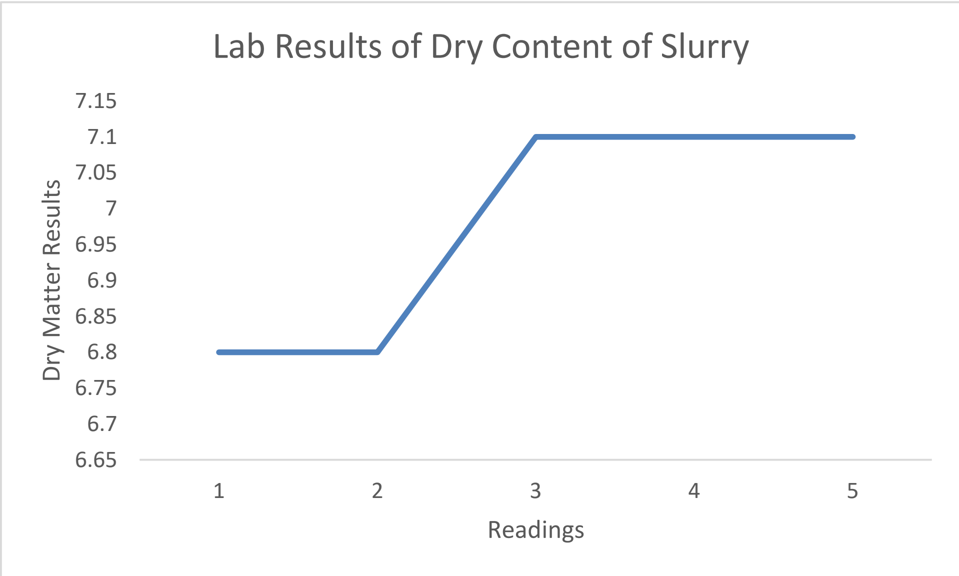


## 4.3 FOS/ TAC ratio

Prior examining the FOS/ TAC ratio, the researcher examined the variations in the dry content of the slurry taken from a specific biodigester tank during different time periods of the same day. It was revealed that there was an increase in the dry content of the slurry in readings 3, 4 and 5 which is used further to examine the relationship between Dry content and FOS/ TAC ratio. Figure 1 depicts the lab results of dry content of the slurry.

**Figure 1: Lab Results of Dry Content of Slurry**




Based on the samples collected from the three tanks with varying dry matter content, the researcher calculated the FOS/ TAC ratio which revealed specific results. On a specific date, five different samples were collected and were analysed for the dry matter results wherein it was revealed that there were little variations in the dry matter content in the samples analysed. The results for water content of feedstock and other values such as TAC and FOS and their ratios have been investigated.

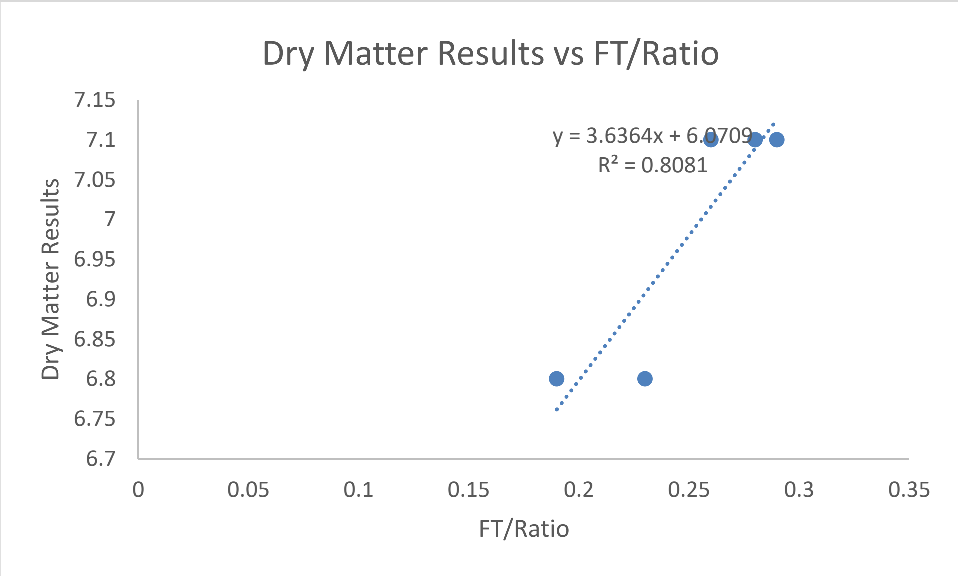
**Table 5: Feedstock random readings**

| Date Tested | Dry Matter Results | FOS-TAC ratio |
|---|---|---|
| 28/08/2017 | 6.8 | 0.23 |
| 28/08/2017 | 6.8 | 0.19 |
| 28/08/2017 | 7.1 | 0.28 |
| 28/08/2017 | 7.1 | 0.29 |
| 28/08/2017 | 7.1 | 0.26 |

Based on the readings acquried from the analysis of the dry matter content, the relationship between Dry Matter content and the FOS/ TAC ratio was examined. Simple linear regression was performed which led to the following graph (Figure 2).

**Figure 2: Dry Matter versus FOS/ TAC ratio**






Biogas production depends on various parameters that affect the yields of the gas from different substrates. Prominent among the factors are the pH, concentration of slurry, and more importantly, the FT ratio that controls the pH value of the slurry. The total solids, volatile matter, mineral concentrations are among the factors affecting biogas yields. From the graph of dry matter vs FOS-TAC ratio shown above, the results of analysis show that there is a positive correlation between FOS-TAC ratio and dry matter content wherein the p-value is also found to be significant. In other words, the more the FOS-TAC ratio, the more the dry matter content. The coefficient of determination R2 shows that 80.8% of the variability in dry matter content is explained by the FOS-TAC ratio. Conclusively, from the results of the analysis, there is a linear relationship between the water content of the bio digester feedstock and the energy and volumetric efficiency of the domestic bio digesters.

## 4.4 Summary

In the present chapter, the researcher has analysed the collected data and identified the existence of relationship between FOS TAC ration and dry matter content. However, the results will be discussed and the applicability of the water based optimisation technique in Pakistan scenario will be elaborated in the next chapter

# CHAPTER V- DISCUSSION AND CONCLUSION

## 5.1 Introduction

The present research aims to examine the potentials of water optimisation in biodigesters in Ireland wherein the same will be considered as a premise for the generation of opportunities for Biogas plant developments in a select case nation (Pakistan). The world population is increasing every day wherein the demand for energy also increases in line with the growing population especially in the developing nations. While the demand for energy is expected to improve by more than 30 per cent[1], and with more than 80 per cent of the entire world's energy demand satiated through fossil fuels[2], it is clear that fossil fuels will diminish sooner or later and increased usage of the same leading to the generation of greenhouse gases[3]. Anaerobic digestion acts a viable solution to mitigate the problems faced by world in association with the burning of fossil fuels as well as increasing demand for energy.

While AD sources of energy are found to possess better benefits than conventional energy sources, there are disadvantages. From the operational point of view, water content in the feedstock is deemed to decrease the operational efficiency of the digesters which results in reduced energy generation. Hence an optimal energy and water consumption balance is required to embrace process efficiency which could maximise the economic benefits of the biodigester system[4]. In this regard, the researcher has considered the examination of water content variations in biodigester tanks and its impact on bio-gas production. In Ireland, biodigesters plants operate with slurry that has reduced dry matter content which decreases the potential biogas production[5]. In this regard, the researcher has collected data from a local biodigester plant and examined the amount of dry content in the samples. Based on the variations of the dry matter content in the slurry, the researcher has examined its impact on the FOS/ TAC ratio.



## 5.2 Overall findings of the research

### 5.2.1 Optimal pH value found in all tanks

For the present research, the researcher has collected samples from three different tanks at the local biodigester plant. It was identified that in all the three tanks, the pH value of the samples was found to be at an optimal value. As per the findings of (Tudelft, 2017), it was stated that the values of pH in a biodigester tank should lie between 7-8.5 which is the

[1] ExxonMobil. The Outlook for Energy: A View to 2040. 2012. ExxonMobil.
[2] International energy agency, "Key world energy statistics" (2010).
[3] file:///C:/Users/user/Downloads/21119-48167-1-SM%20(2).pdf
[4] https://erefdn.org/wp-content/uploads/2015/12/Griffin_Laura.pdf
[5] https://www.afbini.gov.uk/articles/3-potential-performance-farm-anaerobic-digestion-northern-ireland

stablised scenario for the generation of biogas. The pH range in all the tanks was found to be around 8.09 to 8.45 which is the optimal range for the methanogenic bacteria to function[6].

Since the pH value is found to be optimal, the researcher considered the plant to operate optimally and hence took 5 samples to examine the dry matter content in the slurry and its impact on FOS TAC ratio.

### 5.2.2 FOS/ TAC ratio and Dry matter content

Five samples were taken from the biodigester plants wherein each sample was taken during different periods on the same date. It was revealed that there were variations in the dry matter content in the samples taken and for each sample, the FOS/ TAC ratio was calculated and its results were linear regressed. It was revealed that with increase in the dry matter content, the FOS/ TAC ratio has improved and was found to be around 0.26-0.29. A positive relationship was found between FOS-TAC ratio and dry matter content. There are researches which discerned the fact that increasing dry matter content to an optimal level in the biodigester tanks increases the process efficiency in the bioreactors[7].

Due to the high water content in the slurries, it is deemed that the specific methanogenic capacities of the biodigester plants become low which makes the biogas plants more less viable economically[8] . This is the case of the local Irish biodigester plant considered for the research wherein the collected samples contain considerable water content in the slurries. The processing of large watery wastes in the reactors is a complex and expensive task which necessitates the implementation of additional equiment in the plant. There are other implications with the increased water content in the biodigester tanks. Firstly, parasitic demand also increases due to the need for increasing water temperature in the tanks. This is true especially in Ireland which utilise cattle and pig farm manure for the production of bio gas with more number of thermophilic digester plants in the nation.



In the present research, we identified that with increasing dry matter content, the ratio of FOS/ TAC increases which is a sign that increased water content does not contribute to the production of biogas significantly since heating water becomes unproductive in the processes of generation of biogas. Since farm slurries are generally low in dry matter content, it needs to be improved to acquire better FOS/ TAC values[9].

## 5.3 Recommendations for improvement

Anaerobic digestion of wastes, especially organic wastes is found to be a viable option for the production of biogas which has the potentials to replace the conventional fossil fuels as the

[6] N.T. Sibiya, and E. Muzenda, "A review of biogas production optimization from grass silage," International Conference on Chemical Engineering and Advanced Computational Technologies, Nov. 24- 25,2014,Pretoria, South Africa
[7] B. A. Adelekanand A. I. Bamgboye. Effect of mixing ratio of slurry on biogas productivity of major farm animal waste types. Journal of Applied Biosciences 22: 1333–1343(ISSN 1997–5902).
[8] https://www.ucc.ie/en/media/research/hydromet/AsamPaper.2011.pdf
[9] https://www.afbini.gov.uk/articles/2-factors-consider-anaerobic-digestion

primary energy source. Some of the main constitutents of a biogas are methane and Carbon di oxide. The production of methane generates CO2 and water and the potential for methane is colossal with the presence of swine and cattle all over the world. However, one main drawback of the anaerobic production of biogas is the long hydraulic retention times as well as increased amount of water present in the solid portion which appears to be ineffective for the production of biogas[10]. In this regard, the researcher has identified certain solutions to reduce the inefficient operation of biodigestor plants. One major solution would be to import feedstock from other locations in the world which has increased dry matter content than the feedstock that is available in Ireland. The results from feedstock analysis show that there is very low dry content in the feedstock mixture in Ireland. Since the random analysis of samples taken depicted the need for increasing the dry matter content in the feedstock, it is recommended that feedstock be imported from other locations to increase the energy output. However, this is not a completely feasible solution since waster matter in the region of Ireland may not be used if the feedstock is completely imported. In Ireland, feedstock for biodigesters was acquired from agricultural and muncipal wastes, energy crops (grass silage), and cattle wastes[11]. The mixture of feedstock in Ireland contains more amount of water which needs to be reduced. Hence, water content could be reduced through the use of various separation techniques such as filter presses, mechanical screen separators, biological treatment, sedimentation, reverse osmosis and so on[12].



From an economic perspective, the removal of water slurry from the dry matter aids in reduced costs of transportation from one farm to another. However, the process of removing water content and separating dry matter has its own cost constraints. Local biodigester plants in Ireland should look at the ways of removing water content from dry matter in an efficient manner through the use of techniques such as centrifugation, sedimentation and mechanical separation. However, if the plants are economically stable then then can also implement other treatments such as reverse osmosis, evaporation and ultrafiltration which are expensive and complex techniques[13].

## 5.4 Case study- Pakistan

An analysis of the prospects of optimising the feedstock water content as a basis for improving biogas production in Ireland led the researcher to examine the same prospects in a developing nation. The researcher has considered Pakistan which is known for its strides to develop bio gas usage in the nation through the policy changes. The government of Pakistan has initiated the scheme for biogas generation in the year 1974 wherein they commissioned more than 4000 biogas units by the end of 1980s throughout the nation. However, the

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[10] Methane productivity of manure, straw and solid fractions of manure. / Møller, H.B.; Sommer, S.G.; Ahring, Birgitte Kiær.
In: Biomass & Bioenergy, Vol. 26, 2004, p. 485-495.
Research - peer-review › Journal article – Annual report year: 2004

[11] https://www.ifa.ie/wp-content/uploads/2013/10/Future-of-Rewable-Gas-in-Ireland-Bord-Gais-2010.pdf

[12] Møller HB, Lund I, Sommer SG. Solid–liquid separation of livestock slurry: efficiency and cost. Bioresour Technol 2000;74:223–9

[13] file:///D:/Madhan/Madhan/MDF/MDF209/20.11.2017/mller2000.pdf

 

Government failed to progress any further due to lack of support from the Government as well as from financial supporters[14]. Till date, there is a need to promote biogas projects in the nation to satiate the energy demands of its rural regions[15]. Though the Pakistan Council for Appropriate Technology (PCAT) has impletmented a number of biogas plants in the region[16], the popularity of the energy source was not reached to the masses due to several limitations. Firstly, the size, design and construction of digesters require skilled masons wherein the non-availability of such labour has been a key reason. Secondly, the operation of digesters in the region is generally at low concentration of solids wherein the feedstock is diluted with more than 1:1 ratio of waste and water. When such dilutions are used, large sized digesters will be required which further generates large amount of effluent that are difficult to be handled[17]. This is similar to the case of Ireland wherien high water content and low dry matter content are found in the feedstock .

Against the backdrop, the researcher has developed a framework for the efficient production of biogas and improved dry matter content in the feedstock.

High Solids Anaerobic Digestion (HSAD) which is developed by Liao and Li, 2015[18] is a system which supports increased Total Solids/ Dry Matter content when compared with other Conventional Anaerobic Digestion (CAD) systems. In addition, thehandling capability of HSAD is found to be the same as that of CAD. The procedure for the HSAD system is as follows:

**Step 1:** the collected feedstock should be dewatered using any of the following economically feasible methods (centrifugation, sedimentation and mechanical separation)

**Step 2:** The feedstock subjected to dewatering procedures needs to be filtered using a biological aerated filter.



**Figure : Biologically Aerated Filter**

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14 http://www.bibalex.org/Search4Dev/files/338859/172360.pdf

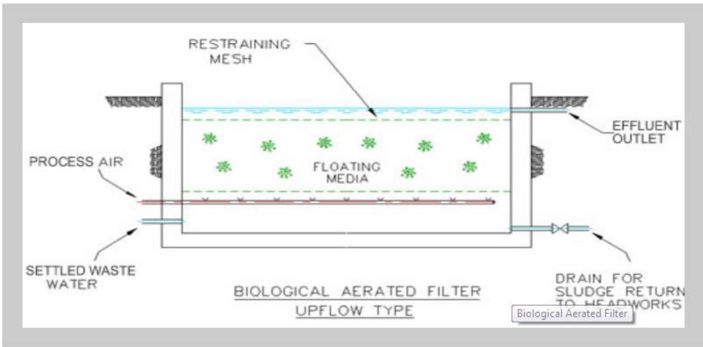
15 https://www.waterinfo.net.pk/sites/default/files/knowledge/Portable%20and%20Environment%20Friendly%20Digester%20for%20Biogas%20Generation.pdf

16 Akhtar, P., 1998. Renewable Energy Technologies – Current Status and Activities for their Development & Promotion in Pakistan. Proceeding of International Conference on Role of Renewable Energy Technology for Rural Development, Katmandu, Nepal.

17 https://www.waterinfo.net.pk/sites/default/files/knowledge/Portable%20and%20Environment%20Friendly%20Digester%20for%20Biogas%20Generation.pdf

18 Liao, X., Li, H., 2015. Biogas production from low-organic-content sludge using a high-solids anaerobic digester with improved agitation. Appl. Energy 148, 252– 259.




**Source**: [19]

**Step 3:** Mix the excess biofilm sludge and the primary sludge and thicken the same with polyacrylamide. Once again dewater the sludge using a centrifugator

**Step 4:** Inoculum to be added to convert solid waste to liquid effluent

This design of AD system could be used to increase the volumetric yield of biogas and enhancement biodigester treatment capability; however, the rate of organic degradation and treatment duration are same as that of conventional Anaerobic digesters.

## 5.5 Conclusion



The present research was an attempt to examine the benefits of domestic bio-digester feedstock water content optimisation for biodigester plants in Ireland wherein the researcher considered the findings to provide more technical benchmarks towards enhancing the performance of biodigester plants in Pakistan, a developing nation which has better prospects for renewable energy resources. As renewable energy has become the need of the hour, extent literature has examined the ways of optimising biodigester plants; however, there is lack of information especially in the Irish context to examine the ways of improving dry matter content in biodigesters and how the same affects the production of biogas. The collected samples were examined based on their FOS TAC ratio which is the measure of biogas production of a biodigester plant. The findings of the research revealed that biogas production in the select local biodigester plant was not optimal due to reduced dry matter content. However, to improve dry matter content two solutions were suggested by the researcher: import feedstock from other locations which have less water content (however an implication of such an act is that when feedstock is imported from various destinations of the world, the waste management system in Ireland completely collapses; furthermore, this add ups as a financial burden to local plants which operate on a small scale basis). However, the second

[19] http://www.watermaxim.co.uk/biological-aerated-filter.php

solution would be improve the dry matter content in the feedstock through dewatering techniques. Furthermore, the researcher has suggested the various dewatering techniques based on their cost and complexity in implementing in the biodigester plant.

Considering the ways of improving biogas production in Ireland led the researcher to provide ample recommendations for optimising biogas production for the developing nations. The researcher selected Pakistan based on the nation's interests in improving its renewable energy base. The researcher recommends the implementation of HSAD systems which has reduced water content and increased dry matter in the biodigester tanks thereby improving production efficiency.

## 5.6 Recommendations for future researches

The present study is a novel addition to the research community as the researcher has examined the need for optimising water content in the feedstock for improved biogas production. Data collected from Ireland was analysed which led to the conclusion that FOS/ TAC ratio increases with increasing dry matter content. However, there could be other parameters which were not considered in the research due to lack of availability of data. Future researchers can consider other parameters that impact biogas production and the ways of optimising them. Furthermore, future researches should consider the different AD systems used in developed and developed nations and can develop a AD system which can have better energy output considering all the AD systems used in the developed and developing nations.



## References

Abbassi-Guendouz, A., Brockmann, D., Trably, E., Dumas, C., Delgenès, J.-P., Steyer, J.-P. & Escudié, R. (2012). Total solids content drives high solid anaerobic digestion via mass transfer limitation. *Bioresource Technology*. [Online]. 111. pp. 55–61. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0960852412002258.

Abdoun, E. & Weiland, P. (2009). Optimization of monofermentation fromrenewable raw materials by the addition of trace elements. *Bornimer Agrartechnische Berichte*. 68. pp. 69–78.

Achinas, S., Achinas, V. & Euverink, G.J.W. (2017). A Technological Overview of Biogas Production from Biowaste. *Engineering*. [Online]. 3 (3). pp. 299–307. Available from:

http://linkinghub.elsevier.com/retrieve/pii/S2095809917304228.

AgSTAR (2012). *U.S. Anaerobic Digester Status: A 2011 Snapshot*. [Online]. 2012. Landcan. Available from: https://www.landcan.org/pdfs/2011_digester_update.pdf. [Accessed: 24 October 2017].

Alvarez-Gallego, C. (2005). *Testing different procedures for the startup of a dry anaerobic Co-digestion process of OFMSW and sewage sludge at thermophilic range*. University of Cádiz.

Amjid, S.S., Bilal, M.Q., Nazir, M.S. & Hussain, A. (2011). Biogas, renewable energy resource for Pakistan. *Renewable and Sustainable Energy Reviews*. 15. pp. 2833–2837.

Angelidaki, I., Alves, M., Bolzonella, D., Borzacconi, L., Campos, J.L., Guwy, A.J., Kalyuzhnyi, S., Jenicek, P. & van Lier, J.B. (2009). Defining the biomethane potential (BMP) of solid organic wastes and energy crops: a proposed protocol for batch assays. *Water Science & Technology*. [Online]. 59 (5). p.p. 927. Available from: http://wst.iwaponline.com/cgi/doi/10.2166/wst.2009.040.

Angelonidi, E. & Smith, S.R. (2015a). A comparison of wet and dry anaerobic digestion processes for the treatment of municipal solid waste and food waste. *Water and Environment Journal*. [Online]. 29 (4). pp. 549–557. Available from: http://doi.wiley.com/10.1111/wej.12130.

Angelonidi, E. & Smith, S.R. (2015b). A comparison of wet and dry anaerobic digestion processes for the treatment of municipal solid waste and food waste. *Water and Environment Journal*. 29 (4). pp. 549–557.

Appels, L., Lauwers, J., Degrève, J., Helsen, L., Lievens, B., Willems, K., Van Impe, J. & Dewil, R. (2011). Anaerobic digestion in global bio-energy production: Potential and research challenges. *Renewable and Sustainable Energy Reviews*. [Online]. 15 (9). pp. 4295–4301. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1364032111003686.

Bacenetti, J., Negri, M., Fiala, M. & González-García, S. (2013). Anaerobic digestion of different feedstocks: Impact on energetic and environmental balances of biogas process. *Science of The Total Environment*. [Online]. 463–464. pp. 541–551. Available from:



http://linkinghub.elsevier.com/retrieve/pii/S0048969713007109.

Batstone, D.., Keller, J., Angelidiaki, I., Kalyuzhnyi, S.., Pavlostathis, S.G.Rozzi, A., Sanders, W.T.., Siegrist, H. & Vavlin, V.. (2001). *Anaerobic Digestion Model No 1; IWA Task Group for Mathematical Modelling of Anaerobic Digestion Process*. London: IWA Publishing.

Beevi, S. (2015). *A Study of Single Stage Semi-Dry Anaerobic Digestion of Organic Fraction of Municipal Solid Waste*. [Online]. Cochin University. Available from: https://dyuthi.cusat.ac.in/xmlui/bitstream/handle/purl/5027/Dyuthi-2093.pdf;sequence=1.

Bobeck, M. (2010). *Organic Household Waste in Developing Countries*. [Online]. Mid Sweden University. Available from: http://miun.diva-portal.org/smash/get/diva2:321886/FULLTEXT01.pdf.

Bogner, J., Pipatti, R., Hashimoto, S., Diaz, C., Mareckova, K., Diaz, L., Kjeldsen, P., Monni, S., Faaij, A., Gao, Q., Zhang, T., Ahmed, M.A., Sutamihardja, R.T.M., Gregory, R. & Intergovernmental Panel on Climate Change (IPCC) Working Group III (Mitigation) (2008). Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Working Group III (Mitigation). *Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA*. [Online]. 26 (1). pp. 11–32. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18338699.

Bond, T. & Templeton, M.R. (2011). History and future of domestic biogas plants in the developing world. *Energy for Sustainable Development*. [Online]. 15 (4). pp. 347–354. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0973082611000780.

Borjesson, P. & Mattiasson, B. (2008). Biogas as a resource-efficient vehicle fuel. *Trends in Biotechnology*. [Online]. 26 (1). pp. 7–13. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0167779907002910.

Boske, J., Wirth, B., Garlipp, F., Mumme, J. & Van den Weghe, H. (2015). Upflow anaerobic solid-state (UASS) digestion of horse manure: Thermophilic vs. mesophilic performance. *Bioresource technology*. [Online]. 175. pp. 8–16. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25459798.

Caputo, A.C., Palumbo, M., Pelagagge, P.M. & Scacchia, F. (2005). Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. *Biomass and Bioenergy*. [Online]. 28 (1). pp. 35–51. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0961953404001205.

Chapman, D. (1992). *Water quality assessments. A guide to the use of biota, sediments and water in environmental monitoring*. London: Chapman & Hall.

Chaudhary, B.K. (2008). *Dry continuous anaerobic digestion of municipal solid waste in thermophilic conditions*. [Online]. Asian Institute of Technology. Available from: http://faculty.ait.ac.th/visu/public/uploads/Data/AIT-Thesis/Master Thesis final/Binod.pdf.

Chawla, O. (1986). *Advances in biogas technolog*. New Delhi: Publications and Information Division, Indian Council of Agricultural Research.

Cheng, S., Li, Z., Mang, H.-P., Huba, E.-M., Gao, R. & Wang, X. (2014). Development and application of prefabricated biogas digesters in developing countries. *Renewable and Sustainable Energy Reviews*. [Online]. 34. pp. 387–400. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1364032114001968.

Choorit, W. & Wisarnwan, P. (2007). Effect of temperature on the anaerobic digestion of palm oil mill effluent. *Electronic Journal of Biotechnology*. [Online]. 10 (3). pp. 0–0. Available from: http://www.ejbiotechnology.info/content/vol10/issue3/full/7/index.html.

Cioabla, A., Ionel, I., Dumitrel, G.-A. & Popescu, F. (2012a). Comparative study on factors affecting anaerobic digestion of agricultural vegetal residues. *Biotechnology for Biofuels*. [Online]. 5 (1). p.p. 39. Available from: http://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/1754-6834-5-39.

Cioabla, A., Ionel, I., Dumitrel, G.-A. & Popescu, F. (2012b). Comparative study on factors affecting anaerobic digestion of agricultural vegetal residues. *Biotechnology for Biofuels*. 5 (1). p.p. 39.



CPCB (n.d.). *Selection Criteria of Waste Processing Technologies*. [Online]. Available from: http://www.cpcb.nic.in/upload/Latest/Latest_125_SW_treatment_Technologies.pdf. [Accessed: 30 October 2017].

Cuellar, A.D. & Webber, M.E. (2008). Cow power: the energy and emissions benefits of converting manure to biogas. *Environmental Research Letters*. [Online]. 3 (3). p.p. 34002. Available from: http://stacks.iop.org/1748-9326/3/i=3/a=034002?key=crossref.6a924fab7181eab98db9af39ec5ac756.

Demirbas, M.F., Balat, M. & Balat, H. (2009). Potential contribution of biomass to the sustainable energy development. *Energy Conversion and Management*. [Online]. 50 (7). pp. 1746–1760. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0196890409000946.

Demirer, G.N. & Chen, S. (2005). Anaerobic Digestion of Dairy Manure in a Hybrid Reactor with Biogas Recirculation. *World Journal of Microbiology and Biotechnology*. [Online]. 21 (8–9). pp. 1509–1514. Available from: http://link.springer.com/10.1007/s11274-005-7371-6.



Den, J. (2016). *Bioenergy for Electricity Generation*. [Online]. The University of Texas at Austin. Available from: https://cns.utexas.edu/images/CNS/Jen_Den-Bioenergy.pdf.



Deng, Y., Xu, J., Liu, Y. & Mancl, K. (2014). Biogas as a sustainable energy source in China: Regional development strategy application and decision making. *Renewable and Sustainable Energy Reviews*. [Online]. 35. pp. 294–303. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1364032114002585.

Dincer, I. (2000). Renewable energy and sustainable development: a crucial review. *Renewable and Sustainable Energy Reviews*. [Online]. 4 (2). pp. 157–175. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1364032199000118.

Doelle K, O.F. (2015). Anaerobic Digestion of Food Waste to Produce Biogas: A Comparison of Bioreactors to Increase Methane Contact a Review. *Journal of Food Processing & Technology*. [Online]. 6 (8). Available from: https://www.omicsonline.org/open-access/anaerobic-digestion-of-food-waste-to-produce-biogas-a-comparison-of-bioreactors-to-increase-methane-contenta-review-

2157-7110-1000478.php?aid=58850.

Drosg, B., Fuchs, W., Al Seadi, T. & Madsen, M. (2015). *Nutrient Recovery by Biogas Digestate Processing; IEA Bioenergy*. Paris: IEA.

E-MFP (2014). *Domestic Biodigester*. [Online]. 2014. E-MFP. Available from: http://www.e-mfp.eu/sites/default/files/resources/2014/11/Domestic Biodigester_2014_web.pdf. [Accessed: 30 October 2017].

Energy.Gov (2017). *Biomass Feedstocks*. [Online]. 2017. Energy.Gov. Available from: https://www.energy.gov/eere/bioenergy/biomass-feedstocks. [Accessed: 30 October 2017].

Energypedia (2015). *Parameters and Process Optimisation for Biogas*. [Online]. 2015. Available from: https://energypedia.info/wiki/Parameters_and_Process_Optimisation_for_Biogas#Reduction_of_the_Moisture_Content. [Accessed: 30 October 2017].

FAO (1996). *"Biogas Technology: A Training Manual for Extension*. [Online]. 1996. Consolidated Management Services Nepal (P) Ltd. Available from: http://www.fao.org/docrep/008/ae897e/ae897e00.htm. [Accessed: 30 October 2017].

FAO (1997). *A system approach to biogas technology*. [Online]. 1997. Wcasfmra. Available from: http://www.wcasfmra.org/biogas_docs/Sustainable Biogas 1997.pdf. [Accessed: 24 October 2017].

Fdez.-Güelfo, L.A., Álvarez-Gallego, C., Sales Márquez, D. & Romero García, L.I. (2011). Dry-thermophilic anaerobic digestion of simulated organic fraction of Municipal Solid Waste: Process modeling. *Bioresource Technology*. 102 (2). pp. 606–611.

Fehrenbach, H. (2007). Criteria for sustainable bioenergy use on a global scale. In: *Nature Conservation and Agriculture in Dialogue: 'Biomass Production - A Blessing for the Land (Economy)?' Conference at the Federal Office for Nature Conservation*. 2007, Island: International Nature Conservation Academy, pp. 118–130.

Fernández, J., Pérez, M. & Romero, L.I. (2008). Effect of substrate concentration on dry mesophilic anaerobic digestion of organic fraction of municipal solid waste (OFMSW).



*Bioresource Technology*. 99 (14). pp. 6075–6080.

Fernández, J., Pérez, M. & Romero, L.I. (2010). Kinetics of mesophilic anaerobic digestion of the organic fraction of municipal solid waste: Influence of initial total solid concentration. *Bioresource Technology*. [Online]. 101 (16). pp. 6322–6328. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0960852410005237.

Fernández-Rodríguez, J., Pérez, M. & Romero, L.I. (2013). Comparison of mesophilic and thermophilic dry anaerobic digestion of OFMSW: Kinetic analysis. *Chemical Engineering Journal*. [Online]. 232. pp. 59–64. Available from: http://linkinghub.elsevier.com/retrieve/pii/S138589471300973X.

Ferrara, L., Iannace, M., Patelli, A.M. & Arienzo, M. (2013). Geochemical survey of an illegal waste disposal site under a waste emergency scenario (Northwest Naples, Italy). *Environmental Monitoring and Assessment*. 185 (3) pp. 2671–2682.

Food and Agriculture Organization of the United Nations (2010). *Bioenergy and Food Security: The BEFS Analytical Framework*. Environment and Natural Resources Management Series. [Online]. Rome: Food and Agriculture Organization of the United Nations. Available from: http://www.fao.org/docrep/013/i1968e/i1968e.pdf.



Foreest, F. Van (2012). *Perspectives for biogas in Europe*. Oxford, United Kingdom: Oxford Institute for Energy Studies.

Garfí, M., Ferrer-Martí, L., Villegas, V. & Ferrer, I. (2011). Psychrophilic anaerobic digestion of guinea pig manure in low-cost tubular digesters at high altitude. *Bioresource Technology*. [Online]. 102 (10). pp. 6356–6359. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0960852411003464.

Ghimire, P. (2007a). *Technical Study of Biogas Plants Installed*. [Online]. 2007. Netherlands Development Organisation. Available from: file:///C:/Users/1040/Downloads/2-5-11-614.pdf. [Accessed: 24 October 2017].

Ghimire, P.C. (2007b). *Final Report on Technical Study of Biogas Plants Installed in Pakistan*. [Online]. 2007. Netherlands Development Organisation. Available from: http://www.bibalex.org/Search4Dev/files/338859/172360.pdf. [Accessed: 24 October 2017].

Goswami, U. & Sarma, H.. (2007). Study of groundwater contamination due to municipal solid waste dumping in Guwahati city. *Pollution Research*. 26 (2). pp. 211–214.

Gripentrog, H., Barelli, D. & Csambalik, L. (2009). Economical and environmental analysis of a biogas plant within the context of a real farm. *The Royal Veterinary and Agricultural*. [Online]. 27 (1). pp. 163–73. Available from: http://jehsd.ssu.ac.ir/article-1-77-en.pdf.

Guendouz, J., Buffiere, P., Cacho, J., Carrere, M. & Delgenes, J. (2010). Dry anaerobic digestion in batch mode: Design and operation of a laboratory-scale, completely mixed reactor. *Waste Management*. 30 (10). pp. 1768–1771.

Hach Company (2015). *Determination of FOS/TAC Value in Biogas Reactors*. [Online]. 2015. Hach Company. Available from: https://www.hach.com/asset-get.download.jsa?id=29641556309. [Accessed: 17 November 2017].

Hartmann, H. & Ahring, B.K. (2005). Anaerobic digestion of the organic fraction of municipal solid waste: Influence of co-digestion with manure. *Water Research*. [Online]. 39 (8). pp. 1543–1552. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0043135405000618.



Hernández-Berriel, M.C., Márquez-Benavides, L., González-Pérez, D.J. & Buenrostro-Delgado, O. (2008). The effect of moisture regimes on the anaerobic degradation of municipal solid waste from Metepec (México). *Waste Management*. [Online]. 28. pp. S14–S20. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0956053X0800144X.

Holm-Nielsen, J.., Al Seadi, T. & Oleskowicz-Popiel, P. (2009). The future of anaerobic digestion and biogas utilization. *Bioresource Technology*. [Online]. 100 (22). pp. 5478–5484. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0960852408011012.

Howley, M., Holland, M. & Dineen, D. (2015). *Energy in Ireland: Key Statistics 2015*. [Online]. Ireland: Sustainable Energy Authority of Ireland. Available from: http://docplayer.net/36674822-Energy-in-ireland-key-statistics.html.

Hu, X. & Wang, J. (2010). Estimation of livestock greenhouse gases discharge in China. *Transactions of the Chinese Society of Agricultural Engineering*. 26 (10). pp. 247–252.

IFAS (2017). *Biogas: Feedstocks for Biogas Production*. [Online]. 2017. IFAS. Available from: http://biogas.ifas.ufl.edu/feedstocks.asp. [Accessed: 30 October 2017].

Jaber, N. & Noguchi, N. (2007). Literature Review of Recent Research on Biogas and its Usage in Diesel Engines. *Journal of JSAM*. [Online]. 69 (1). pp. 89–98. Available from: https://www.jstage.jst.go.jp/article/jsam1937/69/1/69_1_89/_pdf.

Jarvis, A., Nordberg, A., Jarlsvik, T., Mathisen, B. & Svensson, B.H. (1997). Improvement of a grass-clover silage-fed biogas process by the addition of cobalt. *Biomass and Bioenergy*. [Online]. 12 (6). pp. 453–460. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0961953497000159.

Jiang, X., Sommer, S.G. & Christensen, K. V. (2011). A review of the biogas industry in China. *Energy Policy*. [Online]. 39 (10). pp. 6073–6081. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0301421511005301.

Jingura, R. & Matengaifa, R. (2009). Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. *Renewable and Sustainable Energy Reviews*. 13. pp. 1116–1120.

Juanga, J.P. (2005). *Optimizing dry anaerobic digestion of organic fraction of municipal solid waste*. [Online]. Asian Institute of Technology. Available from: http://faculty.ait.ac.th/visu/public/uploads/images/pdf/2005/JeangerPJuanga.pdf.

Kamat, P. V. (2007). Meeting the Clean Energy Demand: Nanostructure Architectures for Solar Energy Conversion. *The Journal of Physical Chemistry C*. [Online]. 111 (7). pp. 2834–2860. Available from: http://pubs.acs.org/doi/abs/10.1021/jp066952u.

Kaparaju, P., Buendia, I., Ellegaard, L. & Angelidakia, I. (2008). Effects of mixing on methane production during thermophilic anaerobic digestion of manure: Lab-scale and pilot-scale studies. *Bioresource Technology*. [Online]. 99 (11). pp. 4919–4928. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0960852407007559.

Khalid, A., Arshad, M., Anjum, M., Mahmood, T. & Dawson, L. (2011). The anaerobic digestion of solid organic waste. *Waste Management*. [Online]. 31 (8). pp. 1737–1744. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0956053X11001668.

Kigozi, R., Aboyade, A. & Muzenda, E. (2014). Biogas Production Using the Organic Fraction of Municipal Solid Waste as Feedstock. *Journal of Research in Chemical, Metallurgical and Civil Engg*. [Online]. 1 (1). pp. 107–114. Available from: http://iieng.org/images/proceedings_pdf/8652E1113563.pdf.

Kjerstadius, H. (2017). *Enhancing anaerobic digestion in urban wastewater management*. [Online]. Lund University. Available from: http://portal.research.lu.se/ws/files/22098807/Ph.d._Thesis_without_papers_Hamse_Kjerstadius.pdf.

Kossmann, W., Pönitz, U., Habermehl, S., Hoerz, T., Krämer, P. & Klingler, B. (1999). *Biogas digest*. [Online]. 1999. Biogas. Available from: https://www.scopus.com/record/display.uri?eid=2-s2.0-84897394339&origin=inward&txGid=4a7de61eaff7fba223ef0104cfe8c395. [Accessed: 30 October 2017].

Kothari, R., Tyagi, V.V. & Pathak, A. (2010). Waste-to-energy: A way from renewable energy sources to sustainable development. *Renewable and Sustainable Energy Reviews*. [Online]. 14 (9). pp. 3164–3170. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1364032110001437.



Krich, K. (2005). *A Sourcebook for the Production and Use of Renewable Natural Gas in California*. [Online]. 2005. Available from: http://213.229.136.11/bases/ainia_agrobiomet.nsf/0/924924DF073CD292C12575130062328C/$FILE/California(USA).pdf. [Accessed: 2 November 2017].

Langholtz, M.., Stokes, B.. & Eaton, L.. (2016). 2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy. In: *Volume 1: Economic Availability of Feedstocks*. Oak Ridge: Oak Ridge National Laboratory.

Lay, J.., Li, Y.., Noike, T., Endo, J. & Ishimoto, S. (1997a). Analysis of environmental factors affecting methane production from high-solids organic waste. *Water Science and Technology*. [Online]. 36 (6–7). Available from: http://wst.iwaponline.com/content/36/6-7/493.

Lay, J.-J., Li, Y.-Y. & Noike, T. (1997b). Influences of pH and moisture content on the methane production in high-solids sludge digestion. *Water Research*. [Online]. 31 (6). pp. 1518–1524. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0043135496004137.

Leistritz, F.L., Hodur, N.. ., Senechal, D.M., Stowers, M.. ., McCalla, D. & Saffron, C.. . (2007). *Biorefineries Using Agricultural Residue Feedstock in the Great Plains*. [Online]. 2007. UMN. Available from: http://ageconsearch.umn.edu/bitstream/7323/2/ae070001.pdf. [Accessed: 30 October 2017].

Li, H., Li, C., Liu, W. & Zou, S. (2012). Optimized alkaline pretreatment of sludge before anaerobic digestion. *Bioresource Technology*. [Online]. 123 (2). pp. 189–194. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0960852412011856.

Lossie, U. & Putz, P. (2009). *Targeted control of biogas plants with the help of FOS/TAC*. [Online]. 2009. Science Open. Available from: https://www.scienceopen.com/document?vid=9d68043b-884f-4d73-afa2-c69ab288f7fe. [Accessed: 17 November 2017].

Majd, S.S., Abdoli, M.A. & Karbassi, A. (2017). Effect of Physical and Chemical Operating Parameters on Anaerobic Digestion of Manure and Biogas Production: A Review. *Journal of Environmental Health and Sustainable Development*. [Online]. 2 (1). pp. 235–47. Available from: http://jehsd.ssu.ac.ir/article-1-77-en.pdfQ.

Manahan S. E. (2005). *Environmental chemistry*. 8th Ed. Boca Raton, Florida: CRC Press LLC.

Manyi-Loh, C., Mamphweli, S., Meyer, E., Okoh, A., Makaka, G. & Simon, M. (2013). Microbial Anaerobic Digestion (Bio-Digesters) as an Approach to the Decontamination of Animal Wastes in Pollution Control and the Generation of Renewable Energy. *International Journal of Environmental Research and Public Health*. [Online]. 10 (9). pp. 4390–4417. Available from: http://www.mdpi.com/1660-4601/10/9/4390/.

Mao, C., Feng, Y., Wang, X. & Ren, G. (2015). Review on research achievements of biogas from anaerobic digestion. *Renewable and Sustainable Energy Reviews*. [Online]. 45. pp. 540–555. Available from:



http://linkinghub.elsevier.com/retrieve/pii/S1364032115001203.

Mata-Alvarez, J., Macé, S. & Llabrés, P. (2000). Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource Technology*. [Online]. 74 (1). pp. 3–16. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0960852400000237.

Matheri, A.N., Mbohwa, C., Ntuli, F., Belaid, M., Seodigeng, T., Catherine Ngila, J. & Kinuthia Njenga, C. (2017a). Waste to energy bio-digester selection and design model for the organic fraction of municipal solid waste. *Renewable and Sustainable Energy Reviews*. [Online]. 82. pp. 1113–1121. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1364032117313047.

Matheri, A.N., Mbohwa, C., Ntuli, F., Belaid, M., Seodigeng, T., Catherine Ngila, J. & Kinuthia Njenga, C. (2017b). Waste to energy bio-digester selection and design model for the organic fraction of municipal solid waste. *Renewable and Sustainable Energy Reviews*. 82. pp. 1113–1121.

Mezes, L., Bai, A., Nagy, D., Cinka, I. & Gabnai, Z. (2017). Optimization of Raw Material Composition in an Agricultural Biogas Plant. *Trends in Renewable Energy*. [Online]. 3 (1). pp. 61–75. Available from: http://futureenergysp.com/index.php/tre/article/view/31.

Morita, M. & Sasaki, K. (2012). Factors influencing the degradation of garbage in methanogenic bioreactors and impacts on biogas formation. *Applied Microbiology and Biotechnology*. [Online]. 94 (3). pp. 575–582. Available from: http://link.springer.com/10.1007/s00253-012-3953-z.

Nasir, I.M., Mohd Ghazi, T.I. & Omar, R. (2012). Production of biogas from solid organic wastes through anaerobic digestion: a review. *Applied Microbiology and Biotechnology*. [Online]. 95 (2). pp. 321–329. Available from: http://link.springer.com/10.1007/s00253-012-4152-7.

Nayono, S.E. (2010). *Anaerobic digestion of organic solid waste for energy production*. [Online]. Available from: file:///C:/Users/1040/Downloads/978-3-86644-464-5_pdfa.pdf.

Nizami, A., Korres, N. & Murphy, J. (2009). A review of the integrated process for the production of grass biomethane. *Environmental Science and Technology*. [Online]. 43. pp. 8496–508. Available from: https://www.scribd.com/document/210735075/Review-of-the-Integrated-Process-for-the-Production-of-Grass-Biomethane.

Oilgae (2017). *Anaerobic Digester - Definition, Glossary, Details - Oilgae*. [Online]. 2017. Oilgae. Available from: http://www.oilgae.com/ref/glos/anaerobic_digester.html. [Accessed: 30 October 2017].

Oreggioni, G., Gowreesunker, B., Tassou, S., Bianchi, G., Reilly, M., Kirby, M., Toop, T. & Theodorou, M. (2017). Potential for Energy Production from Farm Wastes Using Anaerobic Digestion in the UK: An Economic Comparison of Different Size Plants. *Energies*. [Online]. 10 (9). p.p. 1396. Available from: http://www.mdpi.com/1996-1073/10/9/1396.

Pillai, S., Peter, A.E., Sunil, B.M. & Shrihari, S. (2014). Soil Pollution near a Municipal Solid Waste Disposal Site in India. In: *International Conference on Biological, Civil and Environmental Engineering*. 2014, pp. 148–152.

Potts, L. & Martin, D. (2009). Anaerobic digestion, gasification, and pyrolysis. *Encyclopedia of Life Support Systems: Waste Management and Minimization*. [Online]. pp. 194–294. Available from: https://pdfs.semanticscholar.org/3c6d/83977df06b7324c847c19c262242985a43bb.pdf.

Qi, X., Zhang, S., Wang, Y. & Wang, R. (2005). Advantages of the integrated pig-biogas-vegetable greenhouse system in North China. *Ecological Engineering*. [Online]. 24 (3). pp. 175–183. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0925857404001454.

Rafique, R., Poulsen, T.G., Nizami, A.-S., Asam, Z.-Z., Murphy, J.D. & Kiely, G. (2010). Effect of thermal, chemical and thermo-chemical pre-treatments to enhance methane production. *Energy*. [Online]. 35 (12). pp. 4556–4561. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0360544210003750.

Rao, P. V, Baral, S.S., Dey, R. & Mutnuri, S. (2010). Biogas generation potential by anaerobic digestion for sustainable energy development in India. *Renewable and Sustainable Energy Reviews*. 14. pp. 2086–2094.



Rapport, J., Zhang, R., Jenkins, B.M. & Williams, R.B. (2008). *Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste*. [Online]. University of California. Available from: http://www.calrecycle.ca.gov/publications/Documents/1275/2008011.pdf.

Rehl, T. & Müller, J. (2011). Life cycle assessment of biogas digestate processing technologies. *Resources, Conservation and Recycling*. [Online]. 56 (1). pp. 92–104. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0921344911001686.

Resch, C., Braun, R. & Kirchmayr, R. (2008). The influence of energy crop substrates on the mass-flow analysis and the residual methane potential at a rural anaerobic digestion plant. *Water Science and Technology*. [Online]. 57 (1). p.p. 73. Available from: http://wst.iwaponline.com/cgi/doi/10.2166/wst.2008.733.

Rigby, H. & Smith, S.R. (2014). The nitrogen fertiliser value and other agronomic benefits of industrial biowastes. *Nutrient Cycling in Agroecosystems*. [Online]. 98 (2). pp. 137–154. Available from: http://link.springer.com/10.1007/s10705-014-9602-4.

RISE-AT (1998). *Review of current status of anaerobic digestion technology for treatment of municipal solid waste*. Chiang Mai University.



Sahir, M.H. & Qureshi, A.H. (2008). Assessment of new and renewable energy resources potential and identification of barriers to their significant utilization in Pakistan. *Renewable and Sustainable Energy Reviews*. [Online]. 12 (1). pp. 290–298. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1364032106000918.

Sakar, S., Yetilmezsoy, K. & Kocak, E. (2009). Anaerobic digestion technology in poultry and livestock waste treatment--a literature review. *Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA*. 27 (1). pp. 3–18.

Schnurer, A. & Jarvis, A. (2010). *Microbiological handbook for biogas plants 2010: Swedish Waste Management U2009*. [Online]. 2010. Researchgate. Available from: https://www.researchgate.net/publication/285684745_Microbiological_Handbook_for_Biogas_Plants. [Accessed: 30 October 2017].

Al Seadi, T., Rutz, D., Prassl, H., Köttner, M., Finsterwalder, T. & Volk, S. (2008). *Biogas* *handbook.* [Online]. Denmark. Available from: http://sci-hub.bz/10.1016/j.rser.2017.09.051.

Seai (2017). *Assessment of Cost and Benefits of Biogas and Biomethane in Ireland*. [Online]. 2017. Seai. Available from: https://www.seai.ie/resources/publications/Assessment-of-Cost-and-Benefits-of-Biogas-and-Biomethane-in-Ireland.pdf. [Accessed: 17 November 2017].

Senior, K. & Mazza, A. (2004). Italian 'Triangle of death' linked to waste crisis. *Lancet Oncology*. 5 (9). pp. 525–527.

Shanthi, P. & Natarajan, M. (2016). Anaerobic digestion of Municipal Solid biodegradable wastes for methane production: A Review. *International Journal for Research in Applied Science & Engineering Technology*. [Online]. 4 (7). pp. 208–215. Available from: http://www.ijraset.com/fileserve.php?FID=5935.

Sheikh, M.A. (2010). Energy and renewable energy scenario of Pakistan. *Renewable and Sustainable Energy Reviews*. 14. pp. 354–363.

Sorrell, S. (2015). Reducing energy demand: A review of issues, challenges and approaches. *Renewable and Sustainable Energy Reviews*. [Online]. 47. pp. 74–82. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1364032115001471.

Stover, T.R. (2011). *Anaerobic Digestion Optimization for Enhanced Renewable Biomethane Production*. [Online]. 2011. OK state. Available from: http://dc.library.okstate.edu/digital/collection/Dissert/id/72820/. [Accessed: 17 November 2017].

Sunarso, S., Johari, S., Widiasa, I.N. & Budiyono, B. (2012). The Effect of Feed to Inoculums Ratio on Biogas Production Rate from Cattle Manure Using Rumen Fluid as Inoculums. *International journal of Science and Engineering*. [Online]. 1 (2). Available from: http://ejournal.undip.ac.id/index.php/ijse/article/view/1233.

Surroop, D. & Mohee, R. (2011). Comparative assessment of anaerobic digestion of municipal solid waste at mesophilic and thermophilic temperatures. *International Journal of Environmental Technology and Management*. [Online]. 14 (1/2/3/4). p.p. 238. Available from: http://www.inderscience.com/link.php?id=39272.



Tambone, F., Scaglia, B., D'Imporzano, G., Schievano, A., Orzi, V., Salati, S. & Adani, F. (2010). Assessing amendment and fertilizing properties of digestates from anaerobic digestion through a comparative study with digested sludge and compost. *Chemosphere*. [Online]. 81 (5). pp. 577–583. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0045653510009422.

Tchobanoglous, G., Theisen, H. & Vigil, S. (1993). *Inte- grated Solid Waste Management: Engineering Principles and Management Issue*. Boston: McGraw-Hill.

Tsegaye, G. (2016). *Optimization of Biogas Production from Slaughterhouse Waste and Digester Sizing*. [Online]. Addis Ababa University. Available from: http://etd.aau.edu.et/bitstream/123456789/12563/1/Genet Tsegaye.pdf.

Tudelft (2017). *Bio Gas Digester*. [Online]. 2017. Tudelft. Available from: https://tudelft.openresearch.net/image/2017/1/22/bio_gas_digester.pdf. [Accessed: 18 November 2017].

Vieitez, E.., Mosquera, J. & Ghosh, S. (2000). Kinetics of accelerated solidstate fermentation of organic-rich municipal solid waste. *Water Science and Technology*. 41 (3). pp. 231–238.



Wang, X., Yang, G., Feng, Y., Ren, G. & Han, X. (2012). Optimizing feeding composition and carbon-nitrogen ratios for improved methane yield during anaerobic co-digestion of dairy, chicken manure and wheat straw. *Bioresource technology*. [Online]. 120. pp. 78–83. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22784956.

Ward, A.J., Hobbs, P.J., Holliman, P.J. & Jones, D.L. (2008a). Optimisation of the anaerobic digestion of agricultural resources. *Bioresource Technology*. [Online]. 99 (17). pp. 7928–7940. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0960852408001880.

Ward, A.J., Hobbs, P.J., Holliman, P.J. & Jones, D.L. (2008b). Optimisation of the anaerobic digestion of agricultural resources. *Bioresource technology*. [Online]. 99 (17). pp. 7928–40. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18406612.

Ward, A.J., Hobbs, P.J., Holliman, P.J. & Jones, D.L. (2008c). Optimisation of the anaerobic digestion of agricultural resources. *Bioresource technology*. 99 (17). pp. 7928–40.

Weiland, P. (2010). Biogas production: current state and perspectives. *Applied Microbiology and Biotechnology*. [Online]. 85 (4). pp. 849–860. Available from: https://link.springer.com/article/10.1007%2Fs00253-009-2246-7.

Wilkie, A.C. (2005). Anaerobic Digestion of Dairy Manure. In: *Dairy Manure Management: Treatment, Handling and Community Relations*. [Online]. Ithaca, NY, USA: Natural Resource, Agriculture, and Engineering Service, Cornell University, pp. 301–312. Available from: http://biogas.ifas.ufl.edu/Publs/NRAES176-p63-72-Mar2005.pdf.

Yadvika, Santosh, Sreekrishnan, T.R., Kohli, S. & Rana, V. (2004). Enhancement of biogas production from solid substrates using different techniques--a review. *Bioresource technology*. [Online]. 95 (1). pp. 1–10. Available from: http://www.ncbi.nlm.nih.gov/pubmed/15207286.