"BIOGAS GENERATION FROM SLUDGE CO-DIGESTED WITH PINE NEEDLES "

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

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IN

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Under the supervision of

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"BIOGAS GENERATION FROM SLUDGE CO-DIGESTED WITH PINE NEEDLES"** in partial fulfillment of the requirements for the award of the degree of Master of Technology in Civil Engineering with specialization in **" Environmental Engineering"** and submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Ankita Kumari** during a period from July 2016 to May 2017 under the supervision of **Dr. Ashish Kumar** , Associate Professor, Department of Civil Engineering and **Dr. Sudhir Kumar,** Associate Professor, , Department of Biotech & Bioinformatics, Jaypee University of Information Technology, Waknaghat, Solan.

The above statement made is correct to the best of our knowledge.

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ABSTRACT

The purpose of this research is to study co-digestion of sewage sludge and pine needles. When we talk about the major problems we are facing now days, we come across one of the most debatable problem of depletion of non- conventional energy sources. So, one should divert the attention to one of the economic alternative energy source, Biogas. Anaerobic digestion of sewage sludge and pine needles will alleviate a number of environmental concern associated with them. Biogas or Anaerobic digestion technology has become a reliable source of renewable energy in state of Himachal Pradesh, facing a large climatic variation. Anaerobic digestion can help to reduce the load on the landfill by recycling the organic material of sludge and reduce the number of pathogens. Co-digestion will help to maintain a nutrient balance in both substrate and increase the performance of biogas digester in low temperature range. The substrate were studied for their physico-chemical characteristics, such as pH, Total solids, Volatile Solids, Total Organic Carbon, Total Kjeldahl Nitrogen, organic matter and C/N. The Cellulose, Hemicellulose and Lignin content of pine needles were also determined. The batch study was done in two different anaerobic digesters AD1 and AD2 of 45 L which consist of sludge and mixture of sewage sludge and pine needles for a retention time of 70 days during winter season and its continuation in the summer season for 55 days .Initial and final values of slurry before and after degradation process of various physico-chemical parameters like pH, Total solids, Volatile Solids, Alkalinity, Chemical Oxygen Demand were analyzed. The result from the study shows that adding pine needles to the sewage sludge significantly increased the biogas production caused by balanced C/N ratio of the digester.

Keywords- Biogas, Sewage Sludge, Pine needles, Co-digestion, Kinetic Models.

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LIST OF ABBREVIATIONS

AD	*Anaerobic Digester*
AD1	*Digester slurry consist of sewage sludge*
AD2	*Digester slurry consisting of sewage sludge and pine needles.*
BOD	*Biological Oxygen Demand*
COD	*Chemical Oxygen Demand*
CPCB	*Central Pollution Control Board*
C/N	*Carbon to Nitrogen Ratio*
FS	*Fixed Solids*
HRT	*Hydraulic Retention Time*
OLR	*Organic Loading Rate*
STP	*Sewage Treatment Plant*
SRT	*Solid Retention Time*
TKN	*Total Kjeldahl Nitrogen*
TOC	*Total Organic Carbon*
TS	*Total Solids*
VS	*Volatile Solids*
VFA	*Volatile Fatty Acids*
WWTP	*Waste Water Treatment Plant*

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CHAPTER-1

INTRODUCTION

1.1 GENERAL

The worldwide energy demand is increasing energetically and it will grow by factor of two or three in coming years. As indicated by the International Energy Agency, petroleum products represented up to 77.7% of the world's essential vitality supply though sustainable power sources just contributed 22.3% [1]. So there is enormous need of substitution of these non-renewable energy sources like oil, oil, coal, petroleum gas and so on by a source which is inexhaustible, shoddy and also eco-accommodating. Biogas from waste, energy crops, litter , animal waste and human waste is one of economical vitality hotspot for creating nation like, India. It can be one of the solid choice utilized for substitution of petroleum derivatives in power and warmth generation, particularly in a nation like India where still today a large portion of the families rely on charcoal and fuel wood for their survival, which they finish by heedless tumbling down of the backwoods, prompting deforestation. It might radiate the harmful gases like CO_2 and CH_4 which additionally exhaust the ozone layer and may prompted a worldwide temperature alteration on the grounds that the consuming of the petroleum products delivers around 21.3 billion tons of CO_2 for each year, yet it is evaluated that regular procedures can ingest about portion of the sum, so there is a net increment of 10.65 billion tons of environmental CO_2 every year [2]. Mr. Piyush Goyal has given the accompanying data because of various inquiries that were brought up in New and Renewable Energy Ministry in the Lok Sabha on Biogas plants and the generation of Biogas the nation over." In 2011-15 around 20,757 lakh cubic meters of biogas is delivered in nation which is comparable to 5% of the aggregate LPG utilizations in a nation. This is comparable to 6.6 crore of local LPG chambers. Biogas plants can be a solid choice for in giving wellspring of sustainable power source from natural waste, in hilly state like Himachal Pradesh where 90% of the population is rural and the majority of the families rely on fuel wood for their household cooking needs [3]. As indicated by Forest Survey of India report, woods territory constitute 66.52% of the range of Himachal Pradesh. Subsequently it is required to discover best appropriate vitality sources from the inexhaustible biomass accessible.

As indicated by CPCB contemplates there are 269 STPs in India, out of which just 231 are operational. Metropolitan waste water administration is assessed 38254 million litres for each

day of wastewater which is created in urban areas and towns having population of more than 50,000 [4]. As a by-item Sewage sludge is made and has significant potential for use as a wellspring of vitality and supplements. The calorific estimation of the gas created in the digesters amid anaerobic adjustment adds up to roughly 6.5 kWh/m3. This compares with the greater part of the calorific estimation of petroleum gas (~10 kWh/m3) [5]. Sewage sludge is turning into an overall natural issue on account of its expanding creation and its high substance of natural waste and pathogens, and additionally xenobiotics and overwhelming metals. It might make colossal risk human, creatures, and condition if not being dealt with or arranged appropriately [6]. Anaerobic Digestion is the most established process which is utilized for the stabilization of the solids and the bio solids. It includes deterioration of both natural and inorganic matter present in the sewage without atomic oxygen. Promote it will meet the vast majority of the vitality prerequisite for the plant operation [6]. Sewage sludge have a low C/N proportion i.e. Nitrogen substance is high when contrasted with the Carbon content which may come about into arrival of ammonia generation and may repress biogas generation. Co-digestion of a few substrates increments biogas yield and enhances handle efficiency[7]. With co-processing the Carbon substance will give extra vitality which can disintegrate the natural matter legitimately and in a lesser maintenance time. The primary favorable position will that there will be more adjust of the supplements because of support of the adequate buffering limit by the sludge. In my present study the capability of methane generation from sewage sludge which is acquired from our own University Campus will be examined. Furthermore, facilitate co-digestion of sewage sludge was done with the pine needles. Pine needles are accepted to have high gas yield because of its enduring nature of biomass and high cellulose content so can be utilized as substrate. Pine needles are broadly accessible in Himachal Pradesh. As indicated by Forest Survey of India (FSI), 2011, Subtropical Pine Cover is 22.35 % which is equivalent to 3281 sq km [8]. Pine Needles are non-biodegradable like alternate biomass, highly–inflammable in nature, can't fill in as grain yet are notwithstanding, a great wellspring of biomass fuel [9]. This entire review is a lab scale study. What's more, further Cumulative Biogas Production rate were modelled using different equations like linear model, exponential equation, logistic kinetic model, exponential rise to maximum and modified Gompertz condition. The data was fitted into these conditions and different constants were determined using Non-Linear Regression technique.

1.2 BIOGAS

Biogas is formed when natural material is decayed with the assistance of microorganisms by a process called AD in an oxygen free condition with methane having high composition followed by carbon dioxide. Different microorganisms take an participation in an complex chain of interacting processes which result in the decay of complex organic compounds, for example, starches, fats and proteins otherwise called polymers to the last items methane and carbon dioxide. The typical composition of biogas is shown in table 1.1

Table-1.1 Composition of Biogas. Data Source [10]

S. No.	Typical Biogas Composition	Concentration in terms of volume (%)
1.	**Methane (CH_4)**	55 to 60 %
2.	**Carbon dioxide (CO_2)**	35 to 40 %
3.	**Water (H_2O)**	2 to 7 %
4.	**Hydrogen sulphide (H_2S)**	2%
5.	**Ammonia (NH_3)**	0 to 0.05 %
6.	**Nitrogen (N)**	0 to 2 %
7.	**Oxygen (O_2)**	0 to 2 %
8.	**Hydrogen (H)**	0 to 1 %

This procedure happens normally in conditions where there is restricted access to oxygen, for instance in lowlands and swamps like marshy areas, rice paddies and in the stomach of ruminants, for example, bovines where methane content is generally high. This natural procedure is exploited in a biogas plant, where natural material, for example, sludge from WWT plants or STP, or IWWT plants , fertilizer like dairy animals excrement, different energy yield crops and food waste is pumped inside digester . Raw biogas is formed finally, which essentially comprises of methane and carbon dioxide as significant segment, additionally trace amount of nitrogen gas, ammonia and hydrogen sulphide are also formed which are toxic and inhibit the rate of production. Biogas is frequently saturated with water vapour and along with addition to biogas, a supplement-rich digestion residue is additionally formed after complete digestion process that can is used as a fertilizer by the different agriculturists. The digestion residue obtained from digestion slurry after complete process is rich in N, P, K i.e. Nitrogen, Phosphorus and Potassium. When biogas is compared with air, biogas is generally found to be lighter, so in case like when a leakage occurs through digester, methane ascends through the surrounding air. Biogas generally has a higher temperature of ignition as compared to petrol and diesel, which is useful to reduce the risk of fires and

explosions at mishaps. The gas tank should have robust construction so that it gives a larger resilience to various stresses than conventional petrol tanks [9]. The smell of biogas is just similar to smell of hydrogen sulphide just like rotten or bad egg. These are the properties distinguish biogas from other gases and it is cheap and economical to use, eco-friendly, effective and easy to handle. The typical details of biogas are further described in table given below [10].

TABLE 1.2 Typical details of biogas .Data Source [10]

S.NO	Various Parameter	Typical Details
1	**Typical Composition**	55-70% methane, 30-45% carbon dioxide, traces amount of other gases
2	**Energy content**	6.0-6.5 kWm^{-3}
3	**Fuel equivalent**	0.6-0.65 L oil/m^3 biogas
4	**Explosion limits**	6-12% biogas in air
5	**Ignition temperature**	650-750 ^{O}C
6	**Critical pressure**	75-89 bar
7	**Critical temperature**	-82.5 ^{O}C
8	**Normal density**	1.2 kg/m^{-3}
9	**Odour**	Bad eggs (similar to smell of hydrogen sulphide)

1.2.1 Overview of various Biogas components

Typical components and impurities in biogas present in the biogas are described below are listed in Table 1.3

1. Methane and carbon dioxide: These constitutes major constituent of biogas composition and it depends upon the following various factors such as mentioned given below:

a. The amount of long-chain hydrocarbon compounds present.

b. Longer the retention time greater will be the anaerobic degradation of various biomass which are rich in organic matter.

c. The material inside the bioreactor should be well stirred and homogenous in nature so that fermentation takes place at faster rate and when the fluid content in the reactor is higher than the level of CO_2 in the gas phase decreases and the higher temperature and the higher pressure causes higher dissolved level of CO_2 in the water and more over the organic substrate should be well prepared.

d. When the substrate is well enclosed in lignin structures then the type of disintegration is important.

2. Nitrogen and oxygen: Biogas contains a ratio of 4:1 of nitrogen and oxygen. However, when the sufficient ventilation is present then the sulfide is removed and if the gas pipes are not fully tight and there are chances of any leakage , then this ratio can be changed.

3. Carbon monoxide: It is under the detection limit of 0.2% in terms of volume.

4. Ammonia: Generally the level of ammonia is very low. It may exceed 1.5 mg m^{-3} when a high amount of nitrogen rich substrates are used in the digesters [11].

Table 1.3 Typical details of impurities in biogas. Data Source [11]

S. No	Component	Content (% volume)	Effect
1	**CO_2**	25-50%	• It lowers the calorific value. • Increases the methane number and the anti-knock properties of the engines and it causes corrosion i.e. low concentrated carbon acid. If the gas is wet and damages alkali fuel cells.
2	**H_2S**	0-0.5%	• It has Corrosive effect on equipment and piping systems therefore many manufacturers of engines set an upper limit of 0.05% by vol. • SO_2 emissions after burners or H_2S emissions with imperfect combustion. • Upper limit 0.1% by volume and it spoils catalysts.
3	**NH_3**	0-0.5%	• It causes NOx emissions after burners damage fuel cells and increases the various anti-knock properties of the engines.
4	**Water vapour**	1-5%	• It causes corrosion of equipment and piping system. It Condensates damage instruments and plants. • There may be risk of freezing of piping systems and nozzles
5	**Dust**	>5μm	• It blocks the nozzles and fuel cells.
6	**N_2**	0-5%	• It lowers the calorific value and enhances the anti-knock properties of engines.
7	**Siloxanes**	0-50 mg m^{-3}	• It acts like an abrasive and damages engines.

5. Hydrogen sulphide : Its concentration depends on the process and type of the waste. The concentration of H_2S may exceed 0.2% by volume without desulfurizing step. Due to the harmful effects on plant components downstream, it should be kept at the lowest level possible. So for this reason biogas is always desulfurized when it is still in the reactor.

6. Chlorine, fluorine and mercaptans: The concentration of these components is below the detection limit of 0.1mg m^{-3}.

7. BTX, PAK, etc.: Except toluene, generally the concentrations of benzene, toluene, ethyl benzene, xylene and cumene are under the detection limit of 0.1mg m^{-3} and these special wastes are responsible for high concentration of toluene.

8. Siloxanes: High concentrations of siloxanes are carried over into the sewage gas. At high temperatures, siloxanes and oxygen form SiO2 which remains on the surface of the machine and cause a decline in the flow levels [11].

1.2.2 Substrate - the raw material for biogas production

Organic materials which are suitable for substrates in the biogas production process are sewage sludge from the WWT plants, food wastes from households and restaurants, manure like cow dung, different plant residues and process waters from various food industries. Co-digestion of two different materials has advantage of higher methane production, that is the produced amount of biogas per unit of organic matter fed into the digester is greater than when individual substrate is digested separately[12].

Table 1.4 Organic materials with potential for methane generation. Data source [12]

S.NO	Waste	Organic material
1.	**Crop waste**	Sugarcane thrash, weeds, corn and related stubble, straw, spoiled fodder.
2.	**Animal waste**	Cattle shed waste, poultry litter, sheep and goat droppings, slaughter house waste, fishery waste, leather,wool waste.
3.	**Human waste**	Faeces, urine, refuse (night soil).
4.	**Agriculture based industry**	Oil cakes, bagasse, rice brass, tobacco wastes and seeds, wastes from fruit and vegetable processing, press mud from sugar industry.
5.	**Forest litter**	Twigs, bark, tree branches, tree and plant leaves.

6.	**Aquatic plants**	Marine algae, sea weeds, water hyacinths.

Biomass which contains carbohydrates, proteins, fats, cellulose as the major components, can be used for biogas production. The necessary information needed for substrate selection are :

1. Substrates are selected depending upon contents present in them.

2. Higher the nutritional value of substrate higher will be the biogas generation.

3. Substrate should not consist of any harmful pathogen and harmful substances should be in trace amounts so that enough stability is maintained inside digester.

4. Biogas residue should be used for other applications and can be used as fertilizer as it is rich in macro nutrients such as N, P, and K [11].

1.2.3 Advantages of Biogas

1) It is renewable energy source and reduces waste in landfill, dump sites and various farms all over the world.

3) It is also non-polluting in nature because of oxygen free environment resources are not using any more fuel.

4) It creates job opportunities for many people in rural areas.

5) It is low in price i.e. economical technology. It can be used for generation of electricity. CNG biogas which is compressible in nature can be used as fuel for Automobile.

6) The use of landfill gas in the form of energy production can reduce greenhouse effect and are easy to set up and needs little investment on a very small scale [13-14].

1.2.4 Disadvantages of Biogas

1) Little new technology is used for simplification of the process.

2) It consist of a number of impurities even after refining processes and is generally unsustainable, and prone to explosion if the methane comes in contact with oxygen and flammable nature has become.

4) The use of biogas on a large scale is not economically capable of working successfully [13-14].

1.3 QUALIFICATIONS OF ORGANIC MATERIAL AS A SUBSTRATE

The availability of the main parameters like carbon (C) and nitrogen (N) are required for the qualification as a substrate. The carbon acts as energy source while nitrogen will affect the growth rate of micro-organisms and in order to speculate how uninterrupted and effective the biogas process will become, the C/N-ratio should be determined. It will describe the

relationship with context to Carbon and Nitrogen present in the organic matter and different material have different Carbon availability hence the ratio is not always but in case of sewage sludge fractions and organic household waste the amount of carbon can be easily accessed. A ratio of around 20:30 is needed by the micro organisms. Excess of nitrogen i.e. ratio over 10-15 might lead to increase in ammonium accumulation and can be toxic and in case there is deficiency of Nitrogen i.e. ratio above 30, it will take longer retention time to break down the material. By using values for TOC and TKN, the C/N-ratio of substrate can be determined. With the digestion process the C/N-ratio decreases in the sludge because carbon is released as methane (CH_4) and carbon dioxide (CO_2). To keep the stability of biogas process either carbon need to be added or nitrogen need to be removed and relative deficiencies in the nutrient ratio of various types of organic substrates can be rectified by the process of co-digestion, which means that two different substrates are added, mixed and are digested together in one digester [15].

1.3.1 SEWAGE SLUDGE AS A SUBSTRATE:

From last few years sludge is widely used as an important source and substrate for the biogas production and it will increase the performance of digester and will help in promoting energy efficiency and will reduce the cost of STP i.e. 50 % of running fee for a municipal wastewater treatment plant [16]. Sewage sludge is abundant organic waste or by product generated in WWTP facilities after primary and secondary treatment processes [17].

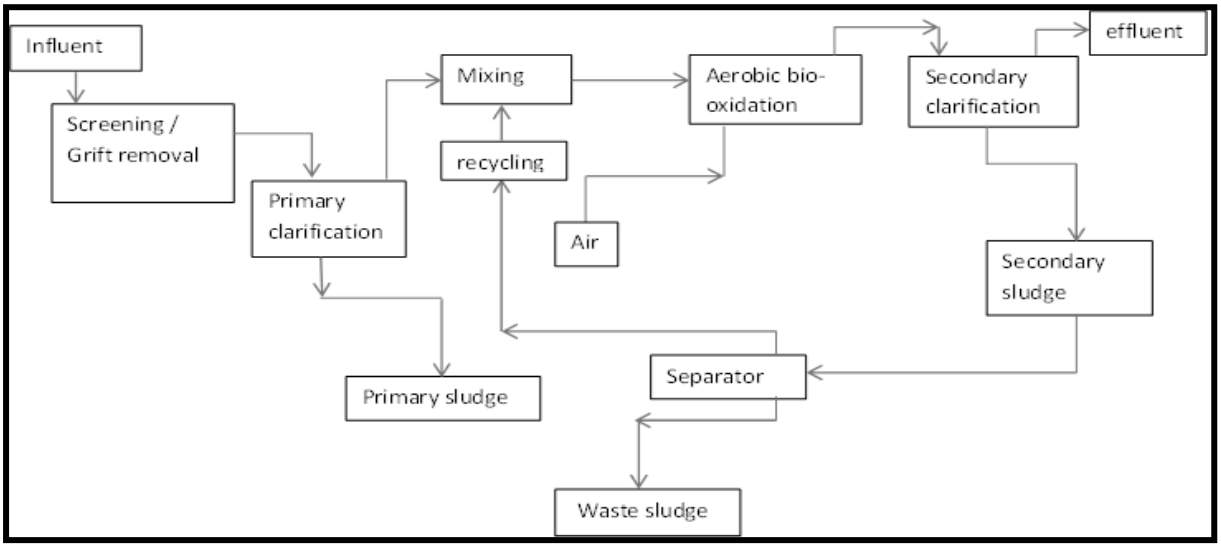

Fig. 1.1: Schematic Diagram of a conventional municipal WWT plant. Data Source [17]

1.3.1.1 Different Types of Sludge:

The characteristic of the sludge vary from place to place and depends mostly on the origin

e.g. Treatment of industrial, domestic or drinking water and technical parameters that are used in each treatment plant. Sewage sludge can be divided into different types according to the conventional treatment process.

Primary sludge*:* The sludge is obtained after the primary treatment, generally physical or chemical processes to screen suspended particles, large and dense particles e.g. solids, grease and scum. It removes about 50-70% of suspended particles. It has a low level of Volatile Solids content (VS around 55% to 60%). This type of sludge ferments very easily inside the digester.

Secondary sludge: It is also known as activated sludge and is generated from the biological treatment of wastewater and it uses a mixture of living microorganisms like bacteria, that will break down the organic material and contaminants that remain after the primary treatment.

Mixed sludge: It is a mixture of primary and secondary sludge prior to sludge treatment.

Digested sludge: It is also known as secondary or mixed sludge that has gone through a biological stabilizing process known as digestion. This digestion can be done under different temperatures that can be mesophillic or thermophillic and in aerobic or anaerobic conditions. It is less odorous, reduced in mass, reduced in pathogens and is more easily dewatered as compared to other [16].

1.3.1.2 Constituents present in the sewage sludge:

A wide variety of organic and inorganic compounds like detergents, pesticides, fats, oil and grease, colourings, solvents, phenols etc. are present in the waste water. The sewage sludge constituents are shown in Table 1.2. Recent restrictions on the use of sewage sludge, however, have resulted in increased disposal problems and separation of lipids from waste water or sludge yields a fruitful source of cheap feed stock for biodiesel production. Its viable alternative to sludge management and disposal challenge is to utilize the sludge as a source for bio fuel production [17].

TABLE 1.5: Constituents present in the sewage sludge

S.NO	Inorganic compounds	Various Constituents present
1	Microorganisms	Pathogenic bacteria, virus and worms eggs.
2	Biodegradable organic materials	Oxygen depletion in rivers, lakes.
3	Other organic materials	Detergents, pesticides, fat, oil and grease, colourings, solvents, phenols, cyanide
4	Nutrients	Nitrogen, phosphorus, ammonium
5	Heavy Metals	Hg , Pb , Cd , Cr, Cu, Ni

6	Other inorganic materials	Acids, for example hydrogen sulphide, bases

1.3.2 Pine needles as substrate

Lignocelluloses - containing biomasses, as for example pine needles (*pinus roxburghi),* are not fermentable in a biogas plant without special pre-treatment or co-digestion. They must be disintegrated thermally and chemically so that they can be biodegraded easily. Today, pine needles are often burned in forests without any energy recovery, in spite of burning we can use pine needles in fermentation because burning will only lead to release of harmful gases but fermentation will make some substantial contribution to the power supply. The energy - efficient fermentation of pine needles, seems to be a great idea for developing countries like India and would be more economic and would contribute to environmental protection. The fermentation of pine needles is possible without any additives but it takes longer time to ferment it so it is preferred to ferment it with sludge as co- substrate so that fermentation runs off more stably and biogas production can be increased [18].

1.4 ANAEROBIC DIGESTION

AD is one of the oldest process. Energy crises in 1970 renewed the interest in AD when there was increase in the rates of petroleum products and it can be used for handle almost any type of biodegradable organic materials such as plant and animal waste, cow manure, waste paper, grass crippling, leftover food, solids and bio solids [19].

AD is a biological process in which organic material of a substrate is degraded by microorganisms in a oxygen free environment. As a result methane, carbon dioxide and some small quantities of H_2S, H_2 and NH_3 are formed. The composition of the biogas is dependent on the type of digested material and the functioning parameters of the process [16].

The main features of AD process which differentiates it from other processes are:

1. Mass or volume reduction.
2. Biogas production
3. Improved dewatering properties of the treated sludge.

There are four key biological or we can say that chemical steps of AD process:

1. Hydrolysis stage
2. Acidogenesis stage
3. Acetogenesis stage

4. Methanogenesis stage

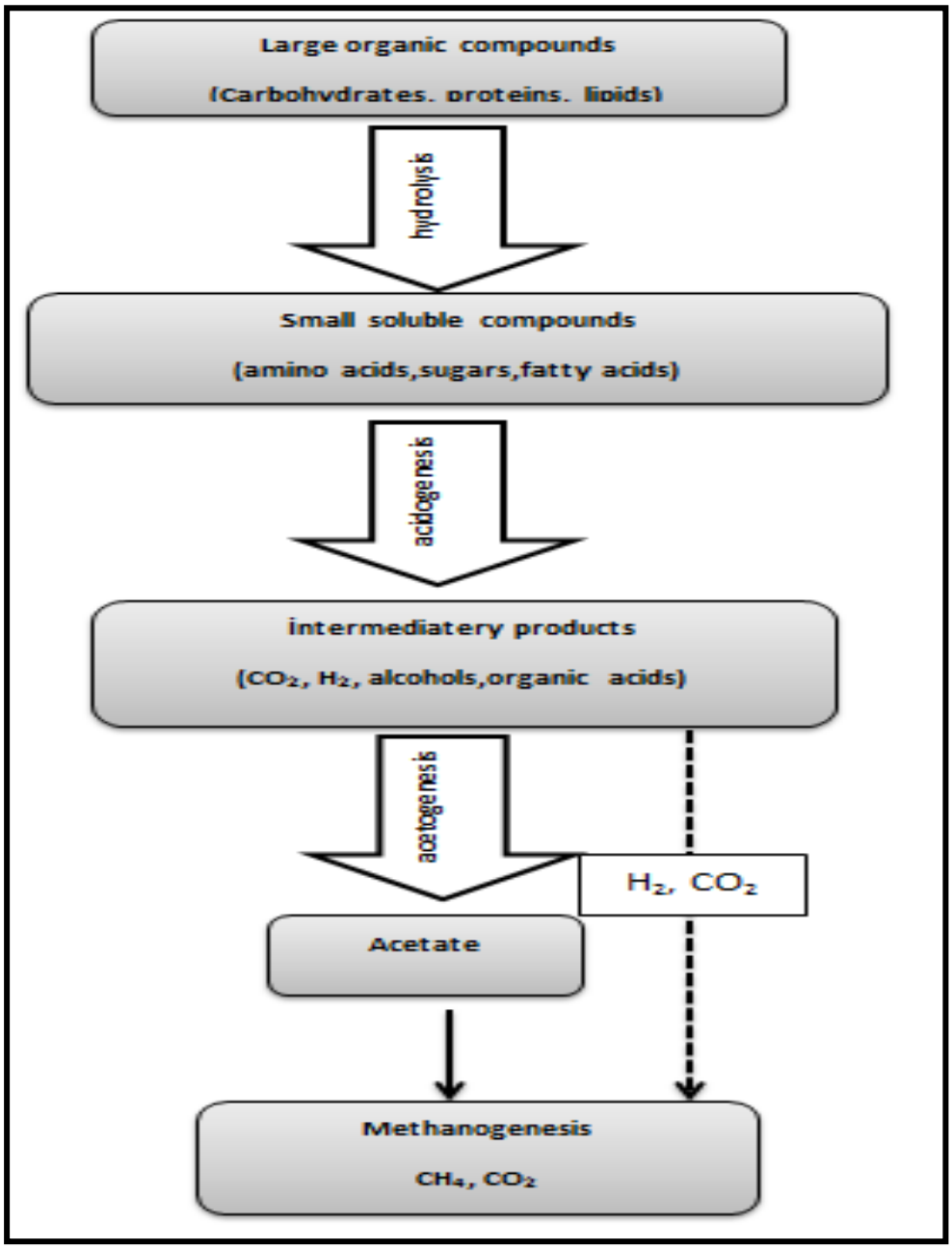

Fig. 1.2 Detail AD Process. Data source [11]

1st Stage - Hydrolysis: It is the breaking of a large number of complex compounds like carbohydrates, lipids and proteins into small compounds by the addition of water. Insoluble components such as carbohydrates, fats and proteins undergo hydrolysis in this stage and are degraded into small soluble components by breaking their chemical bonds. Bacteria responsible for this stage are Hydrolytic or facultative anaerobes.

Complex Carbohydrates ⟹ Simple sugars

Complex lipids ⟹ Fatty acids

Complex proteins ⟹ Amino acids

2nd Stage- Acid genesis: In this stage, soluble components that were produced in the 1st step are degraded by facultative anaerobes . During degradation, carbon dioxide, hydrogen gas, alcohols, organic acids, some organic-nitrogen compounds and some organic- sulphur compounds are produced in the reaction. Some of the other compounds are then used to form new bacterial cells.

3rd Stage - Acetogenesis: It is the rate limiting step and occurs in the acid-forming stage. Many of the acids and alcohols such as butyrate, propionate and ethanol may be degraded into acetate and will be used as a substrate by methanogens and also carbon dioxide and hydrogen can form directly acetate with the help of fermentative bacteria.

4th Stage - Methanogenesis: In this last step, methane is mainly produced from acetate and carbon dioxide and hydrogen gas. Here all of the compounds must be converted into compounds that can be easily used up by the methane forming bacteria. Acids, alcohols and other organic-nitrogen compounds cannot be used directly by methane-forming bacteria, which results accumulation of these components as the digester supernatant.

1.4.1. Factors affecting the gas production inside digester

Temperature: Temperature plays a vital role in the gas production and biogas digestion process is directly dependent on temperature. There are mesophilic methane forming bacteria which are active in 30 - 35 ^{o}C and thermophilic methane forming bacteria which are active in 50 – 60 ^{o}C. Between 40 - 50 ^{o}C, bacteria are inhibited. Biogas production can occur better at 35 ^{o}C because methane forming bacteria are temperature sensitive. However, methane production can occur over a wide range of temperatures. When temperatures decrease below 32 ^{o}C, more attention should be given to volatile acid to alkalinity ratio. When temperatures rise higher than 32 ^{o}C, a greater destruction rate of volatile solids and the production of methane occurs inside the digester.

pH and alkalinity: Anaerobes bacteria can be classified into two groups i.e. acidogens and methanogens. The optimum pH range is 5.5 - 6.5 for acidogens and 7.8 - 8.2 for methanogens. If we combine both the cultures, then the optimum pH ranges from 6.8 to 7.4. Methanogesis is the most important rate limiting step, so pH should be kept close to neutral. Methanogens are more sensitive to pH changes as compared to acidogens. Increase in pH would result in increased ammonia toxicity. This instability is due to accumulation of ammonia, and results in volatile fatty acids (VFAs) accumulation, which leads to a sudden drop in pH. The control of pH within the growth optimum of microorganisms may reduce ammonia toxicity .

In order to solve pH decrease problem, sufficient buffering capacity which is maintained by alkalinity is an important factor. Organic matter destruction releases ammonia-N and one equivalent of alkalinity equals to one mole of nitrogen. Ammonia-N and carbon dioxide are converted into ammonium bicarbonate which contributes towards alkalinity and sufficient alkalinity should be maintained inside the digester. While high sulfate substrates create alkalinity, carbohydrate-rich substrates do not create alkalinity. Stability of biogas digestion process can be determined by VFA/ALK ratio and 0.1-2.5 is considered as optimum ratio. Alkalinity can also be supplied with the use of chemicals such as sodium bicarbonate, sodium carbonate, ammonium hydroxide, gaseous ammonia, lime, sodium and potassium hydroxide.

Nutrients: Nutrients are subdivided into two main groups of micro nutrients and macro nutrients.

1. Macronutrients: Nitrogen and Phosphorous are the main macro nutrients that are needed for all biological treatment process. These nutrients are available for methanogens as ammonical-nitrogen and orthophosphate-phosphorus and ammonical nitrogen is the preferable nitrogen nutrient for methanogens. The amount of nitrogen and phosphorus to be available in the digester can be determined from the quantity of substrate or COD of the substrate.

2. Micronutrients: Methane-forming bacteria consist of different types of enzymes that will be provided by various micronutrients such as cobalt, iron, nickel and sulphide. The inclusion of micronutrients in enzyme system is important for a digester. These micronutrients are required by methane-forming bacteria in order to convert acetate into methane.

Cobalt is required as an activator of enzyme systems in methanogens.

Iron concentration should be in solution so that methanogens can easily digest it.

Nickel is not an essential micronutrient for most of the bacteria, but it is needed to produce some solitary enzymes that are needed for methane production.

Sulfide is the fundamental source of sulfur for methane-forming bacteria. Sulfide is required in proportionately high concentrations for methanogens.

Toxic Materials: Various types of organic and inorganic wastes cause toxicity inside digesters. It can be acute or chronic. Intense toxicity happens from the fast exposure of an unabsorbed population of microorganisms to a high concentration of a lethal or toxic waste waste. Chronic toxicity happens from the long exposure of an unabsorbed population of a bacteria to a toxic waste. Wastes that are toxic to the digestion system are ammonia, hydrogen sulfide and various heavy metals when in high concentration.

Retention times: Solids retention time (SRT) and hydraulic retention time (HRT) form two types of retention times in biogas digestion. HRT refers to the time that waste water or sludge is hold inside the digester, SRT refers the time that bacteria (solids) are in the digester. SRT>12 days is suggested for the digester because bacteria take longer time to grow . If retention time is less than 10 days, washout of some important bacteria may occur. HRT controls the conversion of volatile solids into gaseous products [11].

1.5 COMPARISON OF KINETIC MODELS FOR BIOGAS PRODUCTION RATE FROM CO-DIGESTING SLUDGE WITH PINE NEEDLES

The investigation of biogas production kinetics for the depiction and assessment of methanogenesis was completed by fitting the experimental data of biogas production to various kinetic equations. Biogas production rates were simulated using linear, exponential and Gaussian plots. In addition to this cumulative biogas production was simulated using logistic growth model, exponential rise to maximum and modified Gompertz plots [40].It will determine relevant kinetic parameter for predicting performance of digesters [43]. Development of proper models are the best step for complete process. The advantages of modelling are as follows:

1. It will permit to decide ideal working conditions or parameters which are theoretically possible, to analyze and estimate various potential outcomes.
2. This will decrease extra cost for constant and repeated experiments.
3. The probability of saving time and money during the process of technology or process determination.
4. Rapid examination of choices and correlation of the systems performance in a quantitative rather than qualitative way permits in numerous cases for easier decision making.
5. Monitoring Parameters.
6. Possibilities of limiting risks and upgrade plant productivity [44].

1.6 OBJECTIVES:

Several research papers were studied in order to decide the objectives of the current thesis. From the past researches it was concluded that most of the research has been done on

production of biogas from the cow dung, food waste, agricultural waste, crop waste and the co-digestion of sewage sludge has been done with agricultural waste, municipal organic waste, crop waste like wheat straw, rice straw, corn stalk, food waste, grease trap sludge. Few studies have been done on biogas production from pine needles but in none of the study co-digestion of sewage sludge and pine needles have been done. Modelling studies are also not so prevalent so on the basis of above conclusions following objectives were decided for my study:

1. Substrate characterisation i.e. sewage sludge and pine needles.
2. Comparative study of primary sludge and Co- digestion of primary sludge with pine needles in winter season and its continuation in summer season.
3. Comparison of various kinetic models of biogas production from co-digestion of sewage sludge with pine needles.

1.7 SIGNIFICANCE OF THE STUDY:

1. Create a source of fuel for cooking.
2. Provide a fertilizer from the digested waste.
3. Solve the problem of sludge disposal.
4. Pine needles have high cellulose content: 51% and enhances the growth of beneficial agricultural microbes. Reduce the Risk of forest fires and environmental pollution.

1.8 LIMITATIONS OF THE STUDY:

1. Pine needles take longer time for decomposition without pre-treatment.
2. Floating type gas holder has been used in this experiment.
3. Batch digesters has been used because study has been conducted in batch conditions.

CHAPTER-2

LITERATURE REVIEW

2.1 GENERAL

So as to work and plan the present project work on production of biogas, several research writing which are important were gathered and reviewed. The literature review is a collection of materials on a topic, including research articles published in national and international journals and technical reports prepared by the government departments and research agencies. The present study is on:

1. Substrate characterisation i.e. sewage sludge and pine needles.
2. Comparative study of primary sludge and Co- digestion of primary sludge with pine needles in winter season and its continuation in summer season.
3. Comparison of various kinetic models of biogas production from sewage sludge co-digested with pine needles.

2.2 LITERATURE REVIEW ON BIOGAS PLANT IN HIMACHAL PRADESH

Shiv P. Singh et.al. (1997) studied the problems related with biogas in Himachal Pradesh. As we know that H.P. is a hilly state and with undulating topography and wide temperature variations there was problem in propagation of all approved biogas plants for whole state and he basically discussed main approved models of plants for the state into different groups like Floating Drum type, Fixed dome type, Flexi type model and also potential of biogas plants. At last discussed about main factors affecting and requirement to improve, the efficiency of plants in H.P [20].

2.3 LITERATURE REVIEW ON BIOGAS PRODUCTION FROM SEWAGE SLUDGE

Wim Rulkens (2008) conducted a study on Sewage Sludge as a Biomass Resource for the Production of Energy: Overview and Assessment of the Various Options. Numerous on alternatives in which creation of vitality (warmth, power, or bio fuel) is one of the key treatment steps were examined and the most essential alternatives that were said are anaerobic digestion, co-digestion, incineration in combination with energy recovery, co-

incineration in coal-fired power plants, co-incineration in combination with organic waste focused on energy recovery, use as an energy source in the production of cement or building materials, pyrolysis, gasification, supercritical (wet) oxidation, hydrolysis at high temperature, production of hydrogen, acetone, butanol, or ethanol, and direct generation of electrical energy by means of specific micro-organisms [21].

D. S. Malik and Umesh Bharti (2009) conducted a study on Biogas production from Sludge of Sewage Treatment Plant at Haridwar (Uttarakhand) . The sewage was gathered from sewage pumping stations and treated in the primary and secondary treatment steps. The STP plant gets roughly 40 mld sewage from different pumping stations and 18 mld sewage is utilized for treatment at sewage treatment plant from which around 96X105 l liquid sludge is being collected per day. The present review was centred on biogas production from 1kg of sludge received 0.6 m3 volume on calculating value and the maximum biogas production was seen in volume 84952.34 m^3 during summer and minimum volume of gas production was observed during winter as 76252.81 m^3 in 2008 [22].

Onyenobi C. Samuel et al., (2013) led a review on Biogas Production from Municipal Sewage Sludge using Ultrasound Speeding Digestion Process. The waste activated sewage sludge Sample of Wupa Abuja STP was used. Semi- continuous lab-scale digestion experiment was done with the four reactors and work indicated how the waste activated sludge sample can be utilized in an anaerobic arrangement with ultrasound treatment to encourage improved gas production at a faster rate of sludge disintegration at reduced residence time. The ultrasound utilized was 420W limit and the treatment time was set 6 min, which identifies with an energy input of 8.4KWh/m3. The physiochemical parameters of the sludge like the TS , VS and pH of the sludge were equally investigated. The concentration of filterable chemical Oxygen demand (*F*COD) was found to increase to 37.5% from 2.8% to 11% of total COD with the use of the ultrasonic treatment and further brought about an increase in gas production of 13% subsequent to speeding digestion process through hydrolysis and sludge disintegration [23].

2.4 LITERATURE REVIEW ON BIOGAS PRODUCTION FROM PINE NEEDLES

Yan Wang and ShanShan Zhang (2014) conducted a study on the investigation based on heating with biomass energy for biogas digesters winter gas production technology in cold regions by aiming family unit biogas digesters as subjects, from the test materials,

experimental methods, experimental test outcomes and economic examination. This experiment studied the feasibility of heating with biomass energy for biogas digester to fulfill the digesters gas production in winter in cold regions. The author concluded that in spite of the fact that similar materials were embraced in the two trials over, the gas creation in the second trial is higher than the first [24].

Abhilash Kumar Tripathi (2015) conducted a continuous study on generation of Biogas using Pine Needles as Substrate in Domestic Biogas and also focuses on proficient and cost effective use of biogas digester for the production of biogas from waste pine needles. The cellulose content in pine needles is observed to be around 55% making it reasonable biomass for energy generation. It is seen that biogas production peaked from 1.4 l\day to 1.9 l\day during winter month, where as it was 7.3 l\day during months of March and April and there was decrease in volatile solids was also noticed during the months of March and April which was close to 64% during April higher compared to its value in winters [3]

R. K. Dwivedi (2016) conducted a study on bio-pre-treatment of pine needles for sustainable energy thereby preventing wild forest fires. In the present review an endeavor has been made to improve the biodegradability what's more, biomethanation capability of treated pine needles, the leaves of a coniferous tree (Pinus roxburghii) by utilizing Trichoderma spp. what's more, Pseudomonas spp. in this manner, using the pine needles for efficient power vitality. Studies were completed in four liter limit polymer reagent bottles as anaerobic bioreactor at mesophilic conditions (35□ C) for 80 days. The tests were duplicated thrice and the outcomes contrasted and untreated ground pine needles substrate (control) and results show that bio-pretreated substrate delivered a combined biomethane yield of 21.3 l/kg pine needles which was 285% higher when contrasted with the untreated pine needles substrate (5.53 l/kg) [25].

2.5 LITERATURE REVIEW ON BIOGAS PRODUCTION FROM CO-DIGESTION OF DIFFERENT SUBSTRATE

E.T. Iyagba (2009) conducted a batch co-digestion study on cow dung as substrate with rice husk in biogas production. The study was conducted for a retention time of 52 days and at room temperature and biogas produced was collected by water displacement method. Test A (50 wt % cow waste, 50 wt % rice husk) demonstrated an aggregate biogas generation of 161.5 ml toward the finish of the 38th day of the trial after which there was no further generation. The generation from test B (25 wt % cow waste, 75 wt % rice husk) was not

critical , while there was no creation from test C(0 wt % cow dung, 100 wt % rice husk) [26].

Hamed M. El-Mashad and Ruihong Zhang (2010) conducted a study on biogas production from co-digestion of dairy manure and food waste in batch digesters under mesophilic temperature conditions. A first order energy kinetic developed to ascertain the methane yield from various food waste and unscreened fertilizer following 30 days and the predicted results from model concluded that with the addition of food waste into manure digester at levels upto 60% of the initial volatile solids significantly increased the methane yield for 20 days of digestion [27].

S. Vivekanandan and G. Kamaraj (2010) conducted a study on biogas production from rice chaff (karukka) as co-substrate with cow dung in a mesophilic condition between (26-30^{o}C) for a retention time of 60 days .The study was directed for three diverse extent case (i) half weight of bubbled rice debris in addition to half weight of cow dung (ii) 75% weight of rice refuse (bubbled) in addition to 25% weight of cow dung (iii) half weight of crude rice waste (without bubbled) in addition to half of cow manure. The result demonstrated an aggregate biogas creation of 161.5ml in the case that (i) for the maintenance time of 60 days. In the case that (ii) demonstrated the biogas creation of 140.5 ml for the maintenance time of 70 days and in the case (iii) there was no huge gas creation because of high percent of lignin in crude rice waste [28].

Ewa Neczaj et al., (2013) conducted a semi-continuous experiment study on boosting production of methane from sewage sludge by adding grease trap sludge as a co-substrate for improving biogas production in anaerobic digestion with sewage sludge at 37 °C with HRT of 10 days. The grease trap sludge represented for 20, 22, 24, 26, 28 and 30% of the mixture based on volatile solids. The consequences of the laboratory study show that the use of GTW as a co substrate is thought to be interesting option for digestion of sewage sludge due to increased methane production [29].

Garcia K., Perez M. (2014) conducted a batch study on Anaerobic Co-digestion of Cattle Manure and Sewage Sludge: Influence of Composition and Temperature and the objective of the study was to choose suitable operating conditions in terms of both composition and temperature of anaerobic co-digestion process of cattle manure and sewage sludge so as to optimize the process in the biogas generation at mesophilic and thermophilic conditions .The acquired outcomes indicate that the anaerobic biodegradability of raw sludge and cattle manure mixtures is more proficient at thermophilic conditions because a greater elimination of organic matter with a greater methane yield is obtained and the most effective process relates to the mixture with 25% v/v of cattle manure and 75% v/v of raw sludge with values

of 62% and 75.7% of COD and DOC removals, respectively and methane yields of 2200 mL CH_4/g COD_r and 306 ml CH_4/g VS , presenting a period of beginning of 12 days [30].

Mingxing Zhao et.al. (2014) conducted a study on Synergistic and Pretreatment effect on anaerobic co-digestion from Rice straw and Municipal Sewage sludge and results shows that co-digestion of alkali-treated rice straw and sewage sludge had the best biogas yield of 338.9 mL/gVS, which was 1.06 and 1.75 times that of either alkali-treated rice straw or sewage sludge alone [31].

Agnieszka Pilarska et al., (2014) conducted a study on impact of organic additives on biogas efficiency of sewage sludge. The objective of the paper was to verify susceptibility to the methanation process of the selected organic substrates (refined glycerine, beet molasses, and whey) with sewage sludge and the highest concentration of methane was obtained from the mixture of sewage sludge with refined glycerine (63.10%), whereas the least – from the mixture with whey (49.8%) [32].

P. Sosnowski , (2015) investigated Anaerobic co-processing of sewage sludge and organic fraction of MSW along with consequences of examination of methane fermentation of sewage sludge and organic fraction of MSW (OFMSW) and in addition the co-digestion of both substrates under thermophilic and mesophilic conditions were accounted. The following information were determined during study: biogas content and productivity, pH, total suspended and volatile solids, essential composition (C, H, N, S) of sludge, OFMSW and inoculums, TOC, total alkalinity and volatile fatty acids. Methane productivity in the biogas was over 60% in all the said cases. Biogas productivity shifted in the vicinity of 0.4 and 0.6 dm3g VSS relying upon substrate added to the digester [33].

M. Elsayed et al. (2015) led a review on Methane Production by Anaerobic Co-Digestion Of Sewage Sludge and Wheat Straw Under Mesophilic Conditions and uncovered the conceivable outcomes of expanding methane yield generation from the anaerobic co-digestion of wheat straw and primary sludge. The batch test was led under mesophilic conditions with distinctive mixtures of WS and PS depending upon its C/N proportion were carried out to explore the ideal C/N proportion for effective methane production. The cumulative methane yields for co-digestion of PS with WS at C/N proportions of 35, 25, 20, 15 and 10 were 1.29, 1.62, 1.33, 2.44 and 2.16 time than digesting PS alone, respectively. The most extreme CMYS was seen at C/N proportion of 15 with an expansion of 89 %, 50.93 %, 83.61 % and 13.12 % contrasted and the other C/N proportion of 35, 25, 20 and 10 individually. This outcome demonstrated the positive synergy of co-digesting of PS and WS

for methane generation brought about by enhancing the C/N proportion of the feed stock [34].

E. Fathi Aghdam (2015) This paper presents mesophilic anaerobic digestion (AD) of organic part of civil strong waste (OFMSW), bio waste (BW), sewage ooze (SS), and co-digestion of BW and SS. Normal methane yields of 386 ± 54, 385 ± 82, 198 ± 14, and 318 ± 59 L CH4/kg unstable solids (VS) were gotten for OFMSW, BW, SS, and co-digestion of BW and SS separately in reactor experiment with organic loading rate (OLR) of 1 and 2 kg VS/m3 d. Normal methane yield of SS was expanded by 61% therefore of co-digestion with BW. Methane possibilities of 603, 534, and 369 L CH4/kg VS were obtained for BW, OFMSW and SS individually in batch tests at 35°C. Methane capability of source-isolated BW was 12% higher than methane yield observed for mechanically treated OFMSW, which can be interpreted as a constructive outcome of source-separation on methane potential [35].

Zihan Yong et.al., (2015), conducted a study on Anaerobic co-digestion of food waste and straw for biogas production. The experimental biochemical methane possibilities (BMP) of typical food waste (FW) and straw from Northern China were exclusively measured in a 1 L encased reactor at 35 C, and were 0.26 and 0.16 m3/ kg-VS (volatile solids), respectively. Lab-scale blends of various FW and straw piece were conducted with an total organic load of 5 g VS/L and the ideal mixing proportion of FW to straw appears to near 5:1, and the methane generation yield (MPY) achieved 0.392 m3/kg-VS, i.e., expanded by 39.5% and 149.7% contrasted and individual digestion comes about, separately. In addition, the gas generation (GP) furthermore, methane substance was achieving 0.58 m3/kg-VS and 67.62%, individually. Further study about the ideal straw molecule size was investigated, and the suggested estimate scope of straw was 0.3-1 mm for the efficient digestion [36].

Meghanath S Prabhu and Srikanth Mutnuri (2016) investigated anaerobic co-digestion of sewage sludge with food waste and in the present work, food waste was gathered from the institution cafeteria and two sorts of sludge (before centrifuge and after centrifuge) were gathered from the fluidised bed reactor of the treating sewage wastewater. Substrates were considered for their physico–chemical qualities, for example, pH, COD, TS, VS, ammonical nitrogen, and total nitrogen. A bio methane potential examine was done to discover the ideal blending proportion and results shows showed that in the proportion of 1:2 delivered the most extreme biogas of 823 ml gVS−1 (21 days) with a normal methane substance of 60%. Batch studies were led in 5 L lab-glass reactors at a mesophilic temperature and impact of various substrate stacking rates on biogas generation was examined. A loading rate of 1 gVS L d−1 gave the most extreme biogas creation of 742 ml g−1 VS L d−1 with a methane substance of

half, trailed by 2 gVS L d−1 with biogas of 539 ml g−1 VS L d−1. Microbial diversity of the reactor during batch studies was explored by terminal confinement piece length polymorphism. A pilot-scale co-digestion of food waste and sludge (before centrifuge) showed the prepare soundness of anaerobic processing [37].

2.6 LITERATURE REVIEW ON KINETIC MODEL OF BIOGAS PRODUCTION

M.O.L. Yusuf et.al., (2011) conducted a study on Ambient temperature kinetic assessment of biogas production from co-digestion of horse and cow dung from five batch digesters containing shifting proportion of blend of horse and cow manure was examined for a time of 30 days at surrounding temperature. It was observed that biogas production was streamlined when blended in a proportion of 3:1. The Modified Gompertz equation was utilized to satisfactorily describe the total biogas production from these digesters and likewise, an first order model was created to evaluate the kinetics of the biodegradation procedure and demonstrated that the digester containing horse manure and cow fertilizer in the proportion of 3:1 had the most highest short term biodegradability index of 3.96 at room temperature [38].

Iqbal Syaichurrozi et.al., (2013) conducting a study on identification of the kinetic model of biogas production and biodegradability of vinasse at variation of COD/N ratio and biogas fermentation of vinasse (TS 7.015 ± 0.007%) was examined inside an extensive variety of COD /N proportion. Urea (46% nitrogen substance) was included into substrate to modify COD/N proportion of 400/7–700/7. This review utilized batch anaerobic digesters in research center scale that were worked at room temperature in 60 days and outcomes demonstrated that control variable, 400/7, 500/7, 600/7, 700/7 produced add up to biogas of 107.45, 123.87, 133.82, 139.17, 113.27 mL/g COD and had the estimation of COD evacuation of 31.274 ± 0.887, 33.483 ± 0.266, 36.573 ± 1.689, 38.088 ± 0.872, 32.714 ± 0.881%, separately. Variable with COD/N proportion of 600/7 was the best factor. In the active model of biogas generation, variable with COD/N of 600/7 had active consistent of A (mL/g COD), l (mL/g COD.day), k (days) of 132.580, 15.200, 0.213, individually [39].

Manjula Das Ghatak and P. Mahanta (2014), conducted a study on comparison of kinetic models for biogas production rate from saw dust and examined the impacts of temperature on anaerobic co-absorption of saw dust with cows dung is examined. Results demonstrated that high temperature could enhance the anaerobic digestion and consequently increment the biogas creation rates. The working temperatures utilized as a part of this review were 35°C, 45°C, and 55°C and experimental study uncovered that exponential plot recreated better in

both climbing and sliding limb at all the three temperatures. However in rising limb exponential plot was better for biogas creation at 55°C and 35°C though in dropping appendage exponential plot was better for biogas generation at 45°C. Gaussian plot had higher relationship at 35°C contrasted with different temperatures. Logistic growth model and Gompertz plot demonstrated better connection of combined biogas generation than exponential rise to maximum plot for every one of the temperatures [40].

Anthony Njuguna Matheri et.al. (2015), studies the Kinetic of Biogas Rate from Cow Dung and Grass Clippings and utilized of lab scale batch anaerobic digester to infer energy parameters for anaerobic co-digestion of cow waste and grass crippling. C/N proportion of dairy animals manure was observed to be 17.17 furthermore, grass clippings to be 20.54. Through co-digesting, the C/N ratio was 9.02. Experimental data of 10 L batch digester at mesophilic temperature of 37^0C and pH of 6.9 was utilized to determine parameters for Modified Gompertz model and the predicted biogas yield was observed to be 4370ml/g COD. In model of biogas production of A (ml/g COD), μ (ml/g COD. day), λ (day) were 4319.20, 939.71, 1.91 individually with coefficient of determination 0.996 [41].

G.K Latinwo and S.E Agarry (2015) led a review on Modeling the Kinetics of Biogas Generation from Mesophilic Anaerobic Co-Digestion of Sewage Sludge with Municipal Organic Waste and investigate the impact of Industrial sewage sludge for effective and high biogas creation. The experiments were done in two 30 L anaerobic digesters D1 and D2 which contained sewage sludge & blend of sewage and municipal waste, individually and were hatched for 25 days at surrounding mesophilic temperatures (28^oC to 32°C). The outcomes demonstrates that co-assimilation of sewage sludge and municipal waste as co-substrate lessened start-up time for biogas era and expanded biogas yield by 132% when contrasted with sewage slop alone and peak biogas was acquired for both digesters at pH of 6.85 and 7.85 and also temperature of 30 and 31.5^{o}C, individually. Modelling study demonstrates that exponential plot simulated superior to the linear plot, the biogas production rates in D1 (sewage sludge) & D2 (sewage sludge and municipal waste), individually. Results shows that Gompertz plot demonstrated better relationship of combined biogas generation than exponential rise to maximum plot [42]

H.I. Owamah and Izinyon (2016) learned about ideal combination of the food waste and maize husk for increasing the biogas production and conducted experimental and modelling study. This review was centered around the streamlining of biogas generation from the co-digestion of food waste (FW) and maize husk (MH). The co-digestion of FW and MH at different blend proportions was completed in digesters A to E at 37 ± 1 °C. Digesters A, B, C,

D and E contained FW: MH of (100:0; 75:25; 50:50; 25:75; 0:100) individually. Result about got experiment shows that normal biogas yields of 0.50±0.04, 0.71±0.07, 0.54±0.05, 0.30± 0.03, and 0.24± 0.02 L/g VS were acquired from digesters A, B, C, D, and E individually. The Modified Gompertz demonstrating of the experimental information demonstrated that digesters A, B, C, D, and E had latency (λ) of 4.1, 4.9, 6.9, 7.4, and 10.6 days individually. Digester B had the most noteworthy greatest specific biogas production R_m, and greatest biogas generation potential (A) of 0.50 L/gVS/day and 20.7 L/gVS separately. The R^2 values amongst experimental and modelling information went from 0.9913 to 0.9989 in all digesters with the help of Post hoc Test in ANOVA utilizing the Least Significant Difference (LSD) and finally affirmed that there were huge contrasts in the mean biogas yield from the diverse digesters. The review accordingly demonstrates that the best mixture of FW and MH for upgraded biogas production occured happened in digester B [43].

A.N Matheri et.al. (2016) investigated modelling the Kinetic of Biogas Production from Co-digestion of Pig Waste and Grass Clippings and work explored the utilization of laboratory batch anaerobic digester to determine kinetic parameters for anaerobic co-digestion of pig waste and grass clippings. Research facility test data from 10 liters batch AD working at mesophilic temperature of 37 ^{0}C and pH of 6.9 was used to decide parameters for Modified Gompertz show. The C/N proportion of Pig waste was observed to be 16.16 and grass clippings to be 20.54. Through co-digestion in proportion of 1:1, the C/N proportion settled at 17.28. The actual biogas yield was observed to be 7725 ml/g COD. In the model of biogas generation expectation, the energy constants of A (ml/g COD), μ (ml/g COD. day), λ (day) was 7920.70, 701.35, 1.61 separately with coefficient of assurance (R^2) of 0.9994. Modified Gompertz plot indicated better connection of total biogas production and these outcomes demonstrate biogas generation can be improved from co-digestion of substrates [44].

2.7 CONCLUDING REMARKS:

After studying the above research papers on biogas generation from different substrates, it was concluded that a vast amount of literature is available on studies of biogas generation from food waste , cow dung, sewage sludge, co-digestion of sewage sludge with agricultural residues included mostly rice husk ,wheat straws etc. There are no studies on co-digestion of sewage sludge with pine needles. So the overall purpose of the study was to increase the knowledge about this topic and apply the prevalent condition into my state (Himachal Pradesh).

CHAPTER-3

EXPERIMENTAL SETUP AND METHODOLOGY

3.1 GENERAL

The following chapter describes the experimental setups and protocol used in the thesis work, as well as a characterization of the inoculums and substrates i.e. sludge and pine needles used. The physico-chemical characteristics of both the substrates were determined. Batch digestion tests were performed to analyze the biogas production in both the digesters. Various physico-chemical properties of digester slurry initially and finally were also determined. Daily monitoring of the digesters was done in terms of temperature, rise in gas holder and pH after some days was noted down. Various models are also described in this section .The experimental data of study was fitted into these kinetic equations and various constants were determined. The experimental setup and methodology has been described in detail in this chapter.

3.2 DETAILS OF EXPERIMENTAL SETUP

This section explained the digester and material prepared and that has been used for the study. The batch digestion has been done for the lab scale study. The digester can was self fabricated and was bucket type digesters. The Study comprises of two digesters named as AD1 and AD2 and each comprise of two plastic made cans, one for digestion and second as gas holder. AD1 consist of 100% sewage sludge and AD2 comprises of 50% sewage sludge and 50% pine needles. The capacity of the digestion cans is 45 liters and the limit of gas holder can is 20 liters. The working volume was 40 litres. The internal diameter of the fermentation can is 0.45 m and 0.30 m for the gas holder. The structure of batch digester comprises of Galvanized Iron fittings. The fitting contain ½ inch nipple, ½ inch tank connection nipple, ½ " valve and gas cork. The AD1 digester is for sludge and AD2 digester is for co-digestion of sludge with pine needles. The retention time for the study is 70 days during winters and 45 days during summer season.

The digesters were set inside the Fluvial Hydraulics Laboratory at the Civil Department in the Jaypee University of Information Technology, Waknaghat (H.P). During day time digesters were kept outside exposing to sun so that enough temperature is maintained inside the

digesters for micro-organisms to work. The plate 3.1 demonstrates the pictorial perspective of the digesters utilized for the review**.**

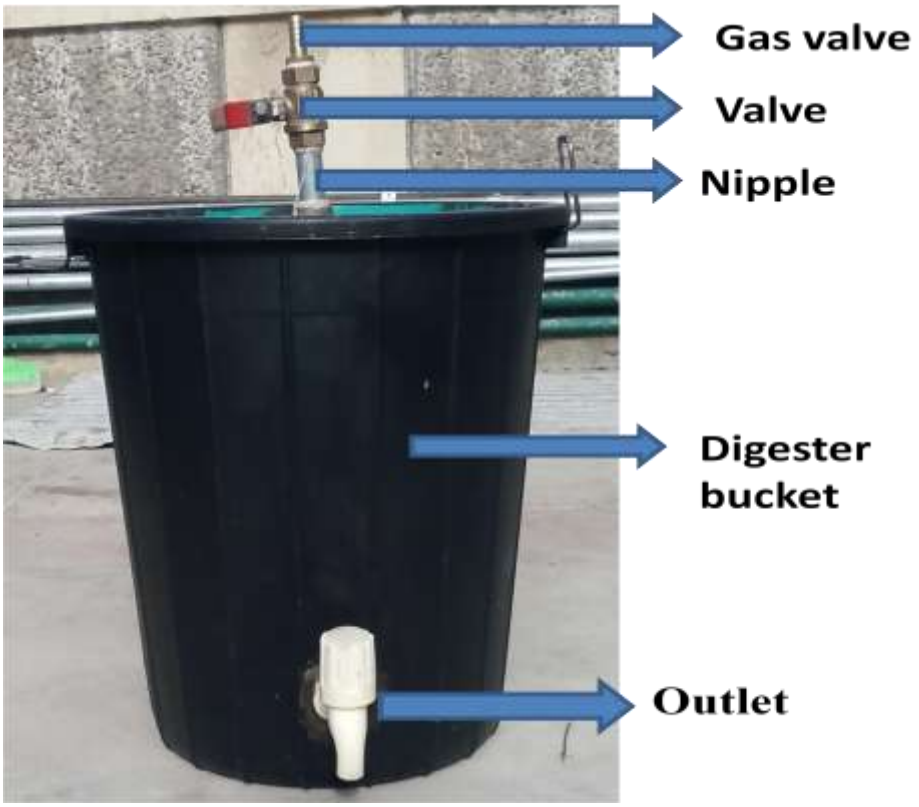

Plate 3.1 Digesters used for biogas production

3.3 SAMPLE COLLECTION AND MATERIAL PREPARATION

The study aimed at evaluating biogas potential of sludge and Co-digestion of sewage sludge and pine needles. The materials were selected on the basis of their availability inside the campus and which are of no use . The sewage sludge samples together with the microbial inoculum were provided by the sewage treatment plant of university campus itself, whereas pine needles was collected from the jungle which were fallen on the forest floor inside the campus.

3.3.1 Inoculum Source

Inoculum was taken from the effluent of biogas plant already installed at Jaypee University Campus. In this plant wastewater was co-digested with pine needles. It comprises of two plastic tanks: a digester of 1000L capacity (fermentation tank) and a gas holder of 750L . Around 1 litre of the sample was taken in a closed container and brought in the laboratory and was analysed on the basis of pH for biogas production .The pH was checked with the

assistance of pH meter and it was figured as 7.32 . Inoculum ought to have great biodegradability. The fundamental reason of adding inoculums to the digester slurry was that when fresh substrate was added to it the microbial activity has effectively occured. This further will help in digestion prcedure of the fresh substrate and will increase the biogas production of the digester. The plate 3.2 demonstrate the pictorial view of the Inoculum .

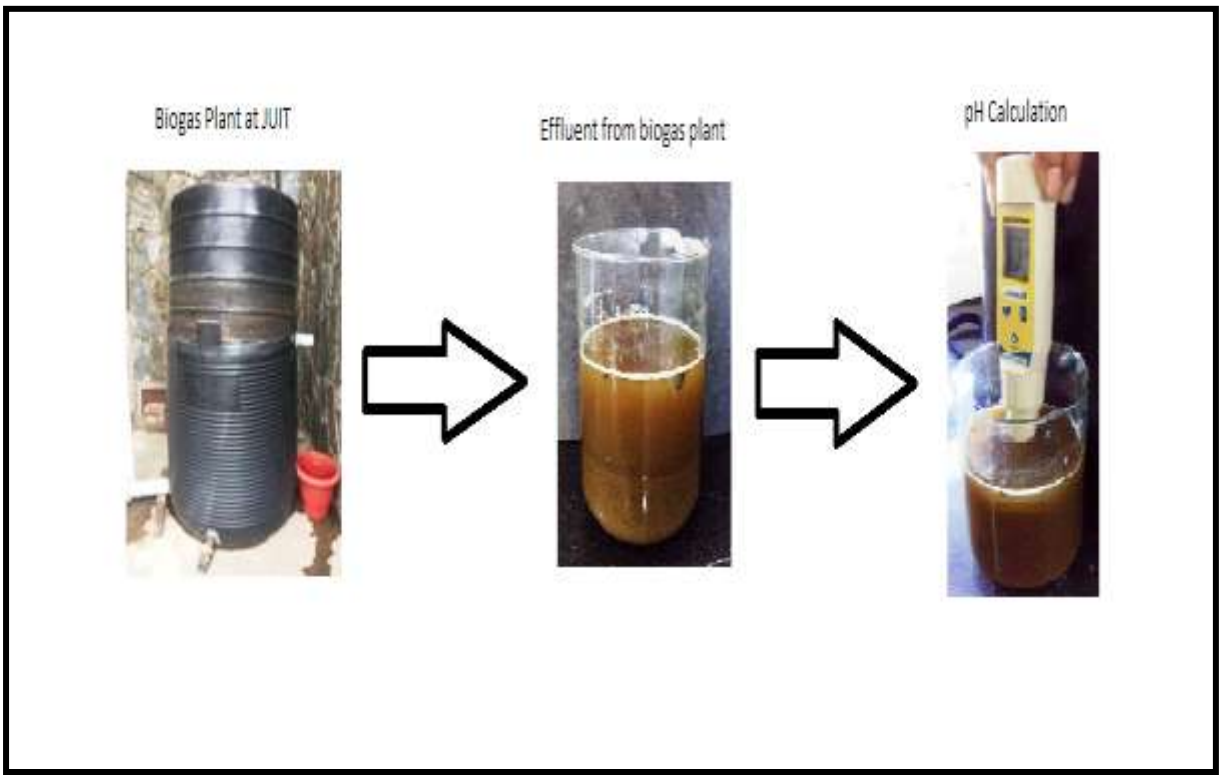

Plate 3.2 Inoculum used for biogas production

3.3.2 Sludge

The sewage sludge utilized for the biogas production was primary sludge. Primary sludge is sludge from primary settling tank of STP plant and is generally grey and slimy and has extremely offensive odour. Primary sludge was utilized for the study since it can readily be digested under appropriate conditions of operation. It varies heavily in composition and quality. The sludge was gathered from Sewage treatment plant at Jaypee University of Information Technology, Waknaghat. The STP Plant receives 300 m^3/ day of waste water each day and the treating capacity of the plant is 240 m^3/day. About 6m^3/day of sludge is collected. The dried sludge sample was collected from the same source and its various physico-chemical properties were determined. Plate 3.3 shows the picture of sludge collected from STP Plant. For the purpose of digestion semi-solid sludge was collected. Care should be taken that it ought to be free from any lumps and if any should be broken down with hands

and also should be free from any other undesirable substance which may inhibit the digestion process. It was stored in cold storage room which was maintained at a temperature of 4ºC . This restrain the growth of microorganisms.

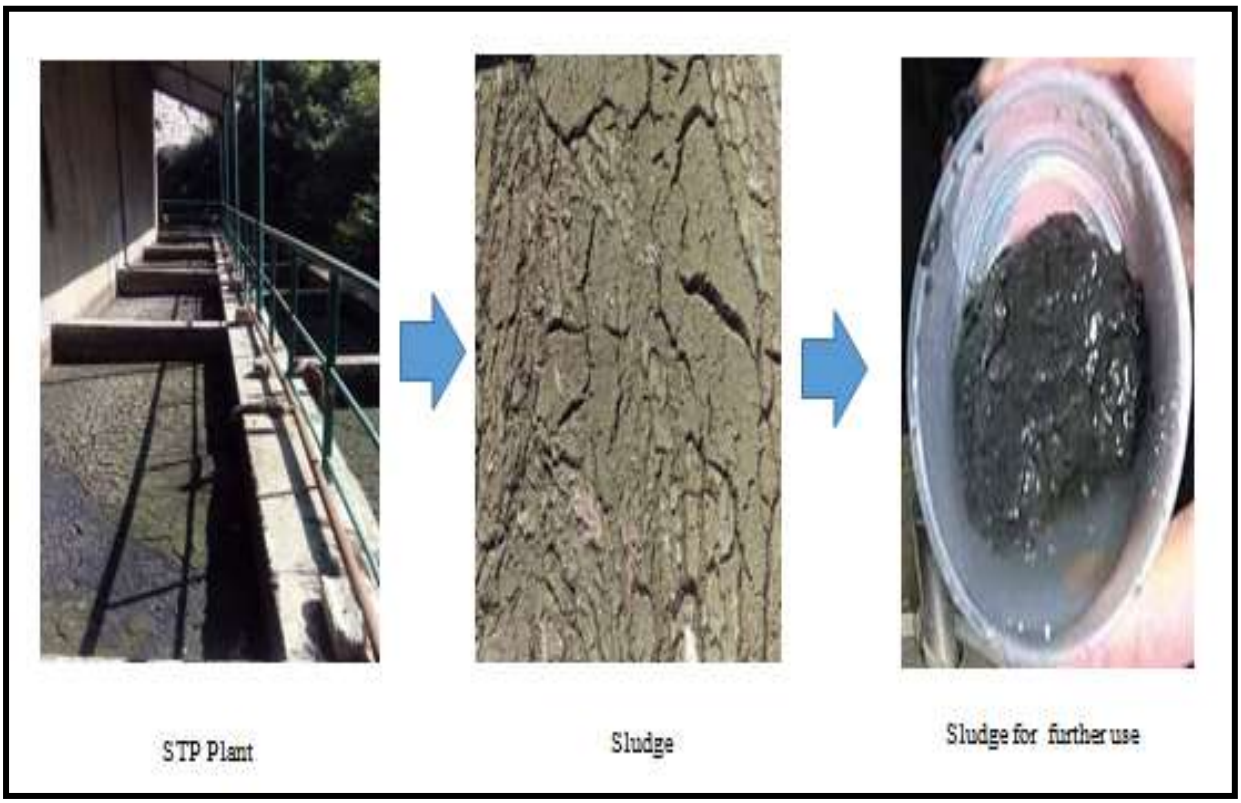

Plate 3.3 Sewage sludge used for biogas production.

3.3.3 Pine needles

Pine needles (*pinux roxburghii)* are co-digested with the sewage sludge. The pine needles were gathered from the adjacent forest region of JUIT campus. The pine needles were collected from the forest floor and the impurities were removed. Pine needles are also additionally known by name of Chir pine and belongs to family Pinaceae. It is around 98-160 ft high i.e about 30-50 mts and trunk diameter of about 6.6 ft i.e. 2 mts. The bark is generally red brown,thick and deeply fissured at the base of trunk, thinner and flaky in the upper crown. The needles are needle-like, in fasciles of three, very slender,20-35 cm long and distinctly yellowish green. It is the only tree with an ornamental specimen nd having different medicinal values found in the Himalyan region of Bhutan, Nepal, Kashmir, Sikkim, Tibet, and other part of North India. Pine needles consist of high lignin, cellulose and hemicelluloses content so it takes times for the degradation. For this purpose pine needles was subjected to the physical pre-treatment. Physical pretreatment of lignocelluloses materials through a combination of chipping, grinding,and milling can be applied to reduce

cellulose crystallinity. Pine needles were dried for 2 hrs at 70ºC in the oven and then converted into fine powder using the electrical grinder. It was sieved through mesh of 2mm size. Smaller the size faster will be the degradation rate [3].Plate 3.4 shows the picture of pine needles before and after grinding procedure.

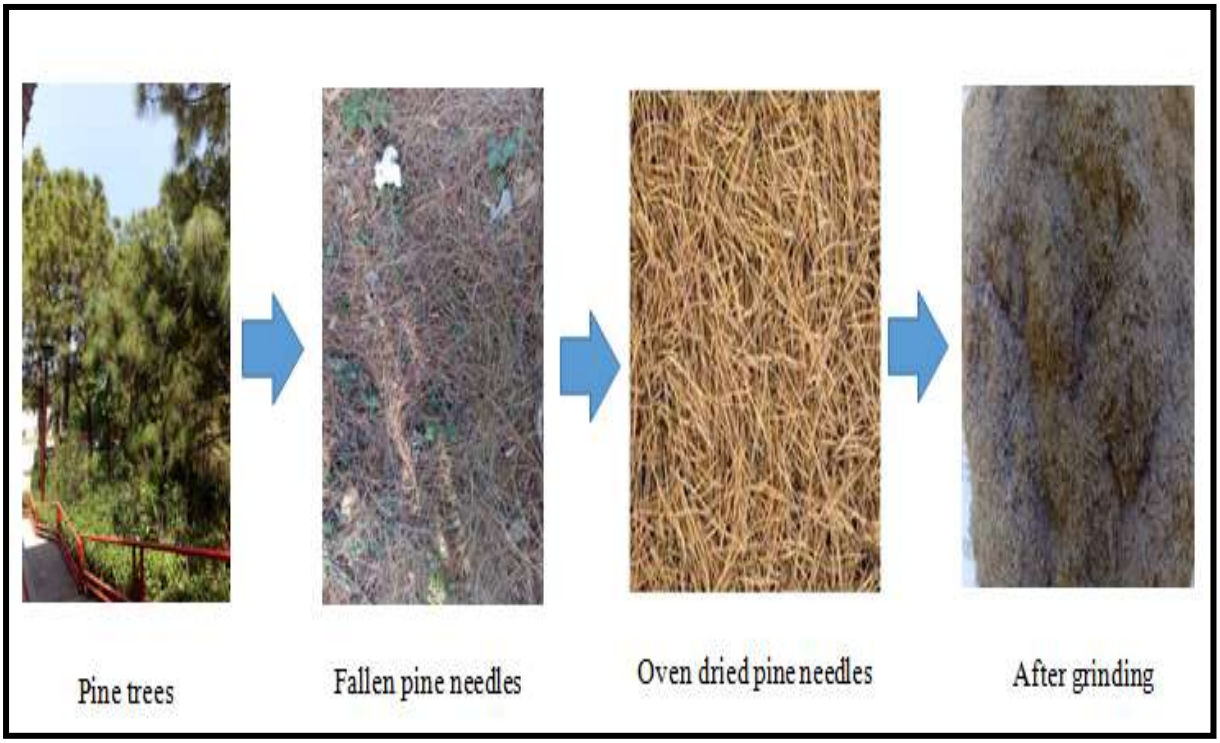

Plate 3.3 Pine needles used for biogas production.

3.4 CHARACTERIZATION OF SUBSTRATE

In this method the physico-chemical characteristics of the substrate are determined according to various standard methods. The pH, TS, VS, FS were measured in triplicates according to protocols of APHA Standard Methods. TOC was determined according to Walkley- Black method, TKN was determined by Micro Kjeldahl method and C/N ratio was determined by dividing TOC and TKN. Cellulose content was determined by method of Crampton and Maynard (1938). Hemicellulose content of the substrate was determined by estimating the percentage of NDF and ADF by the method of Georing and Vansoest (1970). Lignin content was determined by Georing and Vansoest (1970).

3.5 METHODOLOGY

In this two digesters were used for two different fermentation slurry samples. The results were then compared with each other. The digesters used were AD1 and AD2. AD1 consist of sewage sludge only and AD2 consist of mixture of sewage sludge and pine needles.

3.5.1 Experimental Procedure for before and after Digestion in Digester AD1:

In digester AD1 2.5 kg of sludge was mixed with tap water and inoculums. The ratio of sludge and tap water was taken as 1:8 by weight in this experiment. In AD1 2.5 kg sludge was mixed with 20 lt water and 1 lt Inoculum. All lumps were broken and slurry was prepared and then filled in the fermentation bucket. The gas holder bucket was placed in inverted position over the fermentation bucket with open gas cork so that air could escape out from the gas holder during the sinking of the gas holder. When the gas holder completely touched the bottom of the fermentation bucket with open gas cork, the gas cork was closed. Thus biogas upliftment was indicted by the upliftment of gas holder bucket. The experiment readings are from date 7th Dec 2016 to 14th Feb 2017 during winters having retention time of 70 days and from 16th Feb to 11th April during summer season having retention time of 55 days during summer season.

(a) Experimental Observation Before and after Digestion in the AD1

The experimental observations for the digester AD1 before digestion slurry was analyzed in terms of temperature, pH, TS, VS, FS, Alkalinity and COD. The APPENDIX C.1 and D.1 has shown the cumulative biogas generation in AD1 during winter and summer season.

APPENDIX C.2 and D.2 has shown the pH variation with time. The pH is measured after five days with the help of the pH strip during winter and summer season.

APPENDIX C.3 and D.3 has shown the inside outside and ambient temperature variation during winter and summer season.

(b) Measurement of Biogas

Biogas production was calculated on the daily basis by rise in the height of the gas holder. This raise in height was multiplied by $\pi/4d^2$ and calculated volume of the biogas production every day. The rise in height of the gas holder was observed. Biogas was measured on the daily basis. The uplift height of the gas holder was measured on the daily basis. The cumulative biogas production was calculated by the increase in the height multiplied by $\pi/4d^2$. APPENDIX C.1 and D.1 has shown the cumulative biogas production in AD1 during winter and summer season.

3.5.2 Experimental Procedure, Observation Before and After Digestion in Digester AD2

In digester AD2 1.25 kg of sludge and 1.25 kg of pine needles was mixed with tap water and inoculums. The ratio of sludge and tap water was taken as 1:8 by weight in this experiment. In AD2 1.25 kg sludge and 1.25 kg of pine needles was mixed with 20 lt water and 1 lt Inoculums. All lumps were broken and slurry was prepared and then filled in the fermentation bucket. The gas holder bucket was placed in inverted position over the fermentation bucket with open gas cork so that air could escape out from the gas holder

during the sinking of the gas holder. When the gas holder completely touched the bottom of the fermentation bucket with open gas cork, the gas cork was closed. Thus biogas upliftment was indicted by the upliftment of gas holder bucket. The experiment readings are from date 7^{th} Dec 2016 to 14^{th} Feb 2017 during winters having retention time of 70 days and from 16^{th} Feb to 11^{th} April during summer season having retention time of 55 days during summer season.

(a) Experimental Observation Before and After Digestion in the AD2

The experimental observations for the digester AD2 before digestion slurry was analyzed in terms of temperature, pH, TS, VS, FS, Alkalinity,and COD. The APPENDIX C.4 and D.4 has shown the cumulative biogas generation in AD2 during winter and summer season.

APPENDIX C.5 and D.5 has shown the pH variation with time . The pH is measured after five days with the help of the pH strip during winter and summer season.

APPENDIX C.6 and D.6 has shown the inside outside and ambient temperature variation during winter and summer season.

(b) Measurement of Biogas

Biogas production was calculated on the daily basis by rise in the height of the gas holder. This raise in height was multiplied by $\pi/4d^2$ and calculated volume of the biogas production every day. The rise in height of the gas holder was observed .Biogas was measured on the daily basis. The uplift height of the gas holder was measured on the daily basis. The cumulative biogas production was calculated by the increase in the height multiplied by $\pi/4d^2$.

APPENDIX C.4 and D.4 has shown the cumulative biogas production in AD2 during winter and summer season.

3.6 STANDARD TESTING METHODS

3.6.1 Temperature

It is measured with the assistance of thermometer.

3.6.2 pH

pH was measured with the assistance of pH meter.

(a) For dry sample

Take around 10 g of sample in a beaker and add 20 ml of distilled water and stir for half an hour with glass stirrer. Take the pH meter and adjust it with pH of known water and plunge it inside sample and wait for 15 sec. Note down the readings.

(Dilution will depend upon type of substrate. In case of Pine needles dilution will be more).

(b) For liquid sample

Put some sample in a beaker. Take the pH meter and calibrate it with pH of known water and plunge it inside sample and wait for 15 sec. Note down the readings.

3.6.3 Total solids, Volatile solids, Fixed solids

(a) For dry sample

Take the crucible and put some quantity of dry sample in it . Evaporate to dryness in an oven at 103ºC -105 ºC for 24 hours and dry to constant weight. Cool the dish and note down the weight.

W1= Weight of crucible, g

W2= Final weight of Crucible and sample, g

W3= Weight of dried residue and crucible, g

W4= Weight of residue and crucible after ignition at 600 ºC, g

$$\textbf{TS (\%)} = \frac{w3-w1}{w2-w1}\textbf{x100}$$

Ignite the residue obtained in 600 ºC in a muffle furnace, cool and weigh.

$$\textbf{VS (\%)} = \frac{w3-w4}{w3-w1}\textbf{ x 100}$$

$$\textbf{FS (\%)} = \frac{w4-w1}{w3-w1}\textbf{x100}$$

(b) For liquid sample

W1= Weight of empty crucible, g

W2 = Weight of crucible and sample

W = Weight of residue= (W2-W1) g

V= Volume of sample taken, ml.

W3= Weight of crucible with residue heated to 600 ºC, g

$$\textbf{TS (mg/lt)} = \frac{w2-w1}{V}\textbf{x1000X1000}$$

$$\textbf{VS (mg/lt)} = \frac{W2-W3}{V}\textbf{x1000 X 1000}$$

$$\textbf{FS (mg/lt)} = \frac{W3-W1}{V}\textbf{x1000 X 1000}$$

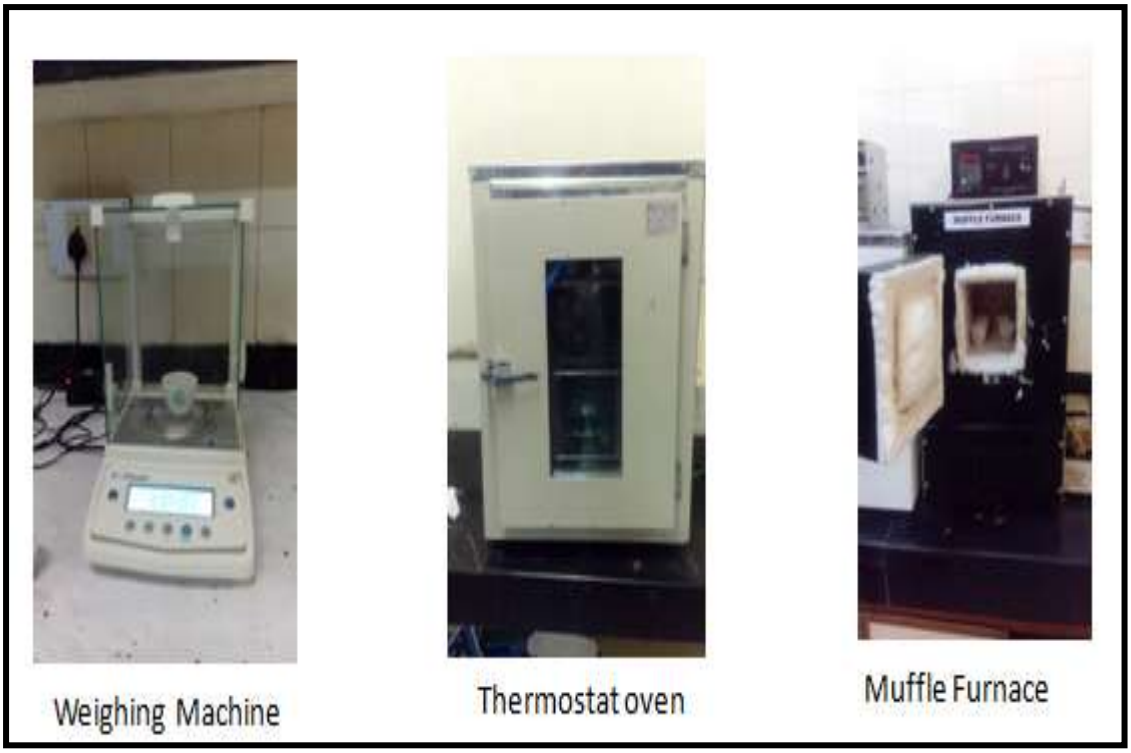

Plate 3.5 Pictures of weighing machine, oven and muffle furnace.

3.6.4 Total organic carbon (TOC)

1. Weigh 0.05 g sample into a 250 ml. Erlenmeyer flask.

2. Add 10 ml. of 1N potassium dichromate solution into it .

3. Add 20 ml. sulfuric acid in the flask and mix by rotating it for about 1 minute. Wait for about 30 minutes until mix cools down.

5. Dilute to 200 ml. with deionized water.

6. Add 10 ml. phosphoric acid, 0.2g Sodium fluoride, and 10 drops diphenylamine indicator.

7. Titrate with 0.5N ferrous ammonium sulfate solution until the color changes from dull green to a turbid blue. Add the titrating solution drop by drop until the end point is reached when the color shifts to a brilliant green.

8. Prepare and titrate a blank sample following the protocol in the same manner.

Calculation

$$\% \text{ TOC} = \frac{10(B-S) * 0.003 * 100}{B * \text{weight of the sample}}$$

S = sample titration

B = blank titration

1 ml of 1N $K_2Cr_2O_7$ – 3mg or 0.003g organic carbon

% Organic matter = 1.724 * TOC

Plate 3.6 Sample for TOC Estimation.

3.6.5 Total Kjeldahl nitrogen (TKN)

Digestion: Take about 0.5 g of sample into a Kjeldahl flask. Add 30 ml of conc. H_2SO_4 and shake by swirling for about 15 min. Then add 10 g of Hibbard's mixture, 1 g salicylic acid and 5 g of sodium thiosulphate. Heat at low heat till there is no frothing . Then raise the heat and continue digestion until the contents of the flask are grey or greenish yellow in colour. Cool and add about 100 ml of water. Swirl well and transfer the contents to 250 ml volumetric flask and make the volume upto the mark. Filter the contents of this flask for carrying out distillation.

Distillation: Take exactly 20 ml of 0.1 N H_2SO_4 into a conical flask, add two drops of mixed indicator (methyl red indicator and bromo cresol green) and place under the delivery tube of the condenser in the distillation assembly. Pipette out 10 ml of the filtrate in the distillation flask, add 10 ml of 45% NaOH solution in this flask through a funnel connected through a tube to the distillation flask and distil the filtrate. Collect about 30 ml of the distillate and when the distillation is over remove the receiver (conical flask) and then switch off the heater. Titrate the excess of the acid in the receiver against 0.1 N NaOH until the colour changes from colorless to pink. Note down the volume of 0.1 N NaOH used.

$$\text{TKN (\%)} = \frac{0.0014 * \text{Titration value} * \text{Total volume of liquid prepared}}{\text{ml of sample taken} * \text{weight of sample}}$$

TKN (%) = 0.0014 * T * 1OO

5*Weight of sample

Plate 3.7 Micro TKN apparatus

3.6.6 Chemical oxygen demand (COD)

1. Take about 2.5 ml water sample in a tube and 2.5 ml of distilled water in another tube.
2. Add 1.5 ml of Potassium dichromate to both the tubes.
3. Carefully add 3.5 ml of sulphuric acid reagent to both tubes.
4. Tightly close the tube kept in COD digester at 150 ºC FOR 2 hrs.
5. After cooling to room temperature transfer the content to the conical flask.
6. Fill the burette with freshly prepared ferrous Ammonia sulphate.
7. Continue the titration till the colour change to reddish brown.

(mg/lt) = (A-B)*N*8*1000

Volume of sample taken

A= Volume of ferrous ammonia sulphate for blank.

B= Volume of ferrous ammonia sulphate for sample.

N = Normality of ferrous ammonia sulphate = 0.1

Plate 3.8 COD Digester

3.6.7 Alkalinity

1. Take about 25 ml of sample in a conical flask.

2. Add two drops of phenolphthalein indicator , if it changes to pink then titrate against 0.02 N H_2SO_4 .

3. If no colour changes add 2 drops of methyl orange indicator and titrate with 0.02 N H_2SO_4.

4. Titrate till the colour changes yellow orange to orange red.

5. Note down the readings and repeat to get concordant readings.

ALKALINITY= $\frac{V*\text{Normality of } H_2SO_4*1000*500}{\text{Volume of sample taken}}$

3.6.8 Cellulose content

Cellulose content of the substrate (Pine Needles) was determined by the method of Crampton and Maynard (1938).

Sample collection and maintenance

Pine Needles were collected and were chopped into size of 2 cm to 5 cm long. These were then dried in the oven at 50°C overnight. The sample was stored for further use. Care should be taken that sample should be free from moisture.

Reagent preparation

Acetic Nitrate Reagent: It is prepared by mixing 73.86 ml of Acetic Acid, 9.09 ml of Nitric Acid, 17.04 ml of Distilled Water in a beaker.

Procedure

1. 1g of oven dried sample was taken in a 250 ml beaker.Then 25 ml of Acetic Nitrate Reagent was added and contents were boiled till the brown fumes and evolved.

2. The residue was then filtered using filter paper. After filteration three washings each of Water, Alcohol and Acetone were given, till all the residue was filtered.

3. The residue was then transferred in a pre weighted crucible and placed in oven overnight at 150°C.

4. The sample was cooled in a desiccater, it was weighed (W1).

5. Finally , the crucible was kept in muffle furnace for 1 hour at 450°C and weighed (W2).

6. Loss in weight was observed as the amount of Cellulose present in the sample.

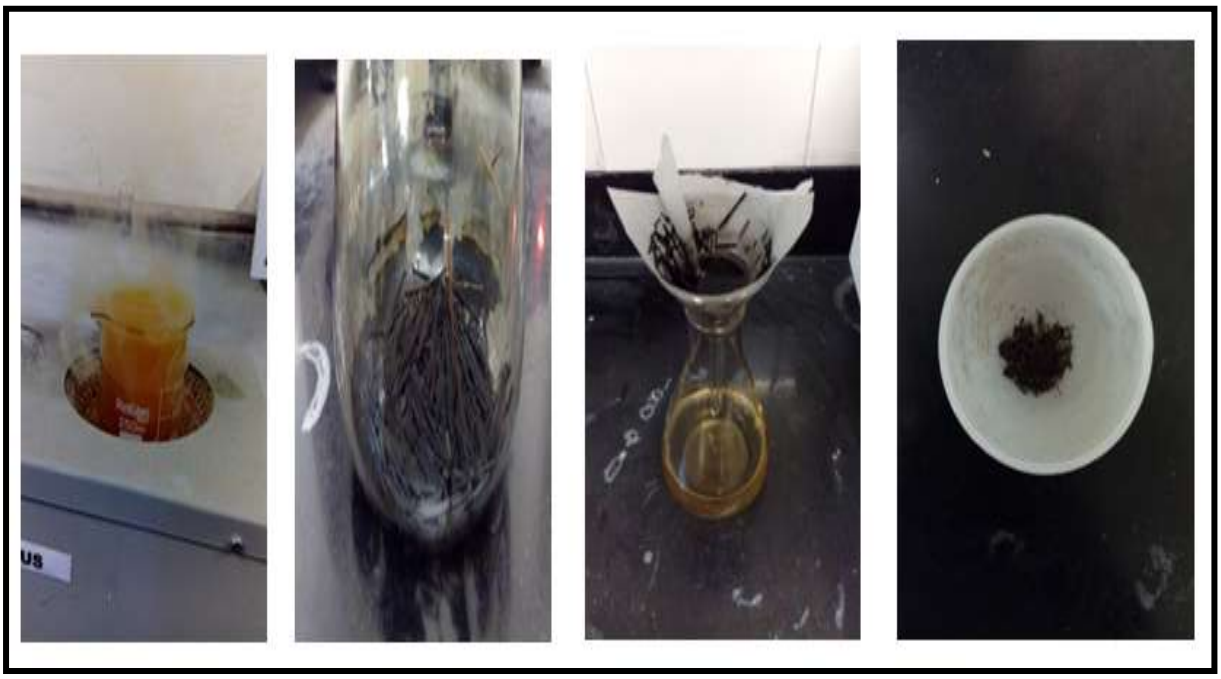

PLATE 3.9 Procedure during Cellulose content test.

3.6.9 Hemi cellulose content:

This was determined by the method of Georing and Vansoest (1970) by estimating the percentage of NDF and ADF.

(a) Determination of NDF (Neutral detergent fibre)

Reagent:

NDS-Natural detergent solution (SDS=6g/100ml, EDTA=3.72g/100ml, Sodium Borate Decahydrate=1.36g/100ml, Disodium Hydrogen Phosphate= 2.28 g/100ml, 2-ethoxy ethanol= 10 ml).

Prepration of NDS:

EDTA and Sodium Borate Decahydrate were taken in a beaker containing 50 ml of distilled water and dissolved by heating. SDS and 2-ethoxy ethanol were dissolved separately in boiling distilled water and then mixed with above solution. Disodium Hydrogen Phosphate was separately dissolved in boiling water and then added to the above solution. The pH was adjusted to 7 to completely dissolve all the solvents and volume was made to 100ml with distilled water.

Procedure:

1. 1g of oven dried sample (W) was taken in a beaker.

2. 100 ml of NDS, 2ml of Decaline and 0.5 g of Sodium Sulphite were added in sequence.

3. The contents were boiled for about 5-10 min and refluxed slowly for one hour.

4. The refluxed sample was filtered and transferred into the weighed crucible (A1). Three washings were given to it each of hot water, absolute ethanol and acetone.

5. The crucible was then dried at 105°C for 12 hours and then weighed (A2).

6. The NDF (%) was calculated as:

$$\text{NDF}(\%) = \frac{A2-A1}{W} \text{ X } 100$$

(b) Determination of ADF (Acid detergent fibre):

Reagent prepration:

1. ADS-Acid Detergent Solution : Cetyl Trimethyl Ammonium Bromide (CTAB) 2 g in 100 ml of).

2. 1N Sulphuric Acid-Mix 2.75ml Sulphuric Acid and 97.25 ml distilled water.

Procedure:

1. 1g of oven dried sample (W) was taken in a beaker.

2. 100 ml of ADS and 2ml of Decaline were added in sequence.

3. The contents were boiled for about 5-10 min and refluxed slowly for one hour.

4. The refluxed sample was filtered and transferred into the weighed crucible (A3). Three washings were given to it each of hot water, absolute ethanol and acetone.

5. The crucible was then dried at 105°C for 12 hours and then weighed (A4).

6. The ADF (%) was calculated as:

ADF (%) = $\frac{A4-A3}{W}$ **X 100**

Hemicellulose (%) = NDF (%) - ADF (%)

PLATE 3.10 Reflux Procedure during Testing.

3.6.10 Lignin content

Procedure:

1. The Crucible containing of residue of ADF was kept on 500 ml flask containing water in it and were covered with 20 ml of 72% Sulphuric Acid and contents were stirred with Glass Rod to a smooth paste.

2. The crucible was then refilled with acid and kept on ice bucket.

3. After 3 hour's excess of acid was filtered through filter paper. The residue was then given three washings each of hot water, Ethanol and Acetone, till it was acid free. The crucible was then placed in oven at100℃ till it was completely dried and then cooled in a desiccators and weighed (A5)

4. The crucible was then placed in Muffle Furnace at 500°C for 3 hrs and then weighed (A6).

ADL (%) = Lignin Content (%) = $\frac{A5-A6}{W}$ **X100**

3.6.11 Flame Test

It was done the end of the retention time to check the presence of methane gas and the colour of flame indicates the presence of methane gas in it.

3.7 FITTING OF EXPERIMENTAL DATA USING VARIOUS KINETIC MODELS

The experimental data was fit into various kinetic models as described below using non-linear regression and out of that various kinetic constants were determined. For fitting data into various equations the use of software like POLYMATH were used. The various equations are described in detail given below.

3.7.1 Linear Equation

The experimental data of biogas production rate of single digestion of sewage sludge and co-digesting sewage sludge and pine needles was simulated using linear equation. It was assumed that biogas production rate will increase linearly with increase in time. When it will reach a maximum point then after sometime it would decrease linearly to zero with increase in time. The linear equation is described given below.

y = a + b T

Where,

y = Biogas production rate in l/gm/day

t = time for digestion in days

a, b = constants obtained from slope and intercept of the plot of y vs T in l/gm/day

b = positive for ascending limb and negative for descending limb.

3.7.2 Exponential Plot

In exponential plot of biogas production it was assumed that biogas production rate will increase exponentially with increase in time and after reaching a point the maximum point it will decrease to zero exponentially with increase in time.

y =a + b exp (c T)

Where,

y=biogas production rate in l/gm/day

T=time needed for digestion in days

a, b = constants in l/gm/day

c = constant in 1/day, for the ascending limb, c is positive and it is negative for the descending limb.

3.7.3 Logistic Growth Model

Cumulative biogas production was simulated using logistic growth model. It is shown as given below.

$$y = \frac{a}{1+b\exp(-kT)}$$

Where,

y = Cumulative biogas production in l/gm.

k = kinetic rate constant in 1/day.

T = HRT in days

a, b are the constants.

3.7.4 Exponential Rise to Maximum

The equation is given below:

y = A (1-exp (-k T))

3.7.5 Modified Gompertz Equation

The equation is modified form of Gompertz equation and is used to simulate cumulative biogas production rate. The equation is described as given below:

$y = A \exp \{-\exp [\frac{\mu_m e}{A} (\lambda - T) + 1]\}$

Where,

P = The cumulative of the specific biogas production in l/gm.

A = The biogas production potential in l/gm.

U = The maximum biogas production rate in l/gm/day.

λ = The lag phase period or the minimum time required for production of biogas in day.

CHAPTER-4

RESULTS AND DISCUSSION

4.1 GENERAL

The results of the present study are examined in this chapter. Most importantly various physico-chemical characteristics of sewage sludge and pine needles are discussed. Then comparative study of single digestion of sewage sludge and co-digesting sewage sludge with pine needles was done and experimental data was gathered which was further fitted into various kinetic equations and data was analysed using Non-linear regression.

4.2 RESULTS OF CHARACTERIZATION OF SUBSTRATE

To evaluate the biogas potential of the substrates, sewage sludge as well as pine needles samples were described as far as in terms of TS (%),VS (%),VS/TS, FS (%), TOC (%), % Organic matter, TKN (%), C/N Ratio, Cellulose content, Hemicellulose content and Lignin content. All measurements were led in duplicates or triplicate, statistical outliers deviating over 20% from the average were excluded from the outcomes. Results are examined and compared in the following table 4.1 and also discussed below.

Table 4.1 Physico-chemical characterization of sewage sludge and pine needles.

S.NO	PARAMETERS	SEWAGE SLUDGE	PINE NEEDLES
1.	**TS (%)**	7.33 ± 0.13	91.52±0.14
2.	**VS (%)**	4.78 ± 0.15	69.60±1.67
3.	**FS (%)**	2.55 ± 0.03	21.92±1.79
4.	**VS/TS**	0.65 ± 0.02	0.76±0.02
5.	**TOC (%)**	30.57 ± 0.29	49±0.29
6.	**% Organic matter**	52.71 ± 0.49	84±0.49
7.	**TKN (%)**	4.01 ± 0.16	1.03±0.16
8.	**C/N RATIO**	7.62 ± 0.24	48.21±0.61
9.	**Cellulose Content (%)**	-	51±1.53
10.	**Hemicellulose Content (%)**	-	12±1
11.	**Lignin Content (%)**	-	21.52±0.02

The outcomes are summarized in the above table. Characterization is needed to ensure that anaerobic digestion process is balanced in terms of carbon, nitrogen, TS, VS content and where waste needed to be mixed and to guarantee ideal mixing[34].In general, two different gatherings of the substrates could be distinguished – the sewage sludge and the Pine needles.

The sludge were characterised by a lower TS, VS, TOC, Organic matter and C/N ratio content than pine needles , while pine needles are characterised by lower FS and TKN%. The TS content of the fine fraction depends firmly on the measure of water added during dilution process. The measure of water added ought to be assessed precisely because of fact that it influences digester configuration as well as volume of digestate to be consequently disposed off. The higher VS content of pine needles when contrasted with sewage sludge depicts higher energy content which is attractive from economic perspective of biogas production [27].

For the capability as a substrate C/ N ratio plays an essential role. This we have as of now examined in the above section. This is critical parameter for the prediction of how effective the biogas process can be. Ideal C/N ratio should be maintained in range of 20-30. From the table it is concluded that C/N ratio of sewage sludge is lower i.e. 7.62 when contrasted with pine needles i.e. 48.21. Because of lower C/N proportion lacks in either C or N will take place which will result into lower biogas production. With a specific goal to keep biogas process in shape either C or N must be provided. This is done by adding substrate which have adequate C/N ratio i.e. pine needles. For this reason co-digestion is done .So in our study Co-digestion of sewage sludge has been finished with pine needles. Co-digestion will additionally improve the rate of biogas production. Additionally % organic matter is observed to be greater in case of pine needles. Increasingly the organic content more will be the degradation rate. TS content of pine needles is very high as when contrasted to sewage sludge.

Cellulose content of Pine Needles was likewise high when contrasted with hemicelluloses and lignin content. Cellulose can be fundamentally divided into crystalline and amorphous region, which constitute the essential skeleton of cell divider in pine needles. At the point when microorganisms begin to degrade the hemicellulose, the degradation of cellulose can be steadily increased. In the meantime, the skeleton structure was additionally damaged and the degradation of hemicellulose was empowered. Crystalline cellulose can by weekend by physical pre-treatment making it simpler to be degraded by microorganisms [31].

4.3 COMPARISON OF BIOGAS PRODUCTION AND DIFFERENT PARAMETERS IN AD1 and AD2 DURING WINTERS

The initial and final values of different physico-chemical parameters are discussed in following table for winter season. There effect is also discussed below w.r.t Retention time. The detail of calculation work is done in APPENDIX B.

Table 4.2 Parameters for AD1 and AD2 before and after digestion

S.NO	PARAMETER	BEGINNING (AD1)	ENDING (AD1)	BEGINNING (AD2)	ENDING (AD2)
1.	Temperature (ºC)	18°C	21°C	18°C	22°C
2.	pH	7.7	8	5.8	7.5
3.	TS (mg/l)	14533	11667	12533	9667
4.	VS (mg/l)	12400	8600	11133	7333
5.	FS (mg/l)	2133	3067	1400	2334
6.	VS/TS	0.85	0.73	0.88	0.75
7.	Alkalinity (mg/l)	1387	2727	920	2667
8.	COD (mg/l)	437	320	512	331

4.3.1 Effect on variation in pH with retention time:

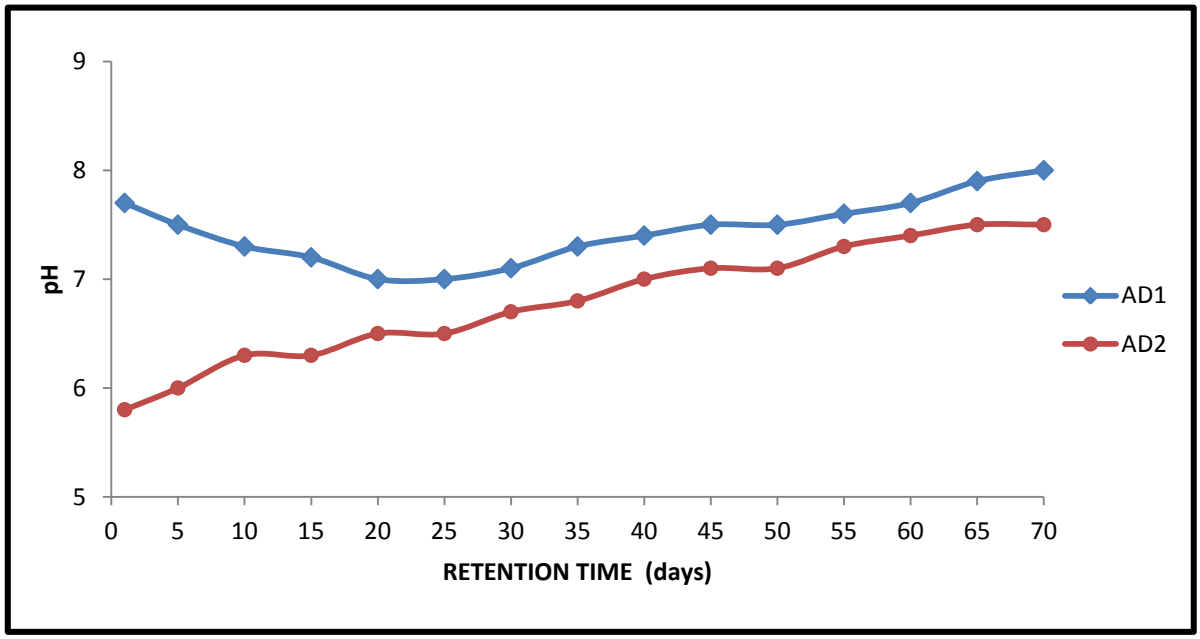

Figure 4.1: Variation of pH with time (winters)

pH is an essential element that affects the biogas production. So for the efficient gas production it is imperative to maintain it in desired range as it influences the growth of microbes [34]. However in our study no acid or base was added up maintain pH in desired range. In AD1 pH was observed in the range of 7-8 and in AD2 pH was observed in range of 5.8 to 7.5. In AD1 the initial pH was 8 and with time there was sharp reduction in the pH and further with time it was kept to a desired pH range and towards at the end it again starts to ascend. In AD2 the underlying pH was less i.e. 5.8 because of acid formation in hydrolysis stage yet with time it begins to increase and pH was in optimum range till the end because of accumulation of VFA and Ammonia. The comparable observation were reported [30].

The results demonstrate that co-digestion of sewage sludge and pine needles increased the buffer capacity of the AD2 [34]. This distinction in pH can be due to the high VS in Sewage Sludge. There was no biogas production in the starting because of pH being out of desired range, however when pH came into its desired range the Biogas production begin to take place. Low or high pH has been accounted for to hinder methanogenic bacteria responsible for biogas production. pH value under 5 or greater than 8 restrains methanogenesis[30].The favourable range for biogas generation is 6.5-7.5 in AD , so when pH was in this range there was significant increment in biogas production.

4.3.2 Effect on COD reduction with time:

COD is a parameter which is utilized to quantify the quantity of organic matter in waste and anticipate the potential for biogas generation. In substrate organic material i.e. COD was changed into biogas by the action of bacteria. The measure of COD that is degraded by the bacteria is known as COD removal. Larger the COD removal larger will be Biogas generation [39].

As we can see from fig 4.2 initial estimation of COD was greater than final COD estimation. In AD1 the initial COD value was observed to be 437 mg/lt and final COD value was observed to be 320 mg/lt. In AD2 the initial COD value was observed to be 512 mg/lt and final COD value was observed to be 331 mg/lt. The COD removal rate was 26.7% for AD1 and 35% for AD2. So Biogas production was higher in AD2 due to higher COD removal rate when compared to AD1.

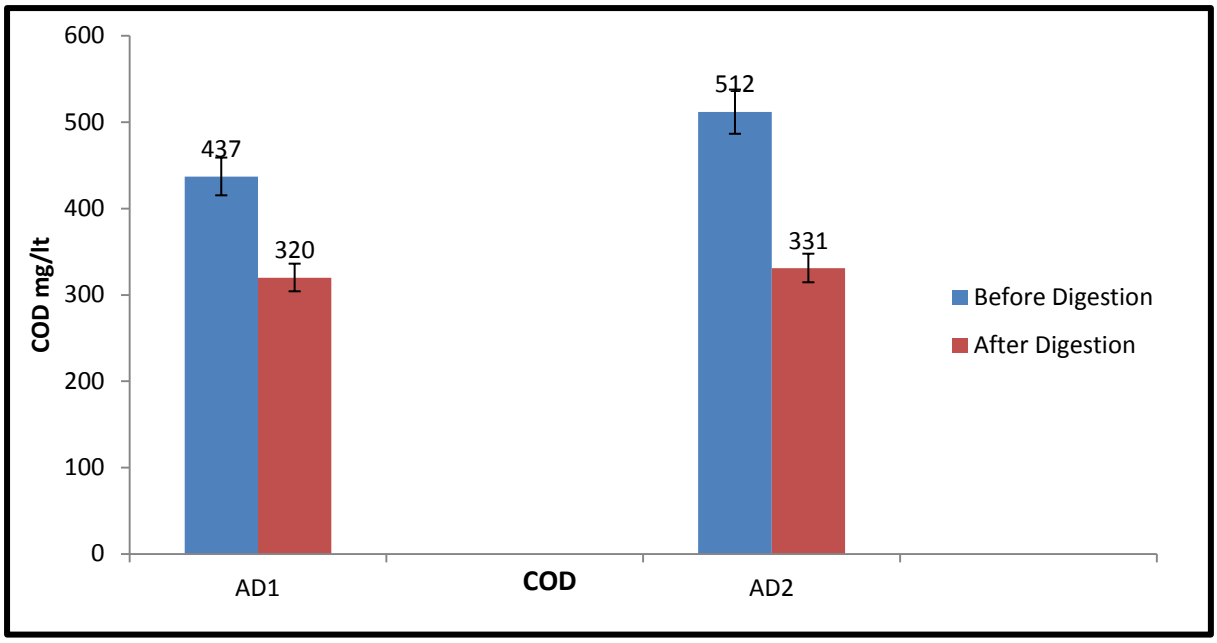

Figure 4.2: COD Reduction (winters)

4.3.3 Effect on Alkalinity with time:

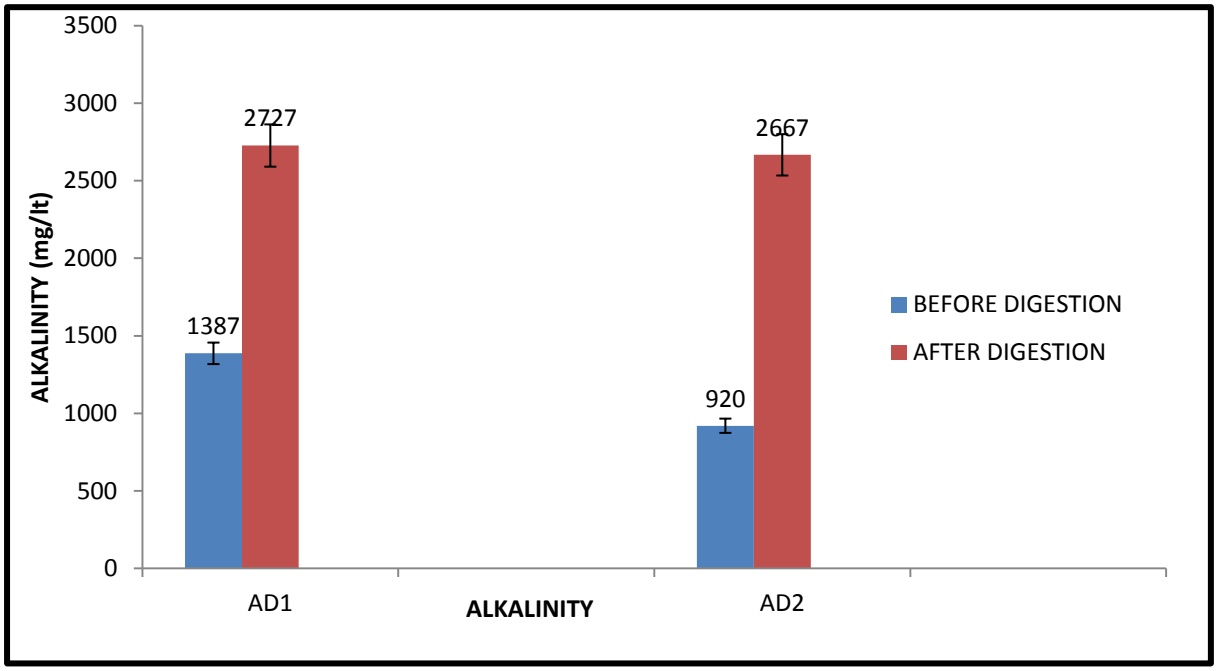

Figure 4.3: Effect on Alkalinity with time (winters)

Alkalinity is given by Calcium, Magnesium, Ammonium bicarbonates. These help to keep up adequate buffering capacity inside the digester. These are formed due to breakdown of protein in the substrate. Concentration of Alkalinity relies on the solids feed concentration to a great extent. For keeping up adequate buffering capacity alkalinity has to be maintained between 2000 mg/lt and 5000 mg /lt [6]. Alkalinity increases with time. From fig 4.2 it can be seen that in both the digesters alkalinity has increased. In AD1 initial alkalinity was 1387

mg/lt and final alkalinity was 2727 mg/lt. In AD2 initial alkalinity was 920 mg/lt and final alkalinity was 2667 mg/lt. So alkalinity was increased with time and was maintained within limit of 2000 mg/lt and 5000 mg /lt. There was more increase in alkalinity in AD2 so there was more biogas production in AD2.

4.3.4. Effect on TS and VS reduction with time:

TS indicate organic as well as inorganic matter in the feedstock. In both digesters the TS were held as 14533 mg/ lt and 12533 mg/ lt demonstrated a decrease after the retention period of 70 days which were found to be 11667 mg/ lt and 9667 mg/lt. Thus there was 19.7% and 22.8 % diminishing in both the digesters. TS play an critical role in the process. TS in the beginning was more but however when degradation began to occur TS start to decrease, as microorganisms began to utilize the TS content as their food. As the study was batch study so new substrate is coming inside digester, so microorganisms need feed upon TS in the digester. So its value starts to decrease. TS reduction was more in AD2 as compared to AD1.

VS are the solids that are lost on ignition of the dry solids at 550°C. VS additionally plays role in biogas production as they are responsible for the biogas production. The Volatile reduction in AD1 and AD2 was observed to be and 30.64% and 34.13%. VS removal was greater in AD2 this may be due to fact that smaller size of particles which are easy for bacterias to digestate. Greater the VS reduction greater will be biogas production. So there was greater biogas production in AD2 [34] .Co-digestion also helps to reduce the TS and VS content to a great extent.

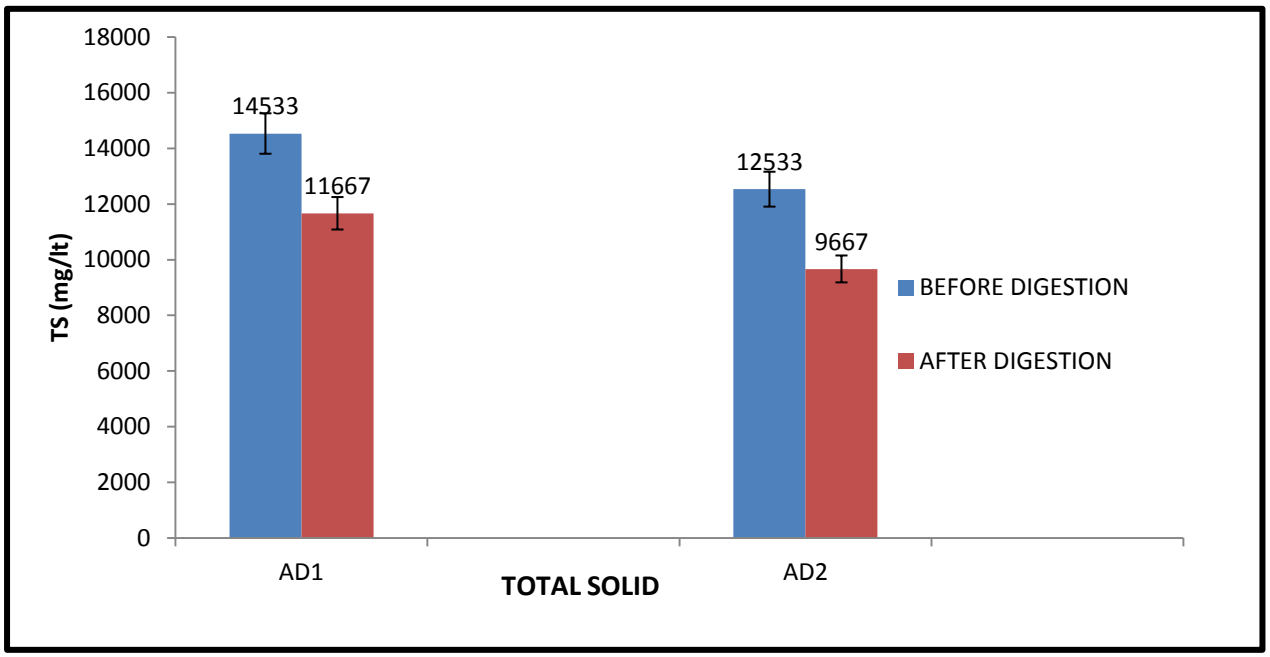

Figure 4.4: Total Solid Reduction (winters)

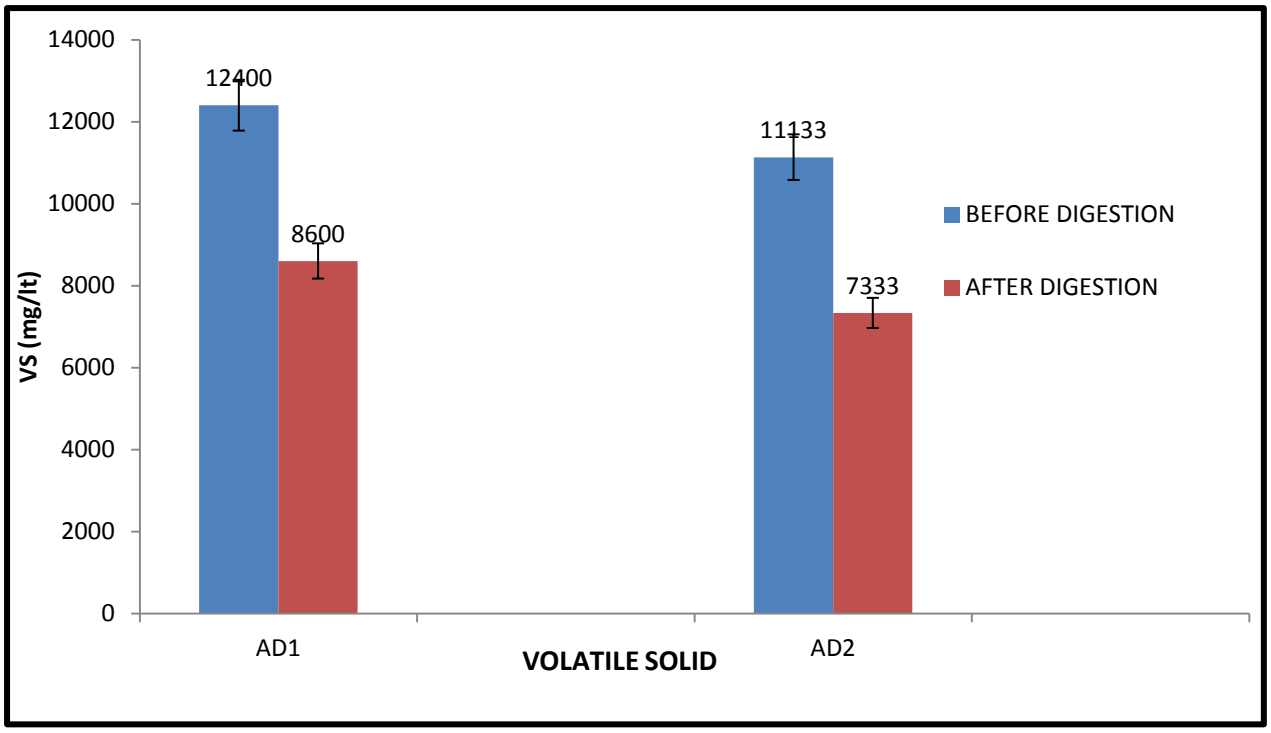

Figure 4.5 Volatile Solid Reduction (winters)

4.3.5 Effect on temperature with time:

Temperature influences the metabolic activities of bacterias so it is an essential parameter in biogas production. Hence at higher temperature the bacterial activity increases which results in higher yield of biogas production. A Stable temperature is needed inside digester because some bacteria are temperature sensitive for e.g. methanogens [6]. Temperature inside and outside the AD1 and AD2 are shown in fig.4.6 and 4.7.In AD1 the inside temperature varies from 15°C to 25°C and outside temperature varies from 2°C to 18°C. In AD2 the inside temperature varies from 15°C to 25°C and outside temperature varies from 2°C to 20°C.

The study was done during winter season. Outside Temperature was same for both the digesters. The inside temperature was observed more than temperature of outside in both the digesters due to microbial degradation of bacteria's the inside temp was more. Both the digesters were kept at outside for exposing in sun to increase the temperature. This shows that microbial degradation of the waste by the bacteria's raises the inside temperature of the digester. The inside temperature of AD2 was more as compared to AD1 so Biogas production was more in AD2 as compared to AD1.

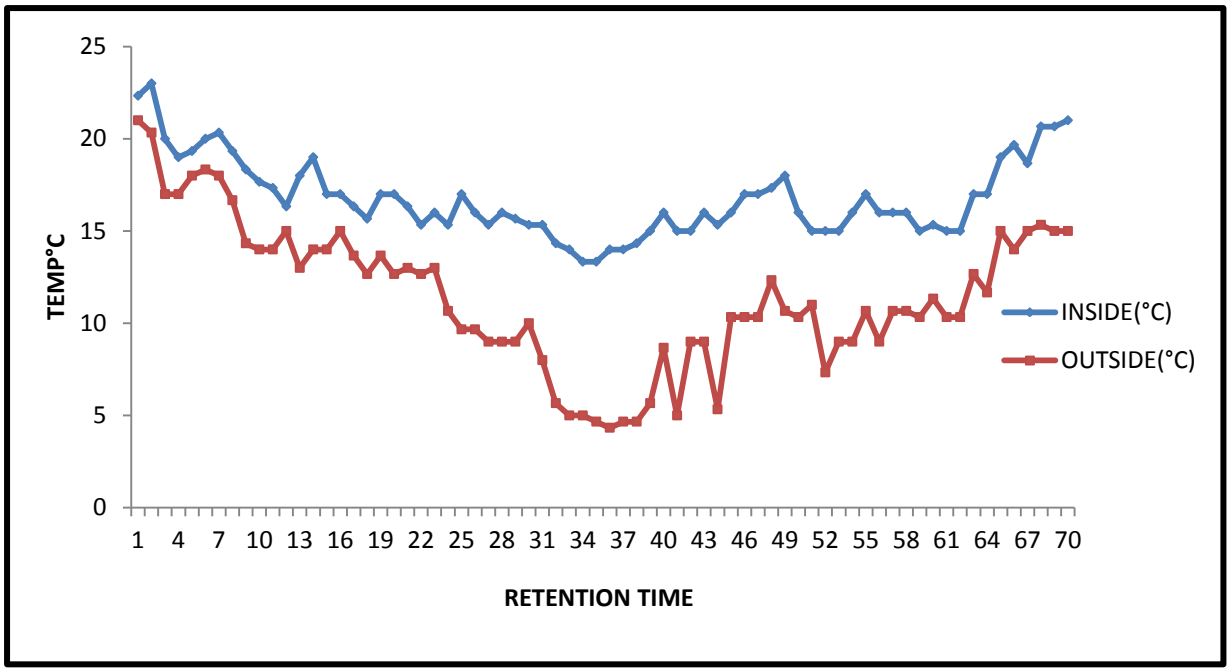

FIGURE 4.6: Variation of Temp with time in AD1 (winters)

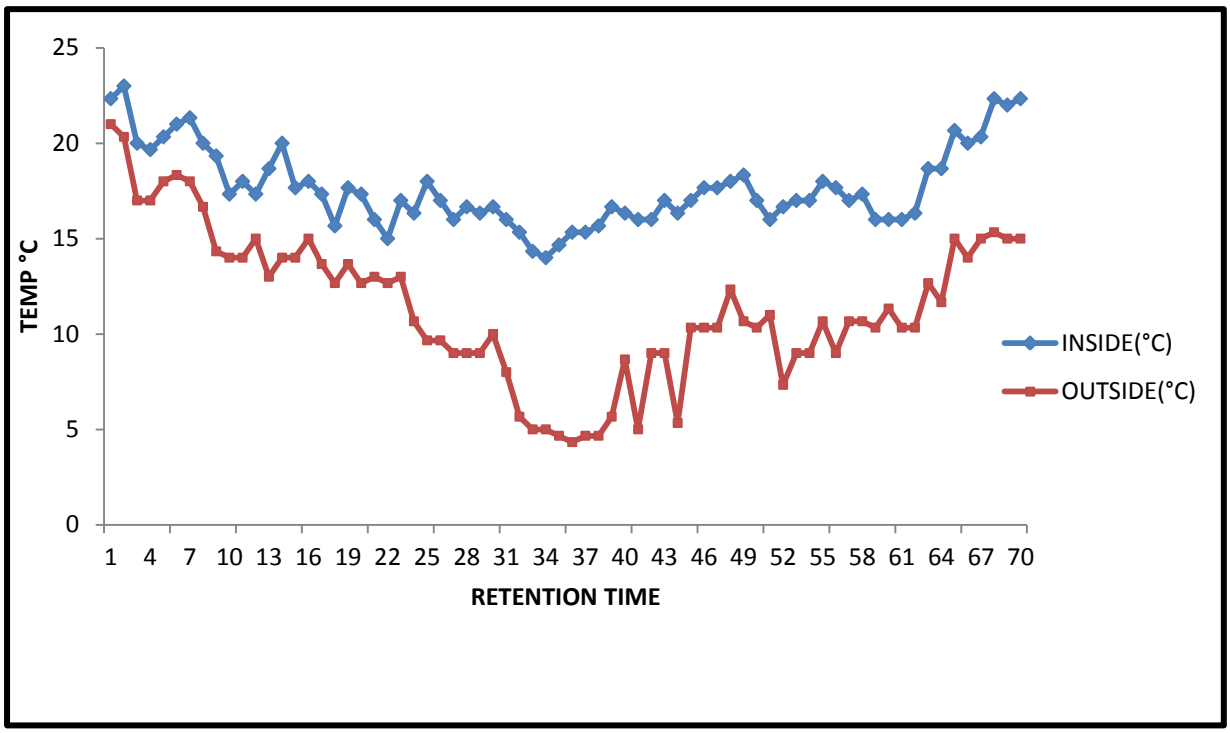

FIGURE 4.7: Variation of Temp with time in AD2 (winters)

4.3.6 CUMULATIVE BIOGAS PRODUCTION:

The Biogas Production in both the digesters is shown in fig 4.8. In AD1 the ascent in gas holder was observed 12th day while in AD2 the rise was observed from 8th day after the slurry

feeding inside the digester. Biogas started producing early in AD2. The results have demonstrated that there was increment in biogas production and accumulation all through the retention time. This might be because of increase in alkalinity and pH being in optimum range. At beginning there was no Biogas production in AD1 due to high pH i.e. 7.8 and in AD2 pH was 5.8 but with time as the degradation start to take place by bacteria pH range was optimum for AD2 due to which there was increase in biogas production while in AD1 pH 1st start to decrease, then come at optimum range and then again start to increase. This implies that biogas production from Co-Digestion of Sewage Sludge and Pine needles is high as compared to single digestion of sewage sludge alone. Another reason can be enhanced C/N ratio and nutrient balance. Similar results were accounted as per [42].Cumulative biogas production in AD1 is 4.2 litres and in AD2 was 10.4 litres.

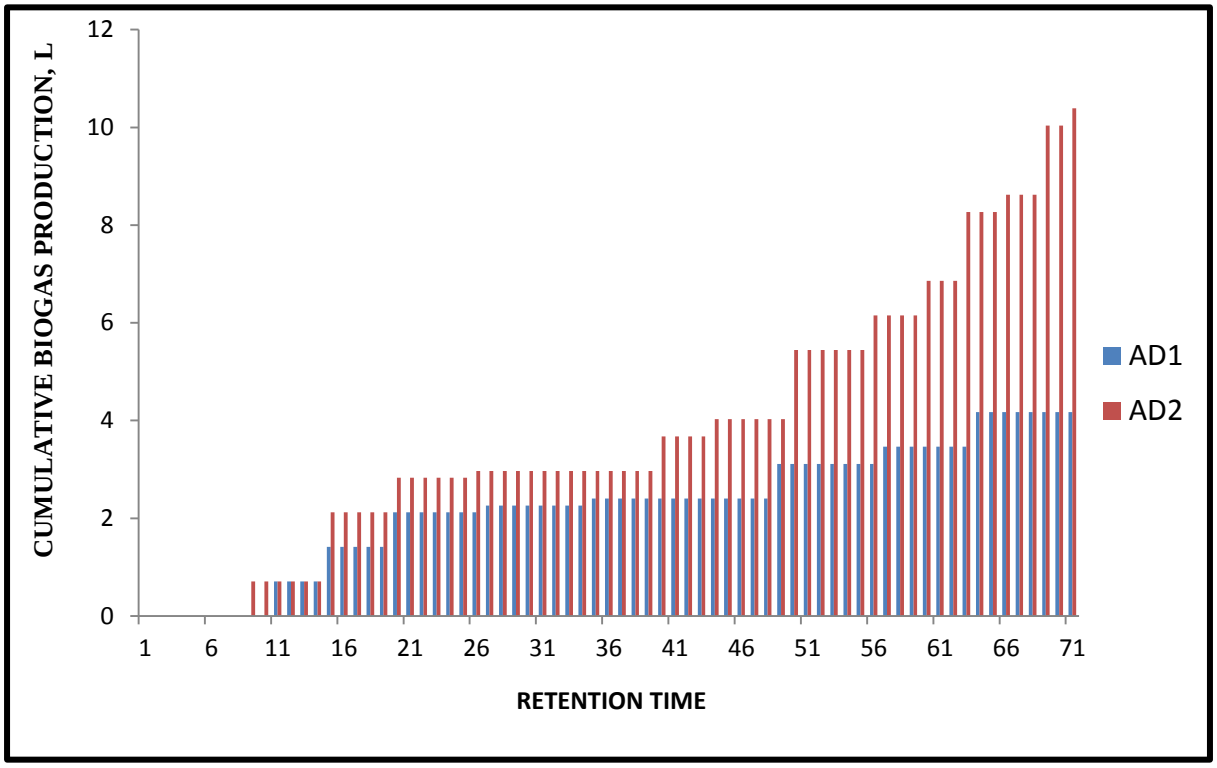

Figure 4.8: Cumulative Biogas Production (winters)

4.4 COMPARISON OF BIOGAS PRODUCTION AND DIFFERENT PARAMETERS IN AD1 and AD2 DURING SUMMERS

The initial and final values of different physico-chemical parameters are discussed in following table for summer season. There effect is also discussed below w.r.t Retention time.

Readings were taken from 15-02-2017 to 10-4-2017.The detail of calculation work is done in APPENDIX C.

Table 4.3 Parameters for AD1 and AD2 before and after digestion

S.NO	PARAMETER	BEGINNING (AD1)	ENDING (AD1)	BEGINNING (AD2)	ENDING (AD2)
1.	Temperatur (ºC)	21°C	31°C	22°C	33°C
2.	pH	8	7.6	7.5	7.3
3.	TS (mg/l)	11667	9267	9667	7133
4.	VS (mg/l)	8600	5933	7333	4867
5.	FS (mg/l)	3067	3333	2334	2267
6.	VS/TS	0.73	0.64	0.75	0.68
7.	Alkalinity (mg/l)	2727	3973	2667	4467
8.	COD (mg/l)	320	213	331	203

4.4.1 Effect on variation in pH with retention time:

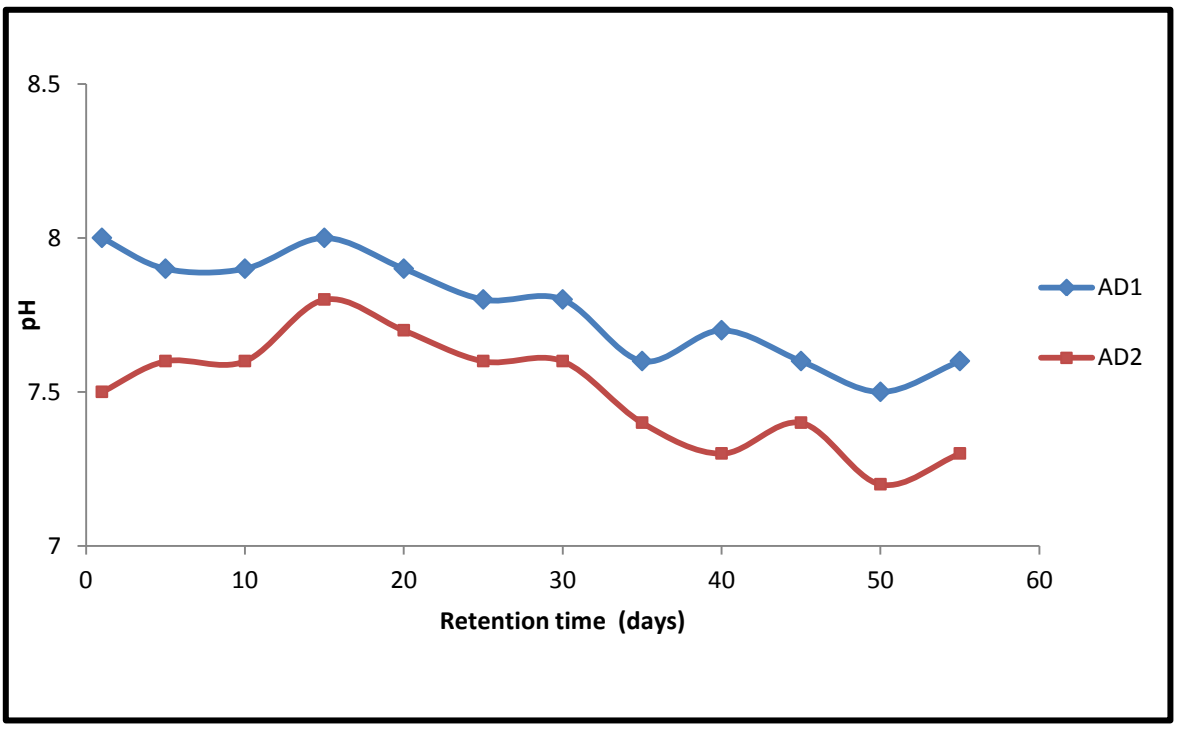

Figure 4.9: Variation of pH with time (Summers)

In AD1 pH was observed in the range of 7.5-8 and in AD2 pH was in the range of 7.2 to 7.8. Low or high pH has been accounted for to hinder methanogenic bacteria responsible for biogas production. pH value under 5 or greater than 8 restrains methanogenesis[30].The favourable range for biogas generation is 6.5-7.5 in AD , so when pH was in this range there was significant increment in biogas production. The pH was in optimum range and no need to add any acid or bases to make pH in neutral conditions. In AD1 pH was mostly around 8 during 1st fifteen days so there was less biogas production due to more accumulation of ammonia inside the digester. pH greater than 8 will further increase the toxicity inside digester. so there was less biogas production in AD1 as compared to AD2 where Ph was mostly in favourable range.

4.4.2 Effect on COD reduction with time:

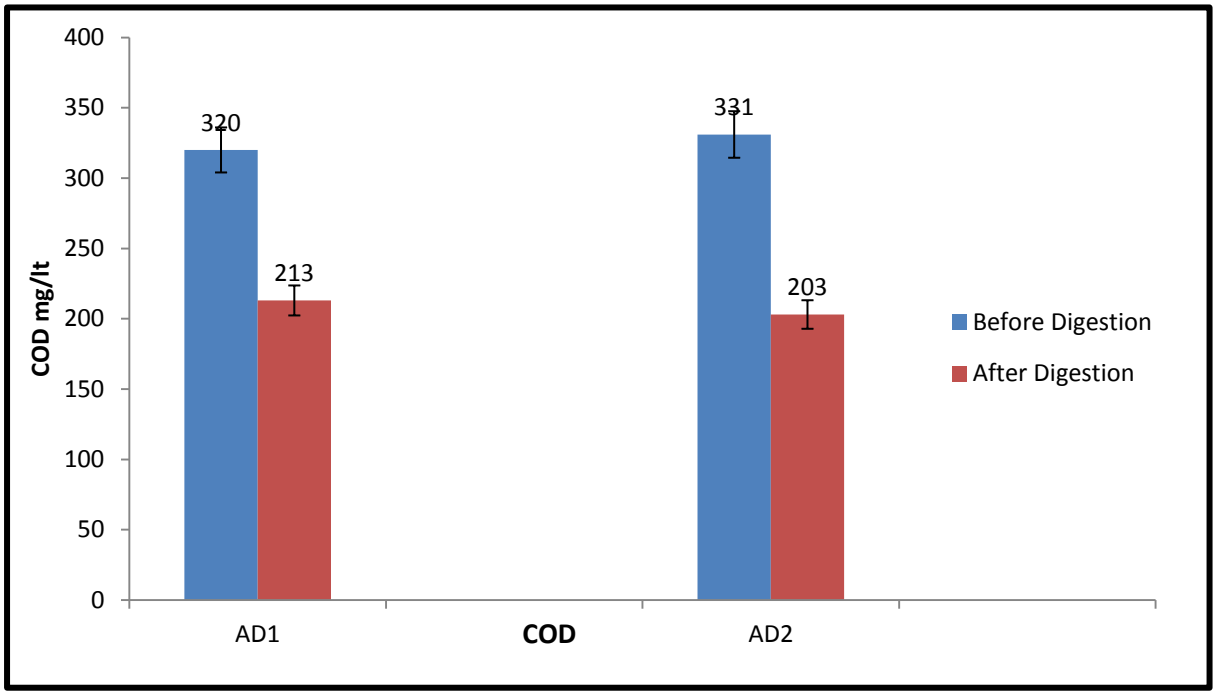

Figure 4.10: COD Reduction (Summers)

As already discussed in above section COD is a parameter which is utilized to quantify the quantity of organic matter in waste and anticipate the potential for biogas generation. In substrate organic material i.e. COD was changed into biogas by the action of bacteria. The measure of COD that is degraded by the bacteria is known as COD removal. Larger the COD removal larger will be Biogas generation [39]. As we can see from fig 4.10 initial value of COD was greater than final COD value. In AD1 the initial COD value was observed to be 320 mg/lt and final COD value was observed to be 213 mg/lt. In AD2 the initial COD value was observed to be 331 mg/lt and final COD value was observed to be 203 mg/lt. The COD removal rate was 33.4% for AD1 and 38.6% for AD2. So Biogas production was higher in

AD2 due to higher COD removal rate when compared to AD1.

4.4.3 Effect on Alkalinity with time:

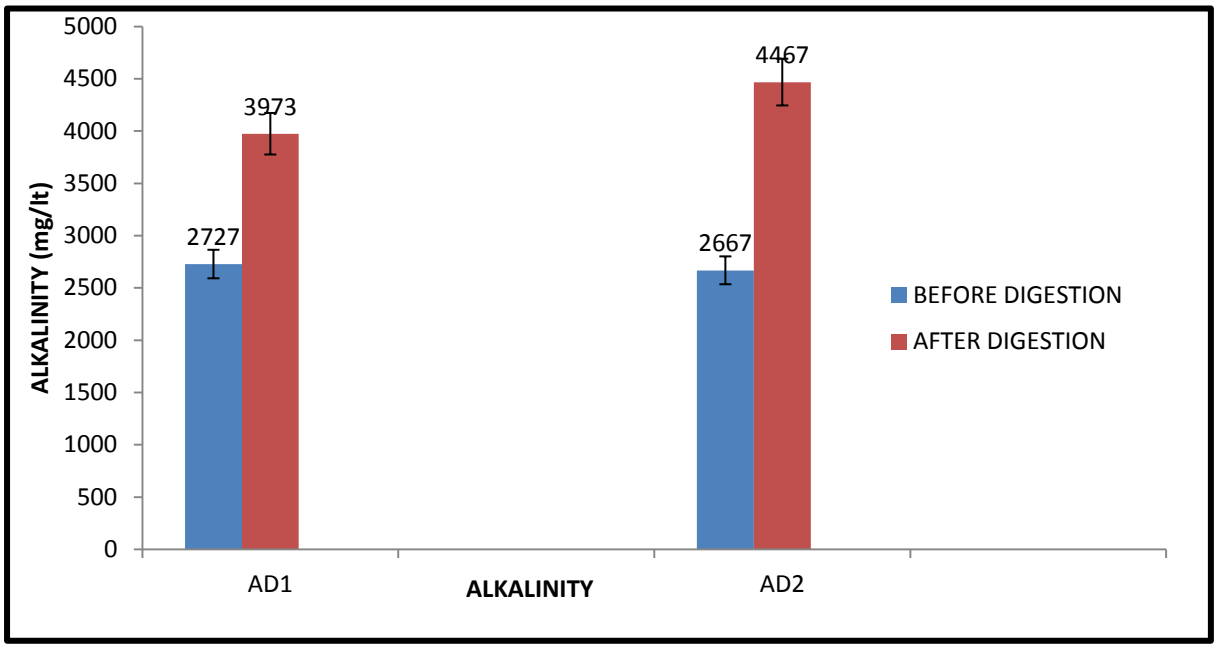

Figure 4.11: Effect on Alkalinity with time (Summers)

Alkalinity is provided by Calcium, Magnesium, Ammonium bicarbonates. These help to keep up adequate buffering capacity inside the digester. These are formed due to breakdown of protein in the substrate. Concentration of Alkalinity relies on the solids feed concentration to a great extent. For keeping up adequate buffering capacity alkalinity has to be maintained between 2000 mg/lt and 5000 mg /lt [6]. Alkalinity increases with time. From fig 4.2 it can be seen that in both the digesters alkalinity has increased. In AD1 initial alkalinity was 2627 mg/lt and final alkalinity was 3973 mg/lt. In AD2 initial alkalinity was 2667 mg/lt and final alkalinity was 4467 mg/lt. So alkalinity was increased with time and was maintained within limit of 2000 mg/lt and 5000 mg /lt. There was more increase in alkalinity in AD2 so there was more biogas production in AD2.

4.4.4. Effect on TS and VS reduction with time:

TS indicate organic as well as inorganic matter in the feedstock. In both digesters the TS were held as 11667 mg/ lt and 9667 mg/ lt demonstrated a decrease after the retention period of 55 days which were found to be 9267 mg/ lt and 7133 mg/lt. Thus there was 20.5% and 26.21 % diminishing in both the digesters. TS play a critical role in the process. TS in the beginning was more but however when degradation began to occur TS start to decrease, as microorganisms began to utilize the TS content as their food. As already discussed in the above section the study was batch study so new substrate is coming inside digester, so microorganisms need feed upon TS in the digester. So its value starts to decrease. TS

reduction was more in AD2 as compared to AD1. Fig 4.12 shows total solid reduction. VS are the solids that are lost on ignition of the dry solids at 550°C. VS additionally plays role in biogas production as they are responsible for the biogas production. The Volatile reduction in AD1 and AD2 was observed to be and 30.64% and 34.13%. VS removal was greater in AD2 this may be due to fact that smaller size of particles which are easy for bacterias to digest. Greater the VS reduction greater will be biogas production. So there was greater biogas production in AD2 [34] .Co-digestion also helps to reduce the TS and VS content to a great extent. Fig 4.13 shows total volatile reduction.

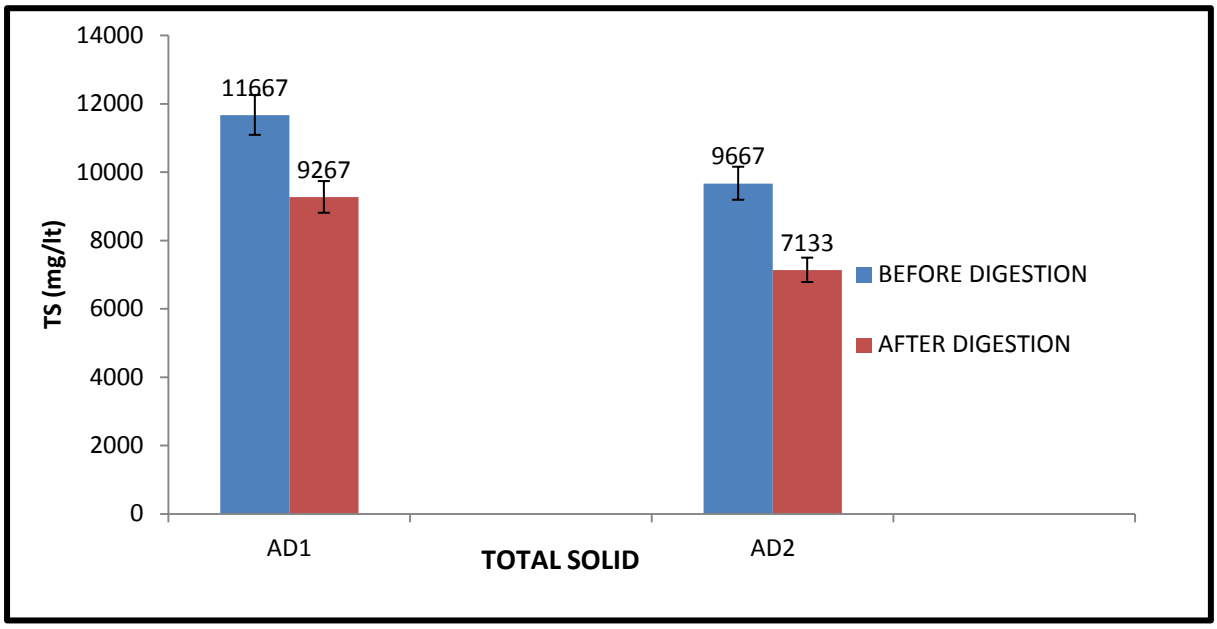

Figure 4.12: Total Solid Reduction (Summers)

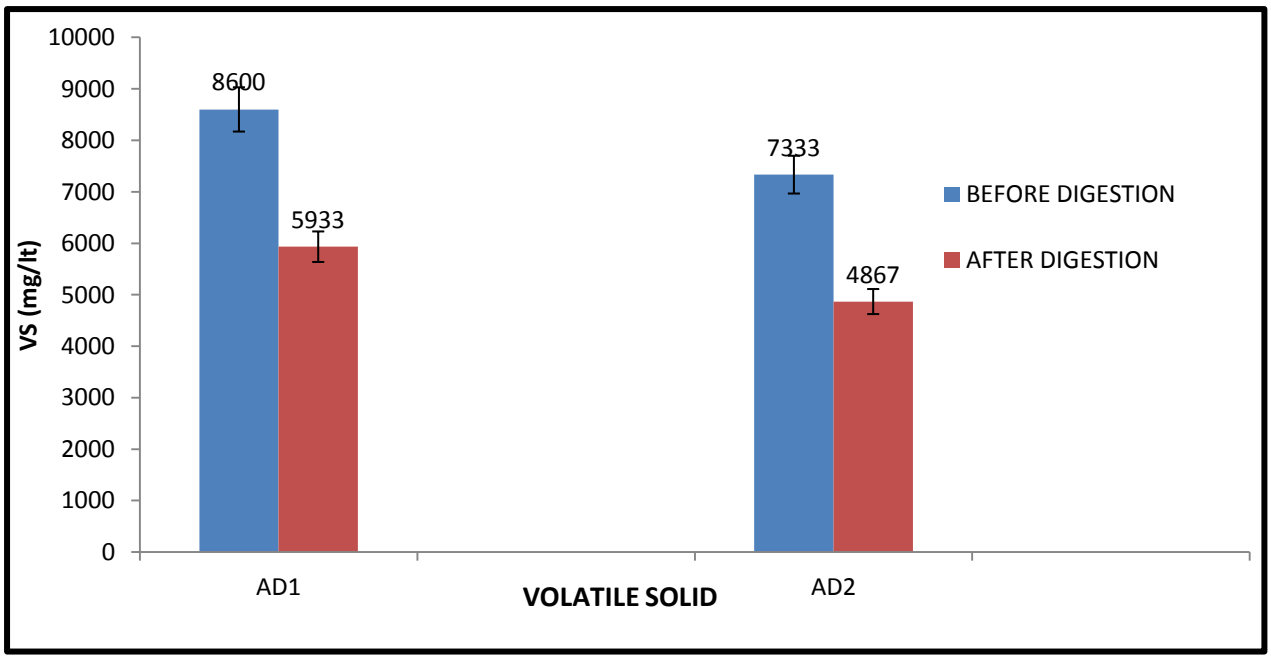

Figure 4.13 Volatile Solid Reduction (Summers)

4.4.5 Effect on temperature with time:

Temperature influences the metabolic activities of microorganisms so it is an essential parameter in biogas production. Hence at higher temperature the bacterial activity increases which results in higher yield of biogas production. A Stable temperature is needed inside digester because some bacteria are temperature sensitive for e.g. methanogens [6]. Temperature inside and outside the AD1 and AD2 are shown in fig.4.14 and 4.15.In AD1 the inside temperature varies from 21°C to 31°C and outside temperature varies from 15°C to 28°C.

In AD2 the inside temperature varies from 22°C to 33°C and outside temperature varies from 15°C to 28°C. The study was done during summer season so adequate temperature was maintained inside digesters for the bacteria's to grow. Outside Temperature was same for both the digesters. The inside temperature was observed more than temperature of outside in both the digesters due to microbial degradation of bacteria's the inside temp was more. Both the digesters were kept at outside for exposing in sun to increase the temperature. This shows that microbial degradation of the waste by the bacteria's raises the inside temperature of the digester. The inside temperature of AD2 was more as compared to AD1 so Biogas production was more in AD2 as compared to AD1.

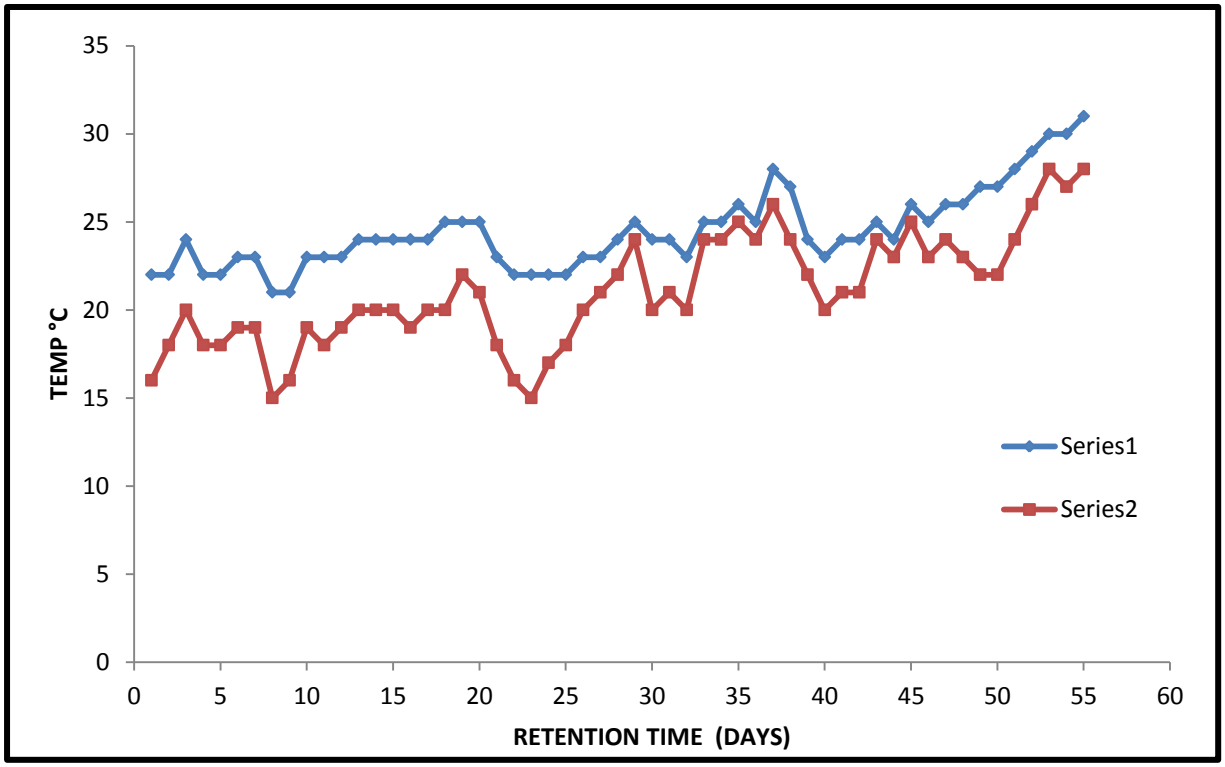

FIGURE 4.14: Variation of Temp with time in AD1 (Summers)

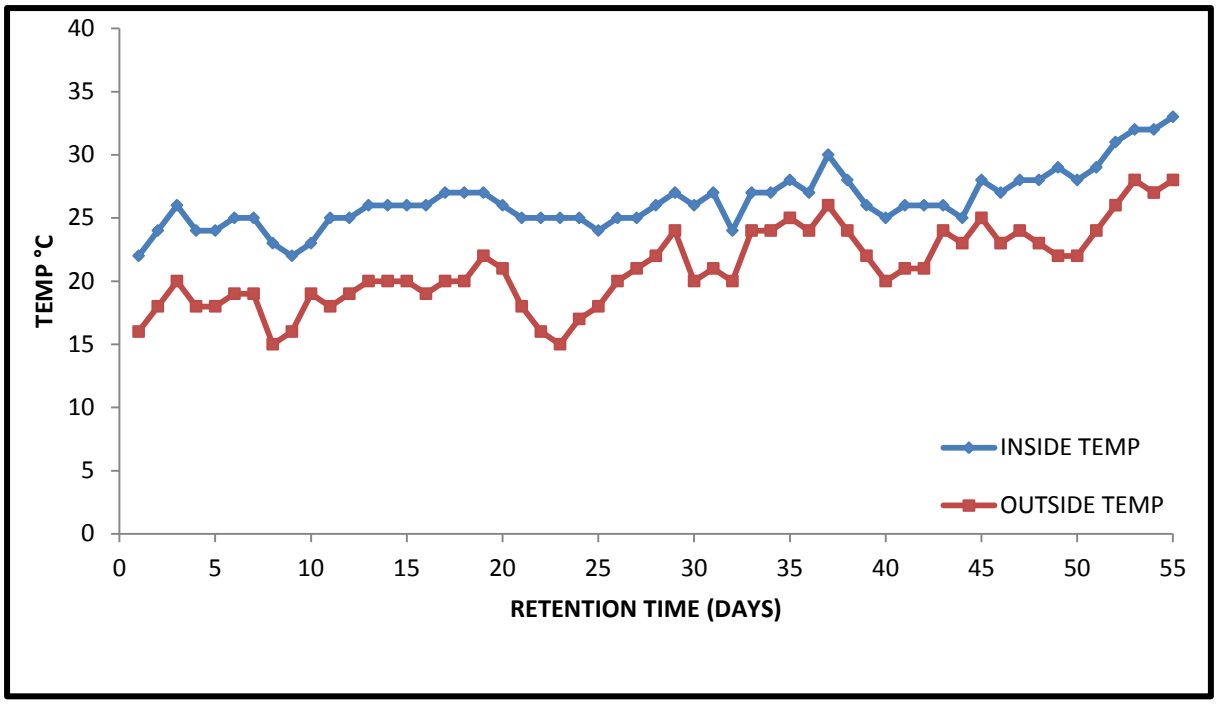

FIGURE 4.15: Variation of Temp with time in AD2 (Summers)

4.4.6 CUMULATIVE BIOGAS PRODUCTION:

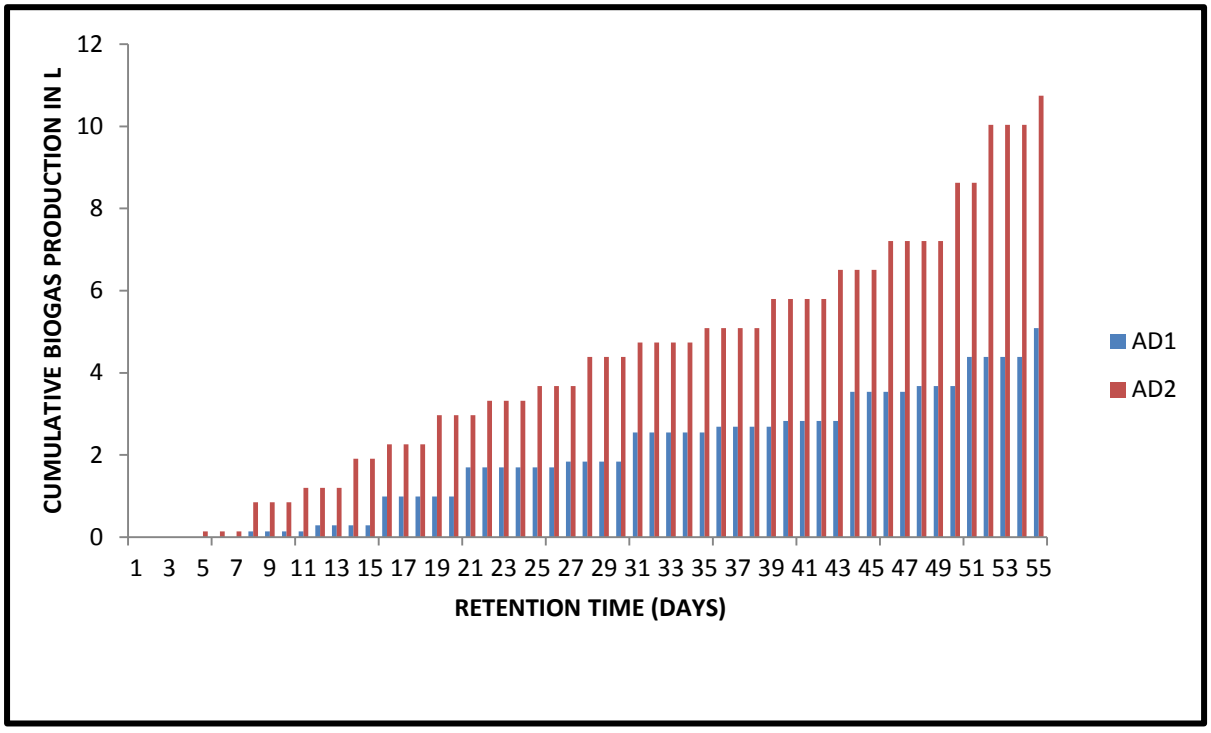

Figure 4.16: Cumulative Biogas Production (Summers)

The Biogas Production in both the digesters is shown in fig 4.16. In AD1 the ascent in gas holder was observed 8th day while in AD2 the rise was observed from 5th day after the slurry feeding inside the digester. Biogas started producing early in AD2. The results have demonstrated that there was increment in biogas production and accumulation all through the

retention time. This might be because of increase in alkalinity and pH being in optimum range. Another reason can be temperature range being in optimum range. This implies that biogas production from Co-Digestion of Sewage Sludge and Pine needles is high as compared to single digestion of sewage sludge alone. Another reason can be enhanced C/N ratio and nutrient balance. Biogas production in AD1 is 5.1 litres and in AD2 was 10.7 litres.

4.5 COMPARISON OF DIFFERENT MODELS IN AD1 AND AD2:

4.5.1 LINEAR PLOTS:

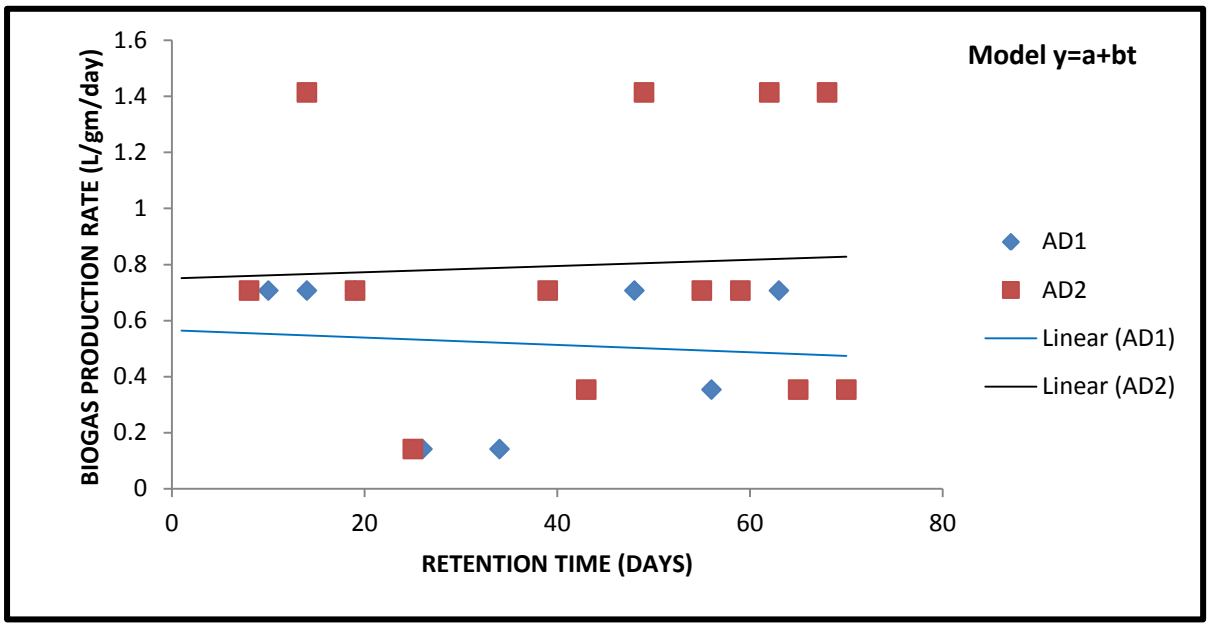

Figure 4.17: Linear Plots of biogas production rates in AD1 and AD2 during winters.

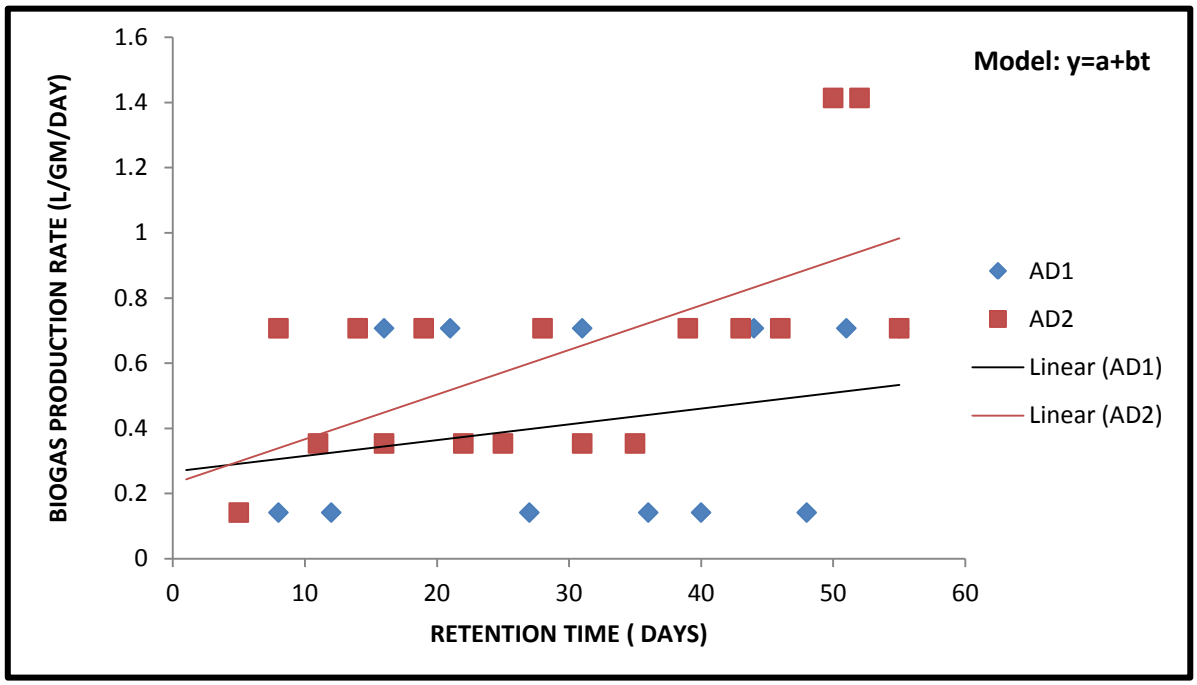

Figure 4.18 Linear Plots of biogas production rates in AD1 and AD2 during summers

Figure 4.17 and Figure 4.18 shows the linear plots of biogas production rates for AD1 and AD2 during winter season and summer season. During winters Coefficient of determination (R^2) was found to be 0.0096 for AD1 and for AD2 0.0026. While in summer season R^2 was found to be 0.067 for AD1 and for AD2 it was found to be 0.3968. R^2 value was more in case of AD2 as compared to AD1 during summer season. While it was low during winters due lesser biogas production there was no increase in height of digesters. So there was gap in production of biogas.

The kinetic parameters computed are shown in table given below:

Table 4.5 Linear model Parameters

S.NO.	SEASON	DIGESTER	a (L/gm/day)	b (L/gm/day)	R^2
1	WINTERS	AD1	-0.0013	0.5652	0.0096
2		AD2	0.0011	0.7507	0.0026
3	SUMMERS	AD1	0.0048	02673	0.0670
4		AD2	0.2673	0.2298	0.3968

4.5.2 EXPONENTIAL PLOTS:

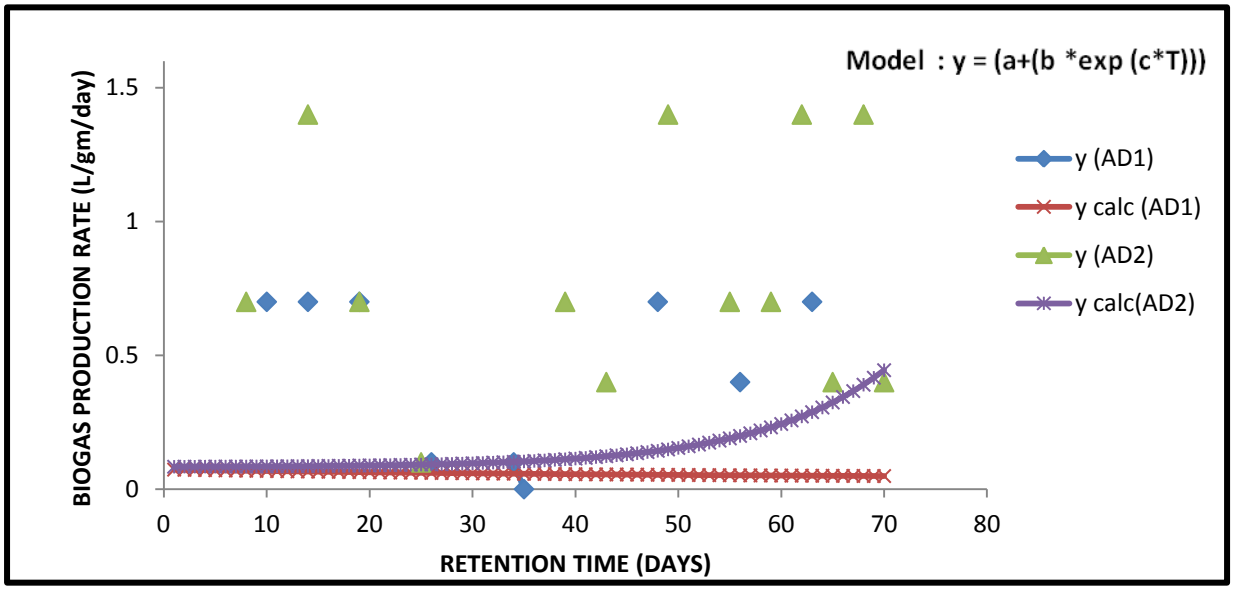

Figure 4.19 Exponential Plots of biogas production in AD1 and AD2 during winters.

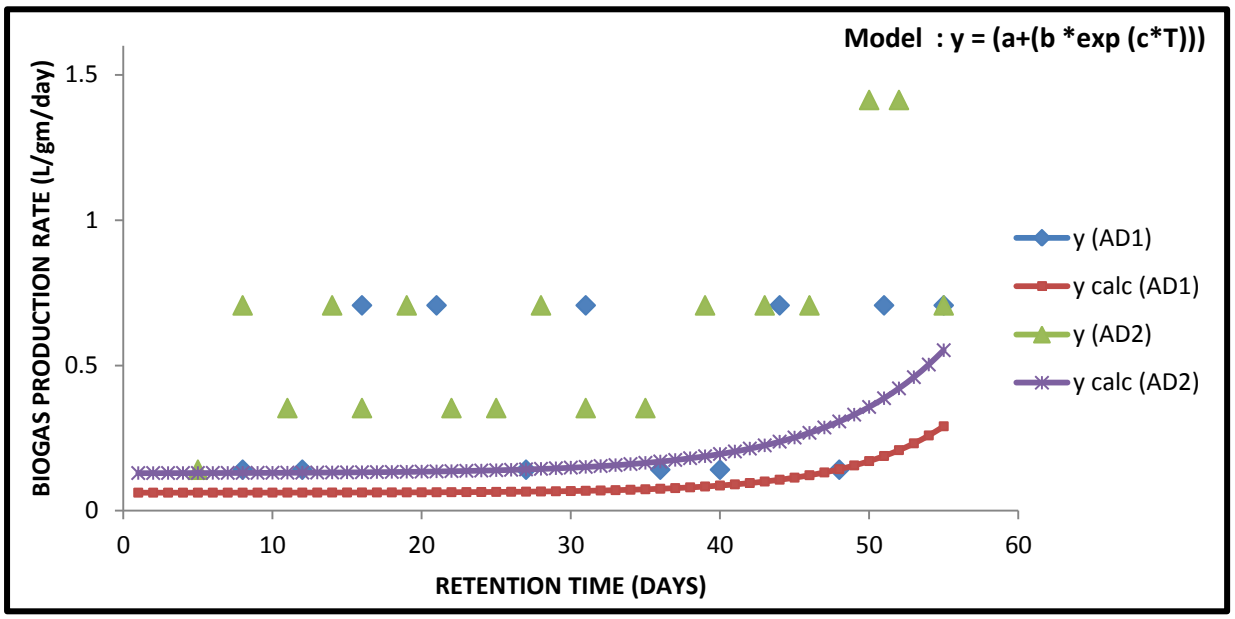

Figure 4.20 Exponential Plots of biogas production in AD1 and AD2 during Summers

Figure 4.19 and Figure 4.20 shows the exponential plot of biogas production for AD1 and AD2 during winter season and summer season. During winters Coefficient of determination (R^2) was found to be 0.0014 for AD1 and for AD2 0.0616. While in summer season R^2 was found to be 0.0573 for AD1 and for AD2 it was found to be 0.0866, R^2 value was more in case of AD2 as compared to AD1 during summer season. While it was low during winters due lesser biogas production there was no increase in height of digesters. So there was gap in production of biogas. The kinetic parameters of exponential plots are shown in table given below:

Table 4.4 Exponential model Parameters

S.NO.	SEASON	DIGESTER	a (L/gm/day)	b (L/gm/day)	c (day^{-1})	R^2
1	WINTERS	AD1	0.0390	0.0345	-0.0179	0.0014
2		AD2	0.0823	0.0012	0.0818	0.06165
3	SUMMERS	AD1	0.0623	6.52×10^{-3}	0.1483	0.0573

4		**AD2**	0.1290	0.0004	0.1234	0.0866

4.5.3 LOGISTIC GROWTH EQUATION:

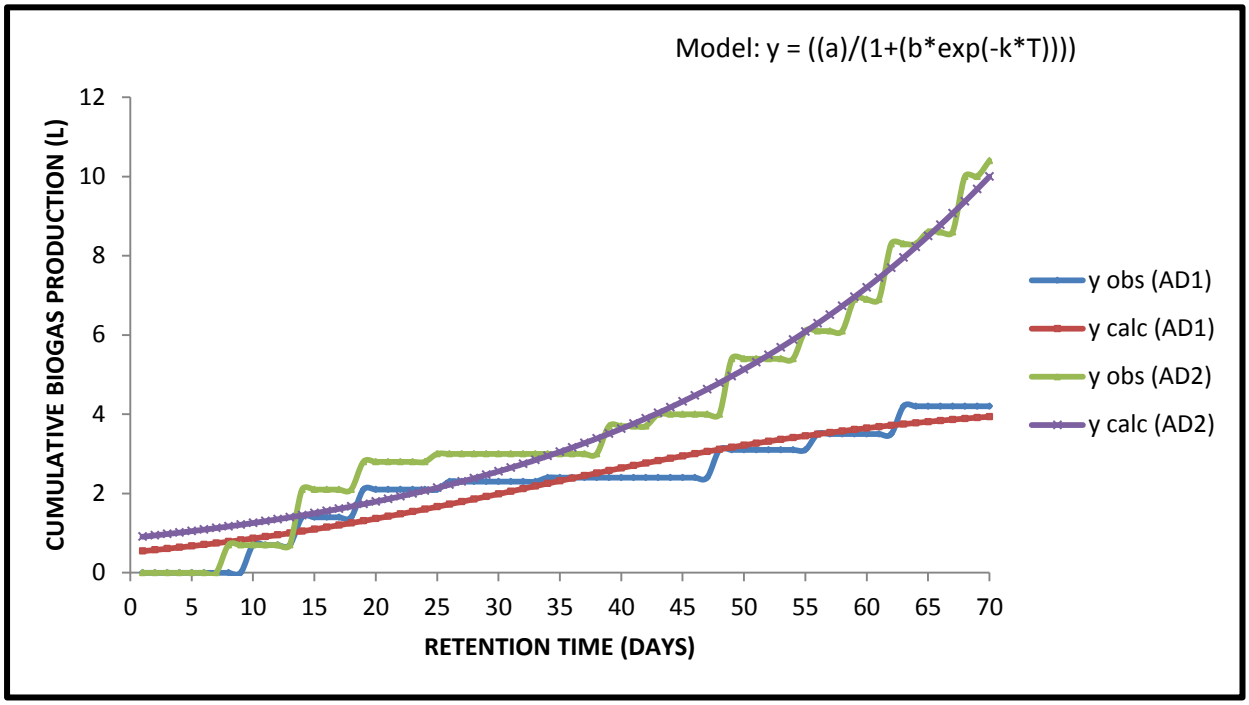

Figure 4.21 Logistic growth Plots of biogas production in AD1 and AD2 during winters.

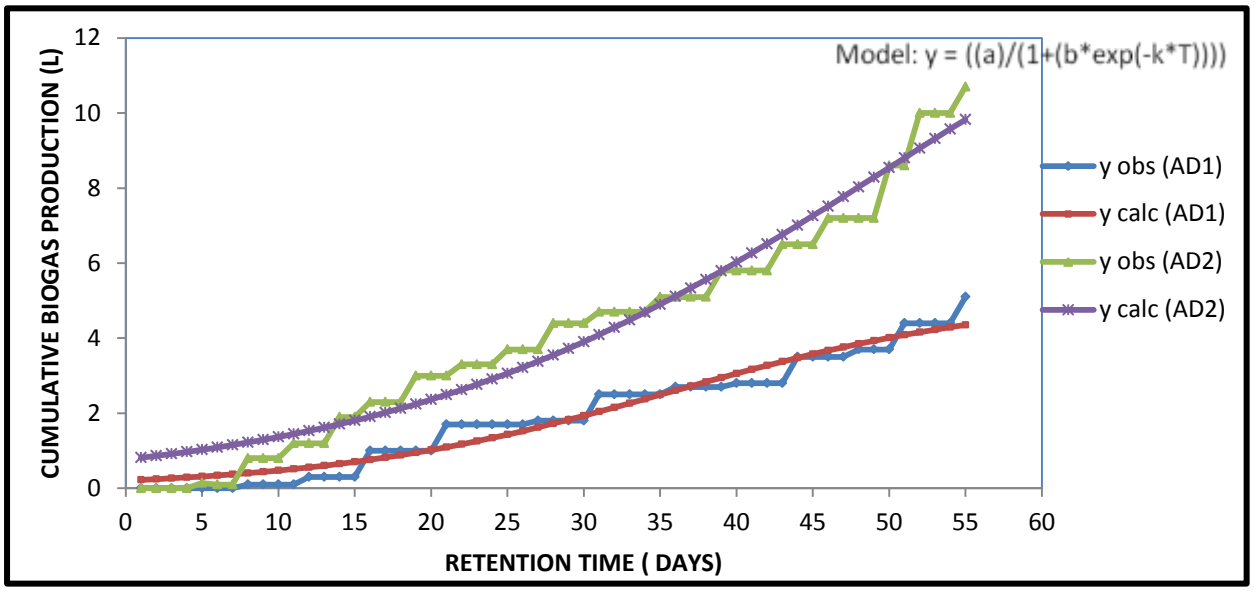

Figure 4.22 Logistic growth Plots of biogas production in AD1 and AD2 during summer.

Figure 4.20 and Figure 4.22 shows the logistic growth plot of biogas production for AD1 and AD2 during winter season and summer season. During winters Coefficient of

determination (R^2) was found to be 0.88 for AD1 and for AD2 is 0.95 . While in summer season R^2 was found to be 0.9555 for AD1 and for AD2 it was found to be 0.9586, R^2 value was more in case of AD2 as compared to AD1 during summer season. While it was low during winters due lesser biogas production there was no increase in height of digesters. Logistic growth model parameters are shown in table given below:

Table 4.4 Logistic Growth model Parameters

S.NO.	SEASON	DIGESTER	a	b	k (day^{-1})	R^2
1	WINTERS	AD1	4.34	7.37	0.060	0.8865
2		AD2	90.49	101.99	0.030	0.9535
3	SUMMERS	AD1	5.12	23.98	0.089	0.9555
4		AD2	16.85	20.93	0.061	0.9586

4.5.4 EXPONENTIAL RISE TO MAXIMUM EQUATION:

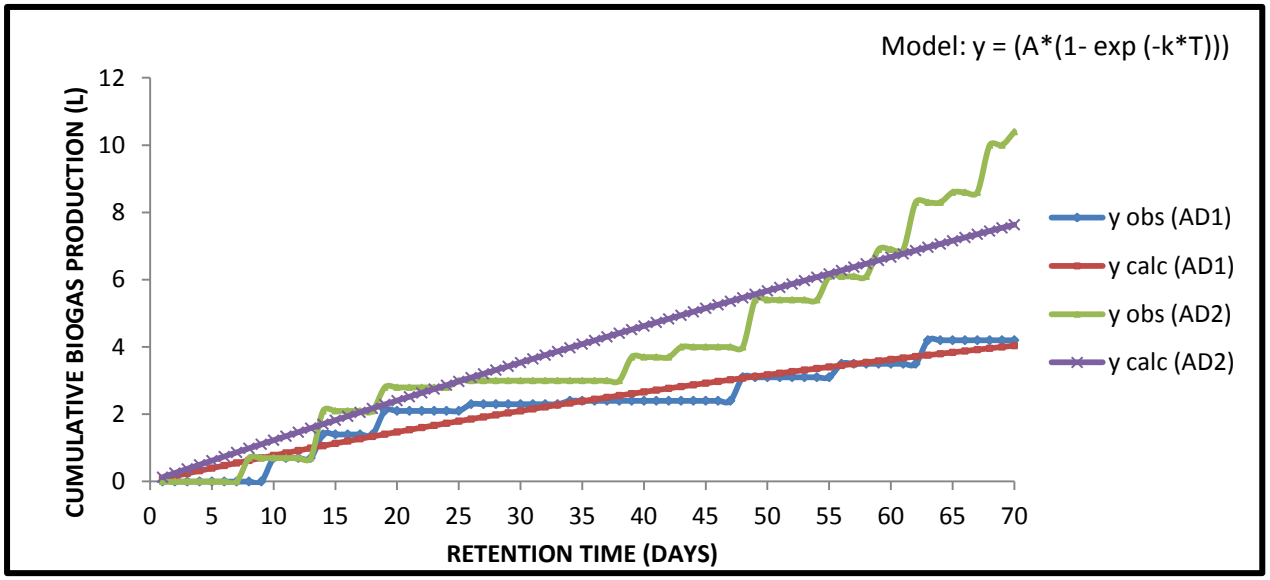

Figure 4.23 Exponential rise to maximum Plots of biogas production in AD1 and AD2 during winters

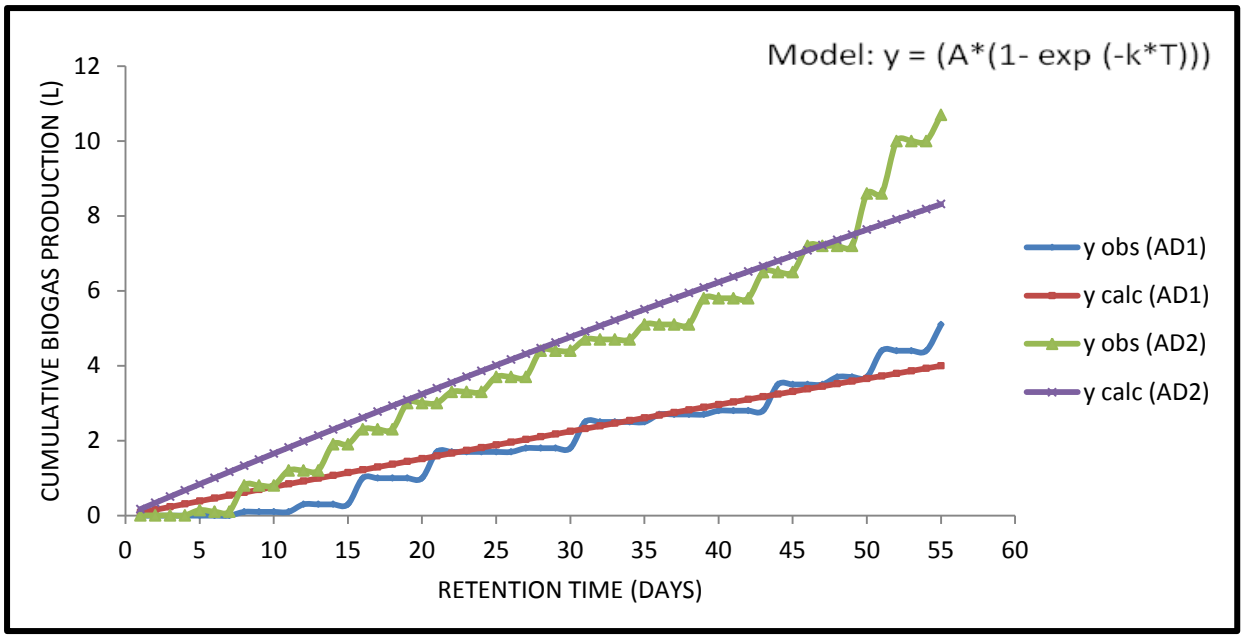

Figure 4.24 Exponential rise to maximum Plots of biogas production in AD1 and AD2 during summers

Figure 4.23 and Figure 4.24 shows the exponential rise to maximum plot of biogas production for AD1 and AD2 during winter season and summer season. During winters Coefficient of determination (R^2) was found to be 0.9290 for AD1 which was higher as compared to AD2 for which value was 0.8809. While in summer season R^2 was found to be 0.9211 for AD1 and for AD2 it was found to be 0.9296. R^2 value was more in case of AD2 as compared to AD1 during summer season. As we can see from table below that co-digestion of sewage sludge and pine needles has maximum specific biogas production as compared to sewage sludge alone. Exponential Rise to Maximum model parameters is shown in table given below:

Table 4.5 Exponential Rise to maximum model Parameters.

S.NO.	SEASON	DIGESTER	A (L/gm)	k (day^{-1})	R^2
1	WINTERS	AD1	7.72	0.010	0.9290
2		AD2	31.29	0.003	0.8909
3	SUMMERS	AD1	31.29	0.002	0.9211
4		AD2	41.39	0.007	0.9296

4.5.5 MODIFIED GOMPERTZ KINETIC MODEL EQUATION:

Table 4.6 Modified Gompertz model Parameters.

S.NO.	SEASON	DIGESTER	A (L/gm)	λ (day^{-1})	μ_m	R^2
1	WINTERS	AD1	3.917	0.99	0.086	0.8842
2		AD2	16.77	10.08	0.14	0.9230
3	SUMMERS	AD1	6.031	8.06	0.094	0.9609
4		AD2	17.988	10.08	0.20	0.9638

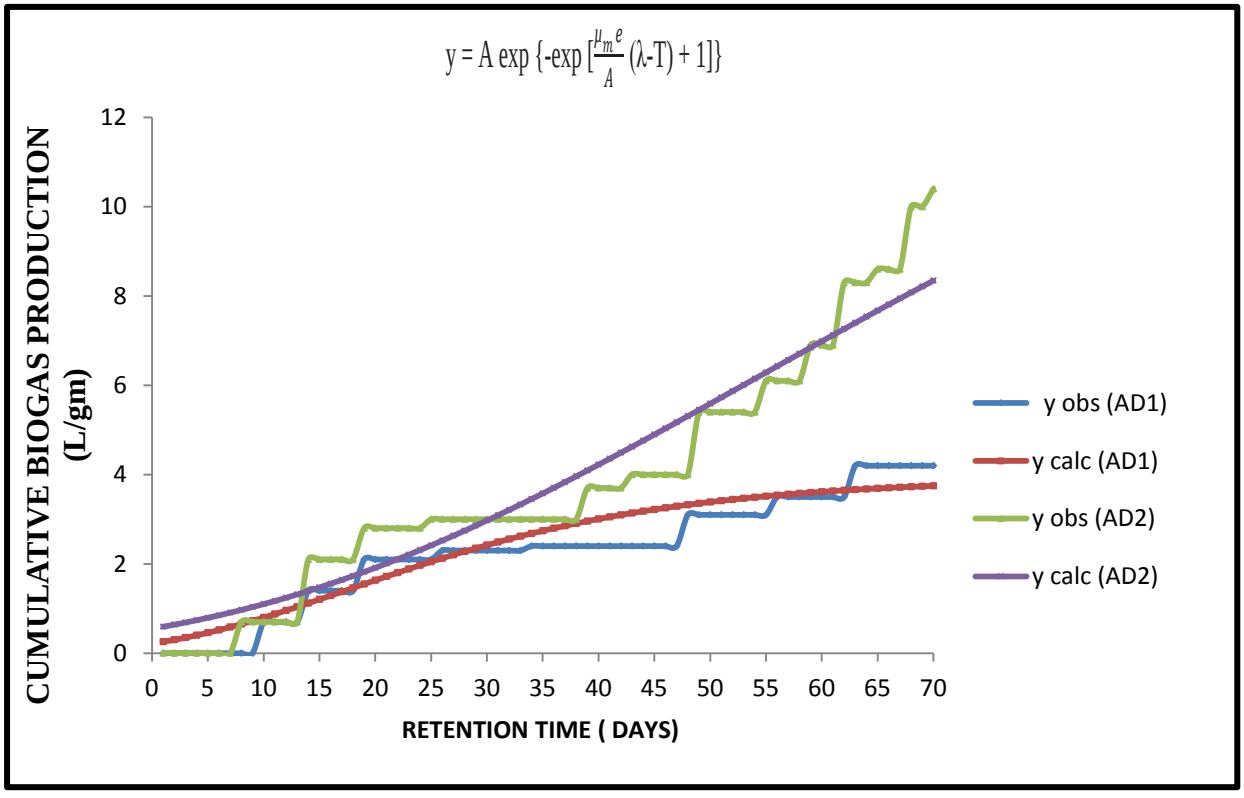

Figure 4.25 Modified Gompertz Plots of biogas production in AD1 and AD2 during winters

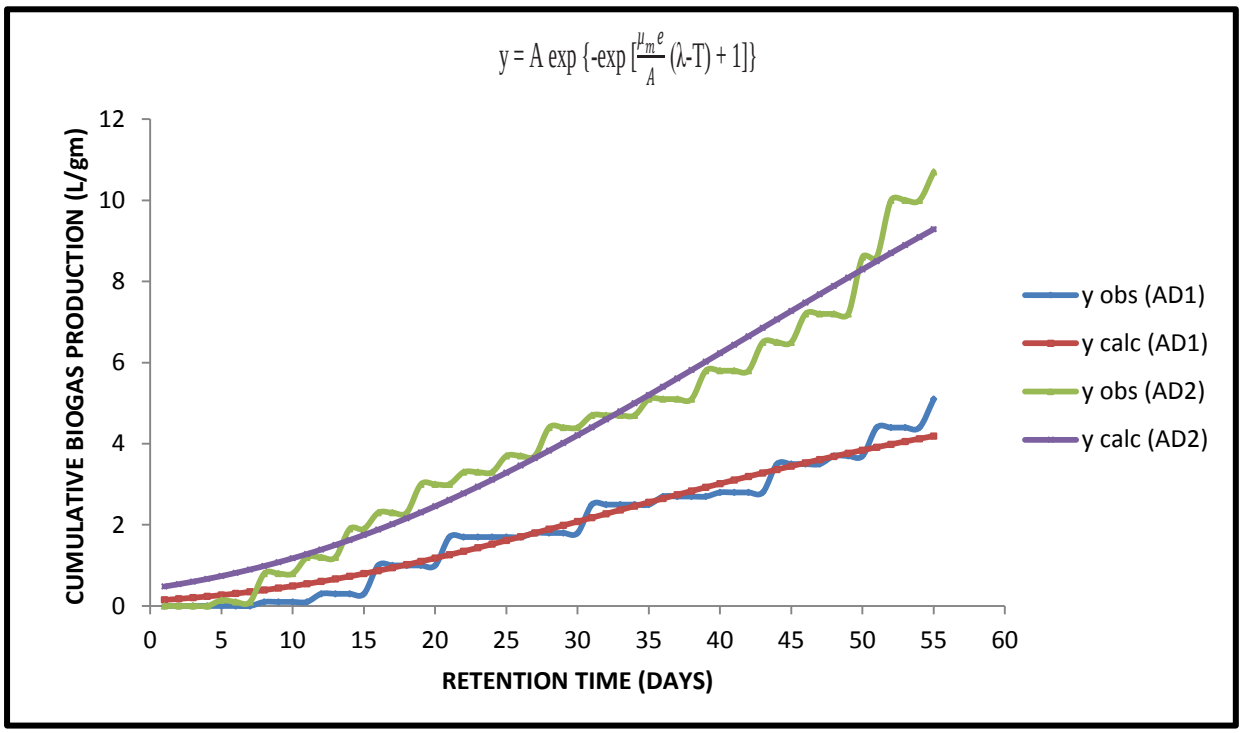

Figure 4.26 Modified Gompertz Plots of biogas production in AD1 and AD2 during summers

Figure 4.25 and Figure 4.26 shows the exponential rise to maximum plot of biogas production for AD1 and AD2 during winter season and summer season. During winters Coefficient of determination (R^2) was found to be 0.8842 for AD1 which was lower as compared to AD2 for which value was 0.9230 . While in summer season R^2 was found to be 0.9609 for AD1 and for AD2 it was found to be 0.9238. R^2 value was more in case of AD2 as compared to AD1 during summer season. As we can see from table below that co-digestion of sewage sludge and pine needles has maximum specific biogas production as compared to sewage sludge alone. The latency time for AD2 was found to be much higher as compared to AD1 because pine needles takes much time for degradation process.

CHAPTER-5

CONCLUSION

5.1 GENERAL

As per the results of substrate and digestate characterisation and fermentation tests, pine needles and sludge turns out to be a valuable substrate for biogas production. The investigation detected no inhibitory effects, showing on the appropriate composition of the substrates for anaerobic digestion. Biogas production was described by a high production rate in the beginning of the experiment, which demonstrates the ability of the microbial group to begin digestion without an earlier adaption period.

The substrates utilized in the thesis were provided by the STP Plant at JUIT campus and forest near JUIT Campus which has not been taken into utilization in large scale yet. Sewage sludge was not much in use until now , it was just disposed off without any utilization. Also pine needles are likewise less utilized. This study gave confirmation of the reasonableness of the novel system as the outcomes demonstrated a high energetic value of the sewage sludge long with pine needles collected with this technology. Future studies could additionally analyse the ideal technical solutions as well as implementation of the framework to contribute to the spread of the technology.

It is prescribed to continue pine needles co-digestion with sewage sludge. Anaerobic digestion represents for the stabilisation of sewage sludge from STP Plant gives an alternative source of energy. The utilization of pine needles as a co-substrate proved to increase energy yields. The ideal proportion between sewage sludge and pine needles should be addressed by future studies in order to fully utilise sewage sludge and maximise biogas production.

5.2 CONCLUSION FOR SUBSTRATE CHARACTERIZATION:

1. The sludge were characterised by a lower TS, VS, TOC, Organic matter and C/N ratio content than pine needles , while pine needles are characterised by lower FS and TKN%.

2. The TS content of the fine fraction depends firmly on the measure of water added during dilution process. The measure of water added ought to be assessed precisely because of fact that it influences digester configuration as well as volume of digestate to be consequently disposed off.

3. The higher VS content of depicts higher energy content which is attractive from economic perspective of biogas production.

4. For the capability as a substrate C/ N ratio plays an essential role. This is critical parameter for the prediction of how effective the biogas process can be. Ideal C/N ratio should be maintained in range of 20-30. Co-digestion additionally improve the rate of biogas production.

5. Increasingly the organic content more will be the degradation rate.

6. Cellulose content of Pine Needles was likewise high when contrasted with hemicelluloses and lignin content. Crystalline cellulose can by weekend by physical pre-treatment making it simpler to be degraded by microorganisms.

5.3 CONCLUSIONS FOR BIOGAS PRODUCTION IN AD1 AND AD2 DURING WINTERS:

1. Low or high pH i.e. value less than 5 or greater than 8 has been reported to prevent growth of methanogenic bacteria responsible for biogas production. The favourable range for biogas production is 6.5-7.5 in AD, so when pH was in this range there was considerable increment in biogas production.
2. TS in the beginning were more but when degradation started to take place TS start to decrease. There was 19.7 % decrease in AD1 and 22.8 % decrease in AD2.

3. Volatile reduction in AD1 and AD2 was found to be 30.64% and 34.13% Volatile reduction is found to be greater in AD2 this may be due to fact that small size of digestate which is easy for micro-organisms to digest.

4. The COD removal rate was 27% for AD1 and 35% for AD2. So Biogas production was higher in AD2 due to higher COD removal rate as compared to AD1.
5. In AD1 initial alkalinity was 1387 mg/lt and final alkalinity was 2627 mg/lt. In AD2 initial alkalinity was 920 mg/lt and final alkalinity was 2667 mg/lt. So alkalinity was increased with time and was maintained within limit of 2000 mg/lt and 5000 mg /lt. There was more increase in alkalinity in AD2 so there was more biogas production in AD2.
6. In AD1 the inside temperature varies from 15°C to 20°C and outside temperature varies from 2°C to 25°C. In AD2 the inside temperature varies from 15°C to 25°C and

outside temperature varies from 2°C to 20°C. The inside temperature was observed more than temperature of outside in both the digesters. Temperature plays an crucial role in the biogas generation. Both are directly proportional to each other. Optimum temperature should be maintained for increase in biogas production.

7. Cumulative Biogas production in AD1 was 4.2 litres and for AD2 Cumulative Biogas production was 10.2 litres. Co-Digestion of sewage sludge and pine needles is more effective than single digestion of sewage sludge only. It increases the potential of increasing biogas yield and has positive influence on early biogas production.

5.4 CONCLUSIONS FOR BIOGAS PRODUCTION IN AD1 AND AD2 DURING SUMMERS:

1. Low or high pH i.e. value less than 5 or greater than 8 has been reported to prevent growth of methanogenic bacteria responsible for biogas production. The favourable range for biogas production is 6.5-7.5 in AD, so when pH was in this range there was considerable increment in biogas production.
2. TS in the beginning were more but when degradation started to take place TS start to decrease. There was 20.5 % decrease in AD1 and 26.21 % decrease in AD2.Which was more as compared to winter season.
3. Volatile reduction in AD1 and AD2 was found to be 31.01 % and 33.6 %. Volatile reduction is found to be greater in AD2 this may be due to fact that small size of digestate which is easy for micro-organisms to digest. The reduction was more as compared to winter season.
4. The COD removal rate was 33.4% for AD1 and 38.6% for AD2. So Biogas production was higher in AD2 due to higher COD removal rate as compared to AD1.
5. In AD1 initial alkalinity was 2627 mg/lt and final alkalinity was 3973 mg/lt. In AD2 initial alkalinity was 2667 mg/lt and final alkalinity was 4467lt. So alkalinity was increased with time and was maintained within limit of 2000 mg/lt and 5000 mg /lt. There was more increase in alkalinity in AD2 so there was more biogas production in AD2.
6. In AD1 the inside temperature varies from 21°C to 31°C and outside temperature varies from 15°C to 31°C. In AD2 the inside temperature varies from 22°C to 33°C and outside temperature varies from 15°C to 31°C. The inside temperature was observed more than temperature of outside in both the digesters. Temperature plays

an crucial role in the biogas generation. Both are directly proportional to each other. Optimum temperature should be maintained for increase in biogas production. Temperature was mesophilic so there was more biogas production as compared to winter season in both the digesters with less retention time.

7. Cumulative Biogas production in AD1 was 5.1 litres and for AD2 Cumulative Biogas production was 10.7 litres. Co-Digestion of sewage sludge and pine needles is more effective than single digestion of sewage sludge only. It increases the potential of increasing biogas yield and has positive influence on early biogas production.

5.6 FLAME TEST

Flame test was done at the end of the study which gives blue flame indicating the presence of 50-60 % methane gas and 50-40 % carbon dioxide along with trace gases.

5.5 CONCLUSION ON MODELLING STUDY:

1. It was concluded from the modelling study of co-digesting sewage sludge with pine needles that exponential plot had higher correlation when contrasted with linear plot for simulating the biogas production rate.

2. Logistic Growth model and modified Gompertz equation plot demonstrate better correlation than exponential rise to maximum plot in indicating simulating cumulative biogas production rate.

3. Modified Gompertz model show predicted lag phase time alongside prediction of biogas potential of the study.

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APPENDIX-A

SUBSTRATE CHARACTERIZATION

A.1 PHYSICO-CHEMICAL CHARACTERISTICS OF SEWAGE SLUDGE

A.1.1 TOTAL SOLIDS, VOLATILE SOLIDS AND FIXED SOLIDS

W1= Weight of crucible , g

W2= Final weight of Crucible and sample, g

W3= Weight of dried residue and crucible, g

W4= Weight of residue and crucible after ignition at 600 ºC, g

$$TS\ (\%) = \frac{(W3-W1)}{(W2-W1)} \times 100$$

Ignite the residue obtained in 600 ºC in a muffle furnace, cool and weigh.

$$VS\ (\%) = \frac{(W3-W4)}{(W3-W1)} \times 100$$

$$FS\ (\%) = \frac{(W4-W1)}{(W3-W1)} \times 100$$

OBSERVATION TABLE

S.NO	W1, g	W2, g	W3, g	W4, g
1	28.58	58.04	30.71	29.34
2	30.99	60.55	33.2	31.74
3	28.9	58.46	31.05	29.65

RESULTS:

S.NO	TS%	VS (% OF TS)	VS %	FS(% OF TS)	FS%
1	7.23	64.32	4.65	35.68	2.58
2	7.48	66.06	4.94	33.94	2.54
3	7.27	65.12	4.74	34.88	2.54
Mean	**7.33**	**65.17**	**4.78**	**34.83**	**2.55**
Std dev	**0.13**	**0.87**	**0.15**	**0.87**	**0.02**

S.NO	VS/TS
1	0.64
2	0.66
3	0.65
Mean	**0.65**
Std dev	**0.01**

A.1.2. TOTAL ORGANIC CARBON

$$\% \text{ TOC} = \frac{10(B-S) * 0.003 * 100}{B * weight\ of\ the\ sample}$$

S = sample titration

B = blank titration

1 ml of 1N $K_2Cr_2O_7$ – 3mg or 0.003g organic carbon

% Organic matter = 1.724 * TOC

OBSERVATION TABLE:

S.NO	SAMPLE NO	Wt. OF SAMPLE	INITIAL READING	FINAL READING	REQUIRED VOL (ml)
1	**BLANK**	0	0	21	21
2	**S1**	0.05	0	10.3	10.3
3	**S2**	0.05	0	10.2	10.2
4	**S3**	0.05	0	10.4	10.4

RESULTS

S.NO	SAMPLE	TOC %	% ORGANIC MATTER
1	**S1**	30.57	52.71
2	**S2**	30.86	53.20
3	**S3**	30.29	52.21
Mean		**30.57**	**52.71**
Std dev		**0.29**	**0.49**

A.1.3 TOTAL KJELDAHL NITROGEN

$$\text{TKN (\%)} = \frac{0.0014 * \text{Titration value} * \text{Total volume of liquid prepared}}{\text{ml of sample taken} * \text{weight of sample}}$$

$$\text{TKN (\%)} = \frac{0.0014 * T * 1OO}{5 * \text{Weight of sample}}$$

OBSERVATION TABLE

S.N0	SAMPLE NO.	TITRATION VALUE	TKN (%)
1	**S1**	1.4	**3.92**
2	**S2**	1.5	**4.2**
3	**S3**	1.4	**3.92**
	Mean		**4.01**
	Std dev		**0.16**

A.1.4 C/ N RATIO

S.NO	C/N
1	7.80
2	7.35
3	7.73
Mean	**7.62**
Std dev	**0.24**

A.2 PHYSICO-CHEMICAL CHARACTERISTICS OF PINE NEEDLES

A.2.1 TOTAL SOLIDS, VOLATILE SOLIDS AND FIXED SOLIDS

W1= Weight of crucible , g

W2= Final weight of Crucible and sample, g

W3= Weight of dried residue and crucible, g

W4= Weight of residue and crucible after ignition at 600 ºC, g

$$TS\ (\%) = \frac{(W3-W1)}{(W2-W1)} \times 100$$

Ignite the residue obtained in 600 ºC in a muffle furnace, cool and weigh.

$$VS\ (\%) = \frac{(W3-W4)}{(W3-W1)} \times 100$$

$$FS\ (\%) = \frac{(W4-W1)}{(W3-W1)} \times 100$$

OBSERVATION TABLE

S.NO	W1, g	W2, g	W3 ,g	W4 ,g
1	30.95	41.76	40.83	33.1
2	32.51	43.31	42.41	35.02
3	30.83	41.65	40.73	33.28

RESULTS

S.NO	TS%	VS (% OF TS)	VS %	FS (% OF TS)	FS%
1	91.40	78.24	71.51	21.76	19.89
2	91.67	74.65	68.43	25.35	23.24
3	91.50	75.25	68.85	24.75	22.64
Mean	**91.52**	**76.05**	**69.60**	**23.95**	**21.92**
Std dev	**0.14**	**1.92**	**1.67**	**1.92**	**1.79**

S.NO	VS/TS RATIO
1	0.78
2	0.75
3	0.75
Mean	**0.76**
Std dev	**0.02**

A.2.2. TOTAL ORGANIC CARBON

$$\% \text{ TOC} = \frac{10(B-S) * 0.003 * 100}{B * weight\ of\ the\ sample}$$

S = sample titration

B = blank titration

1 ml of 1N $K_2Cr_2O_7$ – 3mg or 0.003g organic carbon

% Organic matter = 1.724 * TOC

OBSERVATION TABLE:

S.NO	SAMPLE NO	Wt. OF SAMPLE	INITIAL READING	FINAL READING	REQUIRED VOL (ml)
1	**BLANK**	0	0	21	21
2	**S1**	0.05	0	3.9	3.9
3	**S2**	0.05	0	4.2	4.1
4	**S3**	0.05	0	4	4

RESULTS

S.NO	SAMPLE	TOC %	% ORGANIC MATTER
1	**S1**	49	84
2	**S2**	48	83
3	**S3**	49	84
Mean		**49**	**84**
Std dev		**0.29**	**0.49**

A.2.3 TOTAL KJELDAHL NITROGEN

$$\text{TKN (\%)} = \frac{0.0014 * \text{Titration value} * \text{Total volume of liquid prepared}}{\text{ml of sample taken} * \text{weight of sample}}$$

$$\text{TKN (\%)} = \frac{0.0014 * T * 1OO}{5 * \text{Weight of sample}}$$

OBSERVATION TABLE:

S.N0	SAMPLE NO.	TITRATION VALUE	TKN (%)
1	**S1**	0.3	0.84
2	**S2**	0.4	1.12
3	**S3**	0.4	1.12
	Mean		**1.03**
	Std dev		**0.16**

A.2.4 C/ N RATIO

S.NO	C/N
1	58
2	43.11
3	43.36
Mean	**48.21**
Std dev	**8.61**

A.2.5 CELLULOSE CONTENT

W = weight of crucible (g)

W1 = Residue after placing in oven 150°C (overnight),g

W2 = After crucible was placed in muffle furnace at 450°C for one hour and cooled,g

Cellulose content = loss of wt. (%)

S.NO	W, g	W1,g	W2,g	CELLULOSE CONTENT (%)
1	32.51	33.01	32.5	51
2	30.95	31.47	31.96	49
3	30.83	31.33	31.85	52
			Mean	**51**
			Std dev	**1.53**

A.2.6. HEMICELLULOSE CONTENT

S.NO	W, g	A1,g	A2,g	NDF(%)
1	1	30.82	31.76	94
2	1	33.01	33.93	92
3	1	31.33	32.23	90
Mean				91

$$\textbf{NDF(\%)} = \frac{(A2-A1)*100}{W}$$

A1= weight of crucible, g

A2= weight of sample dried at 104°C for 12 hr, g

W= weight of sample, g

S.NO	W, g	A3,g	A4,g	ADF (%)
1	1	28.67	29.48	81
2	1	31.47	32.27	80
3	1	33.01	33.80	79
Mean				80

$$ADF(\%) = \frac{(A4 - A3)*100}{W}$$

A3= weight of crucible, g

A4= weight of sample dried at 104°C for 12 hr, g

W= weight of sample, g

Hemicellulose % = NDF (%) - ADF (%)

S.NO	HEMICELLULOSE
1	13
2	12
3	11
Mean	**12**
Std dev	**1**

A.2.7 LIGNIN CONTENT

ADL (%) = Lignin Content (%) = ((A5-A6)/W) X 100

S.NO	W, g	A5, g	A6, g	LIGNIN CONTENT (%)
1	1	31.58	10.04	21.54
2	1	32.67	11.17	21.5
3	1	32.23	10.7	21.53
Mean				**21.52**
Std dev				**0.02**

APPENDIX-B

PHYSICO-CHEMICAL CHARACTERIZATION OF DIGESTION SLURRY

B.1 PARAMETERS FOR AD1 BEFORE DIGESTION (WINTER SEASON)

B.1.1 TOTAL SOLIDS , VOLATILE SOLIDS, FIXED SOLIDS

W1= Weight of empty crucible , g

W2 = Weight of crucible and sample

W = Weight of residue= (W2-W1) g

V= Volume of sample taken, ml.

W3= Weight of crucible with residue heated to 600 ºC, g

$$TS\ (mg/lt) = \frac{(W2-W1)}{V} \times 1000 \times 1000$$

$$VS\ (mg/lt) = \frac{(W2-W3)}{V} \times 1000 \times 1000$$

$$FS\ (mg/lt) = \frac{(W3-W1)}{V} \times 1000 \times 1000$$

OBSERVATION TABLE

S.NO	VOL , ml	W1 , g	W2, g	W3 , g
1	50	28.69	29.42	28.8
2	50	30.95	31.66	31.07
3	50	32.51	33.25	32.6

RESULTS:

S.NO	TS, (mg/lt)	VS , (mg/lt)	FS, (mg/lt)
1	14600	12400	2200
2	14200	11800	2400
3	14800	13000	1800
Mean	**14533**	**12400**	**2133**
Std dev	**305.51**	**600.00**	**305.51**

S.NO	VS/TS RATIO
1	0.85
2	0.83
3	0.88
Mean	**0.85**

Std dev	0.02

B.1.2 COD

COD (mg/lt) = $\frac{(A-B)*N*8*1000}{\text{Volume of sample taken}}$

A= Volume of ferrous ammonia sulphate for blank.

B= Volume of ferrous ammonia sulphate for sample.

N = Normality of ferrous ammonia sulphate = 0.1

OBSERVATION:

S.NO	SAMPLE	VOL	IR	FR	Vol. Of $FeNH_3(SO_4)$	COD	MEAN	std dev
1	**BLANK**	2.5	0	5.8	5.8			
2	**S1**	2.5	0	4.4	4.4	448	**437 mg/lt**	
3	**S2**	2.5	0	4.5	4.5	416	**0.437 g/lt**	**18**
4	**S3**	2.5	0	4.4	4.4	448		

RESULT:

COD = 437 mg/lt

= .4 g/lt

B.1.3 ALKALINITY:

ALKALINITY= $\frac{V*\text{Normality of } H_2SO_4*1000*500}{\text{Volume of sample taken}}$

OBSERVATIONS:

S.NO	SAMPLE DETAILS	VOL, ml	METHYL ORANGE			ALKALINITY	MEAN	STD DEV
			IR	FR	H_2SO_4			
1	**S1**	25	0	3.5	3.5	1400	**1387**	**23.1**
2	**S2**	25	0	3.4	3.5	1360		
3	**S3**	25	0	3.5	3.5	1400		

RESULT:

ALKALINITY= 1387 mg/lt

B.2 PARAMETERS FOR AD1 AFTER DIGESTION:

B.2.1 TOTAL SOLIDS (TS), VOLATILE SOLIDS, FIXED SOLIDS:

W1= Weight of empty crucible, g

W2 = Weight of crucible and sample

W = Weight of residue= (W2 -W1) g

V= Volume of sample taken, ml.

W3= Weight of crucible with residue heated to 600 ºC, g

$$TS\ (mg/lt) = \frac{(W2-W1)}{V} \times 1000 \times 1000$$

$$VS\ (mg/lt) = \frac{(W2-W3)}{V} \times 1000 \times 1000$$

$$FS\ (mg/lt) = \frac{(W3-W1)}{V} \times 1000 \times 1000$$

OBSERVATION TABLE:

S.NO	VOL ,ml	W1 ,g	W2,g	W3,g
1	50	30.82	31.4	30.98
2	50	28.91	29.5	29.07
3	50	32.51	33.09	32.65

RESULTS:

S.NO	TS (mg/lt)	VS (mg/lt)	FS (mg/lt)
1	11600	8400	3200
2	11800	8600	3200
3	11600	8800	2800
Mean	**11667**	**8600**	**3067**
Std dev	**115.47**	**200.00**	**230.94**

S.NO	VS/TS RATIO
1	0.72
2	0.73
3	0.76
MEAN	**0.74**
std dev	**0.02**

B.2.2 COD:

COD (mg/lt) = $\frac{(A-B)*N*8*1000}{\text{Volume of sample taken}}$

A= Volume of ferrous ammonia sulphate for blank.

B= Volume of ferrous ammonia sulphate for sample.

N = Normality of ferrous ammonia sulphate = 0.1

OBSERVATION:

S.NO	SAMPLE	VOL. (ml)	IR	FR	Vol. Of $FeNH_3(SO_4)$	COD	MEAN	Std. Dev.
1	**BLANK**	2.5	0	13	13			
2	**S1**	2.5	0	12.1	12.1	**288**	**320 mg/lt**	**32**
3	**S2**	2.5	0	11.9	11.9	**352**		
4	**S3**	2.5	0	12	12	**320**		

B.2.3 ALKALINITY:

ALKALINITY= $\frac{V*\text{Normality of } H_2SO_4*1000*500}{\text{Volume of sample taken}}$

S.NO	SAMPLE DETAILS	VOL, ml	METHYL ORANGE			ALKALINITY	MEAN	Std dev
			IR	FR	H_2SO_4			
1	**S1**	25	0	7	6.6	**2640**	**2627 mg/lt**	**23**
2	**S2**	25	0	6.5	6.5	**2600**		
3	**S3**	25	0	6.8	6.6	**2640**		

B.3 PARAMETERS FOR AD2 BEFORE DIGESTION:

B.3.1 TOTAL SOLIDS (TS), VOLATILE SOLIDS, FIXED SOLIDS:

W1= Weight of empty crucible, g

W2 = Weight of crucible and sample

W = Weight of residue= (W2 -W1) g

V= Volume of sample taken, ml.

W3= Weight of crucible with residue heated to 600 ºC, g

TS (mg/lt) = $\frac{(W2-W1)}{V}$ x1000X1000

VS (mg/lt) = $\frac{(W2-W3)}{V}$ x1000 X 1000

FS (mg/lt) = $\frac{(W3-W1)}{V}$ x1000 X 1000

OBSERVATION TABLE:

S.NO	VOL, ml	W1,g	W2,g	W3,g
1	50	30.82	31.45	30.9
2	50	28.91	29.53	28.97
3	50	32.51	33.14	32.58

RESULT:

S.NO	TS (mg/lt)	VS (mg/lt)	FS (mg/lt)
1	12600	11000	1600
2	12400	11200	1200
3	12600	11200	1400
Mean	**12533**	**11133**	**1400**
Std dev	**115.47**	**115.47**	**200.00**

S.NO	VS/TS RATIO
1	0.87
2	0.90
3	0.89
MEAN	**0.89**

B.3.2 COD

COD (mg/lt) = $\frac{(A-B)*N*8*1000}{\text{Volume of sample taken}}$

A= Volume of ferrous ammonia sulphate for blank.

B= Volume of ferrous ammonia sulphate for sample.

N = Normality of ferrous ammonia sulphate = 0.1

OBSERVATION

S.NO	SAMPLE	VOL. ml	lR	FR	Vol. Of $FeNH_3(SO_4)$	COD	MEAN	std dev
1	**BLANK**	2.5	0	5.8	5.8			
2	**S1**	2.5	0	4	4.3	**480**	**512**	**32.00**
3	**S2**	2.5	0	4	4.2	**512**		
4	**S3**	2.5	0	4.1	4.1	**544**		

B.3.3ALKALINITY

ALKALINITY= $\frac{V*\text{Normality of } H_2SO_4*1000*500}{\text{Volume of sample taken}}$

S.NO	SAMPLE DETAILS	VOL, ml	METHYL ORANGE			ALKALINITY	MEAN	Std dev
			IR	FR	H_2SO_4			
1	S1	25	0	1.6	2.3	920	920 mg/lt	80.00
2	S2	25	0	1.5	2.1	840		
3	S3	25	0	1.5	2.5	1000		

B.4 PARAMETERS FOR AD2 AFTER DIGESTION

B.4.1 TOTAL SOLIDS (TS), VOLATILE SOLIDS, FIXED SOLIDS

W1= Weight of empty crucible, g

W2 = Weight of crucible and sample

W = Weight of residue= (W2 -W1) g

V= Volume of sample taken, ml.

W3= Weight of crucible with residue heated to 600 ºC, g

TS (mg/lt) = $\frac{(W2-W1)}{V}$ x1000X1000

VS (mg/lt) = $\frac{(W2-W3)}{V}$ x1000 X 1000

FS (mg/lt) = $\frac{(W3-W1)}{V}$ x1000 X 1000

OBSERVATION

S.NO	VOL ,ml	W1,g	W2,g	W3,g
1	50	32.51	33	32.63
2	50	28.67	29.15	28.78
3	50	28.59	29.07	28.71

RESULT

S.NO	TS, mg/lt	VS , mg/lt	FS, mg/lt
1	9800	7400	2400
2	9600	7400	2200
3	9600	7200	2400
Mean	**9667**	**7333**	**2333**
Std dev	**115.47**	**115.47**	**115.47**

S.NO	VS/TS RATIO
1	0.76
2	0.77
3	0.75
Mean	**0.76**
Std dev	**0.01**

B.4.2 COD

$$\text{COD (mg/lt)} = \frac{(A-B)*N*8*1000}{\text{Volume of sample taken}}$$

A= Volume of ferrous ammonia sulphate for blank.

B= Volume of ferrous ammonia sulphate for sample.

N = Normality of ferrous ammonia sulphate = 0.1

S.NO	SAMPLE	VOL. OF SAMPLE (ml)	IR	FR	Vol. Of $FeNH_3(SO_4)$	COD	MEAN	Std dev
1	**BLANK**	**2.5**	**0**	**13**	**13**			
2	**S1**	**2.5**	**0**	**11.8**	**11.8**	**384**	**331**	**49**
3	**S2**	**2.5**	**0**	**12**	**12**	**320**		
4	**S3**	**2.5**	**0**	**12.1**	**12.1**	**288**		

B.4.3 ALKALINITY

ALKALINITY= $\frac{V*\text{Normality of } H_2SO_4*1000*500}{\text{Volume of sample taken}}$

S.NO	SAMPLE DETAILS	VOL , ml	METHYL ORANGE			ALKALINITY	MEAN	Std dev
			IR	FR	H_2SO_4			
1	S1	25	0	7	7	2800	2667 mg/lt	169.7
2	S2	25	0	6.8	6.8	2720		
3	S3	25	0	6.2	6.2	2480		

B.5 PARAMETERS FOR AD1 AFTER DIGESTION (SUMMER SEASON)

B.5.1 TOTAL SOLIDS (TS), VOLATILE SOLIDS, FIXED SOLIDS:

W1= Weight of empty crucible, g

W2 = Weight of crucible and sample

W = Weight of residue= (W2 -W1) g

V= Volume of sample taken, ml.

W3= Weight of crucible with residue heated to 600 ºC, g

TS (mg/lt) = $\frac{(W2-W1)}{V}$ x1000X1000

VS (mg/lt) = $\frac{(W2-W3)}{V}$ x1000 X 1000

FS (mg/lt) = $\frac{(W3-W1)}{V}$ x1000 X 1000

OBSERVATION

S.NO	VOL, ml	W1, g	W2, g	W3, g
1	50	30.82	31.27	30.96
2	50	28.92	29.39	29.09
3	50	32.51	32.98	32.7

RESULTS

S.NO	TS (mg/lt)	VS (mg/lt)	FS (mg/lt)

1	9000	6200	2800
2	9400	6000	3400
3	9400	5600	3800
Mean	**9267**	**5933**	**3333**
Std dev	**230.94**	**305.51**	**503.32**

S.NO	**VS/TS RATIO**
1	0.69
2	0.64
3	0.60
Mean	**0.64**
Std dev	**0.05**

B.5.2 COD

$$\text{COD (mg/lt)} = \frac{(A-B)*N*8*1000}{\text{Volume of sample taken}}$$

A= Volume of ferrous ammonia sulphate for blank.

B= Volume of ferrous ammonia sulphate for sample.

N = Normality of ferrous ammonia sulphate = 0.1

OBSERVATION:

S.NO	**SAMPLE**	**VOL. ml**	**IR**	**FR**	**Vol. Of $FeNH_3(SO_4)$**	**COD**	**MEAN**	**Std dev**
1	**BLANK**	2.5	0	13	13		**235**	**49**
2	**S1**	2.5	0	12.6	12.3	**224**		
3	**S2**	2.5	0	12.1	12.1	**288**		
4	**S3**	2.5	0	12.3	12.4	**192**		

B.5.3 ALKALINITY

$$\text{ALKALINITY} = \frac{V*\text{Normality of } H_2SO_4*1000*500}{\text{Volume of sample taken}}$$

S.NO	SAMPLE	VOL , ml	METHYL ORANGE			ALKALINITY	MEAN	Std dev
			IR	FR	H_2SO_4			
1	**S1**	50	0	20	19.9	3980	**3973**	**31**
2	**S2**	50	0	20.1	19.7	3940	**mg/lt**	
3	**S3**	50	0	20.1	20	4000		

B.6 PARAMETERS FOR AD2 BEFORE DIGESTION

B.6.1 TOTAL SOLIDS (TS), VOLATILE SOLIDS, FIXED SOLIDS

W1= Weight of empty crucible, g

W2 = Weight of crucible and sample

W = Weight of residue= (W2 -W1) g

V= Volume of sample taken, ml.

W3= Weight of crucible with residue heated to 600 ºC, g

$$TS\ (mg/lt) = \frac{(W2-W1)}{V} \times 1000 \times 1000$$

$$VS\ (mg/lt) = \frac{(W2-W3)}{V} \times 1000 \times 1000$$

$$FS\ (mg/lt) = \frac{(W3-W1)}{V} \times 1000 \times 1000$$

OBSERVATION TABLE:

S.NO	VOL, ml	W1,g	W2,g	W3,g
1	50	28.66	29.02	28.79
2	50	28.67	29.02	28.78
3	50	28.59	28.95	28.69

RESULTS:

S.NO	TS (mg/lt)	VS (mg/lt)	FS (mg/lt)
1	7200	4600	2600
2	7000	4800	2200
3	7200	5200	2000
Mean	**7133**	**4867**	**2267**
Std dev	**115.47**	**305.51**	**305.51**

B.6.2 COD

COD (mg/lt) = $\frac{(A-B)*N*8*1000}{\text{Volume of sample taken}}$

A= Volume of ferrous ammonia sulphate for blank.

B= Volume of ferrous ammonia sulphate for sample.

N = Normality of ferrous ammonia sulphate = 0.1

OBSERVATION

S.NO	SAMPLE	VOL, ml	IR, ml	FR, ml	Vol. Of $FeNH_3(SO_4)$	COD	MEAN	std dev
1	**BLANK**	2.5	0	7.2	7.2		**203 mg/lt**	**37**
2	**S1**	2.5	0	6.5	6.5	224		
3	**S2**	2.5	0	6.7	6.7	160		
4	**S3**	2.5	0	6.5	6.5	224		

B.6.3 ALKALINITY

ALKALINITY= $\frac{V*\text{Normality of } H_2SO_4*1000*500}{\text{Volume of sample taken}}$

S.NO	SAMPLE DETAILS	VOL, ml	METHYL ORANGE			ALKALINITY	MEAN	Std dev
			IR	FR	H_2SO_4			
1	S1	20	0	7.8	9	4500	**4467 mg/lt**	70.7
2	S2	20	0	7.9	8.8	4400		
3	S3	20	0	7.5	9	4500		

APPENDIX-C

EXPERIMENTAL OBSERVATION DURING WINTER SEASON

C.1 CUMULATIVE VOLUME OF BIOGAS PRODUCED IN DIGESTER AD1 GAS HOLDER AT DIFFERENT DAYS

S.NO	DATE	RISE IN GAS HOLDER (m)	VOL OF BIOGAS (m3)	CUMULATIVE BIOGAS PRODUCED (m3)	CUMULATIVE BIOGAS PRODUCED (L)
1	07-12-2016		0	0	0
2	08-12-2016		0	0	0
3	09-12-2016		0	0	0
4	10-12-2016		0	0	0
5	11-12-2016		0	0	0
6	12-12-2016		0	0	0
7	13-12-2016		0	0	0
8	14-12-2016		0	0	0
9	15-12-2016		0	0	0.0
10	16-12-2016	0.01	0.000706858	0.000706858	0.7
11	17-12-2016		0	0.000706858	0.7
12	18-12-2016		0	0.000706858	0.7
13	19-12-2016		0	0.000706858	0.7
14	20-12-2016	0.01	0.000706858	0.001413716	1.4
15	21-12-2016		0	0.001413716	1.4
16	22-12-2016		0	0.001413716	1.4
17	23-12-2016		0	0.001413716	1.4
18	24-12-2016		0	0.001413716	1.4
19	25-12-2016	0.01	0.000706858	0.002120573	2.1
20	26-12-2016		0	0.002120573	2.1
21	27-12-2016		0	0.002120573	2.1
22	28-12-2016		0	0.002120573	2.1
23	29-12-2016		0	0.002120573	2.1
24	30-12-2016		0	0.002120573	2.1
25	31-12-2016		0	0.002120573	2.1
26	01-01-2017	0.002	0.000141372	0.002261945	2.3
27	02-01-2017		0	0.002261945	2.3
28	03-01-2017		0	0.002261945	2.3
29	04-01-2017		0	0.002261945	2.3
30	05-01-2017		0	0.002261945	2.3
31	06-01-2017		0	0.002261945	2.3
32	07-01-2017		0	0.002261945	2.3
33	08-01-2017		0	0.002261945	2.3
34	09-01-2017	0.002	0.000141372	0.002403316	2.4

35	10-01-2017		0	0.002403316	2.4
36	11-01-2017		0	0.002403316	2.4
37	12-01-2017		0	0.002403316	2.4
38	13-01-2017		0	0.002403316	2.4
39	14-01-2017		0	0.002403316	2.4
40	15-01-2017		0	0.002403316	2.4
41	16-01-2017		0	0.002403316	2.4
42	17-01-2017		0	0.002403316	2.4
43	18-01-2017		0	0.002403316	2.4
44	19-01-2017		0	0.002403316	2.4
45	20-01-2017		0	0.002403316	2.4
46	21-01-2017		0	0.002403316	2.4
47	22-01-2017		0	0.002403316	2.4
48	23-01-2017	0.01	0.000706858	0.003110174	3.1
49	24-01-2017		0	0.003110174	3.1
50	25-01-2017		0	0.003110174	3.1
51	26-01-2017		0	0.003110174	3.1
52	27-01-2017		0	0.003110174	3.1
53	28-01-2017		0	0.003110174	3.1
54	29-01-2017		0	0.003110174	3.1
55	30-01-2017		0	0.003110174	3.1
56	31-01-2017	0.005	0.000353429	0.003463603	3.5
57	01-02-2017		0	0.003463603	3.5
58	02-02-2017		0	0.003463603	3.5
59	03-02-2017		0	0.003463603	3.5
60	04-02-2017		0	0.003463603	3.5
61	05-02-2017		0	0.003463603	3.5
62	06-02-2017		0	0.003463603	3.5
63	07-02-2017	0.01	0.000706858	0.004170461	4.2
64	08-02-2017		0	0.004170461	4.2
65	09-02-2017		0	0.004170461	4.2
66	10-02-2017		0	0.004170461	4.2
67	11-02-2017		0	0.004170461	4.2
68	12-02-2017		0	0.004170461	4.2
69	13-02-2017		0	0.004170461	4.2
70	14-02-2017		0	0.004170461	4.2

C.2 VARIATION OF pH IN AD1

DATE	DAY	AD1
07-12-2016	1	7.7
11-12-2016	5	7.5
16-12-2016	10	7.3
21-12-2016	15	7.2
26-12-2016	20	7
31-12-2016	25	7
05-01-2017	30	7.1

10-01-2017	35	7.3
15-01-2017	40	7.4
20-01-2017	45	7.5
25-01-2017	50	7.5
30-01-2017	55	7.6
04-02-2017	60	7.7
09-02-2017	65	7.9
14-02-2017	70	8

C.3 VARIATION OF TEMPERATURE IN AD1

		MORNING		AFTERNOON		EVENING	
S.NO	DATE	INSIDE (°C)	OUTSIDE (°C)	INSIDE (°C)	OUTSIDE (°C)	INSIDE (°C)	OUTSIDE (°C)
1	07-12-2016	20	17	24	24	23	22
2	08-12-2016	20	18	25	24	24	19
3	09-12-2016	19	13	20	18	21	20
4	10-12-2016	18	12	20	20	19	19
5	11-12-2016	19	15	20	21	19	18
6	12-12-2016	19	15	21	22	20	18
7	13-12-2016	18	15	22	21	21	18
8	14-12-2016	17	12	21	20	20	18
9	15-12-2016	16	12	20	15	19	16
10	16-12-2016	16	11	19	16	18	15
11	17-12-2016	16	12	18	16	18	14
12	18-12-2016	14	14	18	16	17	15
13	19-12-2016	17	10	19	15	18	14
14	20-12-2016	18	8	20	18	19	16
15	21-12-2016	16	9	18	17	17	16
16	22-12-2016	16	10	18	18	17	17
17	23-12-2016	15	10	17	16	17	15
18	24-12-2016	15	9	16	15	16	14
19	25-12-2016	16	10	18	16	17	15
20	26-12-2016	16	9	18	15	17	14
21	27-12-2016	16	8	17	16	16	15
22	28-12-2016	15	8	16	16	15	14
23	29-12-2016	15	9	17	16	16	14
24	30-12-2016	15	9	16	13	15	10
25	31-12-2016	16	7	18	12	17	10
26	01-01-2017	15	7	17	12	16	10
27	02-01-2017	15	7	16	11	15	9
28	03-01-2017	15	7	17	11	16	9
29	04-01-2017	15	7	16	11	16	9
30	05-01-2017	15	8	16	12	15	10
31	06-01-2017	15	7	16	9	15	8

32	07-01-2017	14	4	15	7	14	6
33	08-01-2017	13	3	15	7	14	5
34	09-01-2017	12	3	14	6	14	6
35	10-01-2017	12	3	14	6	14	5
36	11-01-2017	13	2	15	6	14	5
37	12-01-2017	13	2	15	6	14	6
38	13-01-2017	13	3	15	6	15	5
39	14-01-2017	14	3	16	8	15	6
40	15-01-2017	15	6	17	11	16	9
41	16-01-2017	14	4	16	6	15	5
42	17-01-2017	14	6	16	11	15	10
43	18-01-2017	15	6	17	11	16	10
44	19-01-2017	15	4	16	7	15	5
45	20-01-2017	15	8	17	12	16	11
46	21-01-2017	16	8	18	12	17	11
47	22-01-2017	16	8	18	12	17	11
48	23-01-2017	16	10	18	13	18	14
49	24-01-2017	17	9	19	14	18	9
50	25-01-2017	15	10	17	12	16	9
51	26-01-2017	14	9	16	10	15	14
52	27-01-2017	14	6	16	9	15	7
53	28-01-2017	14	8	16	10	15	9
54	29-01-2017	15	8	17	11	16	8
55	30-01-2017	16	10	18	13	17	9
56	31-01-2017	15	8	17	11	16	8
57	01-02-2017	15	9	17	12	16	11
58	02-02-2017	15	9	17	12	16	11
59	03-02-2017	14	10	16	11	15	10
60	04-02-2017	15	11	16	12	15	11
61	05-02-2017	14	11	16	11	15	9
62	06-02-2017	14	10	16	12	15	9
63	07-02-2017	16	11	18	14	17	13
64	08-02-2017	16	10	18	13	17	12
65	09-02-2017	18	12	20	17	19	16
66	10-02-2017	18	11	21	16	20	15
67	11-02-2017	17	12	20	17	19	16
68	12-02-2017	19	13	22	17	21	16
69	13-02-2017	19	13	22	17	21	15
70	14-02-2017	19	12	23	17	21	16

C.4 CUMULATIVE VOLUME OF BIOGAS PRODUCED IN DIGESTER AD2 GAS HOLDER AT DIFFERENT DAYS

S.NO	DATE	RISE IN GAS HOLDER (m)	VOL OF BIOGAS (m3)	CUMULATIVE BIOGAS PRODUCED(m3)	CUMULATIVE BIOGAS PRODUCED (L)
1	07-12-2016		0	0	0
2	08-12-2016		0	0	0
3	09-12-2016		0	0	0
4	10-12-2016		0	0	0
5	11-12-2016		0	0	0
6	12-12-2016		0	0	0.0
7	13-12-2016		0	0	0.0
8	14-12-2016	0.01	0.000706858	0.000706858	0.7
9	15-12-2016		0	0.000706858	0.7
10	16-12-2016		0	0.000706858	0.7
11	17-12-2016		0	0.000706858	0.7
12	18-12-2016		0	0.000706858	0.7
13	19-12-2016		0	0.000706858	0.7
14	20-12-2016	0.02	0.001413716	0.002120573	2.1
15	21-12-2016		0	0.002120573	2.1
16	22-12-2016		0	0.002120573	2.1
17	23-12-2016		0	0.002120573	2.1
18	24-12-2016		0	0.002120573	2.1
19	25-12-2016	0.01	0.000706858	0.002827431	2.8
20	26-12-2016		0	0.002827431	2.8
21	27-12-2016		0	0.002827431	2.8
22	28-12-2016		0	0.002827431	2.8
23	29-12-2016		0	0.002827431	2.8
24	30-12-2016		0	0.002827431	2.8
25	31-12-2016	0.002	0.000141372	0.002968803	3.0
26	01-01-2017		0	0.002968803	3.0
27	02-01-2017		0	0.002968803	3.0
28	03-01-2017		0	0.002968803	3.0
29	04-01-2017		0	0.002968803	3.0
30	05-01-2017		0	0.002968803	3.0
31	06-01-2017		0	0.002968803	3.0
32	07-01-2017		0	0.002968803	3.0
33	08-01-2017		0	0.002968803	3.0
34	09-01-2017		0	0.002968803	3.0
35	10-01-2017		0	0.002968803	3.0
36	11-01-2017		0	0.002968803	3.0
37	12-01-2017		0	0.002968803	3.0
38	13-01-2017		0	0.002968803	3.0
39	14-01-2017	0.01	0.000706858	0.00367566	3.7
40	15-01-2017		0	0.00367566	3.7
41	16-01-2017		0	0.00367566	3.7

42	17-01-2017		0	0.00367566	3.7
43	18-01-2017	0.005	0.000353429	0.004029089	4.0
44	19-01-2017		0	0.004029089	4.0
45	20-01-2017		0	0.004029089	4.0
46	21-01-2017		0	0.004029089	4.0
47	22-01-2017		0	0.004029089	4.0
48	23-01-2017		0	0.004029089	4.0
49	24-01-2017	0.02	0.001413716	0.005442805	5.4
50	25-01-2017		0	0.005442805	5.4
51	26-01-2017		0	0.005442805	5.4
52	27-01-2017		0	0.005442805	5.4
53	28-01-2017		0	0.005442805	5.4
54	29-01-2017		0	0.005442805	5.4
55	30-01-2017	0.01	0.000706858	0.006149662	6.1
56	31-01-2017		0	0.006149662	6.1
57	01-02-2017		0	0.006149662	6.1
58	02-02-2017		0	0.006149662	6.1
59	03-02-2017	0.01	0.000706858	0.00685652	6.9
60	04-02-2017		0	0.00685652	6.9
61	05-02-2017		0	0.00685652	6.9
62	06-02-2017	0.02	0.001413716	0.008270236	8.3
63	07-02-2017		0	0.008270236	8.3
64	08-02-2017		0	0.008270236	8.3
65	09-02-2017	0.005	0.000353429	0.008623665	8.6
66	10-02-2017		0	0.008623665	8.6
67	11-02-2017		0	0.008623665	8.6
68	12-02-2017	0.02	0.001413716	0.01003738	10.0
69	13-02-2017		0	0.01003738	10.0
70	14-02-2017	0.005	0.000353429	0.010390809	10.4

C.5 VARIATION OF pH IN AD1

DATE	DAY	AD2
07-12-2016	1	5.8
11-12-2016	5	6
16-12-2016	10	6.3
21-12-2016	15	6.3
26-12-2016	20	6.5
31-12-2016	25	6.5
05-01-2017	30	6.7
10-01-2017	35	6.8
15-01-2017	40	7
20-01-2017	45	7.1
25-01-2017	50	7.1

30-01-2017	55	7.3
04-02-2017	60	7.4
09-02-2017	65	7.5
14-02-2017	70	7.5

C.6 VARIATION OF TEMPERATURE IN AD2

S.NO	DATE	MORNING		AFTERNOON		EVENING	
		INSIDE (°C)	OUTSIDE (°C)	INSIDE (°C)	OUTSIDE (°C)	INSIDE (°C)	OUTSIDE (°C)
1	07-12-2016	20	17	24	24	23	22
2	08-12-2016	20	18	25	24	24	19
3	09-12-2016	19	13	20	18	21	20
4	10-12-2016	19	12	21	20	19	19
5	11-12-2016	20	15	21	21	20	18
6	12-12-2016	20	15	22	22	21	18
7	13-12-2016	19	15	23	21	22	18
8	14-12-2016	17	12	22	20	21	18
9	15-12-2016	17	12	21	15	20	16
10	16-12-2016	17	11	18	16	17	15
11	17-12-2016	16	12	19	16	19	14
12	18-12-2016	15	14	19	16	18	15
13	19-12-2016	16	10	20	15	20	14
14	20-12-2016	19	8	21	18	20	16
15	21-12-2016	17	9	18	17	18	16
16	22-12-2016	17	10	19	18	18	17
17	23-12-2016	16	10	18	16	18	15
18	24-12-2016	16	9	16	15	15	14
19	25-12-2016	16	10	19	16	18	15
20	26-12-2016	17	9	18	15	17	14
21	27-12-2016	17	8	16	16	15	15
22	28-12-2016	16	8	15	16	14	14
23	29-12-2016	16	9	18	16	17	14
24	30-12-2016	16	9	17	13	16	10
25	31-12-2016	17	7	19	12	18	10
26	01-01-2017	16	7	18	12	17	10
27	02-01-2017	15	7	17	11	16	9
28	03-01-2017	16	7	17	11	17	9
29	04-01-2017	15	7	17	11	17	9
30	05-01-2017	16	8	17	12	17	10
31	06-01-2017	16	7	16	9	16	8
32	07-01-2017	15	4	16	7	15	6
33	08-01-2017	12	3	16	7	15	5
34	09-01-2017	13	3	15	6	14	6

35	10-01-2017	14	3	15	6	15	5
36	11-01-2017	15	2	16	6	15	5
37	12-01-2017	15	2	16	6	15	6
38	13-01-2017	16	3	16	6	15	5
39	14-01-2017	17	3	17	8	16	6
40	15-01-2017	16	6	17	11	16	9
41	16-01-2017	15	4	17	6	16	5
42	17-01-2017	15	6	17	11	16	10
43	18-01-2017	16	6	18	11	17	10
44	19-01-2017	16	4	17	7	16	5
45	20-01-2017	16	8	18	12	17	11
46	21-01-2017	17	8	19	12	17	11
47	22-01-2017	17	8	19	12	17	11
48	23-01-2017	17	10	19	13	18	14
49	24-01-2017	16	9	20	14	19	9
50	25-01-2017	16	10	18	12	17	9
51	26-01-2017	15	9	17	10	16	14
52	27-01-2017	16	6	17	9	17	7
53	28-01-2017	17	8	17	10	17	9
54	29-01-2017	16	8	18	11	17	8
55	30-01-2017	17	10	19	13	18	9
56	31-01-2017	16	8	19	11	18	8
57	01-02-2017	16	9	18	12	17	11
58	02-02-2017	16	9	19	12	17	11
59	03-02-2017	15	10	17	11	16	10
60	04-02-2017	16	11	17	12	15	11
61	05-02-2017	15	11	17	11	16	9
62	06-02-2017	16	10	17	12	16	9
63	07-02-2017	17	11	20	14	19	13
64	08-02-2017	17	10	19	13	20	12
65	09-02-2017	19	12	22	17	21	16
66	10-02-2017	19	11	21	16	20	15
67	11-02-2017	18	12	22	17	21	16
68	12-02-2017	20	13	24	17	23	16
69	13-02-2017	20	13	23	17	23	15
70	14-02-2017	20	12	24	17	23	16

APPENDIX-D

EXPERIMENTAL OBSERVATION DURING SUMMER SEASON

D.1 CUMULATIVE VOLUME OF BIOGAS PRODUCED IN DIGESTER AD1 GAS HOLDER AT DIFFERENT DAYS

S.NO	DATE	RISE IN GAS HOLDER (m)	VOL OF BIOGAS (m3)	CUMULATIVE BIOGAS PRODUCED (m3)	CUMULATIVE BIOGAS PRODUCED (L)
1	15-02-2017		0	0	0
2	16-02-2017		0	0	0
3	17-02-2017		0	0	0
4	18-02-2017		0	0	0
5	19-02-2017		0	0	0
6	20-02-2017		0	0	0
7	21-02-2017		0	0	0
8	22-02-2017	0.002	0.00014137	0.000141372	0.1
9	23-02-2017		0	0.000141372	0.1
10	24-02-2017		0	0.000141372	0.1
11	25-02-2017		0	0.000141372	0.1
12	26-02-2017	0.002	0.00014137	0.000282743	0.3
13	27-02-2017		0	0.000282743	0.3
14	28-02-2017		0	0.000282743	0.3
15	01-03-2017		0	0.000282743	0.3
16	02-03-2017	0.01	0.00070685	0.000989601	1.0
17	03-03-2017		0	0.000989601	1.0
18	04-03-2017		0	0.000989601	1.0
19	05-03-2017		0	0.000989601	1.0
20	06-03-2017		0	0.000989601	1.0
21	07-03-2017	0.01	0.00070685	0.001696459	1.7
22	08-03-2017		0	0.001696459	1.7
23	09-03-2017		0	0.001696459	1.7
24	10-03-2017		0	0.001696459	1.7
25	11-03-2017		0	0.001696459	1.7
26	12-03-2017		0	0.001696459	1.7
27	13-03-2017	0.002	0.00014137	0.00183783	1.8
28	14-03-2017		0	0.00183783	1.8
29	15-03-2017		0	0.00183783	1.8
30	16-03-2017		0	0.00183783	1.8
31	17-03-2017	0.01	0.00070685	0.002544688	2.5
32	18-03-2017		0	0.002544688	2.5
33	19-03-2017		0	0.002544688	2.5
34	20-03-2017		0	0.002544688	2.5

35	21-03-2017		0	0.002544688	2.5
36	22-03-2017	0.002	0.00014137	0.002686059	2.7
37	23-03-2017		0	0.002686059	2.7
38	24-03-2017		0	0.002686059	2.7
39	25-03-2017		0	0.002686059	2.7
40	26-03-2017	0.002	0.00014137	0.002827431	2.8
41	27-03-2017		0	0.002827431	2.8
42	28-03-2017		0	0.002827431	2.8
43	29-03-2017		0	0.002827431	2.8
44	30-03-2017	0.01	0.00070685	0.003534289	3.5
45	31-03-2017		0	0.003534289	3.5
46	01-04-2017		0	0.003534289	3.5
47	02-04-2017		0	0.003534289	3.5
48	03-04-2017	0.002	0.00014137	0.00367566	3.7
49	04-04-2017		0	0.00367566	3.7
50	05-04-2017		0	0.00367566	3.7
51	06-04-2017	0.01	0.00070685	0.004382518	4.4
52	07-04-2017		0	0.004382518	4.4
53	08-04-2017		0	0.004382518	4.4
54	09-04-2017		0	0.004382518	4.4
55	10-04-2017	0.01	0.00070685	0.005089376	5.1

D.2 VARIATION OF pH in AD1

DATE	DAY	AD1
15-02-2017	1	8
19-02-2017	5	7.9
24-02-2017	10	7.9
01-03-2017	15	7.8
06-03-2017	20	7.7
11-03-2017	25	7.7
16-03-2017	30	7.8
21-03-2017	35	7.6
26-03-2017	40	7.7
31-04-2017	45	7.6
05-04-2017	50	7.5
10-04-2017	55	7.6

D.3 VARIATION OF TEMPERATURE IN AD1

S.NO.	DATE	**MEAN TEMPERATURE**	
		INSIDE TEMPERATURE	OUTSIDE TEMPERATURE
1	15-02-2017	22	16
2	16-02-2017	22	18
3	17-02-2017	24	20
4	18-02-2017	22	18
5	19-02-2017	22	18
6	20-02-2017	23	19
7	21-02-2017	23	19
8	22-02-2017	21	15
9	23-02-2017	21	16
10	24-02-2017	23	19
11	25-02-2017	23	18
12	26-02-2017	23	19
13	27-02-2017	24	20
14	28-02-2017	24	20
15	01-03-2017	24	20
16	02-03-2017	24	19
17	03-03-2017	24	20
18	04-03-2017	25	20
19	05-03-2017	25	22
20	06-03-2017	25	21
21	07-03-2017	23	18
22	08-03-2017	22	16
23	09-03-2017	22	15
24	10-03-2017	22	17
25	11-03-2017	22	18
26	12-03-2017	23	20
27	13-03-2017	23	21
28	14-03-2017	24	22
29	15-03-2017	25	24
30	16-03-2017	24	20
31	17-03-2017	24	21
32	18-03-2017	23	20
33	19-03-2017	25	24
34	20-03-2017	25	24
35	21-03-2017	26	25
36	22-03-2017	25	24
37	23-03-2017	28	26
38	24-03-2017	27	24
39	25-03-2017	24	22

40	26-03-2017	23	20
41	27-03-2017	24	21
42	28-03-2017	24	21
43	29-03-2017	25	24
44	30-03-2017	24	23
45	31-03-2017	26	25
46	01-04-2017	25	23
47	02-04-2017	26	24
48	03-04-2017	26	23
49	04-04-2017	27	22
50	05-04-2017	27	22
51	06-04-2017	28	24
52	07-04-2017	29	26
53	08-04-2017	30	28
54	09-04-2017	30	27
55	10-04-2017	31	28

D.4 CUMULATIVE VOLUME OF BIOGAS PRODUCED IN DIGESTER AD2 GAS HOLDER AT DIFFERENT DAYS

S.NO	DATE	RISE IN GAS HOLDER (m)	VOL OF BIOGAS (m3)	CUMULATIVE BIOGAS PRODUCED (m3)	CUMULATIVE BIOGAS PRODUCED (L)
1	05-02-2017		0	0	0
2	06-02-2017		0	0	0
3	07-02-2017		0	0	0
4	08-02-2017		0	0	0
5	09-02-2017	0.002	0.000141372	0.000141372	0.1
6	10-02-2017		0	0.000141372	0.1
7	11-02-2017		0	0.000141372	0.1
8	12-02-2017	0.01	0.000706858	0.000848229	0.8
9	13-02-2017		0	0.000848229	0.8
10	14-02-2017		0	0.000848229	0.8
11	15-02-2017	0.005	0.000353429	0.001201658	1.2
12	16-02-2017		0	0.001201658	1.2
13	17-02-2017		0	0.001201658	1.2
14	18-02-2017	0.01	0.000706858	0.001908516	1.9
15	19-02-2017		0	0.001908516	1.9
16	20-02-2017	0.005	0.000353429	0.002261945	2.3
17	21-02-2017		0	0.002261945	2.3
18	22-02-2017		0	0.002261945	2.3
19	23-02-2017	0.01	0.000706858	0.002968803	3.0
20	24-02-2017		0	0.002968803	3.0

21	25-02-2017		0	0.002968803	3.0
22	26-02-2017	0.005	0.000353429	0.003322231	3.3
23	27-02-2017		0	0.003322231	3.3
24	28-02-2017		0	0.003322231	3.3
25	01-03-2017	0.005	0.000353429	0.00367566	3.7
26	02-03-2017		0	0.00367566	3.7
27	03-03-2017		0	0.00367566	3.7
28	04-03-2017	0.01	0.000706858	0.004382518	4.4
29	05-03-2017		0	0.004382518	4.4
30	06-03-2017		0	0.004382518	4.4
31	07-03-2017	0.005	0.000353429	0.004735947	4.7
32	08-03-2017		0	0.004735947	4.7
33	09-03-2017		0	0.004735947	4.7
34	10-03-2017		0	0.004735947	4.7
35	11-03-2017	0.005	0.000353429	0.005089376	5.1
36	12-03-2017		0	0.005089376	5.1
37	13-03-2017		0	0.005089376	5.1
38	14-03-2017		0	0.005089376	5.1
39	15-03-2017	0.01	0.000706858	0.005796234	5.8
40	16-03-2017		0	0.005796234	5.8
41	17-03-2017		0	0.005796234	5.8
42	18-03-2017		0	0.005796234	5.8
43	19-03-2017	0.01	0.000706858	0.006503091	6.5
44	20-03-2017		0	0.006503091	6.5
45	21-03-2017		0	0.006503091	6.5
46	22-03-2017	0.01	0.000706858	0.007209949	7.2
47	23-03-2017		0	0.007209949	7.2
48	24-03-2017		0	0.007209949	7.2
49	25-03-2017		0	0.007209949	7.2
50	26-03-2017	0.02	0.001413716	0.008623665	8.6
51	27-03-2017		0	0.008623665	8.6
52	28-03-2017	0.02	0.001413716	0.01003738	10.0
53	29-03-2017		0	0.01003738	10.0
54	30-03-2017		0	0.01003738	10.0
55	31-03-2017	0.01	0.000706858	0.010744238	10.7

D.5 VARIATION OF pH in AD1

DATE	DAY	AD2
15-02-2017	1	7.5
19-02-2017	5	7.6
24-02-2017	10	7.6
01-03-2017	15	7.7
06-03-2017	20	7.6

11-03-2017	25	7.6
16-03-2017	30	7.6
21-03-2017	35	7.4
26-03-2017	40	7.3
31-04-2017	45	7.4
05-04-2017	50	7.2
10-04-2017	55	7.3

D.6 VARIATION OF TEMPERATURE IN AD2

S.NO.	DATE	MEAN TEMPERATURE	
		INSIDE TEMPERATURE	OUTSIDE TEMPERATURE
1	15-02-2017	22	16
2	16-02-2017	24	18
3	17-02-2017	26	20
4	18-02-2017	24	18
5	19-02-2017	24	18
6	20-02-2017	25	19
7	21-02-2017	25	19
8	22-02-2017	23	15
9	23-02-2017	22	16
10	24-02-2017	23	19
11	25-02-2017	25	18
12	26-02-2017	25	19
13	27-02-2017	26	20
14	28-02-2017	26	20
15	01-03-2017	26	20
16	02-03-2017	26	19
17	03-03-2017	27	20
18	04-03-2017	27	20
19	05-03-2017	27	22
20	06-03-2017	26	21
21	07-03-2017	25	18
22	08-03-2017	25	16
23	09-03-2017	25	15
24	10-03-2017	25	17
25	11-03-2017	24	18
26	12-03-2017	25	20
27	13-03-2017	25	21
28	14-03-2017	26	22
29	15-03-2017	27	24
30	16-03-2017	26	20
31	17-03-2017	27	21

32	18-03-2017	24	20
33	19-03-2017	27	24
34	20-03-2017	27	24
35	21-03-2017	28	25
36	22-03-2017	27	24
37	23-03-2017	30	26
38	24-03-2017	28	24
39	25-03-2017	26	22
40	26-03-2017	25	20
41	27-03-2017	26	21
42	28-03-2017	26	21
43	29-03-2017	26	24
44	30-03-2017	25	23
45	31-03-2017	28	25
46	01-04-2017	27	23
47	02-04-2017	28	24
48	03-04-2017	28	23
49	04-04-2017	29	22
50	05-04-2017	28	22
51	06-04-2017	29	24
52	07-04-2017	31	26
53	08-04-2017	32	28
54	09-04-2017	32	27
55	10-04-2017	33	28

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