BIOGAS PRODUCTION USING DIFFERENT SUBSTRATES PINE NEEDLES AND COW DUNG

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CERTIFICATE

This is certify that the work which is being presented in the thesis entitle **"BIOGAS PRODUCTION USING DIFFERENT SUBSTRATES PINE NEEDLES AND COW DUNG"** in partial fulfillment of the requirement for the award of the degree of Master of technology in Civil Engineering with specialization in **"Environmental Engineering"** and submitted in Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Ruchi Devi** during a period from July 2015 to June 2016 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.

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(RUCHI DEVI)

ABSTRACT

The current study describes the results of an experimental investigation taken up to check the suitability and potential of the pine needles as substrate in biogas production under batch digester. There are various lignocellulosic biomasses for biofuel production but the use of pine needles has not been realized so much yet. In the present study two batch digesters (each having two plastic made buckets: one for fermentation and second as gas holder) was used. In the first digester cow dung named as *DIGESTER1* and in the second digester named as *DIGESTER2* ground pine needles were co-digested with cow dung was used as a substrate. The feed material was collected from local sources. In both the digesters; inoculum prepared from cow dung was used. Biogas production using cow dung and pine needles under batch digester has been compared under similar field conditions. In both digesters tap water was used to make slurry in a ratio of 1:15 by weight. The different parameters like Total solid, volatile solid are measured & pH, biogas production & temperature are measured on daily basis. The surrounding temperature range during the testing period was between 15^0C-23^0C and slurry temperature inside the digester was in range of 17^0C-26^0C. The total volume of biogas production of the 70 days in *DIGESTER1* and *DIGESTER2* was 2.47 and 5.30 liters respectively and thus observed that pine needles are better substrate in comparison to cow dung.

In winter season biogas production less as compare to other moth so use green house canopy for the increment of biogas production. In this study comparison of biogas production under green house canopy and the ambient temperature condition has been made. The ambient temperature range measured within the testing period was 15^0C-28^0C and green house canopy temperature inside the digester range was between 18^0C-32^0C. The both digesters have same capacity of slurry. In both the digesters inoculum was prepared from the cow dung. The ratio of substrate and water is (1:15) in both the digesters. The retention period of both digesters was 70 days. The different parameter like Total solid (TS), Volatile solid (VS), Biochemical oxygen demand (BOD), and Chemical oxygen demand (COD) before and after digestion was measured. The pH and temperature was measured on daily basis because temperature plays vital role in the biogas production. The cumulative biogas production in ambient temperature condition and green house canopy was recorded 7.7l and 10.9l respectively. The biogas production under the green house canopy was noticed more as compare to without green house canopy digester.

CONTENTS

Chapter	Title	Page No.
	Certificate	i
	Acknowledgements	ii
	Abstract	iii
	Contents	iv
	List of Tables	viii
	List of Figures	ix
	List of Photographs	x
	List of Abbreviations	xi
1.	**INTRODUCTION**	1-7
	1.1 General	1
	1.2 Biogas	2
	1.3 Characteristics and other properties of Biogas	3
	1.4 Factor Affecting Yield and Production of Biogas	3-5
	1.4.1 Total Solid Content	3
	1.4.2 Temperature	4
	1.4.3 pH	4
	1.4.4 Hydraulic Retention Time	4
	1.4.5 Particle Size	5
	1.4.6 Alkalinity	5
	1.4.7 Carbon to Nitrogen Ratio	5
	1.5 Advantages	5
	1.6 Disadvantages	5
	1.7 Literature Review	6
	1.8 Objectives	6
	1.9 Significance of Study	7
	1.10 Limitations of Study	7

2.	**LITERATURE REVIEW**	8-13
	2.1 General	8
	2.2 Biogas Production using Cow Dung as Substrate	8
	2.3 Biogas Production using Food Waste as Substrate	9
	2.4 Biogas Production using Agricultural Waste as Substrate	10
	2.5 Comparative study of Different Substrate for Biogas Production	11
	2.6 Comparative study of Biogas Production under Green House Canopy and Ambient Temperature	12
	2.7 Concluding Remarks	13
3.	**PRINCIPLE OF BIOGAS GENERATION**	14-15
	3.1General	14
	3.1.1 Aerobic Digestion	14
	3.1.2 Anaerobic Digestion	14
	3.2 Anaerobic Digestion	14
	3.3 Biological Process	15
	3.3.1 Hydrolysis	15
	3.3.2 Acidogenesis	15
	3.3.3 Methanogenesis	15
4.	**EXPERIMENAL SETUP AND METHODOLOGY**	16-24
	4.1 General	16
	4.2 Experimental Setup and Instrumentation	16
	4.3 Material Preparation	17
	4.4 Methodology and Experimental Observation	18
	4.4.1 Experimental Procedure, Observations Before and After Digestion in the First Experiment	18
	(a) Experimental Observations Before and After Digestion in First Experiment	19
	(b) Measurement of Biogas	20

4.4.2 Experimental Procedure, Observations Before and After Digestion in the Second Experiment 20
(a) Experimental Observations Before and After Digestion in Second Experiment 21
(b) Measurement of Biogas 22
4.5 Standard Testing Methods 23-24
4.5.1 pH 23
4.5.2 Total Solids 23
4.5.3 Volatile Solids 23
4.5.4 Biological Oxygen Demand 23
4.5.5 Chemical Oxygen Demand 24
4.5.6 Odour 24
4.5.7 Temperature 24
5. RESULTS AND DISCUSSION 25-40
5.1 Comparison of Biogas Production or Different Parameters using Substrate Cow Dung, Pine needles under similar Ambient Temperature Conditions 25-30
5.1.1 pH 25
5.1.2 BOD and COD Reduction 26
5.1.3 Total Solids and Volatile Solid Reduction 27
5.1.4 Temperature 28
5.1.5 Cumulative Biogas Production 29
5.2 Comparison of Biogas Production or Different Parameters using Pine needles as Substrate under Green House Canopy and Ambient Temperature Conditions 30-35
5.2.1 pH 30
5.2.2 BOD and COD Reduction 31
5.2.3 Total Solids and Volatile Solid Reduction 32
5.2.4 Temperature 33
5.2.5 Cumulative Biogas Production 34

	5.3 Comparison of Biogas Production or Different Parameters using Pine needles as Substrate under Varying Surrounding Temperature Condition	35-40
	5.3.1 pH	35
	5.3.2 Total Solids and Volatile Solid Reduction	36
	5.3.3 BOD and COD Reduction	37
	5.3.4 Temperature	38
	5.3.5 Cumulative Biogas Production	39
6.	**CONCLUSIONS**	41-44
	REFERENCES	45-47
	APPENDIXES	48-66

LIST OF TABLES

Table No.	Description	Page No.
1.1	General Composition of Biogas	3
2.1	Biogas production at different kitchen waste and water ratio	10
4.1	Before and after digestion value of different parameters in DIGESTER 1 and DIGESTER 2	20
4.2	Before and after digestion value of different parameters in DIGESTER 1 and DIGESTER 2	22

LIST OF FIGURES

Figure Number	Description	Page No.
3.1	Biological process	15
5.1	Variation of pH with time	25
5.2	BOD reduction	26
5.3	COD reduction	26
5.4	Total solid reduction	27
5.5	Volatile solid reduction	27
5.6	Variation of Temperature in DIGESTER 1	28
5.7	Variation of Temperature in DIGESTER 2	28
5.8	Cumulative biogas production	29
5.9	Variation of pH with time	30
5.10	BOD reduction	31
5.11	COD reduction	31
5.12	Total solid reduction	32
5.13	Volatile solid reduction	32
5.14	Variation of temperature in DIGESTER1 and DIGESTER2	33
5.15	Cumulative biogas production	34
5.16	Variation of pH with time	35
5.17	Total solid reduction	36
5.18	Volatile solid reduction	36
5.19	BOD reduction	37
5.20	COD reduction	37
5.21	Variation of inside temperature in digesters	38
5.22	Variation of outside temperature in digesters	38
5.23	Cumulative biogas production	39

LIST OF PHOTOGRAPHS

Plate Number	Description	Page No.
4.1	Pictorial view of digester and green house canopy	17
4.2	Pictorial view of inoculum prepared bottle	17
4.3	Pictorial view of pine needles before and after grinding	18
4.4	Pictorial view of DIGESTER1and DIGESTER2	19
4.5	Pictorial view of DIGESTER1 and DIGESTER2	21

LIST OFABBREVIATIONS

AD	:	*Anaerobic digester*
TSC	:	*Total Solids Content*
HRT	:	*Hydraulic Retention Time*
VS	:	*Volatile Solids*
TS	:	*Total Solids*
BOD	:	*Biological Oxygen Demand*
COD	:	*Chemical Oxygen Demand*
B.D	:	*Batch Digester*
GHC	:	*Green House Canopy*
DIGESTER1	:	*Cow Dung as substrate was named as DIGESTER1*
DIGESTER2	:	*Pine Needles as substrate was named as DIGESTER2.*
DIGESTER1	:	*Pine Needles as substrate using under the ambient temperature condition was named as DIGESTER1*
DIGESTER2	:	*Pine Needles as substrate using under green house canopy was named as DIGESTER2*

CHAPTER 1
INTRODUCTION

1.1 General

In the present scenario there is a challenge to meet our energy demands and thus there is need to explore and exploiting new source of energy which are renewable as well as eco-friendly. The energy demand is increasing day by day due to increase in population with higher living standard. To fulfill this energy demand non renewable energy source such as fossil fuels are the key energy generators. The available sources of energy are limited and prices are increasing so we are in need of an alternative source of energy. Biogas is one of the clean and renewable sources of energy. In 2007, the number of biogas plants in china was 26.5 million. In 1999, the number of biogas plants in India was 3 million. About 47.5 million biogas plants have already been installed in the India up to 31st March, 2014. During the year 2014-2015, a goal of setting up 1, 10,000 biogas plants has been set.

Himachal Pradesh has (latitude-31.007; longitude-77.088) – a northern mountainous state of India had total population of 6,856,509 and away of this 6,167,805 (90%) rural population as per 2011 Indian survey. Himachal Pradesh (H.P) has 67% of its total geographical area covered by forests [1]. The Himalayan subtropical pine forests are the biggest in the indo pacific region. The Himalayan subtropical pine forests are a huge forest on covering portions of India, Nepal, Bhutan and Pakistan. They cover nearly 76, 20000 hectares. The Indian Himalayan region is extend across 10 states namely, Himachal Pradesh, Jammu & Kashmir (J&K), Arunachal Pradesh, Uttarakhand, Meghalaya, Sikkim, Nagaland, Tripura, Manipur, and the hill region of 2 states viz. West Bengal and Assam. The most distinctive fact about Pine trees is their perennial nature of biomass. Pinus roxburghii grows at an elevation of 450-2300 m over mean sea level with best forests between 650 m to 1500 m above mean sea level [2]. The pine needles fall mostly during pre-monsoon period and with the hottest months of the year there are chances of forest fires [3]. In the summer season, jungle fires are common in these areas. Even a half burnt cigarette carelessly thrown by a village people or tourist can cause fires that burn up large jungle areas. The pine needles can also cause abortion in cattle and they may also slow down the growth of various helpful agricultural microorganisms. Due to the little density and small heating values of pine needles it was not practical to use them for cooking and heating purposes [4, 5]. Removal of pine needles from jungle ground is required to eliminate these hazards. Biogas technology offers a smart route to develop certain categories of biomass for partial fulfillment of energy requirement [4]. India produced 3000 million tons of macrobiotic waste annually [6]. High amount of biogas can be produced by breakdown of organic matter through anaerobic digestion. It is the one of the renewable energy sources.

In the summer season temperature is lies in the range of 20-40^{0}C but in the winter season temperature range below 20^{0}C [7]. There are many methods to increase the temperature of the biogas plant such as insulation, use hot water for making slurry and green house canopy etc. The ambient temperature in mountainous areas was minimum 2^{0}C or maximum 17^{0}C in winter season [7]. The temperature plays vital role for biogas production. In low temperature the biogas production was reduce or may be stop. In winter season use of green house canopy may increase the production of biogas. The use of green house canopy decrease the retention time and achieve optimum temperature for biogas production.

1.2 Biogas

Biogas produced by the breakdown of organic matter through anaerobic digestion. It is one of the renewable sources of energy like solar and wind energy. There are many characteristics that make different from another source of renewal energy such as this having 20 mega joules/m^3 caloric values, 60% efficient to burn in square biogas stove [8].

The biogas process contains three stages; hydrolysis, acidogenesis and methanogenesis. In the hydrolysis process the complex organic material convert into simple compound such as sugars, fatty acids and amino acids. In the second process acid producing microorganism convert these simple compounds into acetic acid, hydrogen and carbon dioxide. In the final stage methanogenesis microorganisms convert into methane and carbon dioxide. There are some factors which affects the production of biogas likes as quality of organic matter temperature, pH. Biogas can be used for cooking, lighting or to create electricity, thereby replacing other fuel sources. Biogas digested slurry received from biogas plant is rich nutrient and thus it can be used as fertilizer for agricultural purpose. Composition of biogas depends upon feedstock also. There are many characteristics that make difference from another source of renewal energy such as this is 20% lighter than air, odorless & color less gas with blue flame [8]. This gas can be used as alternate fuel in place of firewood, petrol, cow dung, LPG, diesel & electricity, depending on the nature of the task, and local supply conditions and constraints. Biogas technology is particularly valuable in agricultural residual treatment of animal excreta and kitchen waste. Anaerobic biogas digesters also work as waste disposal systems; prevent potential sources of environmental contamination and spread of pathogens and disease causing bacteria. The general composition of biogas shown in Table 1.1 below:

Table 1.1: General Composition of Biogas [8]

Compound	**Molecular Formula**	**%**
Methane	CH_4	50- 60
Carbon Dioxide	CO_2	35- 40
Nitrogen	N_2	0-2
Hydrogen	H_2	0-1
Hydrogen sulphide	H_2S	0.002-2
Ammonia	NH_3	0-0.05
Oxygen	O_2	0-2

1.3 Characteristics and other properties of biogas

1. Change in volume of biogas is also a function of temperature (T) and pressure (P).
2. Change in calorific value as function of temperature, pressure and water vapour content.
3. Change in water (H_2O) vapour as a function of pressure and temperature [8].

1.4 Factors Affecting the Yield and Production of Biogas

Many factors disturbing the fermentation process of organic substances under an anaerobic condition are as follow:

1.4.1 Total Solids Content (TSC)

Total solid content for anaerobic digestion can be divided into three ranges. Low solids content refers to system with TSC less than 10%.Medium solids content refers to TSC between 15-20% and High solids content refers to TSC in the range of 22-40%. Higher TSC requires smaller digester volume due to lower water content [9].

1.4.2 Temperature

Temperature plays an important role in the biogas production. In the summer season biogas production is increased due to the temperature and in the winter season biogas production is less. Anaerobic digestion takes place at three different temperature ranges.

1.4.2.1 Mesophilic conditions 20-45 ^{0}C:

Mesophilic bacteria have lower metabolic rates. Mesophilic digestion requires longer retention times. But they are more robust to the changes in temperature. They are able of producing good quality effluent.

1.4.2.2 Thermophillic conditions 50-65 ^{0}C:

The fermentation is more efficient at the higher temperature process. Destruction of pathogens was more capable at thermophillic temperatures. The bacteria are sensitive to changes of temperature as smaller as 50^{0}C [9].

1.4.2.3 Psychrophilic condition < 20 ^{0}C:

In the pyschrophilic condition temperature was very low as compare to other environment. Psychrophilic digestion requires longer retention times. The biogas production is very low as compare to other temperature conditions.

1.4.3 pH

The optimum pH values for the anaerobic digestion are in the range of 6.4 – 7.2. The optimum pH for Methanogenesis varied from 6.6 -7.0. Growth rate of Methanogenic bacteria is slower than the acidogenic bacteria. At lower pH values and higher feed rates the growth rate of acidogenic bacteria increases [9].

1.4.4 Hydraulic Retention Time (HRT)

Hydraulic retention time is the time required for complete degradation of the macrobiotic material. This depends on the composition of the feedstock, pH, temperature and number of extra variables which affect the anaerobic digestion process. Higher total solid content in feed increases the HRT while favorable temperature ranges decreases the HRT. The smaller the particles size the Shorter with the HRT due to high reaction rates [9].

1.4.5 Particle size

Particle size affects the rate of reaction. The smaller the particles size the more the reaction rate due to increase in surface area. When particle size decreases, increase the surface area and more the biogas generation rate. This increase the gas generation rate and reduce the amount of residue, which is turn reduces the digestion time.

1.4.6 Alkalinity

Alkalinity is the capability of the digestion medium to absorb protons or capability in neutralizing the excess acid or bases conditions. Calcium carbonate is used as a buffer substance in digestion process and also used to indicate the alkalinity of the medium [9].

1.4.7 Carbon to Nitrogen Ratio (C: N)

For effective anaerobic digestion carbon to nitrogen ratio should be maintained between the ranges 20-30. Lower C: N ratio causes ammonia accumulation in the digester and inhibits micro-organism activities. Higher C: N ratio causes lower gas production. Different types of material are mixed together to maintain the optimum C: N ratio of the feedstock [9].

1.5 Advantages

There are different types of advantages of biogas production:

1. Provide a non polluting and renewable source of energy.
2. Efficient way of energy conversion (saves fuel wood).
3. Saves women and children from drudgery of collection and carrying of firewood, exposure to smoke in the kitchen, and time devoted for cleaning and cooking of utensils.
4. Technology is cheaper and much simpler than those for additional bio-fuels, and it is ideal for small extent application.
5. Transformation of organic wastes to very high quality fertilizer, the spent slurry was used for agricultural purpose.
6. Environmental benefits on a global scale: Biogas plants significantly lower the greenhouse effects on the earth’s atmosphere.

1.6 Disadvantages

1. Explosion chances.
2. High capital cost.
3. Incorrect handling of liquid sludge causes pollution.
4. Requires control and maintenance.

1.7 Literature Review

Number of authors has conducted study on the topic of generation of biogas using different type of substrate. The different types of substrate mainly used are cow manure, food waste and agricultural waste etc.

Cow dung was an admirable substrate for biogas production in anaerobic digesters though the gas yield from a single substrate is not high. However, mixing cow dung with new kind of waste materials in co-digestion can optimize the production of biogas.

A number of studies are available on the topic of biogas production using cow dung as substrate (Ismail et al., 2012; Agwu et al., 2014; Ossai et al., 2014 etc.). Similarly few works has been done on the topic of biogas production using food waste as substrate (Shalini et al., 2000; Mohan et al., 2013; Navjot et al., 2013; Agrahari et al., 2013; etc.). Similarly few works has been done on the topic of biogas production using pine needles as substrate (Wati et al., 2011; Tripathi et al., 2015 etc.). Similarly few works has been done for comparative study of biogas production (Ukpai et al., 2012; Sagagi et al., 2000; Ingle et al., 2010 etc.). Similarly few works has been done for relative study of biogas generation under green house canopy (Agrahari 2013., and Kumar et al., 2008 etc.).

On the basis of literature review it can be stated that few study is available on the biogas production using food waste, agriculture waste, cow manure etc. Pine needles have high cellulose content and this cellulose content good for the production of biogas. But a little or no study so far is available where pine needles is used as substrate and hence has been utilized for biogas production.

1.8 Objectives

A number of studies are available in literature on the topic of biogas production using food waste, cow dung and some study on the agricultural waste. However a little or no study is available on the topic of biogas production using pine needles. Keeping in mind the above gaps, the main objectives of the study are:

1. A comparative study of the biogas production using two different substrate viz. pine needles and cow dung.
2. Compare the biogas production in the different seasons mainly winter and summer season.
3. Comparison of biogas production under green house canopy and ambient temperature condition.

1.9 Significance of the study

1. In H.P large surface area of ground is covered with pine needles.
2. High cellulose content: 61.73%.
3. Temperature plays a major role in the biogas production.
4. Gas productions in the winter season lower than other months.
5. Methanogenic bacteria are inactive so biogas production decreases in winter season.

1.10 Limitations of the study

The following are the main limitations of the present study:

1. Pine needles have been used for biogas production.
2. Study has been conducted in batch conditions so only batch digester has used.
3. Floating type gas holder has been used in this experiment.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The biogas is renewable source of energy. The biogas can be produced from the different types of substrate. As a result a large amount of literature is available on the topic of biogas production using cow dung, food waste, and agricultural waste (crop waste, plant material etc) as substrate for the past 10 years. However relatively little study or no study has been done so far on utilization of pine needles for Biogas production. Review of the research papers using different substrates has been carried out in the following section.

2.2 Biogas production using cow dung as substrate

Ismail et al., (2012) [10] conducted experimental study for the biogas production using cow dung alone. The effectiveness of cow dung for biogas production was investigated, using a laboratory scale 10*L* bioreactor functioning in batch and semi-continuous mode at 53^0C. Anaerobic digestion seemed feasible with an organic loading of up to 1.7 kg volatile solids (VS)/ *L d* and an HRT of 10 days during the semi-continuous operation. The averaged cumulative biogas yield and methane content observed was 0.15 *l/kg* VS added and 47%, respectively. The COD, TS and VS removals amounted to 48.5%, 49%, and 47% respectively.

Agwu et al., (2014) [11] conducted study for the biogas production using cow dung. Cow dung as a renewable source of energy supply has been proven to be very efficient. This study was investigated the generation of biogas using cow dung from Abakaliki abattoir located in Abakaliki, Ebonyi State, Nigeria. A 2 m*l*/g of the cow dung was used in this study. The digestion was carried out in a 10 L anaerobic digester and temperature was 25^0C to 30^0C, uncontrolled pH for a period of 3 weeks. About 23 cm^3 of biogas was produced on the 22nd day. Thus biogas generation from cow dung was a good and cheap alternative source of energy.

Ossai et al., (2014) [12] conducted study for analyzed quantitatively and qualitatively the biogas produced from cow dung by indigenous microbial consortia. In this study four 20*l* bioreactors were used. The substrates in the bioreactor were water and manure, rumen fluid and manure. The study lasted for six months and it was carried out at the microbiology lab of Anambra state university, Nigeria. Quantification and qualitative analysis of biogas production was by liquid dislocation and gas chromatography methods respectively. The results of the TS, VS and VFA were 400mg/l, 92 mg/l and 16.7 mg/l in the predigested sample and 92mg/l, 17.4 mg/l and 28.3 mg/l in the postdigested slurry sample. The quantity of biogas production at fourth month was 60 ml, 128 ml and 220 ml respectively.

2.3 Biogas production using food waste as substrate

Shalini et al., (2000) [13] conducted study for the increased biogas production using microbial stimulants. They study the effect of microorganisms on biogas yield from cattle dung and joint residue of cattle manure and kitchen waste respectively. The result shows that addition of cattle dung on first day and 15 day increased the gas generation by 55% over unamended cattle dung and addition of teresan to cattle manure: kitchen waste (1:1) mixed residue 15% increased gas generation.

Mohan et al., (2013) [14] conducted study for biogas production from food waste produced by Mahindra Engineering College Canteen using anaerobic digestion process. Biogas produced from the disintegration of food waste was a mixture of 76% methane and 24% carbon dioxide**.** Biogas has been produced with a considerable rate of decrease in the values of COD, BOD, pH, acidity, alkalinity and the H.R.T was 90 days.

Navjot et al., (2013) [15] conducted study for utilization of kitchen waste for biogas production. They solve the waste disposal problem to some extent. This work was carried out to produce biogas in a compact water plastic tank. The cow dung is used as the inoculums. The ratio of cow dung and water is 1:1.The H.R.T of this study was 21 days. The optimum pH, TS% and temperature which are recorded time to time are i.e. 7, 12% and 37˚C respectively. The biogas production in this paper is 0.535m^3. The study has shown that Kitchen Wet Waste is useful and can be utilized for energy generation. In the above paper waste water is used as inoculums but in this paper cow dung is used as inoculums.

Agrahari et al., (2013) [16] Kitchen waste is the best alternative for biogas production in a community level biogas plant. In this paper, an attempt has been made to test the performance of different ratio of kitchen waste in a metal made portable floating type biogas plant of volume capacity 0.018 m^3 for outdoor climatic condition of New Delhi, India. Aluminum metal is more capable to increase the sufficient temperature inside the digester which increases the production rate of biogas. This analysis has been done under 30 days (1 month) observation. In this observation, we have taken different proportion of kitchen waste and water with fixed amount of inoculum. The different ratio has taken for kitchen waste and water that shown in Table 2.1 below:

Table 2.1: Biogas production at different kitchen waste and water ratio [16]

Characters	Case-A 6 kg(1:3)	Case-B 8kg (1:2)	Case–C 10 kg (1:1.4)	Case–D 12 kg(1:1)
Amount of kitchen waste	6 kg	8 kg	10 kg	12 kg
Water	18lt	16lt	14lt	12lt
Inoculum	6lt	6lt	6lt	6lt
Ratio of kitchen waste and water	1:3	1:2	1:1.4	1:1
pH	7.3	7.4	7.7	7.9
Total biogas production(m^3)	0.2184	0.258	0.12785	0.1216
Maximum methane fraction	42%	48%	44%	No
Duration of methane fraction production in days	3-11	3-15	18-22	No
Number of days methane fraction present	10	15	5	No

In the other author used plastic tanks but Agrahari has used aluminum metal tanks and they have done experiment with different ratio of kitchen waste and water.

2.4 Biogas production using agricultural waste as substrate

Ilaboya et al., (2010) [9] investigated the importance of biogas as an alternative energy sources and surveyed to ascertain the amount of biogas can be generated from various feedstock. They experiment the design with agriculture waste to find out the effects of sodium hydroxide on the volume of biogas generated with mixture of fruit peelings. Results reveals a high volume of biogas generated when the operating anaerobic digestion at moderately alkaline condition. Further anaerobic digestion temperature remained in the range of 27^0C to 35.5^0C throughout the HRT.

Wati et al., (2011) [17] conduct study for utilization of agricultural waste. In this study Leela Wati has done study cattle manure supplemented with rice straw in different ratios was carried out at 15-16% total solid concentration in batch and semi continuous system under laboratory conditions. The biogas production of 28.97 l/kg was observed on supplementation of cattle manure with rice straw in batch conditions which was 26.36 l/kg with cattle manure only. Under semi continuous mode of digestion the biogas production of 0.330l/l/day of paddy straw to cattle dung and 0.283l/l/day for cattle dung only.

Tripathi et al., (2015) [1] has conduct study for generation of biogas using agricultural waste. The pine needles have used feedstock for this study. The present study focuses on efficient and cost effective use of biogas digester for the production of biogas from recalcitrant lignocellulosic waste (pine needles). It is noticed that biogas production peaked from1.4 l/day to1.9 l/day during winter month, where as it was7.3 l/day during months of March and April. In the above author all has done batch study but the Tripathi has done continues study. This is the continuous type study.

2.5 Comparative study of different substrate for biogas production

Ukpai et al., (2012) [18] has conducted comparative study of biogas generation from cow dung, cow pea and cassava peeling. In this study 45*l* capacity metallic prototype biogas digester constructed and the experiment was batch operated. The daily gas production from the plant was measured for 30 days. The digester was charged differently with these wastes in the proportion of 1:2, 1:5 and 1:5 of waste to water respectively. The mesophilic ambient temperature range attained within the testing period. The result obtained from the study showed the biogas generation that cowpea generate the highest methane content of 76.2%, cow dung with 67.9% and cassava peeling has least methane content of 51.4%. In the term of flammability they become flammable at different period during the digestion.

Sagagi et al., (2009) [19] has conducted study on biogas production from fruits and vegetable waste materials and their effect on plants when used as fertilizer. Organic material decomposed under anaerobic condition to yield biogas. It has been observed that the highest weekly individual production rate was recorded for the cow dung slurry with average production of 1554 cm^3, pineapple waste which had 965 cm^3 of biogas, orange waste had 612 cm^3 of biogas and pumpkin and spinach wastes had 373 cm^3 and 269 cm^3 respectively.

Ingle et al., (2010) [20] has conducted comparative study of biogas production from different food wastes. The solid waste contain various components, some of then are biodegradable where as other are non biodegradable. The substrates were used kitchen waste and unprocessed food waste including raw vegetable waste and banana waste. Various types of parameters were studying during biogas production like alkalinity, protein content, carbohydrate and COD. During the comparative study of different substrate it was observed that the protein content carbohydrates and COD decreased with increased in time, whereas pH and alkalinity varied.

2.6 Comparative studies for biogas production under green house canopy and at ambient temperature

Agrahari (2013) [21] conducted experimental study using food waste. The field study was carried out for one month (January 19, 2012-february 17, 2012) in IIT New Delhi India. The green house canopy was used to increase the slurry temperature inside the digester. In order to check the effect of temperature on biogas production he conducted the comparative study. During the winter season one digester was kept in ambient temperature condition and second under green house canopy. An increase of 31.49% by volume of biogas production in digester with canopy was noticed when compared with biogas production of digester without canopy.

Vinoth et al., (2008) [7] conducted study for solar green house assisted biogas plant in hilly region. The field study was carried out for one year in a Nilgiris incorporating solar energy to study its influence on biogas production. During summer (April- June) the temperature reaches to the maximum of 21-25^{0}C and the minimum of 10-12^{0}C. During winter (October-December), the temperature available is maximum of 16- 21^{0}C and minimum of 2^{0}C. This study involves the control conventional Deenabandhu model and the experimental plastic tank with greenhouse canopy of similar capacity. The generated from the biogas plant was utilized for cooking and lightning purposes. The annual average slurry temperature recorded during the study period was 26.3 and 22.40^{0}C in experimental and control biogas plants against temperature of 17^{0}C. The annual average greenhouse chamber temperature recorded was

29.1^{0}C in the experimental biogas plant. The yearly average gas yield from the experimental and biogas plant were 39.1 and 34.61 kg^{-1}day^{-1} respectively. Gas production in the winter season registered lower than other months. It can be concluded that the solar greenhouse assisted plastic biogas plant can be efficiently adopted with minor modifications in hilly regions since the temperature profile plays a major role in biogas production.

2.7 Concluding Remarks

The study of literature review indicated that more study are available on the topic of biogas production with food waste and cow dung but the little or no study has been conducted on the utilization of pine needles for biogas production. No study so far has been reported on the biogas production of using pine needles in ambient and under green house temperature conditions.

CHAPTER 3
PRINCIPLE OF BIOGAS GENERATION

3.1 General

Biomass contents of living organism are beings deteriorated by micro-organisms in presence or absence of oxygen (O) and are composed of carbons. Biomass contains number of combinations of elements such as Hydrogen (H), Nitrogen (N) and Oxygen (O). Here complex variety of organic compounds: Carbohydrates, Fats and Proteins. Accordingly bacteria have role to breaks the complex carbon into smaller substances through digestion process.

There are two different types of bio-digestion mechanisms.

3.1.1 Aerobic digestion

Digestion process occurs in the presence of oxygen known as aerobic digestion and generates mixtures of gases having carbon dioxide (CO_2) and hydrogen sulphide. From these CO_2 is main green houses responsible for global warming.

3.1.2 Anaerobic digestion

Digestion process occurs in the absence of oxygen known as anaerobic digestion which generates mixtures of gases. The main gas produces in anaerobic digestion is methane which when burned at standard room temperature and presents a viable environmentally friendly energy source to replace fossil fuels. However one advantage is that anaerobic digestion produces methane gas, which can be used as fuel.

3.2 Anaerobic digestion

The anaerobic digestion is a natural process that takes place in the absence of oxygen. It involves biological decomposition of complex substrate by various biochemical processes with release of energy rich biogas and production of nutrious effluents [8]. When organic materials are breakdown under anaerobic conditions, the end products include such gases as methane (CH_4), carbon dioxide (CO_2), small amount of hydrogen sulphide, ammonia (NH_3) and few other gases. The methane is excellent fuel long ago prompted waste water treatment plant design engineers to digest waste solid and capture this gas for the treatment plant and used as alternative sources of energy. The methane formation in anaerobic digestion involves different steps such as: hydrolysis, acidogenesis and methanogenesis.

3.3 Biological Process

3.3.1 Hydrolysis

Hydrolysis is the first step in the anaerobic digestion. The complex organic material such as: proteins, carbohydrate and fats broken into their simple constituents' sugar, amino acid and fatty acid [9].

3.3.2 Acidogenesis

Acid- producing bacteria, this is second step of anaerobic digestion. In the step hydrolysis phase are further degraded by fermentative microorganisms into acetic acid, hydrogen and carbon dioxide. These bacteria are anaerobic and can grow under acidic conditions [9]. To generate acetic acid, they use oxygen and carbon. For this they use dissolved oxygen. Hereby the acid producing bacteria generate anaerobic condition which is necessary for methane producing bacteria.

3.3.3 Methanogenesis

This is the last step in the anaerobic digestion. They work under anaerobic conditions. They use hydrogen, carbon dioxide and acetic acid to produced methane and carbon dioxide.

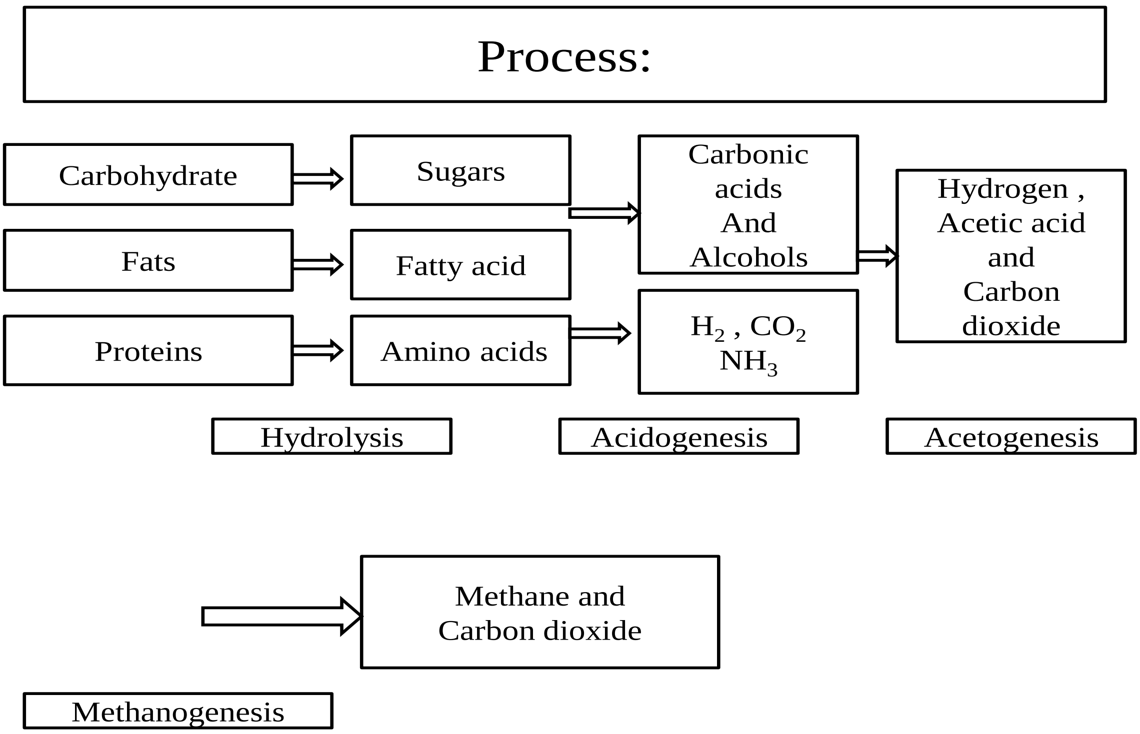


Figure 3.1: Biological process

CHAPTER 4
EXPERIMENTAL SETUP AND METHODOLOGY

4.1 General

Biogas is formed by the breakdown of organic material through anaerobic digester. It is one of the renewable energy sources. In anaerobic digester fermentation of biodegradable material happened to the one carbon compound level like methane and Carbon dioxide in absence of oxygen. Biogas can be used for cooking, lighting or to generate electricity, thereby replacing other fuel sources. The first objectives of the present study was to conduct the comparative study of biogas production using two different substrates viz. pine needles and cow dung under similar field conditions. It was also intended to study the effect of surrounding temperature on biogas production. Second objective of study was to study the effect of temperature by keeping one digester under green house canopy and second digester in ambient temperature Condition used pine needle as substrate for biogas production. In this study pine needle is used as substrate for biogas production. In order to achieve the objectives two experiments were conducted and have been summarized in the following chapter.

4.2 Experimental Setup and Instrumentation

Following section describe the digester and material prepared and utilized for the experiments. The batch digester consists of two plastic made buckets: one for fermentation and second as gas holder in first objective of the study. The capacity of fermentation buckets is 45 *l*. The internal diameter of fermentation bucket is 0.30 m at the bottom and 0.37 m at the top and the height of fermentation bucket is 0.45 m. The diameter of gas holders is 0.30 m and height of gas holders are 0.35 m. The structure of batch digester consists of GI fittings. This fitting contain ½ inch nipple, ½ inch tank connection nipple, ½″ valve and gas cork. The green house canopy stand was made of iron pipe; the height and length of green house canopy stand are 1.42 m and 0.90 m respectively. The pieces of pipe joined with the help of welding. Thus make a structure of green house stand after this the stand was covered with the plastic sheet.

The digesters were placed near the Fluvial Hydraulics Laboratory at the Department of Civil Engineering in the Jaypee University of Information Technology Waknaghat (H.P). The plate 4.1 shows the pictorial view of digester and green house canopy stand.

Plate 4.1: Pictorial view of digester and green house canopy

4.3 Material preparation

Cow dung was collected from the local sources. Cow dung was used to make preinoculums which were just 3 day old. 1.5 kg of cow dung was mixed with 3 liters of tap water in the ratio of 1:2 by weight. All extraneous matter was removed from the mixture and all the lumps were broken and put into the plastic made bottle for 15 days at dark place. The purpose of inoculum was to make a culture of the micro-organisms so that when fresh substrate was added it enhances the biogas production. The plate 4.2 shows the inoculum prepared bottle put into the dark place.

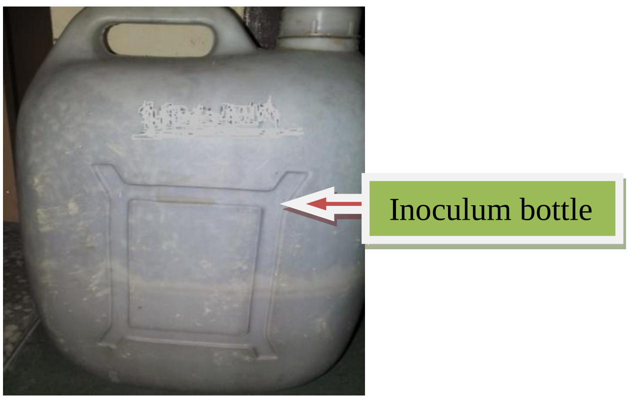


Plate 4.2: Pictorial view of inoculum prepared bottle

The pine needles were collected from the nearby area of JUIT campus. The pine needles were dried for 2 hour at 70^0C in oven and then converted to small particles size using electrical grinder. The plate 4.3 shows the pine needle before grinding and after grinding.

Plate 4.3: Pictorial view of Pine needles before and after grinding

4.4 Methodology & Experimental Observations

Two series of Experiments were conducted. In the first Experiment was conducted to compare the biogas production and other parameter using two different substrate pine needles and cow dung. In the second Experiment was done the comparison of biogas production under green house canopy and in ambient temperature condition by using pine needle as substrate only.

4.4.1 Experimental procedure, observations before and after digestion in the first experiment

In first Experiment 1.5 kg of cow dung was mixed with tap water and inoculum. The ratio of cow dung and water was taken as 1:15 by weight in this experiment, In *DIGESTER1*; 1.5 kg cow dung, 22.5 *l* water and 4.5 *l* inoculum were used while in *DIGESTER2*; 1.5 kg pine needles, 22.5 *l* water and 4.5 *l* inoculum in both the digesters all the lumps were broken and then mixture was filled in the fermentation bucket. The gas holder was placed in inverted position over the fermentation bucket with opened gas cork so that air could escape out from the gas holder during the sinking of gas holder. When gas holder sunk into completely and it touched the bottom of the fermentation bucket then gas cork was closed. Thus biogas generation was indicated by the upliftment of gas holder bucket. The retention period for this study was 70 days. The experimental were started from 17 Nov 2015 to 26 Jan 2016 continues up to when no biogas production was observed in the gas holder. This experiment was done in the same meteorological conditions. A plate 4.4 shows the Pictorial view of *DIGESTER1* and *DIGESTER2* respectively.

Plate 4.4: Pictorial view of DIGESTER 1 and DIGESTER 2

(a) Experimental observations before and after digestion in first experiment

The first experimental observations before and after digestion slurry was analyzed in terms of Total solid (*TS*), Volatile solid (*VS*), Biological oxygen demand (*BOD*), Chemical oxygen demand (*COD*) and pH was analyzed. The Appendix A.1 has shown the cumulative biogas generation in *DIGESTER1* and *DIGESTER2*.

Appendix A.2 has shown the pH variation with time in both digesters. The pH measured in *DIGESTER1* and *DIGESTER2* after five days with the help of pH strip.

Appendix A.3 and A.4 has shown the inside and outside temperature variation in both digesters.

The table 4.1 has shown the different parameters like Biological oxygen demand, Chemical oxygen demand, and Total solid and Volatile solid before and after digestion.

Table 4.1: Before and after digestion value of different parameters in DIGESTER 1 and DIGESTER 2

S.No.	Parameters	Units	DIGESTER 1		DIGESTER 2	
			Before	After	Before	After
1	BOD	mg/*l*	200	197	202	196
2	COD	mg/*l*	9600	6720	10560	4800
3	TS	mg/*l*	11089	6980	16188	5620
4	VS	mg/*l*	2218	1510	6098	1670

(b) Measurement of biogas

Biogas production was also calculated on daily basis by rise in height of gas holder. This raise height was multiplied by $\pi/4d^2$ and calculated volume of biogas production every day. On increment in height of the gas holder was observed in the *DIGESTER 2* during 20 Nov 2015 to 26 Jan 2016 while some increment in height of the gas holder was observed in the *DIGESTER1*. In the *DIGESTER1* biogas production was started from after 40th days and the DIGESTER2 the biogas production started from the 3rd day of the starting the experimental period. Biogas was measured on daily basis. The uplift height of the gas holder was measured on daily basis in both digesters. The cumulative biogas production was calculated by the increase the height of multiplied by $\pi/4d^2$. Appendix A.1 has shown the cumulative Biogas production in *DIGESTER1* and *DIGESTER2*.

4.4.2 Experimental procedure, observations before and after digestion in the second experiment

In the second experiment pine needle are used as substrate for biogas production in both digesters. 1.5 kg of pine needles was mixed with tap water and inoculum. In *DIGESTER1* and

DIGESTER2 the ratio of pine needle and water was taken as 1:15 by weight in this experiment. 1.5 kg pine needle, 22.5 *l* water and 4.5 *l* inoculum were used in both digesters all the lumps were broken and then mixture was filled in the fermentation bucket. The gas holder was placed in inverted position over the fermentation bucket with opened gas cork so that air could escape out from the gas holder during the sinking of gas holder. When gas holder sunk into completely and it touched the bottom of the fermentation bucket then gas cork was closed. The *DIGESTER1* was kept under ambient temperature condition and *DIGESTER2* was kept under the green house canopy to check the suitability of green house canopy for increment of biogas production. Sometime due to the lower temperature biogas production decreased and may be stopped. The use of green house canopy over the *DIGESTER2* for increasing the slurry temperature inside the digester and the output increase the biogas production. It has been observed from the comparative study of the without and with green house canopy biogas digester. A plate 4.5 shows the pictorial view of *DIGESTER1* and *DIGESTER2* respectively.

Plate 4.5: Pictorial view of DIGESTER1 and DIGESTER2

(a) Experimental observations before and after digestion in second experiment

The second experimental observations before and after digestion slurry was analyzed in terms of Total solid (*TS)*, Volatile solid (*VS)*, Biological oxygen demand (*BOD)*, Chemical oxygen demand (*COD)* and pH was analyzed. The Appendix B.1 has shown the cumulative biogas production in *DIGESTER1* and *DIGESTER2.*

Appendix-B.2 has shown the pH variation with time in both digesters. The pH measured on daily basis in *DIGESTER1* and *DIGESTER2* with the help of pH strip. The Appendix B.3 and B.4 has shown the temperature variation in both digesters.

The table 4.2 has shown the different parameters like Biological oxygen demand, Chemical oxygen demand, and Total solid and Volatile solid before and after digestion.

Table 4.2: Before and after digestion value of different parameters in DIGESTER 1 and DIGESTER 2

S.No.	Parameters	Units	DIGESTER 1		DIGESTER 2	
			Before	After	Before	After
1	BOD	mg/l	205	199	205	196
2	COD	mg/l	11520	4800	11520	3840
3	TS	mg/l	16712	5098	16712	3215
4	VS	mg/l	5676	1358	5676	736

(b) Measurement of biogas

Biogas production is also calculated on daily basis by rise in height of gas holder. This raise height is multiplied by $\pi/4d^2$ and calculated volume of biogas production every day. On increment in height of the gas holder was observed in the *DIGESTER1* and *DIGESTER2* during 13 Feb 2016 to 17 April 2016. The *DIGESTER1* was kept under ambient temperature condition and the *DIGESTER2* was kept under green house canopy. The uplift height of the gas holder was measured on daily basis in both digesters. Appendix B.1 has shows the cumulative biogas production in *DIGESTER1* and *DIGESTER2*.

4.5 Standard Testing Methods

4.5.1 pH

pH was measured by pH paper. Put some sample on a beaker and then put the pH test strip into it, make sure both pads on the test narrow piece are sufficiently covered in liquid, remove and then wait 15 second. Match the colour reading against the indicator chart in the pH test strip packaging.

4.5.2 Total solids (*TS*)

Place the required quantity of the sample in a dry crucible dish. Evaporate to dryness in an oven at 103^0C-105^0C and dry to constant weight. Cool the dish and note the increase in weight.

W1= weight of empty crucible (mg)

W2= weight of crucible with residue (mg)

Total solids (mg/l) =

$$\frac{\text{(weight of crucible with residue (W2) –weight of empty crucible (W1) *1000}}{\text{Sample (ml)}}$$

4.5.3 Volatile solids (*VS*): Ignite the residue obtained in at 600^0C in a muffle furnace, cool and weigh.

Volatile solids (mg/*l*) =

$$\frac{\text{(Weight of crucible with residue- weight of empty crucible) - (weight of crucible with residue heated to } 600^0\text{C) mg *1000}}{\text{Sample (ml)}}$$

4.5.4 Biochemical oxygen demand (*BOD*)

BOD is the test to give an idea of the biodegradability of any sample.

Procedure:

1. Take 300 ml glass stopped BOD bottles (one for sample and one for blank).
2. Add 10 ml of the sample of each of the BOD bottles and fill the remaining quantity with the dilution water (we have diluted the sample 30 times).
3. Remaining bottles for blank to add dilution water alone.
4. After the addition place the glass stopper over the BOD bottles.
5. Test the initial value of DO of blank bottles and sample bottles with DO meter.
6. Now preserve blank and sample bottle in a BOD incubator at 20^0C for five days.

7. After five day same procedure follows for the take out the bottle from the BOD incubator.

BOD (mg/*l*) = initial value of DO –final value of DO *DF

DO= Dissolved oxygen

DF = Dilution factor

Dilution factor = $\frac{\text{Total volume of BOD bottle}}{\text{Volume of Sample taken}}$

4.5.5 Chemical oxygen demand (*COD*)

The COD is a measure of the amount of chemical that consumes dissolved oxygen.

Procedure

1. Take 2.5ml water sample in tube and 2.5 ml of distilled water another tube.
2. Add 1.5 ml of potassium dichromate to both the tubes.
3. Carefully add 3.5 ml of sulphric acid regent to both tubes.
4. Tightly close the tube kept in COD digester at 150^0C for 2 hours.
5. After cooling to room temperature transfer the content to the conical flask.
6. Fill the burette with freshly prepared ferrous ammonium sulphate.
7. Add 2 drops of ferroin indicator.
8. Titrate the contents against ferrous ammonia sulphate.
9. Continue the titration till the colour change to reddish brown.

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

A= volume of ferrous ammonia sulphate for blank.

B= volume of ferrous ammonia sulphate for sample.

N= normality of ferrous ammonia sulphate N = 0.1

4.5.6 Odour

Odour is feel by human sensor.

4.5.7 Temperature

Temperature is measured by help of thermometer.

CHAPTER 5

RESULTS AND DISCUSSION

The first experiment of the current study was to compare the biogas potential of Pine needles and cow dung under similar conditions. The second experiment was conducted to check the biogas production under green house canopy and in ambient temperature condition. In order to fulfill the above objectives, experiments were conducted in the laboratory. Two batch digesters namely *DIGESTER1* and *DIGESTER2* were designed. The outcome of the first experiment, second experiment was summarized and discussed in the present chapter.

5.1 Comparison of biogas production or different parameters using substrate cow dung, pine needles, under similar ambient temperature conditions.

Different types of parameter are measured in this experimental study such as: pH, Biological oxygen demand (*BOD),* Chemical oxygen demand (*COD),* Total solid (*TS*) and Volatile solid (*VS*). The temperature is measured on the daily basis at 3 times in a day (Morning, afternoon and evening). Thermometer was used for measurement of the temperature of slurry inside the digester every day. Thermometer having least count 0.5^0C was used for measure temperature of slurry inside the digester every day. Both the digesters were stared on 17 of November, 2015 under similar meteorological conditions. The biogas production is also measured on daily basis by rise height of gas holder.

5.1.1 pH

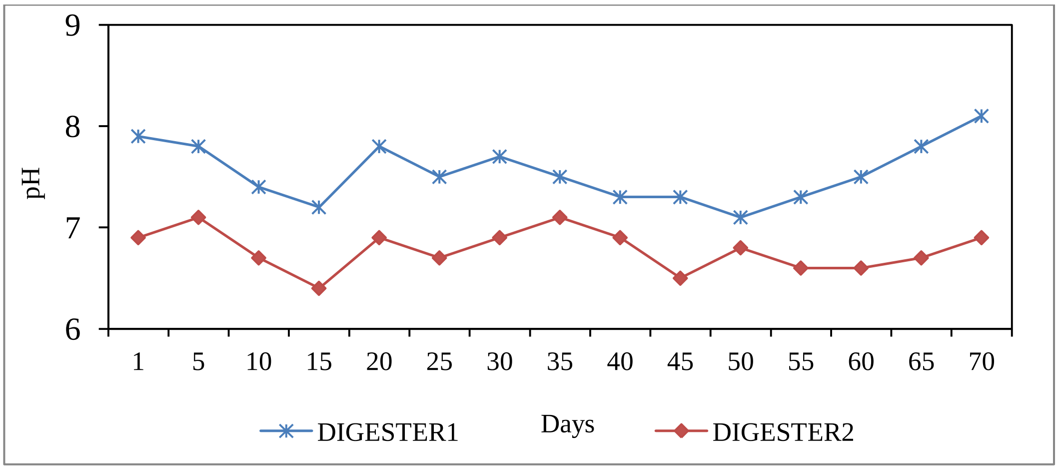


Figure 5.1: Variation of pH with time

In *DIGESTER1* pH was observed in the range of 7.2- 8.1 and in the *DIGESTER2* pH lies in 6.4-7.3. From fig - 5.1 the pH in *DIGESTER1* falls continuously for 15 days and *DIGESTER2* pH increased for first 5 days and then decreased. The pH in this study was unregulated means no acid or bases were added to make the pH in neutral condition. In the ending days the pH in *DIGESTER1* and *DIGESTER2* increased due to the digestion of volatile fatty acid and nitrogen compound through methanogenesis microorganisms and the *DIGESTER2* pH lies in optimal range for biogas production. The pH is important due to the fact that Methanogenic microbes are susceptible in acidic condition. The favorable range of biogas production in anaerobic digestion is 6.5-7.5. So when pH below 6.3 and above 7.8 biogas production is less [22]. When pH was lies in 6.5- 7.2 the biogas production was more. This may be attributed to the increase in growth of methanogenesis bacteria, which are responsible for biogas production and their activity [23]. In *DIGESTER1* pH varies from 7.2-8.1 while in the DIGESTER2 pH lies between 6.4-7.3. In the *DIGESTER1* pH value out of the optimum range of pH for biogas production and in the *DIGESTER2* pH lies in the optimum range of pH for biogas production. In this result observed that in the starting pH was low and the ending pH was increased because in starting decreased due to the acid formation in the hydrolysis phase and the ending increases due to the formation of volatile fatty acid and ammonia [24].

5.1.2 BOD and COD reduction

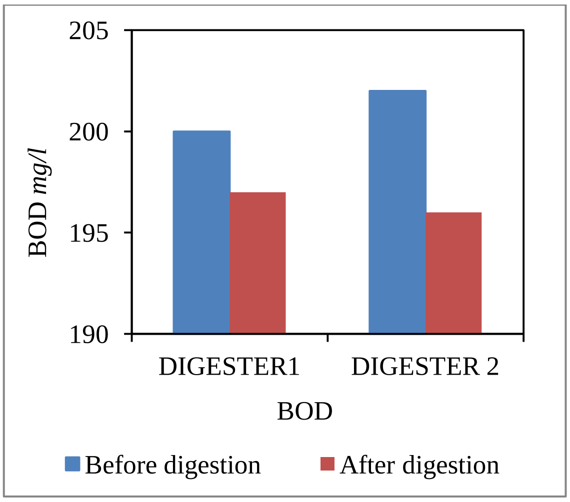


Figure 5.2: BOD reduction

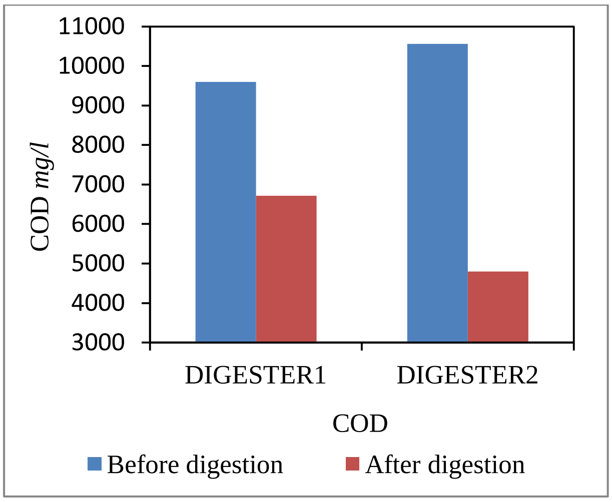


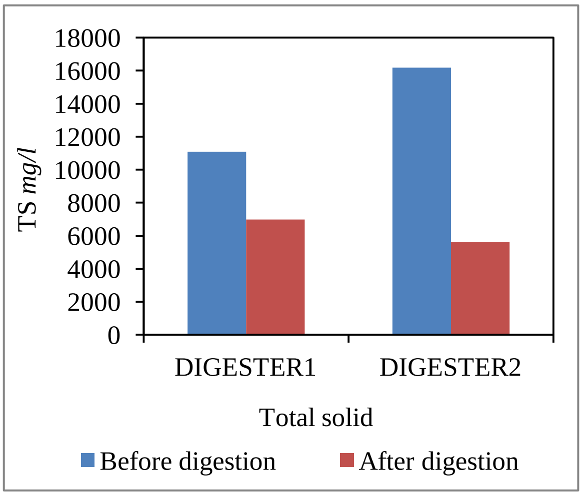
Figure 5.3: COD reduction

Figure 5.2 shows the initial value of *BOD* was observed 200 and 202 for *DIGESTER1* and *DIGESTER2* respectively. The final value of *DIGESTER1* and *DIGESTER2* was observed 197 and 196 respectively. Figure 5.2 shows the comparison of *BOD* in both digesters. In starting

BOD of both digesters was more but with the time *BOD* in both digesters was less. The BOD_5/COD ratio value before and after digestion varied from 0.02-0.03 that's means the organic material is slowly biodegradable in *DIGESTER1*and *DIGESTER2* was varied from 0.01- 0.04 that's means the some quantity of complex biodegradable macrobiotic material present in *DIGESTER2*.

Figure 5.3 shows the initial value of *COD* was observed 9600 and 10560 in *DIGESTER1* and *DIGESTER2* and final value of *COD* was observed 6720 and 4800 respectively. Figure 5.3 shows that *COD* reduction in *DIGESTER1* and *DIGESTER2* was 30% and 55% respectively. The *COD* reduction in *DIGESTER1* was less as compare to *DIGESTER2*. The biogas production increased with increase in *COD* removal so in the *DIGESTER2* has more *COD* removed as compare to the *DIGESTER1*. The *COD* is used to measured the quantity of organic matter in waste and predict the potential for biogas generation. The *BOD* and *COD* will be reduced during anaerobic digestion process in a biogas system. During biological degradation of organic compound amount of *BOD* and *COD* will be decreased with time [20].

5.1.3 Total solid and volatile solid reduction



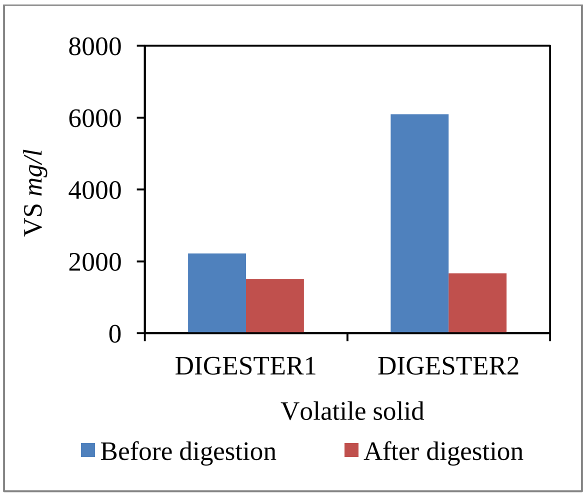


Figure 5.4: Total solid reduction

Figure 5.5: Volatile solid reduction

Total solid content in the starting was observed more but when the degradation start the total solid are decrease, because the organism utilize the total solid content as a food. In the batch system no new food coming in so starting food quantity was more as compare to end of time because food was utilized b bacteria so the total solid content less in digested slurry. Figure 5.4 shows the comparison of total solid in both digesters. In starting total solid value was high but after digestion total solid was less in both digesters.

The total solid reduction in both digesters was 37.05% and 65.2% respectively. In the *DIGESTER1* total solid reduction was less as compare to *DIGESTER2* because in the *DIGESTER1* cow dung used as feedstock and cow dung contains lignocellulosic rich material that makes anaerobic process quite unoptimum [10]. The higher the total solids reduction more will be the biogas generation. In the *DIGESTER2* more total solid reduction as compare to *DIGESTER1* that means more biogas production in *DIGESTER2*.

Figure 5.5 shows the volatile solid reduction in both digesters. The volatile reduction in *DIGESTER1* and *DIGESTER2* was observed 31.93% and 72.61% respectively. In the *DIGESTER1* volatile reduction was less as compare to *DIGESTER2* because volatile solid responsible for biogas generation. More volatile solid reduction more will be the biogas generation [25].

5.1.4 Temperature

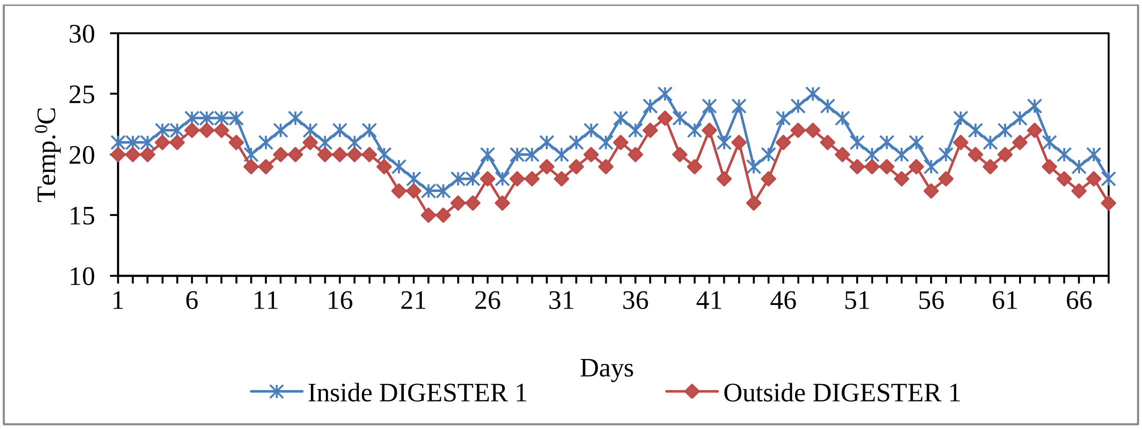


Figure 5.6: Variation of Temperature in DIGESTER 1

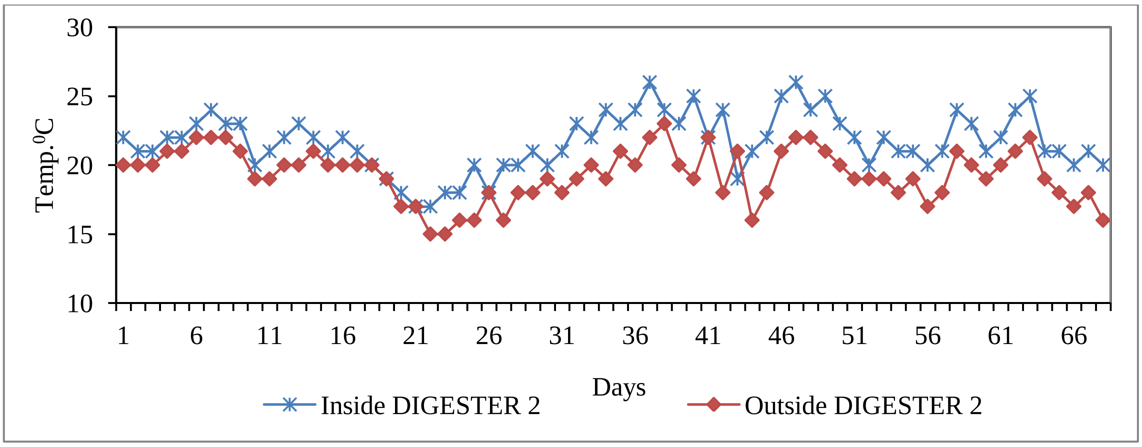


Figure 5.7: Variation of Temperature in DIGESTER 2

Ambient temperature and temperature inside the digester is shown in Figs.5.6-5.7 for *DIGESTER 1* and *DIGESTER 2*. The surrounding temperature range measured within the testing period were 15^0C-23^0C and slurry temperature inside the digester range of 17^0C-26^0C. In both the digesters temperature varies from 17^0C-25^0C (mesophilic 20^0C-45^0C and Psychrophilic < 20^0C).

The temperature inside the digester was observed more than the temperature outside the digester in both digesters. This is attributed to microbial degradation of the waste that raised the temperature of the waste slurry [26]. Temperature is a vital parameter for biogas production and generally at higher temperature the biodegradation process is high and thus the biogas yield is also more.

5.1.5 Cumulative Biogas production

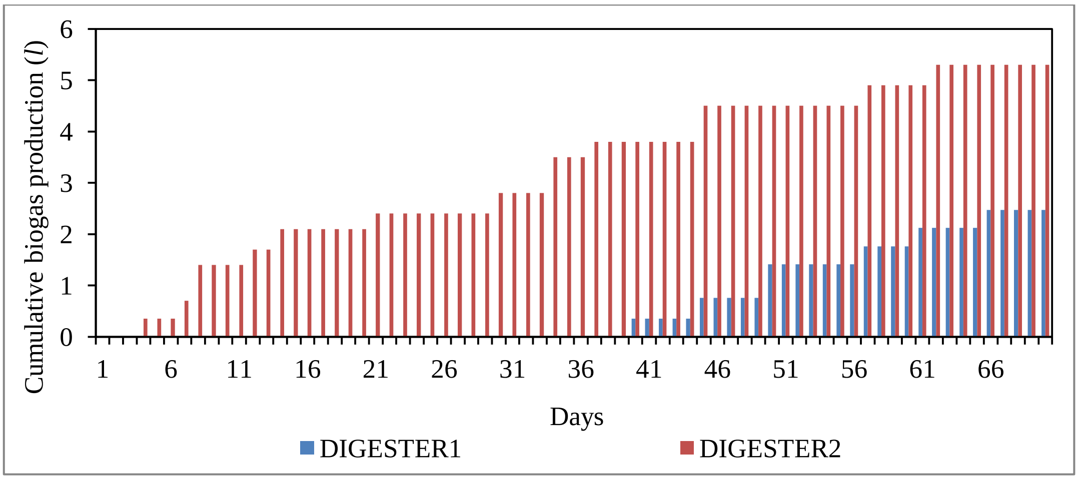


Figure 5.8: Cumulative biogas production

Figure 5.8 shows the comparison of cumulative biogas production in *DIGESTER1* and *DIGESTER2*. In the *DIGESTER1* biogas production was started from the 40^{th} day but in the DIGESTER2 biogas production start from the 3^{rd} day of the slurry feeding inside the fermentation bucket. In *DIGESTER1* biogas production started from 40^{th} day due to the slow growing nature, and environmental changes and long lag period required for these bacteria to adjust to the new environment conditions [28]. The biogas production rate in *DIGESTER2* reached constant on 45^{th} day to 56^{th} day after this day the biogas production rate decreased. In the starting and ending biogas production was less. In the batch operation it predicts that the biogas production is directly equal to the growth of Methanogenic organism [10]. Figure 5.8 show that biogas production in starting less because bacteria put into new environment this was the lag phase of bacterial growth. The cumulative biogas generation in *DIGESTER1* and *DIGESTER2* was 2.4 *l* and 5.3 *l*. The biogas production in *DIGESTER2* was more as compare to *DIGESTER1* because the pine needles was co-digested with cow dung so they increase the biogas production because extra nutrient enhanced the biogas generation, high cellulose content, high calorific value and pH lies in the range of optimum biogas generation as compare to cow dung. The High cellulose content is good for biogas production [1].

5.2 Comparison of biogas production or different parameters using pine needles as substrate under green house canopy and ambient temperature conditions.

Different types of parameter are measured in this experimental study such as: pH, Biological oxygen demand (*BOD)*, Chemical oxygen demand (*COD)*, Total solid (*TS*) and Volatile solid (*VS*). The temperature is measured on the daily basis at 3 times in a day (Morning, afternoon and evening). Thermometer was used for measurement of the temperature of slurry inside the digester every day. Thermometer having least count 0.5^0C was used for measure temperature of slurry inside the digester every day. Both the digesters were stared on 8 of February 2016 to 17 April 2016.In this study done the comparison of biogas production under green house canopy and in ambient temperature condition. The purpose of green house canopy was to check the increment of biogas production under green house canopy and in ambient temperature condition. The biogas production is also measured on daily basis by rise height of gas holder.

5.2.1 pH

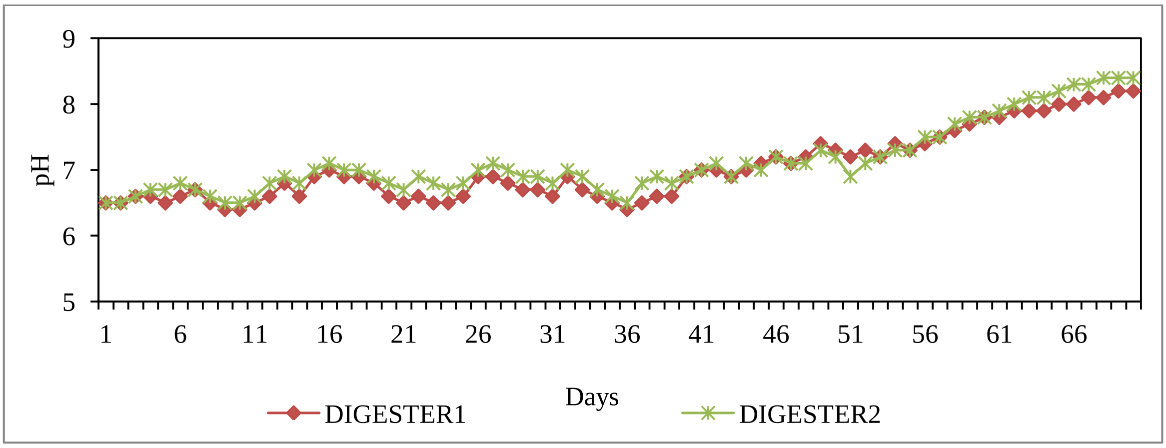


Figure 5.9: Variation of pH with time

In the *DIGESTER1* pH lies in the range of 6.4 - 8.2 and in the *DIGESTER2* pH lies in 6.5 -8.4. The pH in this study was unregulated means no acid or bases add to make the pH in neutral condition. The pH range in *DIGESTER1* lies in 6.4 to 7.3 till 55th day after that day pH increased and in the *DIGESETR2* pH lies in 6.5 - 7.3 till 55th day after that day pH value increased. In the ending days the pH in *DIGESTER1* and *DIGESTER2* increased due to the digestion of volatile fatty acid and nitrogen compound through methanogenesis bacteria [24]. The pH was important due to the fact that Methanogenic microbes are sensitive in acidic condition. The favorable range of biogas production in anaerobic digestion is 6.5-7.5. So when pH below 6.3 and above 7.8 biogas production is less [22]. When pH is lies in 6.5- 7.2 the biogas production was more. This may be attributed to the increase in growth of methanogenesis bacteria, which are responsible for biogas production and their activity [23]. In *DIGESTER1* pH varies from 6.4 - 8.2 and *DIGESTER2* pH varies from 6.5 – 8.4. In the ending period pH value increased in *DIGESTER1* and *DIGESTER2* due to the digestion of volatile fatty acid and nitrogen compound through methanogenesis bacteria. In ending period biogas production rate was less in both digesters.

5.2.2 BOD and COD reduction

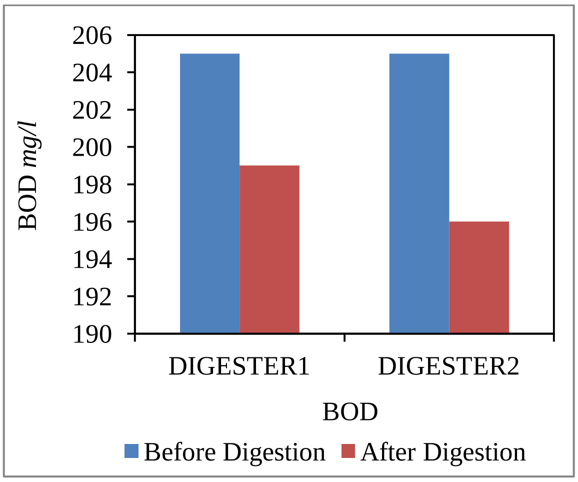


Figure 5.10: BOD Reduction

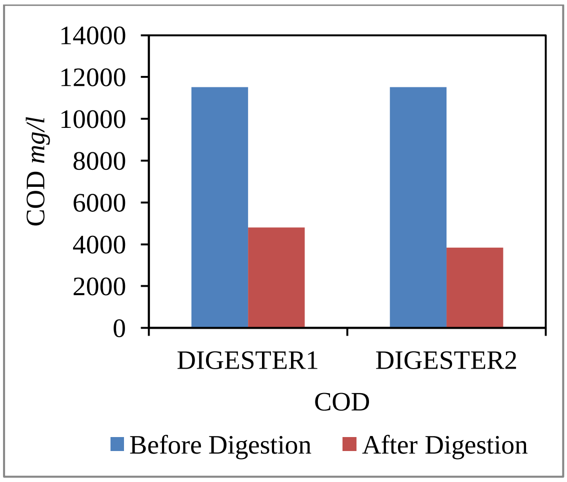


Figure 5.11: COD Reduction

Figure 5.10 shows the initial value of *BOD* was observed 205 in both digesters because in both the digesters same substrate was used and final value of *DIGESTER1* and *DIGESTER2* was observed 199 and 196 respectively. Figure 5.10 shows the comparison of *BOD* in both digesters. In the beginning *BOD* of both digesters are more but with the time *BOD* in both digesters was less. The BOD_5/COD ratio value before and after digestion varied from 0.01-

0.02 that's means the some quantity of complex biodegradable organic material present in both digesters.

Figure 5.11 shows the initial value of *COD* in both digesters was 11520 because in both the digesters same substrate was used. Final value of *COD* was observed as 4800 and 3840 in *DIGESTER1* and *DIGESTER2* respectively. Figure 5.11 shows that *COD* reduction in *DIGESTER1* and *DIGESTER2* was observed 58.3 and 66.6% respectively. The *COD* reduction in *DIGESTER1* was less as compare to *DIGESTER2*. The biogas production increased with increase in *COD* removal so in the *DIGESTER2* has more COD removed as compare to the *DIGESTER1*. The *COD* was used to measured the quantity of organic matter in waste and predict the potential for biogas generation. The *BOD* and *COD* will be reduced during anaerobic digestion process in a biogas system. During biological degradation of organic compound amount of *BOD* and *COD* will be decreased with time [20].

5.2.3 Total solid and volatile solid reduction

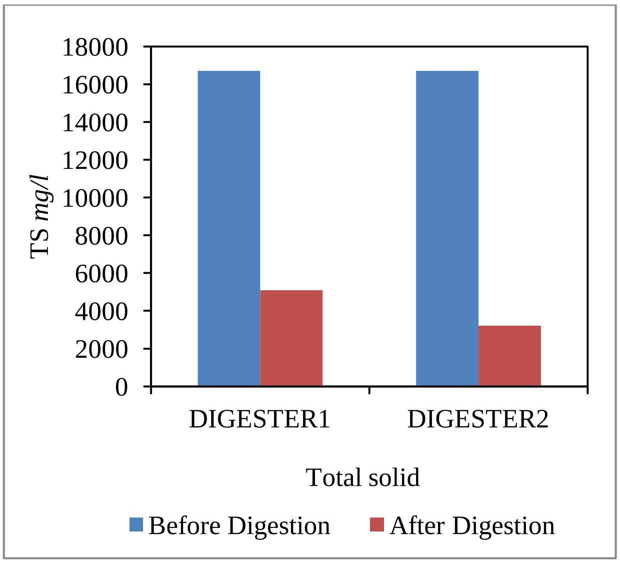


Figure 5.12: Total solid reduction

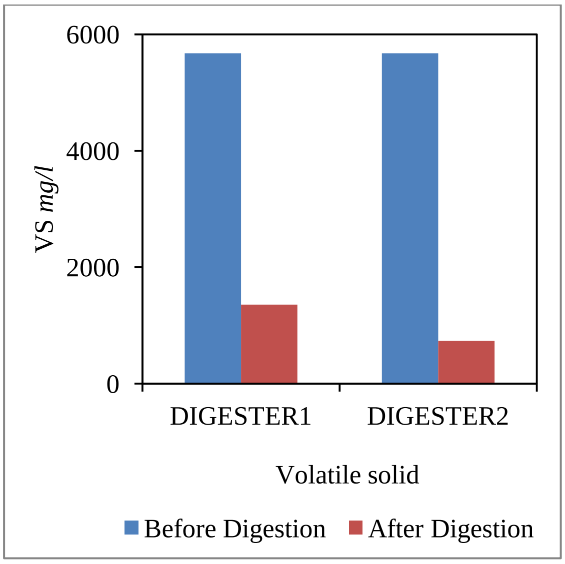


Figure 5.13: Volatile solid reduction

Total solid content in the starting was observed more but when the degradation start the total solid are decrease with time, because the organism utilize the total solid content as a food. In the batch operation no new food coming in the system so starting food are more but after some time food are utilized by the bacteria so food are less and the total solid content less in digested slurry. Figure 5.12 shows the total solid reduction in both digesters. In the starting total solid value was high but after digestion the total solid was less in both digesters.

The total solid percentage reduction in both digesters was observed as 69.4% and 80.7% respectively. In *DIGESTER1* total solid reduction was less as compare to *DIGESTER2* because the *DIGESTER2* was kept under the green house canopy and *DIGESTER1* was kept under the ambient temperature condition so the temperature was more under the green house canopy as compare to ambient temperature condition. The higher total solid reduction higher the biogas generation. In the *DIGESTER2* more total solid percentage reduction as compare to *DIGESTER1* that means more biogas production in *DIGESTER2.*

Figure 5.13 shows the volatile solid reduction in DIGESTER1 and DIGESTER2. The volatile solid reduction in *DIGESTER1* and *DIGESTER2* was 76% and 87.0% respectively. In the *DIGESTER1* volatile solid reduction was less as compare to *DIGESTER2* because the *DIGESTER2* was kept under the green house canopy so the temperature was more as compare ambient temperature. More *VS* reduction more will be the biogas generation [25].

5.2.4 Temperature

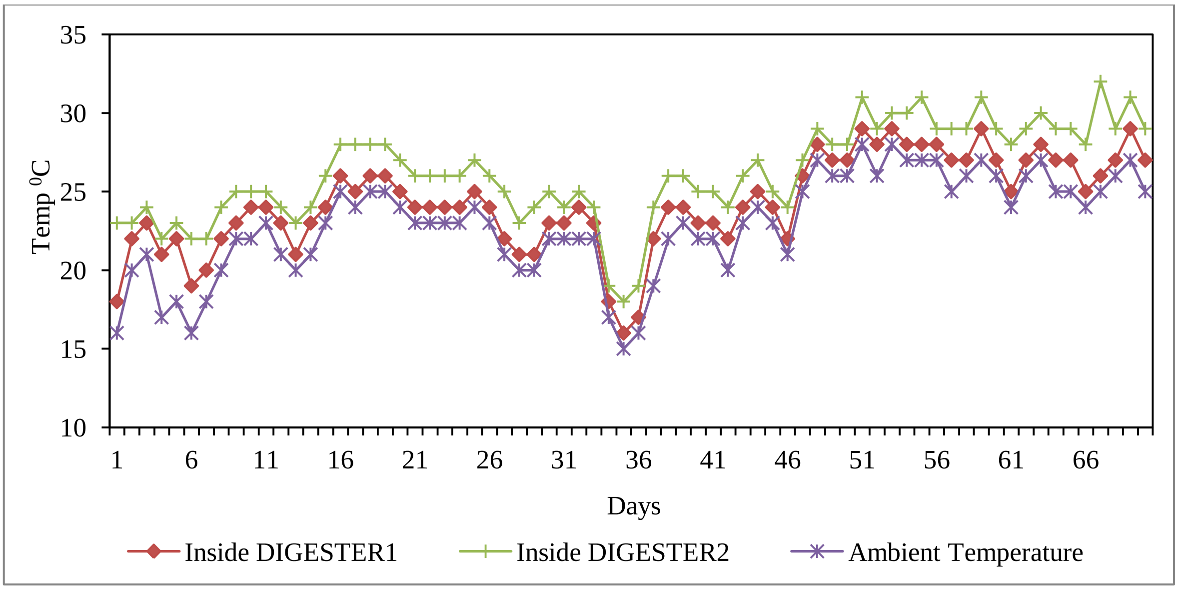


Figure 5.14: Variation of temperature in DIGESTER1 and DIGESTER2

The ambient temperature and slurry temperature inside the *DIGESTER1* and *DIGESTER2* was shown in Figs 5.14. The average ambient temperature range measured within the testing period was 15^{0}C - 28^{0}C and average slurry temperature inside the digester range varies from 16^{0}C - 29^{0}C in *DIGESTER1*. The ambient temperature was for both digesters were same. In *DIGESTER2* the temperature under the green house canopy was lies 18 ^{0}C - 29^{0}C and the slurry temperature inside the green house canopy digester was lies in range 18 ^{0}C - 32 ^{0}C. In both the digesters temperature varies from 15^0C -32^0C (mesophilic 20^0C-45^0C and Psychrophilic < 20^0C).

The temperature inside the digester was observed more than the temperature outside the both digesters. This proved the microbial degradation of the waste that raised the temperature of the waste slurry [26]. The inside temperature in *DIGESTER1* was less as compare to *DIGESTER2* because the *DIGESTER1* was kept under the ambient temperature condition and *DIGESTER2* was kept under the green house canopy so the temperature under the green house canopy was more as compare to ambient temperature condition. Temperature is a vital parameter for biogas production and generally at higher temperature the biodegradation process was high and thus the biogas yield was also more.

5.2.5 Cumulative Biogas production

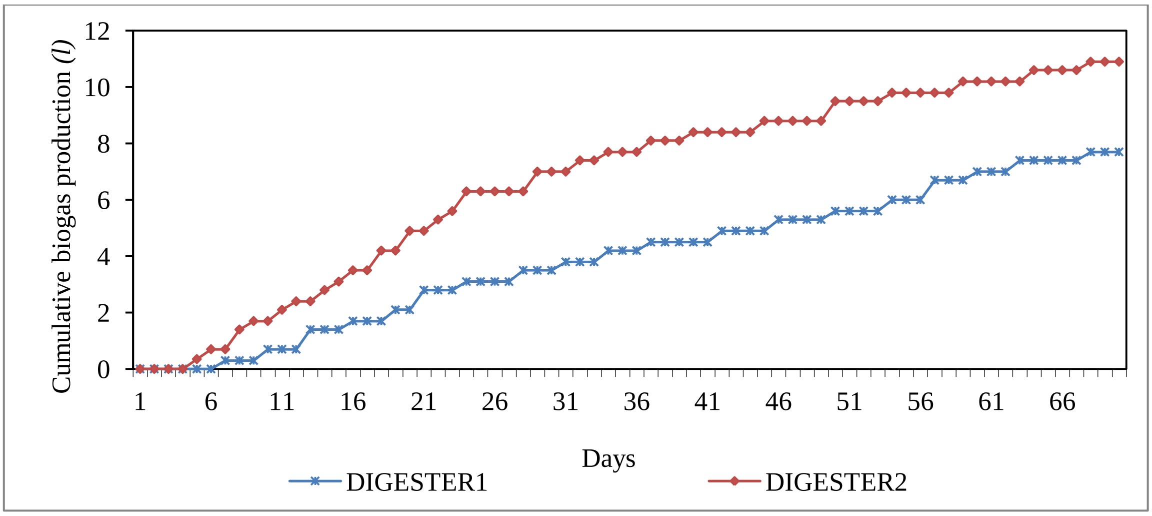


Figure 5.15: Cumulative biogas production

Figure 5.15 shows the comparison of cumulative biogas production in *DIGESTER1* and *DIGESTER2*. In the *DIGESTER1* biogas production was started from the 7th day but in the *DIGESTER2* biogas production start from the 5th day of the slurry feeding inside the fermentation bucket .The biogas production rate in *DIGESTER1* reached constant on 37th day to 41st day and *DIGESTER2* reached constant on 24th day to 28th day after this day the biogas production rate decreased. This decrement may be attributed to low methanogenesis activity [23]. In the starting and ending biogas production was low because bacteria was kept into new environment this was the lag phase of bacterial growth. In the batch operation it predicts that the biogas production is directly equal to the growth of Methanogenic organism [10]. The cumulative biogas production in *DIGESTER1* and *DIGESTER2* was 7.7 *l* and 10.9 *l*. The biogas production in *DIGESTER2* more as compare to *DIGESTER1* because the *DIGESTER2* kept under green house canopy and green house canopy increased the temperature and temperature plays vital role in the biogas production.

5.3 Comparison of biogas production or different parameters using pine needles as substrate under varying surrounding temperature conditions

Different types of parameter are measured in this experimental study such as: pH, Biological oxygen demand (*BOD)*, Chemical oxygen demand (*COD)*, Total solid (*TS*) and Volatile solid (*VS*).

5.3.1 pH

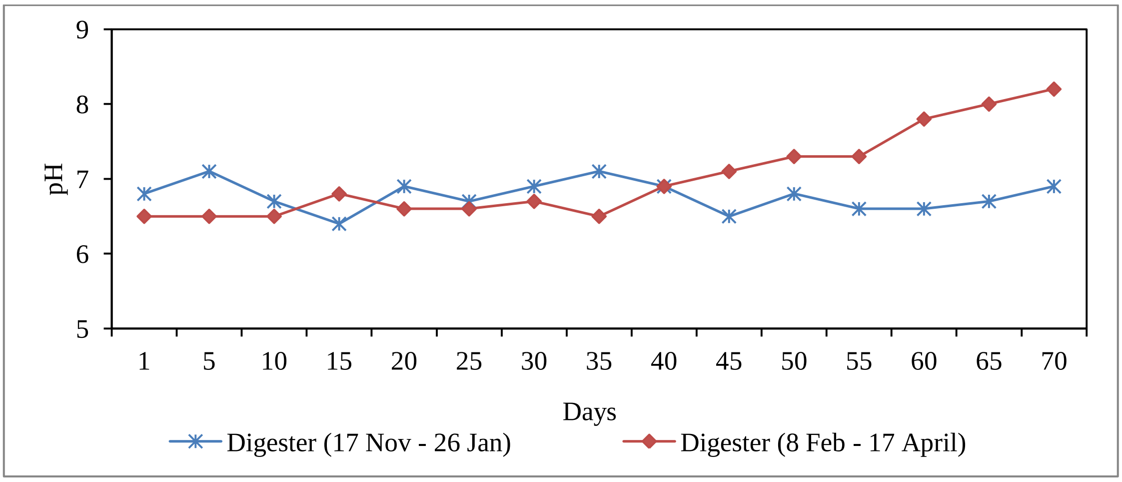


Figure 5.16: pH variation with time

In the Digester (17 Nov to 26 Jan) pH varies from 6.4-7.3 and in digester (8 Feb to 17 April) pH lies in the range of 6.4- 8.2. Figure 5.16 shows that the pH in digester (17 Nov to 26 Jan) increased for first 5 days and after 5th day pH was decreased. The pH in this study was unregulated means no acid or bases add to make the pH in neutral condition. In the ending days the pH in digester (17 Nov to 26 Jan) increased and digester (8 Feb to 17 April) pH lies in 6.4 to 7.3 till 55th day after that day pH was increased due to the digestion of volatile fatty acid and nitrogen compound through methanogenesis bacteria [24]. The pH was important due to the fact that Methanogenic microbes are sensitive in acidic condition. The favorable range of biogas production in anaerobic digestion is 6.5-7.5. So when pH below 6.3 and above 7.8 biogas production is less [22]. When pH is lies in 6.5- 7.2 the biogas production was more. This may be attributed to the increase in growth of methanogenesis bacteria, which are responsible for biogas production and their activity [23]. In digester (17 Nov to 26 Jan) pH varies from 6.4-7.3 and digester (8 Feb to 17 April) pH varies from 6.4-8.2. In this result observed that in the starting pH was low and the ending pH was increased because in starting decreased due to the acid formation in the hydrolysis phase and the ending increases due to the formation of volatile fatty acid and ammonia [24].

5.3.2 Total solid and volatile solid reduction

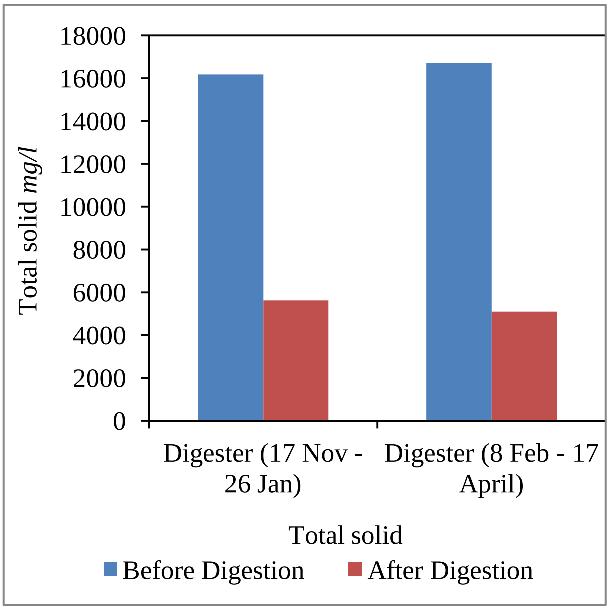


Figure 5.17: Total solid reduction

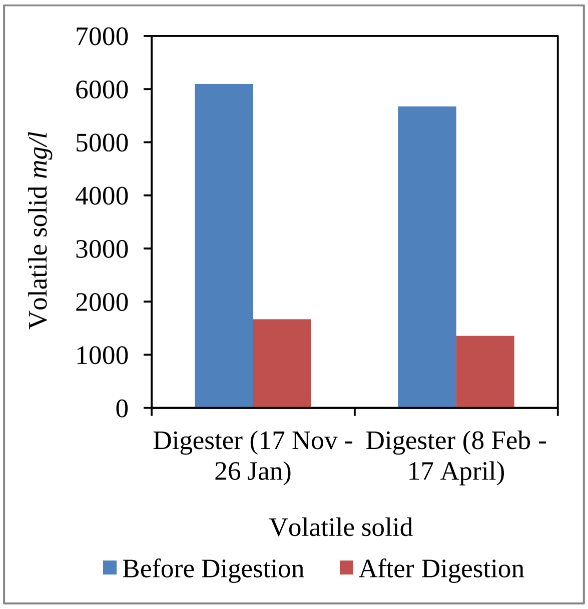


Figure 5.18: Volatile solid reduction

Total solid content in the starting are more but when the degradation start the total solid are decrease, because the organism utilize the total solid content as a food. In the batch system no new food coming in so starting food are more but after some time food are less and the total solid content less in digested slurry. In the starting total solid is high value but after digestion the total solid is less in both digesters.

Figure 5.17 shows the comparison of total solid in both digesters. The total solid percentage reduction in both digesters was observed 65.2% and 69.4% respectively. In the digester (17 Nov to 26 Jan) total solid reduction was less as compare to digester (8 Feb to 17 April) because the digester (17 Nov to 26 Jan) work under winter season so the temperature was quit less than digester (8 Feb to 17 April). The higher total solid reduction higher the biogas generation. In the digester (8 Feb to 17 April) more total solid percentage reduction as compare to digester (17 Nov to 26 Jan) that means more biogas production in digester (8 Feb to 17 April).

Figure 5.18 shows the volatile solid reduction in both digesters. The volatile reduction in both digesters was observed 72.61% and 76.7 % % respectively. More *VS* reduction more will be the biogas generation [25]. Figure 5.18 shows the volatile solid percentage reduction more the volatile solid reduction more will be the biogas production.

5.3.3 BOD and COD reduction

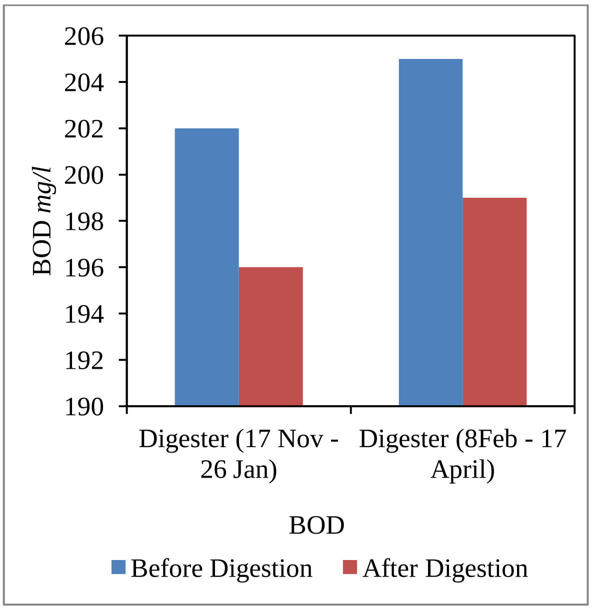


Figure 5.19: BOD reduction

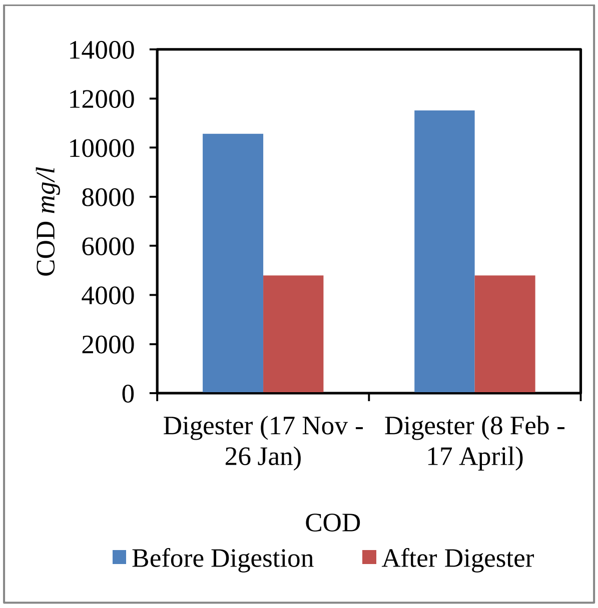


Figure 5.20: COD reduction

In Figure 5.19 the initial value of *BOD* was observed 202 and 205 respectively and the final value of digester (17Nov to 26 Jan) and digester (8 Feb to 17 April) was observed 196 and 199 respectively. Figure 5.19 shows the comparison of *BOD* in both digesters. The BOD_5/COD ratio value before and after digestion varied from 0.01-0.02 that's means the some quantity of complex biodegradable organic material present in both digesters.

Figure 5.20 shows the initial value of *COD* was observed 10560 and 11520 in digester (17 Nov to 26 Jan) and digester (8 Feb to 17 April) and the final value of *COD* was observed 4800 and 4800 respectively. Figure 5.20 shows that *COD* reduction in digester (17 Nov to 26 Jan) and digester (8 Feb to 17 April) 55% and 58.3% respectively. The *COD* reduction in digester (17 Nov to 26 Jan) was less as compare to digester (8 Feb to 17 April). The biogas production increased with increase in *COD* removal so in the digester (8 Feb to 17 April) has more *COD* removal as compare to the digester (17 Nov to 26 Jan). The *BOD* and *COD* will be decreased during anaerobic digestion process in a biogas system. During biological degradation of organic compound amount of *BOD* and *COD* will be decreased with time [20].

5.3.4 Temperature

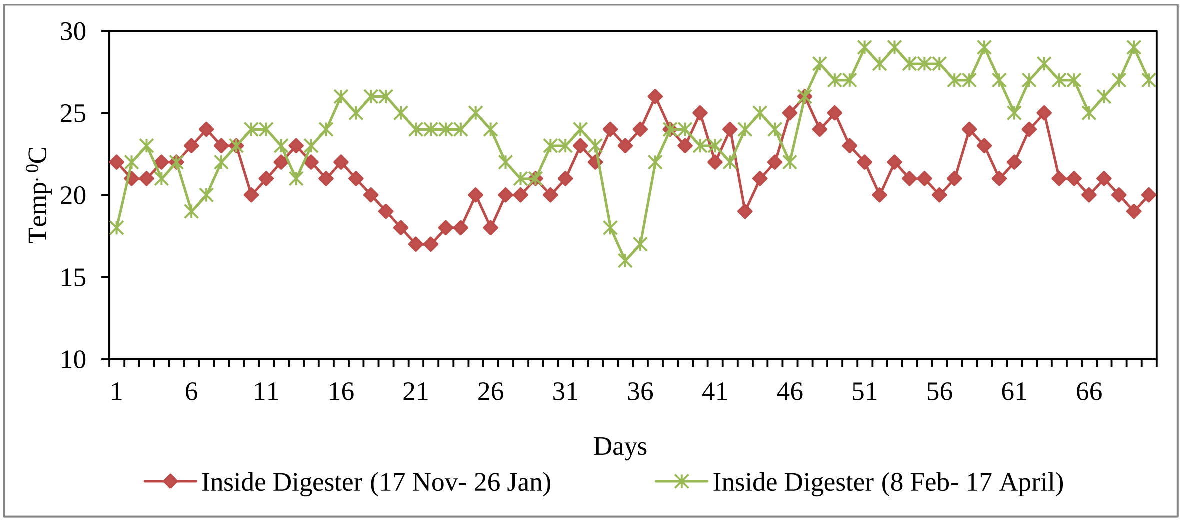


Figure 5.21: Variation of inside temperature in digesters

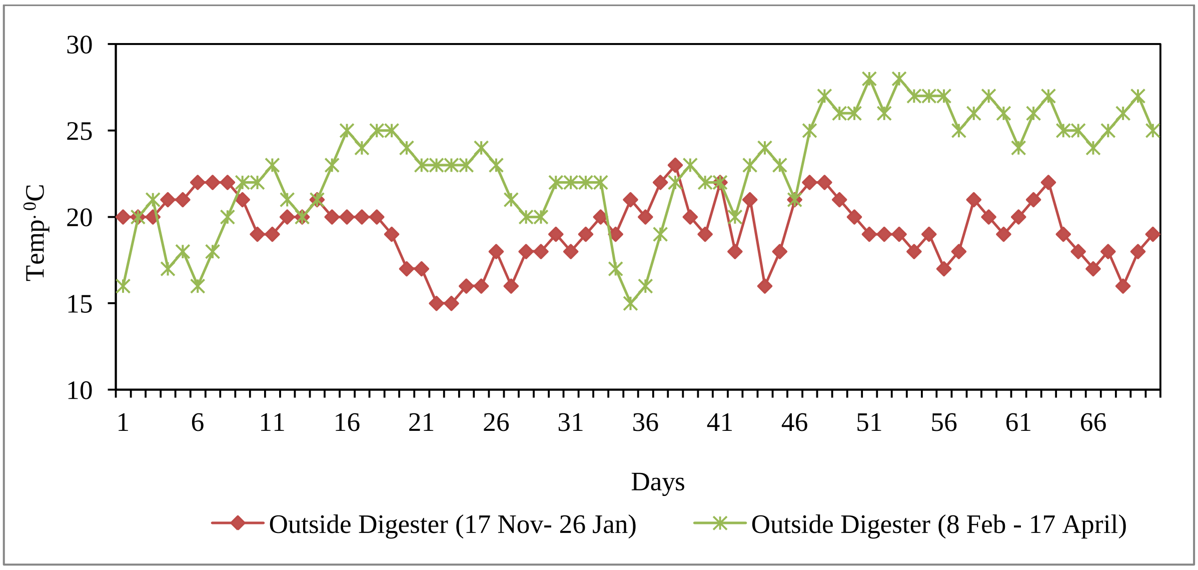


Figure 5.22: Variation of outside temperature in digesters

Ambient temperature and the slurry temperature inside the both digester was shown in Figs.5.21-5.22. The inside temperature range in digester (17 Nov to 26 Jan) measured within the testing period were 16^0C-26^0C and inside temperature range in digester (8 Feb to 17 April) was observed 16^0C to 30^0C. The inside temperature in the digester (8 Feb to 17 April) was observed more as compare to digester (17 Nov to 26 Jan) because the temperature from Nov to Jan was observed less as compare to Feb to April. From fig. 5.22 outside temperature in digester (17 Nov to 26 Jan) was observed range of 15^{0}C-23^{0}C and in digester (8 Feb to 17 April) temperature range varies from 15^{0}C to 28^{0}C. In both the digesters inside temperature and outside temperature varies from 15^{0}C-30^{0}C (mesophilic 20^{0}C-45^{0}C and Psychrophilic < 20^{0}C). The temperature plays a vital role in the biogas production more the temperature more will be the biogas production. In the low temperature biogas generation was observed low as compare to high temperature because in the winter season temperature was low so the biogas production was low.

5.3.5 Cumulative Biogas Production

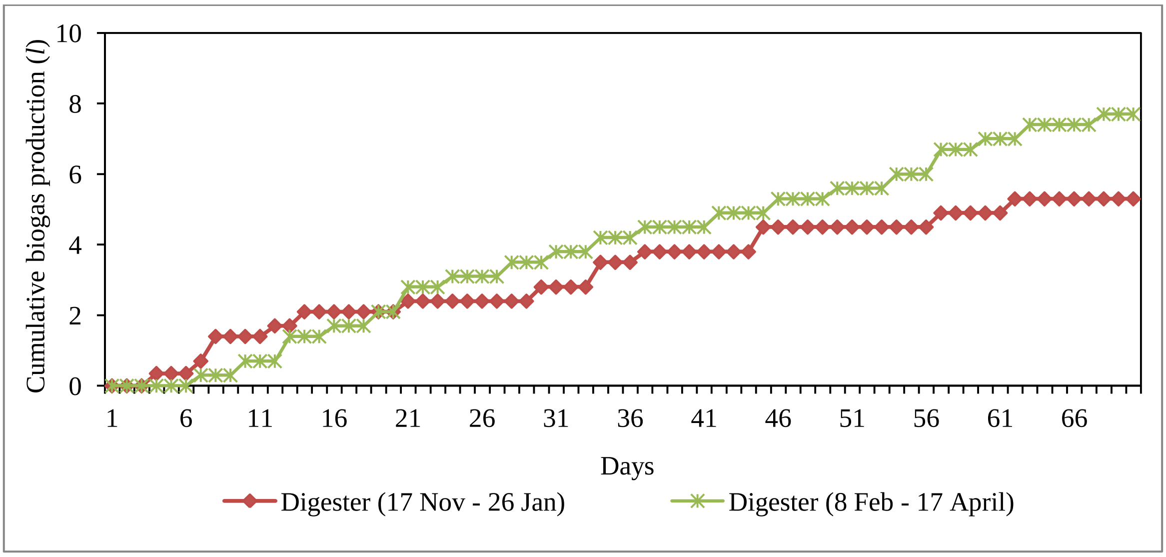


Figure 5.23: Cumulative biogas production

Figure 5.23 has shows the comparison of cumulative biogas production in digester (17 Nov to 26 Jan) and digester (8 Feb to 177 April). In the digester (17 Nov to 26 Jan) biogas production was started from the 3rd day but in the digester (8 Feb to 177 April) biogas production start from the 7th day of the slurry feeding inside the fermentation bucket. The biogas production rate in digester (17 Nov to 26 Jan) was reached constant on 45th day to 56th day and in the digester (8 Feb to 17 April) the biogas production rate was reached constant on 37th day to 41st day after this day the biogas production rate decreased in both the digesters. This decrement may be attributed to low methanogenesis activity [23]. In the starting and ending biogas production is less because bacteria put into new environment this is the lag phase of bacterial growth In the batch operation it predicts that the biogas production is directly equal to the growth of Methanogenic organism [10]. The cumulative biogas production in digester (17 Nov to 26 Jan) and digester (8 Feb to 17 April) was observed 5.3 and 7.7*l*. The biogas production in digester (8 Feb to 17 April) more as compare to the digester (17 Nov to 26 Jan) because in the digester (8 Feb to 17 April) was observed more temperature in the Feb. to April as compare to Nov. to Jan. testing period so temperature plays a vital role in the biogas production thus more the temperature more the biogas production.

CHAPTER 6
CONCLUSIONS

Present study has been conducted to check the suitability and potential of the pine needles as substrate in biogas production under batch digester. Keeping in mind the broad objectives; two series of experiments were conducted. In the first series experiments were conducted for better understanding of comparison of biogas production using two different substrates cow dung and pine needles. The second series of experiments was conducted for better understanding of biogas production under green house canopy and ambient temperature conditions and in the last done the comparison of biogas production using pine needles as substrate for varying ambient temperature conditions.

The following general conclusions can be drawn based on this study:

- The temperature plays a vital role in biogas production. More the temperature more will be the biogas production and when temperature was low, so the biogas production was low or may be stopped so temperature plays a vital role in the biogas production. In winter season biogas production was low as compare to summer season so in this study use green house canopy for increase the biogas production in winter season because green house canopy increase the temperature inside the digester.

6.1. Comparison of biogas production or different parameters using substrates cow dung and pine needles under similar ambient temperature conditions.

(a) The value of pH in *DIGESTER 1* varied from 7.2- 8.1 while in *DIGESTER2* from 6.4-7.3.In *DIGESTER2* pH lies in optimal range for biogas production but in the *DIGESTER1* pH lies out of the optimum range of pH for biogas production so in the *DIGESTER2* more biogas production as compare to *DIGESTER1*.

(b) The surrounding temperature variation in *DIGESTER1* and *DIGESTER2* the measured during the testing period were 15^0C-23^0C and slurry temperature inside the digester range 17^0C-26^0C. In both the digesters temperature varies from 17^0C-25^0C (mesophilic 20^0C-45^0C and Psychrophilic > 20^0C).The temperature plays a vital role in the biogas production.

(c) The total reduction in *COD* values in *DIGESTER1* and *DIGESTER2* was 30% and 55% respectively. More the *COD* reduction more will be the biogas production. The *COD* and BOD value higher in starting but within the time *BOD* and *COD* value decreased.

(d) The total solid reduction in *DIGESTER1* and *DIGESTER2* was 37.05% and 65.2% and volatile solid reduction in *DIGESTER1* and *DIGESTER2* was 31.93% and 72.61% respectively. More the total and volatile solid reduction more will be the biogas production.

(e) The cumulative biogas generation observed more in *DIGESTER2* when compare with DIGESTER1. The total cumulative biogas generation in *DIGESTER1* and *DIGESTER2* was 2.4 *l* and 5.3 *l* respectively. In the pine needles has high cellulose content that's good for biogas production and in *DIGESTER2* pH range lies in optimum biogas production.

6.2. Comparison of biogas production or different parameters using pine needles as substrate under green house canopy and ambient temperature conditions.

(a) The value of pH in *DIGESTER1* varied from 6.4- 8.2 while in *DIGESTER2* varies from 6.5- 8.4. The value of pH lies in optimal range of biogas production in both the digester but in the ending period pH increased so the biogas production rate decreased in both the digester.

(b)The surrounding temperature range measured during the testing period were *DIGESTER1* varied from 15^0C- 28^0C and slurry temperature inside the digester was 16^0C – 29^0C while in the *DIGESTER2* inside temperature under the green house canopy was 18^0C – 29^0C and the slurry temperature inside the digester was 18^0C – 32^0C. In the *DIGESTER2* temperature was more as compare to *DIGESTER1* because *DIGESTER2* was kept under the green house canopy so temperature was more in *DIGESTER2*.

(c) The total reduction in COD value in *DIGESTER1* and *DIGESTER2* was 58.3% and 66.6 % respectively. More the *COD* reduction more will be the biogas production. The

COD and *BOD* value higher in starting but within the time *BOD* and *COD* value decreased.

(d)The total solid reduction in *DIGESTER1* and *DIGESTER2* were 69.4 and 80.7 % while in *DIGESTER1* and *DIGESTER 2* volatile solid reductions were 76% and 87% respectively. In starting the total solid and volatile solid are more but within the time the total solid and volatile solid decreased. More the total and volatile solid reduction more will be the biogas production.

(e) The cumulative biogas production in *DIGESTER2* was observed more when compare with *DIGESTER1*. The value of biogas production in DIGESTER1 and DIGESTER2 was 7.7 *l* and 10.9 *l* respectively. The temperature plays vital role in biogas production. When digester was put under the green house canopy the biogas production was more as compare to ambient temperature condition because under the green house canopy temperature was more as compare to ambient temperature condition.

6.3. Comparison of biogas production or different parameters using pine needles as substrate for varying surrounding temperature conditions.

(a) The value of pH varies in both digester was 6.4- 7.3 and 6.4- 8.2 respectively. In the starting pH value was low but the ending period pH value was high so in the ending biogas production rate decreased in both the digester.

(b) The temperature in the winter season temperature were lies in the range of 17^0C – 25^0C and the starting of summer season temperature were lies in the range of 18^0C – 30^0C. The temperature plays a vital role in the biogas production. In the winter season temperature was low as compare to starting of summer season so biogas production increased in summer season.

(c) The total reduction in *COD* value in both digester was 55% and 58.3% respectively. More the *COD* reduction more will be the biogas production. The COD and BOD value higher in starting but within the time *BOD* and *COD* value decreased.

(d) The total solid reduction in both digesters was 65.2% and 80.7% and volatile solid reduction was 72.61% and 76%respectively. More the total and volatile solid reduction more will be the biogas production.

(e) The cumulative biogas production in both digesters was 5.3 *l* and 7.7 *l* respectively. When done the comparison of winter and starting of summer season in the ambient temperature condition the biogas production was more in starting of summer season as compare to winter season so temperature plays an important role in the biogas production.

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APPENDIX – A

A.1 Cumulative Volume of Biogas Produced in DIGESTER1 and DIGESTER 2 Gas Holders at Different Days

Date	Rise in gas holder (m)		Volume of Biogas (m^3)		Total cumulative biogas produced in DIGESTER1 (m^3)	Total cumulative biogas produced in DIGESTER2 (m^3)
	DIGESTER 1	DIGESTER2	DIGESTER 1	DIGESTER 2		
17-11-2015	-	-	-	-	-	-
18-11-2015	-	-	-	-	-	-
19-11-2015	-	-	-	-	-	-
20-11-2015	-	0.005	-	0.0003534	-	0.0003534
21-11-2015	-	-	-	-	-	0.0003534
22-11-2015	-	-	-	-	-	0.0003534
23-11-2015	-	0.005	-	0.0003534	-	0.0007068
24-11-2015	-	0.01	-	0.0007068	-	0.0014136584
25-11-2015	-	-	-	-	-	0.0014136584
26-11-2015	-	-	-	-	-	0.0014136584
27-11-2015	-	-	-	-	-	0.0014136584
28-11-2015	-	0.005	-	0.0003534	-	0.0017670584
29-11-2015	-	-	-	-	-	0.0017670584
30-11-2015	-	0.005	-	0.0003534	-	0.0021204584
01-12-2015	-	-	-	-	-	0.0021204584
02-12-2015	-	-	-	-	-	0.0021204584
03-12-2015	-	-	-	-	-	0.0021204584
04-12-2015	-	-	-	-	-	0.0021204584
05-12-2015	-	-	-	-	-	0.0021204584
07-12-2015	-	-	-	-	-	0.0021204584
08-12-2015	-	0.005	-	0.0003534	-	0.0024738584
9-12-2015	-	-	-	-	-	0.0024738584
10-12-2015	-	-	-	-	-	0.0024738584
11-12-2015	-	-	-	-	-	0.0024738584
12-12-2015	-	-	-	-	-	0.0024738584
13-12-2015	-	-	-	-	-	0.0024738584
14-12-2015	-	-	-	-	-	0.0024738584
15-12-2015	-	-	-	-	-	0.0024738584
16-12-2015	-	-	-	-	-	0.0024738584
17-12-2015	-	0.005	-	0.0003534	-	0.0028272584

18-12-2015	-	-	-	-	-	0.0028272584
19-12-2015	-	-	-	-	-	0.0028272584
20-12-2015	-	-	-	-	-	0.0028272584
21-12-2015	-	0.01	-	0.0007068	-	0.0035340584
22-12-2015	-	-	-	-	-	0.0035340584
23-12-2015	-	-	-	-	-	0.0035340584
24-12-2015	-	0.005	-	0.0003534	-	0.0038874584
25-12-2015	-	-	-	-	-	0.0038874584
26-12-2015	-	-	-	-	-	0.0038874584
27-12-2015	-	-	-	-	-	0.0038874584
28-12-2015	0.005	-	0.0003534	-	0.0003534	0.0038874584
29-12-2015	-	-	-	-	0.0003534	0.0038874584
30-12-2015	-	-	-	-	0.0003534	0.0038874584
31-12-2015	-	-	-	-	0.0003534	0.0038874584
01-1-2016	-	0.01	-	0.0007068	0.0003534	0.0045942584
02-1-2016	0.005	-	0.0003534	-	0.0007068	0.0045942584
03-1-2016	-	-	-	-	0.0007068	0.0045942584
04-1-2016	-	-	-	-	0.0007068	0.0045942584
05-1-2016	-	-	-	-	0.0007068	0.0045942584
06-1-2016	-	-	-	-	0.0007068	0.0045942584
07-1-2016	0.01	-	0.0007068	-	0.0014136584	0.0045942584
08-1-2016	-	-	-	-	0.0014136584	0.0045942584
09-1-2016	-	-	-	-	0.0014136584	0.0045942584
10-1-2016	-	-	-	-	0.0014136584	0.0045942584
11-1-2016	-	-	-	-	0.0014136584	0.0045942584
12-1-2016	-	-	-	-	0.0014136584	0.0045942584
13-1-2016	-	0.005	-	0.0003534	0.0014136584	0.0049476584
14-1-2016	0.005	-	0.0003534	-	0.0017670584	0.0049476584
15-1-2016	-			-	0.0017670584	0.0049476584
16-1-2016	-			-	0.0017670584	0.0049476584
17-1-2016	-			-	0.0017670584	0.0049476584
18-1-2016	0.005	0.005	0.0003534	0.0003534	0.0021204584	0.0053010584
19-1-2016	-	-	-	-	0.0021204584	0.0053010584
20-1-2016	-	-	-	-	0.0021204584	0.0053010584
21-1-2016	-	-	-	-	0.0021204584	0.0053010584
22-1-2016	0.005	-	0.0003534	-	0.0024738584	0.0053010584
23-1-2016	-	-	-	-	0.0024738584	0.0053010584
24-1-2016	-	-	-	-	0.0024738584	0.0053010584
25-1-2016	-	-	-	-	0.0024738584	0.0053010584
26-1-2016	-	-	-	-	0.0024738584	0.0053010584

A.2 Variation of pH in DIGESTER 1 and DIGESTER 2 with time

S.No.	Parameter pH	DIGESTER 1	DIGESTER 2
1	1st Day	7.9	6.8
2	5th Day	7.8	7.1
3	10th Day	7.4	6.7
4	15th Day	7.2	6.4
5	20th Day	7.8	6.9
6	25th Day	7.5	6.7
7	30th Day	7.7	6.9
8	35th Day	7.5	7.1
9	40th Day	7.3	6.9
10	45th Day	7.3	6.5
11	50th Day	7.1	6.8
12	55th Day	7.3	6.6
13	60th Day	7.5	6.6
14	65th Day	7.8	6.7
15	70th day	8.1	6.9

A.3 Variation of Temperature in DIGESTER 1

Date	**Morning**		**Afternoon**		**Evening**	
	Inside digester ^0C	Outside digester ^0C	Inside digester ^0C	Outside digester ^0C	Inside digester ^0C	Outside digester ^0C
18-11-2015	20	19	24	22	23	20
19-11-2015	20	18	23	22	22	19
20-11-2015	19	19	23	21	21	20
21-11-2015	21	19	23	22	21	21
22-11-2015	20	20	24	23	21	20
23-11-2015	23	21	24	23	21	21
24-11-2015	24	22	25	25	22	21
25-11-2015	23	22	25	24	22	20
26-11-2015	24	21	23	22	21	19
27-11-2015	20	18	21	20	20	19
28-11-2015	22	20	21	19	19	18
30-11-2015	22	20	24	21	20	18
01-12-2015	23	20	25	21	20	19
02-12-2015	22	20	25	23	20	19
03-12-2015	20	19	23	21	21	20

04-12-2015	21	19	24	22	22	20
05-12-2015	20	19	23	21	21	20
07-12-2015	21	20	23	21	21	20
08-12-2015	20	18	21	19	20	19
09-12-2015	19	17	20	18	18	16
10-12-2015	18	16	19	18	18	16
11-12-2015	16	14	17	15	17	16
12-12-2015	16	14	17	15	17	15
13-12-2015	17	16	19	17	18	16
14-12-2015	17	16	19	17	18	16
15-12-2015	21	19	22	20	18	16
16-12-2015	18	16	20	18	16	14
17-12-2015	20	18	22	20	18	16
18-12-2015	18	16	23	21	18	16
19-12-2015	19	17	24	22	20	18
20-12-2015	18	16	23	21	20	18
21-12-2015	20	18	24	22	18	16
22-12-2015	20	18	23	21	21	19
23-12-2015	20	20	24	23	22	21
24-12-2015	21	19	24	22	23	21
25-12-2015	22	21	24	24	22	21
26-12-2015	22	21	25	24	24	23
27-12-2015	22	19	25	23	23	21
28-12-2015	20	18	24	22	23	20
29-12-2015	20	20	24	23	23	23
30-12-2015	20	17	24	21	21	20
31-12-2015	20	20	24	23	22	22
01-1-2016	18	16	19	17	19	16
02-1-2016	19	18	22	20	19	18
03-1-2016	20	19	23	22	19	20
04-1-2016	21	20	24	23	23	22
05-1-2016	22	21	26	24	24	22
06-1-2016	22	21	25	24	24	22
07-1-2016	21	20	25	23	22	21
08-1-2016	20	19	24	21	22	20
09-1-2016	20	19	23	21	21	20
10-1-2016	18	16	21	20	20	19
11-1-2016	20	18	22	21	21	20
12-1-2016	18	17	23	21	20	20
13-1-2016	20	18	22	20	21	19
14-1-2016	18	16	22	20	21	19

15-1-2016	18	17	23	21	21	20
16-1-2016	20	20	24	22	2	21
17-1-2016	20	18	23	23	22	21
18-1-2016	20	17	23	21	20	20
19-1-2016	20	19	24	22	21	21
20-1-2016	20	20	25	23	23	22
21-1-2016	22	20	25	23	23	22
22-1-2016	20	18	22	21	21	20
23-1-2016	18	18	23	21	21	20
24-1-2016	17	16	22	20	20	19
25-1-2016	19	19	23	21	21	18
26-1-2016	16	16	21	20	18	17

A.4 Variation of Temperature in DIGESTER 2

Date	Morning		Afternoon		Evening	
	Inside Digester ^0C	Outside digester ^0C	Inside digester ^0C	Outside digester ^0C	Inside digester ^0C	Outside digester ^0C
18-11-2015	19	19	23	22	22	20
19-11-2015	19	18	22	22	21	19
20-11-2015	19	19	23	21	21	20
21-11-2015	20	19	23	22	22	21
22-11-2015	20	20	24	23	21	20
23-11-2015	23	21	25	23	22	21
24-11-2015	24	22	25	25	21	21
25-11-2015	23	22	25	24	22	20
26-11-2015	24	21	23	22	21	19
27-11-2015	20	18	21	20	20	19
28-11-2015	22	20	21	19	19	18
30-11-2015	23	20	24	21	20	18
01-12-2015	23	20	25	21	20	19
02-12-2015	22	20	25	23	20	19
03-12-2015	20	19	23	21	21	20
04-12-2015	21	19	24	22	22	20
05-12-2015	20	19	23	21	21	20
07-12-2015	21	20	23	21	21	20
08-12-2015	20	18	21	19	20	19
09-12-2015	19	17	20	18	20	16
10-12-2015	18	16	19	18	18	16
11-12-2015	16	14	17	15	17	15
12-12-2015	16	14	17	15	17	15

13-12-2015	17	16	19	17	18	16
14-12-2015	17	16	19	17	18	16
15-12-2015	21	19	22	20	18	16
16-12-2015	18	16	20	18	16	14
17-12-2015	20	18	22	20	18	16
18-12-2015	18	16	23	21	18	16
19-12-2015	19	17	24	22	20	18
20-12-2015	18	16	23	21	20	18
21-12-2015	20	18	24	22	18	16
22-12-2015	20	18	24	21	22	19
23-12-2015	23	20	25	23	24	21
24-12-2015	22	19	24	22	23	21
25-12-2015	23	21	26	24	25	21
26-12-2015	23	21	27	24	25	23
27-12-2015	22	19	25	23	23	21
28-12-2015	21	18	25	22	23	20
29-12-2015	22	20	25	23	24	23
30-12-2015	20	17	24	21	22	20
31-12-2015	21	20	25	23	24	22
01-1-2016	18	16	20	17	19	16
02-1-2016	20	18	23	20	20	18
03-1-2016	21	19	24	22	22	20
04-1-2016	22	20	25	23	23	21
05-1-2016	23	21	26	24	24	22
07-1-2016	22	20	25	23	23	21
08-1-2016	21	19	23	21	22	20
09-1-2016	21	19	23	21	21	20
10-1-2016	18	16	22	20	20	19
11-1-2016	20	18	23	21	22	20
12-1-2016	19	17	23	21	21	20
13-1-2016	20	18	22	20	21	19
14-1-2016	18	16	22	20	20	19
15-1-2016	19	17	23	21	22	20
16-1-2016	21	20	24	22	23	21
17-1-2016	20	18	24	23	22	21
18-1-2016	19	17	23	21	21	20
19-1-2016	20	19	24	22	22	21
20-1-2016	21	20	25	23	24	22
21-1-2016	22	20	26	23	24	22
22-1-2016	20	18	23	21	22	20
23-1-2016	19	18	24	21	22	20
24-1-2016	18	16	22	20	20	19
25-1-2016	20	19	23	21	20	18
26-1-2016	18	16	23	20	19	17

APPENDIX – B

B.1Cumulative Volume of Biogas produced in DIGESTER1 and DIGESTER 2 Gas Holders at Different Days

Date	Rise in gas holder (m)		Volume of Biogas (m^3)		Total cumulative biogas produced in DIGESTER1 (m^3)	Total cumulative biogas produced in DIGESTER2 (m^3)
	DIGESTER 1	DIGESTER 2	DIGESTER 1	DIGESTER 2		
08-2-2016	-	-	-	-	-	-
09-2-2016	-	-	-	-	-	-
10-2-2016	-	-	-	-	-	-
11-2-2016	-	-	-	-	-	-
12-2-2016	-	0.005	-	0.0003534	-	0.0003534
13-2-2016	-	0.005	-	0.0003534	-	0.0007068
14-2-2016	0.005	-	0.0003534	-	0.0003534	0.0007068
15-2-2016	-	0.01	-	0.0007068	0.0003534	0.0014136
16-2-2016	-	0.005	-	0.0003534	0.0003534	0.001767
17-2-2016	0.005	-	0.0003534	-	0.0007068	0.001767
18-2-2016	-	0.005	-	0.0003534	0.0007068	0.0021204
19-2-2016	-	0.005	-	0.0003534	0.0007068	0.0024738
20-2-2016	0.01	-	0.0007068	-	0.0014136	0.0024738
21-2-2016	-	0.005	-	0.0003534	0.0014136	0.0028272
22-2-2016	-	0.005	-	0.0003534	0.0014136	0.0031806
23-2-2016	0.005	0.005	0.0003534	0.0003534	0.001767	0.003534
24-2-2016	-	-	-	-	0.001767	0.003534
25-2-2016	-	0.01	-	0.0007068	0.001767	0.0042408
26-2-2016	0.005	-	0.0003534	-	0.0021204	0.0042408
27-2-2016	-	0.01	-	0.0007068	0.0021204	0.0049476
28-2-2016	0.01	-	0.0007068	-	0.0028272	0.0049476
29-2-2016	-	0.005	-	0.0003534	0.0028272	0.005301
01-3-2016	-	0.005	-	0.0003534	0.0028272	0.0056544
02-3-2016	0.005	0.005	0.0003534	0.0003534	0.0031806	0.0063612
03-3-2016	-	-	-	-	0.0031806	0.0063612
04-3-2016	-	-	-	-	0.0031806	0.0063612
05-3-2016	-	-	-	-	0.0031806	0.0063612
06-3-2016	0.005	-	0.0003534	-	0.003534	0.0063612
07-3-2016	-	0.01	-	0.0007068	0.003534	0.007068
08-3-2016	-	-	-	-	0.003534	0.007068
09-3-2016	0.005	-	0.0003534	-	0.0038874	0.007068

10-3-2016	-	0.005	-	0.0003534	0.0038874	0.0074214
11-3-2016	-	-	-	-	0.0038874	0.0074214
12-3-2016	0.005	0.005	0.0003534	0.0003534	0.0042408	0.0077748
13-3-2016	-	-	-	-	0.0042408	0.0077748
14-3-2016	-	-	-	-	0.0042408	0.0077748
15-3-2016	0.005	0.005	0.0003534	0.0003534	0.0045942	0.0081282
16-3-2016	-	-	-	-	0.0045942	0.0081282
17-3-2016	-	-	-	-	0.0045942	0.0081282
18-3-2016	-	0.005	-	0.0003534	0.0045942	0.0084816
19-3-2016	-	-	-	-	0.0045942	0.0084816
20-3-2016	0.005	-	0.0003534	-	0.0049476	0.0084816
21-3-2016	-	-	-	-	0.0049476	0.0084816
22-3-2016	-	-	-	-	0.0049476	0.0084816
23-3-2016	-	0.005	-	0.0003534	0.0049476	0.008835
24-3-2016	0.005	-	0.0003534	-	0.005301	0.008835
25-3-2016	-	-	-	-	0.005301	0.008835
26-3-2016	-	-	-	-	0.005301	0.008835
27-3-2016	-	-	-	-	0.005301	0.008835
28-3-2016	0.005	0.01	0.0003534	0.0007068	0.0056544	0.0095418
29-3-2016	-	-	-	-	0.0056544	0.0095418
30-3-2016	-	-	-		0.0056544	0.0095418
31-3-2016	-	-	-	-	0.0056544	0.0095418
01-4-2016	0.005	0.005	0.0003534	0.0003534	0.0060078	0.0098952
02-4-2016	-	-	-	-	0.0060078	0.0098952
03-4-2016	-	-		-	0.0060078	0.0098952
04-4-2016	0.01	-	0.007068	-	0.0067146	0.0098952
05-4-2016	-	-	-	-	0.0067146	0.0098952
06-4-2016	-	0.005	-	0.0003534	0.0067146	0.0102486
07-4-2016	0.005	-	0.0003534	-	0.007068	0.0102486
08-4-2016	-	-	-	-	0.007068	0.0102486
09-4-2016	-	-	-	-	0.007068	0.0102486
10-4-2016	0.005	-	0.0003534	-	0.0074214	0.0102486
11-4-2016	-	0.005	-	0.0003534	0.0074214	0.010602
12-4-2016	-	-	-	-	0.0074214	0.010602
13-4-2016	-	-	-	-	0.0074214	0.010602
14-4-2016	-	-	-	-	0.0074214	0.010602
15-4-2016	0.005	0.005	0.0003534	0.0003534	0.0077748	0.0109554
16-4-2016	-	-	-	-	0.0077748	0.0109554
17-4-2016	-	-	-	-	0.0077748	0.0109554

B.2 Variation of pH in DIGESTER 1 and DIGESTER 2 with time

Date	Parameter pH	DIGESTER 1	DIGESTER 2
08-2-2016	1st day	6.5	6.5
09-2-2016	2nd day	6.5	6.5
10-2-2016	3rd day	6.6	6.6
11-2-2016	4th day	6.6	6.7
12-2-2016	5th day	6.5	6.7
13-2-2016	6th day	6.6	6.8
14-2-2016	7th day	6.7	6.7
15-2-2016	8th day	6.5	6.6
16-2-2016	9th day	6.4	6.5
17-2-2016	10th day	6.4	6.5
18-2-2016	11th day	6.5	6.6
19-2-2016	12th day	6.6	6.8
20-2-2016	13th day	6.8	6.9
21-2-2016	14th day	6.6	6.8
22-2-2016	15th day	6.9	7.0
23-2-2016	16th day	7.0	7.1
24-2-2016	17th day	6.9	7.0
25-2-2016	18th day	6.9	7.0
26-2-2016	19th day	6.8	6.9
27-2-2016	20th day	6.6	6.8
28-2-2016	21st day	6.5	6.7
29-2-2016	22nd day	6.6	6.9
01-3-2016	23rd day	6.5	6.8
02-3-2016	24th day	6.5	6.7
03-3-2016	25th day	6.6	6.8
04-3-2016	26th day	6.9	7.0
05-3-2016	27th day	6.9	7.1
06-3-2016	28th day	6.8	7.0
07-3-2016	29th day	6.7	6.9
08-3-2016	30th day	6.7	6.9
09-3-2016	31st day	6.6	6.8
10-3-2016	32nd day	6.9	7.0
11-3-2016	33th day	6.7	6.9
12-3-2016	34th day	6.6	6.7
13-3-2016	35th day	6.5	6.6
14-3-2016	36th day	6.4	6.5
15-3-2016	37th day	6.5	6.8
16-3-2016	38th day	6.6	6.9

17-3-2016	39th day	6.6	6.8
18-3-2016	40th day	6.9	6.9
19-3-2016	41st day	7.0	7.0
20-3-2016	42th day	7.0	7.1
21-3-2016	43rd day	6.9	6.9
22-3-2016	44th day	7.0	7.1
23-3-2016	45th day	7.1	7.0
24-3-2016	46th day	7.2	7.2
25-3-2016	47th day	7.1	7.1
26-3-2016	48th day	7.2	7.1
27-3-2016	49th day	7.4	7.3
28-3-2016	50th day	7.3	7.2
29-3-2016	51st day	7.2	6.9
30-3-2016	52nd day	7.3	7.1
31-3-2016	53rd day	7.2	7.2
01-4-2016	54th day	7.4	7.3
02-4-2016	55th day	7.3	7.3
03-4-2016	56th day	7.4	7.5
04-4-2016	57th day	7.5	7.5
05-4-2016	58th day	7.6	7.7
06-4-2016	59th day	7.7	7.8
07-4-2016	60th day	7.8	7.8
08-4-2016	61st day	7.8	7.9
09-4-2016	62nd day	7.9	8.0
10-4-2016	63rd day	7.9	8.1
11-4-2016	64th day	7.9	8.1
12-4-2016	65th day	8.0	8.2
13-4-2016	66th day	8.0	8.3
14-4-2016	67th day	8.1	8.3
15-4-2016	68th day	8.1	8.4
16-4-2016	69th day	8.2	8.4
17-4-2016	70th day	8.2	8.4

B.3 Variation of Temperature in DIGESTER 1

Date	Morning		Afternoon		Evening	
	Inside Digester ^{0}C	Outside digester ^{0}C	Inside Digester ^{0}C	Outside digester ^{0}C	Inside Digester ^{0}C	Outside digester ^{0}C
08-2-2016	16	12	20	19	18	16
09-2-2016	21	21	25	23	19	17
10-2-2016	22	19	24	23	23	21
11-2-2016	21	17	22	18	20	17
12-2-2016	22	18	22	18	21	17
13-2-2016	18	16	20	17	19	16
14-2-2016	20	17	21	19	20	18
15-2-2016	20	18	24	22	22	20
16-2-2016	22	21	25	24	23	21
17-2-2016	24	22	25	24	22	20
18-2-2016	22	21	25	24	22	21
19-2-2016	23	21	24	23	21	20
20-2-2016	21	20	22	21	21	20
21-2-2016	23	21	24	23	22	21
22-2-2016	23	22	26	25	24	23
23-2-2016	24	23	28	27	26	25
24-2-2016	23	22	27	26	26	25
25-2-2016	24	23	28	27	27	26
26-2-2016	24	23	28	27	26	25
27-2-2016	24	23	27	26	25	24
28-2-2016	22	21	26	25	24	23
29-2-2016	23	22	25	24	24	23
01-3-2016	22	21	26	25	24	23
02-3-2016	23	22	27	26	22	21
03-3-2016	23	22	28	27	24	23
04-2-2016	24	23	27	26	22	21
05-3-2016	22	21	24	23	21	19
06-3-2016	21	20	23	22	20	19
07-3-2016	20	19	24	23	20	18
08-3-2016	22	21	25	24	23	22
09-3-2016	22	21	24	23	23	22
10-3-2016	22	20	26	25	23	22
11-3-2016	22	21	24	23	23	22
12-3-2016	17	16	19	18	17	16

13-3-2016	16	15	17	16	15	14
14-3-2016	16	15	17	16	18	17
15-3-2016	22	19	23	21	22	17
16-3-2016	22	19	26	25	24	23
17-3-2016	22	21	26	25	25	24
18-3-2016	21	20	24	23	23	22
19-3-2016	22	21	25	24	21	20
20-3-2016	21	20	23	21	22	20
21-3-2016	23	22	25	24	24	23
22-3-2016	24	23	26	25	25	24
23-3-2016	23	22	25	24	24	23
24-3-2016	22	21	23	22	22	21
25-3-2016	24	23	28	27	27	26
26-3-2016	25	24	30	29	28	27
27-3-2016	25	24	29	28	27	26
28-3-2016	24	23	30	29	27	26
29-3-2016	27	25	31	30	29	28
30-3-2016	25	24	30	28	29	27
31-3-2016	26	25	31	30	30	28
01-4-2016	25	24	31	30	29	28
02-4-2016	26	25	30	29	28	27
03-4-2016	25	25	31	30	29	28
04-4-2016	24	23	29	27	27	26
05-4-2016	25	24	30	28	26	25
06-4-2016	26	25	31	29	30	28
07-4-2016	25	24	29	27	27	26
08-4-2016	24	23	27	26	25	24
09-4-2016	25	24	29	27	28	26
10-4-2016	26	25	30	29	29	27
11-4-2016	25	24	29	27	26	24
12-4-2016	24	23	29	28	27	25
13-4-2016	23	21	27	26	25	24
14-4-2016	26	24	29	27	26	24
15-4-2016	25	24	30	28	27	25
16-4-2016	26	25	31	29	29	27
17-4-2016	25	23	29	27	27	25

B.4 Variation of Temperature in DIGESTER 2

Date	Morning		Afternoon		Evening	
	Inside digester ^0C	Outside digester ^0C	Inside digester ^0C	Outside digester ^0C	Inside digester ^0C	Outside digester ^0C
08-2-2016	16	12	21	19	19	16
09-2-2016	23	21	26	23	21	17
10-2-2016	23	19	25	23	24	21
11-2-2016	22	17	23	18	21	17
12-2-2016	23	18	23	18	23	17
13-2-2016	21	16	23	17	23	16
14-2-2016	21	17	23	19	23	18
15-2-2016	23	18	25	22	24	20
16-2-2016	23	21	26	24	24	21
17-2-2016	25	22	28	24	24	20
18-2-2016	25	21	26	24	25	21
19-2-2016	24	21	26	23	23	20
20-2-2016	23	20	24	21	23	20
21-2-2016	24	21	25	23	24	21
22-2-2016	24	22	27	25	26	23
23-2-2016	26	23	30	27	29	25
24-2-2016	25	22	29	26	29	25
25-2-2016	25	23	30	27	30	26
26-2-2016	25	23	30	27	28	25
27-2-2016	26	23	29	26	27	24
28-2-2016	24	21	27	25	26	23
29-2-2016	25	22	26	24	26	23
01-3-2016	24	21	28	25	27	23
02-3-2016	24	22	29	26	24	21
03-3-2016	25	22	30	27	26	23
04-2-2016	25	23	29	26	24	21
05-3-2016	24	21	26	23	24	19
06-3-2016	23	20	24	22	23	19
07-3-2016	23	19	26	23	23	18
08-3-2016	24	21	26	24	25	22
09-3-2016	23	21	26	23	24	22
10-3-2016	24	20	28	25	24	22
11-3-2016	23	21	25	23	24	22
12-3-2016	19	16	20	18	18	16

13-3-2016	18	15	19	16	17	14
14-3-2016	18	15	19	16	20	17
15-3-2016	23	19	25	21	24	17
16-3-2016	24	19	28	25	26	23
17-3-2016	24	21	28	25	27	24
18-3-2016	23	20	26	23	25	22
19-3-2016	24	21	27	24	25	20
20-3-2016	23	20	25	21	24	20
21-3-2016	24	22	27	24	26	23
22-3-2016	25	23	29	25	27	24
23-3-2016	24	22	26	24	25	23
24-3-2016	23	21	24	22	24	21
25-3-2016	25	23	29	27	28	26
26-3-2016	26	24	31	29	29	27
27-3-2016	26	24	30	28	28	26
28-3-2016	25	23	32	29	28	26
29-3-2016	29	25	33	30	30	28
30-3-2016	27	24	31	28	30	27
31-3-2016	28	25	32	30	31	28
01-4-2016	27	24	32	30	30	28
02-4-2016	28	25	33	29	31	27
03-4-2016	28	25	31	30	29	28
04-4-2016	27	23	31	27	29	26
05-4-2016	26	24	32	28	28	25
06-4-2016	28	25	33	29	31	28
07-4-2016	27	24	30	27	29	26
08-4-2016	26	23	29	26	29	24
09-4-2016	28	24	30	27	30	26
10-4-2016	29	25	32	29	30	27
11-4-2016	28	24	30	27	29	24
12-4-2016	27	23	31	28	28	25
13-4-2016	25	21	30	26	29	24
14-4-2016	27	24	32	27	30	24
15-4-2016	28	24	31	28	29	25
16-4-2016	29	25	33	29	31	27
17-4-2016	26	23	31	27	30	25

APPENDIX – C

C.1 Cumulative Volume of Biogas Produced in Winter and Summer Seasons

Days	Total cumulative biogas produced in winter season (m^3)	Total cumulative biogas produced in summer season (m^3)
1	-	-
2	-	-
3	-	-
4	0.0003534	-
5	0.0003534	-
6	0.0003534	-
7	0.0007068	0.0003534
8	0.0014136584	0.0003534
9	0.0014136584	0.0003534
10	0.0014136584	0.0007068
11	0.0014136584	0.0007068
12	0.0017670584	0.0007068
13	0.0017670584	0.0014136
14	0.0021204584	0.0014136
15	0.0021204584	0.0014136
16	0.0021204584	0.001767
17	0.0021204584	0.001767
18	0.0021204584	0.001767
19	0.0021204584	0.0021204
20	0.0021204584	0.0021204
21	0.0024738584	0.0028272
22	0.0024738584	0.0028272
23	0.0024738584	0.0028272
24	0.0024738584	0.0031806
25	0.0024738584	0.0031806
26	0.0024738584	0.0031806
27	0.0024738584	0.0031806
28	0.0024738584	0.003534
29	0.0024738584	0.003534
30	0.0028272584	0.003534
31	0.0028272584	0.0038874
32	0.0028272584	0.0038874
33	0.0028272584	0.0038874

34	0.0035340584	0.0042408
35	0.0035340584	0.0042408
36	0.0035340584	0.0042408
37	0.0038874584	0.0045942
38	0.0038874584	0.0045942
39	0.0038874584	0.0045942
40	0.0038874584	0.0045942
41	0.0038874584	0.0045942
42	0.0038874584	0.0049476
43	0.0038874584	0.0049476
44	0.0038874584	0.0049476
45	0.0045942584	0.0049476
46	0.0045942584	0.005301
47	0.0045942584	0.005301
48	0.0045942584	0.005301
49	0.0045942584	0.005301
50	0.0045942584	0.0056544
51	0.0045942584	0.0056544
52	0.0045942584	0.0056544
53	0.0045942584	0.0056544
54	0.0045942584	0.0060078
55	0.0045942584	0.0060078
56	0.0045942584	0.0060078
57	0.0049476584	0.0067146
58	0.0049476584	0.0067146
59	0.0049476584	0.0067146
60	0.0049476584	0.007068
61	0.0049476584	0.007068
62	0.0053010584	0.007068
63	0.0053010584	0.0074214
64	0.0053010584	0.0074214
65	0.0053010584	0.0074214
66	0.0053010584	0.0074214
67	0.0053010584	0.0074214
68	0.0053010584	0.0077748
69	0.0053010584	0.0077748
70	0.0053010584	0.0077748

C.2 Variation of pH in digester (17 Nov to 26 Jan) and digester (8 Feb to 17 April) with time

S.No.	Parameter pH	Digester (17 Nov to 26 Jan)	Digester (8 Feb to 17 April)
1	1st Day	6.8	6.5
2	5th Day	7.1	6.5
3	10th Day	6.7	6.5
4	15th Day	6.4	6.8
5	20th Day	6.9	6.6
6	25th Day	6.7	6.6
7	30th Day	6.9	6.7
8	35th Day	7.1	6.5
9	40th Day	6.9	6.9
10	45th Day	6.5	7.1
11	50th Day	6.8	7.3
12	55th Day	6.6	7.3
13	60th Day	6.6	7.8
14	65th Day	6.7	8
15	70th day	6.9	8.2

C.3 Variation of inside and outside temperature in winter and summer season

Days	Winter season		Summer season	
	Inside digester ^0C	Outside digester ^0C	Inside digester ^0C	Outside digester ^0C
1	22	20	18	16
2	21	20	22	20
3	21	20	23	21
4	22	21	21	17
5	22	21	22	18
6	23	22	19	16
7	24	22	20	18
8	23	22	22	20
9	23	21	23	22
10	20	19	24	22
11	21	19	24	23
12	22	20	23	21
13	23	20	21	20
14	22	21	23	21
15	21	20	24	23

16	22	20	26	25
17	21	20	25	24
18	20	20	26	25
19	19	19	26	25
20	18	17	25	24
21	17	17	24	23
22	17	15	24	23
23	18	15	24	23
24	18	16	24	23
25	20	16	25	24
26	18	18	24	23
27	20	16	22	21
28	20	18	21	20
29	21	18	21	20
30	20	19	23	22
31	21	18	23	22
32	23	19	24	22
33	22	20	23	22
34	24	19	18	17
35	23	21	16	15
36	24	20	17	16
37	26	22	22	19
38	24	23	24	22
39	23	20	24	23
40	25	19	23	22
41	22	22	23	22
42	24	18	22	20
43	19	21	24	23
44	21	16	25	24
45	22	18	24	23
46	25	21	22	21
47	26	22	26	25
48	24	22	28	27
49	25	21	27	26
50	23	20	27	26
51	22	19	29	28
52	20	19	28	26
53	22	19	29	28
54	21	18	28	27
55	21	19	28	27
56	20	17	28	27
57	21	18	27	25
58	24	21	27	26
59	23	20	29	27
60	21	19	27	26
61	22	20	25	24
62	24	21	27	26
63	25	22	28	27

64	21	19	27	25
65	21	18	27	25
66	20	17	25	24
67	21	18	26	25
68	20	16	27	26
69	19	18	29	27
70	20	19	27	25