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Experimental Study of Biogas and Bio-Manure Using Thermophilic Digestion of Different Substrates

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Abstract: -- **Experiments have been conducted to determine the augmentation of nutritional values (organic carbon, nitrogen, potassium and phosphorous) of bio-manure. The main substrates have been taken as wheat husk; paddy straw; dairy waste; poultry waste; municipal solid waste and kitchen waste. The substrates have been digested under thermophilic conditions (55 °C). The results show an enhancement in nutritional values in bio-manure where poultry waste has been found to be the best amongst the mentioned substrates. The increase in temperature results in lower retention time and thus reduces the loss of nutrients. The experimental results also show that the intermixing of crop residues with animal waste reduces the quality of bio-manure.**

Index Terms - **Thermophilic Digestion, Substrates, Nutrients, Bio-digester, Organic C and NPK.**

I. INTRODUCTION

In order to ensure sufficient yield and supply of food grains to the enormous and expeditiously evolving population worldwide, sufficient amount of good quality fertilizers are necessary to be available. If the quality of food grains is not maintained at the standard level due to excessive and non-judicious use of chemical fertilizers, it cause higher cost of agriculture inputs on one hand and deficiency of micro nutrients in the food-grains on the other hand. Higher cost of inputs, lower minimum support price and lower cost of imported food-grains might put the poor farmers in financial bondage [1]. India is the second largest consumer and third largest producer of chemical fertilizers in the world [2]. Consumption of chemical fertilizers in India is more than its indigenous production. Mainly urea, DAP and potassium chloride (MOP) are imported in our country but almost all the requirement of MOP is met through imports only as it is not manufactured so far in India due to non-availability of natural potash deposits [3].

Anaerobic digestion is a promising alternative in disposal of organic waste and co-digestion of mixed organic wastes has recently attracted more interest. Mass reduction, methane production and bio-manure production are the main features of the process. Slow degradation of waste is a disadvantage of anaerobic digestion, leading to high solid retention times (SRTs) of 20–30 days in conventional mesophilic (37°C) digesters [4]. This fact implies significant space requirements due to large digesters. Anaerobic digestion may be carried out under psychrophilic, mesophilic and thermophilic conditions (55°C) [5]. Thermophilic digestion, however, is more efficient in terms of organic matter removal and methane production.

The objective of the work was the enhancement of nutritional value of bio-manure in terms of carbon (C), nitrogen (N), phosphorous (P) and potassium (K) by the help of thermophilic anaerobic digestion on the six samples of different substrates namely municipal solid waste (MSW), dairy waste (DW), poultry waste (PW), paddy straw (PS), kitchen waste (KW) and wheat husk (WH) when treated in a continuous feed reactor under lab conditions. The samples of mixture of animal waste with crop residues were also tested on the same digester to determine the effect of mixing and temperature on NPK values.

1.1 Parameters which affect the anaerobic biological degradation

Methane is produced by the action of microorganism in appropriate temperature and various other factors which directly or indirectly affect other parameters like organic dry matter (oDM) content, methane content and biogas yield.

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2.1.1 Influence of Temperature

Chemical reactions and therefore biochemical reactions are strongly dependent on temperature. The temperature is a critical parameter to control. Anaerobic bacteria can survive in a wide range of temperatures but different groups of microorganisms prefer different temperature ranges in which they can live and grow. The most suitable values are between 20-40 °C (mesophilic optimal range) and between 50-65 °C (thermophilic optimal range) [7-8]. In the scientific literature also other ranges are defined-psychrophrilic (-5°C to 20°C) and hyperthermophilic (65-95°C), but they are not practical used in the biogas technology [6]. The boundaries between the groups are relatively fluid. The temperature influences the activity of bacterial cultures. If it is too low the activity will decline, but microorganisms can recover when the temperature is restored [6-7]. A temperature which is too high leads to destruction of the microorganisms. Thermopile digestion provides higher loading rates and achieves higher rates of sanitation, degradation of the substrate and biogas production. On the other hand mesophilic bacteria are more tolerant to changes in environment conditions and the process is therefore considered to be more stable than thermophilic digestion systems [8]. The present study evaluation is done in mesophilic zone.

2.1.2 Influence of pH

The pH-value is defined as the common logarithm of the activity of dissolved hydrogen ions (H+) which influences the metabolic processes. Therefore the AD process is pH dependent. Each of the microbial groups involved in the reactions has a specific pH range for optimal growth. As well as the biogas production the pH value is a parameter that indicates digester instabilities. In a one-step anaerobic treatment process, the pH is maintained for the optimal growth of methanogens to prevent the dominance of acid forming bacteria, which can cause the accumulation of organic acids [6]. The alkalinity describes a measure of the buffering capacity of the system. The measurement of alkalinity allows declarations of how sensitive the AD process is to disturbances [7,9].

2.1.3 Influence of Hydraulic Retention Time (HRT)

HRT is the theoretical time the material spends in the digester, which is also equal to the volume divided by the daily charged feedstock mass flow, and it can be calculated as the ratio of digester volume and feedstock in tonnes [10]. The retention time is important for bacterial growth because the material has to remain in the digester for a sufficient time so that the microorganisms have enough time to grow and multiply. HRT, due to the 'methane forming microorganisms' doubling time of about 10-12 days, preferably 15 day [11]. In some new types of digestion techniques the solid part is retained in the digester by being separated from the liquid phase. In this way, both measures can be controlled independently of each other. The HRT can be kept short, yet still produce a good bacterial growth. Such a process with a long SRT and a short HRT is advantageous in many respects. Thus long SRT can result in a reduced digester volume and a better buffer capacity for irregularities in the loading process. Low HRT provides a high throughput of substrate. But the great majority of digestion plants at the present time are continuously stirred tank digesters, where the biomass is not separated from the liquid phase and HRT equals the SRT.

2.1.4 Influence of Dry Matter Content

Cattle dung contains about 18% solid matter and the remaining 82% is water. Anaerobic fermentation proceeds at a faster rate if the slurry contains about 9% solid matter. Digester feed is prepared by mixing water in the ratio 1:1 by weight to reduce the solid content. DM content varies from material to material [12].

2.1.5 Influence of C:N

Methanogenic bacteria take nitrogen and carbon as their survival food. Carbon is required for energy while nitrogen for building cell protein. The consumption of carbon is 30 to 35 times faster than that of nitrogen [13]. A favourable ratio of C:N can be taken as 20:1. Any deviation from this ratio lowers the biogas production. A proper balance of C:N ratio is maintained either by adding saw dust having a high C:N ratio or by poultry waste having a low C:N ratio.

2.1.6 Influence of Total Solid Concentration (TCS)

TCS is expressed as the quantity of organic waste fed into the digester per day per unit volume. In general, the municipal sewage treatment plants operate at a TCS of below 20% for wet digestion process. Overloading and underloading reduce the biogas production within a fixed retention time. For a desired retention period of 30 days, a quantity equal to 1/30th of digester volume needs to be fed daily [14].

II. MATERIAL & METHOD

2.1 Bio-Digester design

A continuous feed bio-digester was designed which had five sections namely inlet chamber, digester, recycling line, gas line and outlet. An inlet chamber of 10 L capacity was incorporated to take the waste in slurry form inside digester and was connected to digester by means of an inlet pipe. A separate mixer-grinder was used to crush the solid part of the waste. The total height of the digester was 0.4 m whereas the

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liquid slurry was maintained to 0.27 m height. An opening was provided at 0.27 m height which is connected to recycling unit. A thermometer was inserted inside the digester to keep a check of temperature. The outlet pipe was connected at the bottom of the digester. The main function of the outlet was to take the digested slurry out of digester when the retention period is over. It was also provided with a valve which could be opened at the time when the slurry has to be removed from the digester. Figure 1 shows the schematic of the constructed digester.

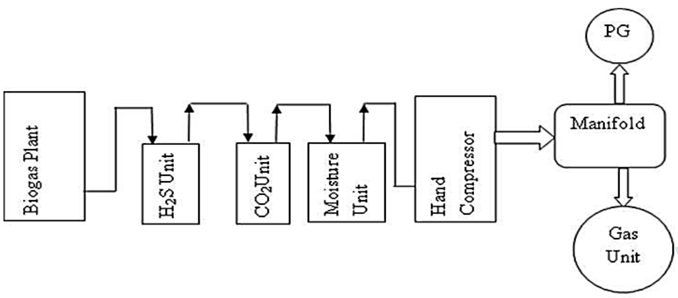

Fig. 1. Schematic of the Bio-Digester

2.2 Preparation of sample

Municipal solid waste (MSW), dairy waste (DW), poultry waste (PW), paddy straw (PS), kitchen waste (KW) and wheat husk (WH) were used as bio-manure substrates. One day old 3 kg cow dung was used to prepare inoculums for all the substrates. One hundred gram of each substrate was mixed with equal proportion of warm water and fed to the digester twice in a day for 7 days. The environmental conditions for the digestion were shown in Table 1.

Parameters	Value
Temperature	Mesophilic: 37±2°C Thermophilic: 52±5°C
pH	5.8-6.8
Moisture Content	50-60%
Digestion Period	15 days

Table 1. Environmental Conditions for AD

During this period the digesters were agitated twice a day (morning and evening) to enable digestion take place in the entire medium. The bio-digesters were painted black to prevent light penetration which can stimulate algae growth and also to trap the heat that has been absorbed in the day. Leakages in the bio-digester systems were checked by immersing bio-digesters into water-bath to check for air bubbles at intervals to prevent loss of medium and the gases generated.

Also, two samples (S1, S2) were prepared and tested in same conditions. Sample, S1 was prepared by mixing of DW, PS and WH in equal proportion and sample, S2 was prepared by mixing PS and WH.

2.3 Physicochemical Analysis

Titration and flame photometer were used for the measurement of organic C and total and available N, P, and K of the bio-manure produced. Total organic C (TOC) content was estimated by the chromic acid oxidation method. Samples were acid digested for total N, P, and K determination. Digested samples were analyzed for N, P, and K by titration, colorimetric, and flame photometric methods, respectively. Available N in the samples was extracted with a potassium chloride solution (1 M) followed by steam distillation using magnesium oxide (MgO) and Devarda's alloy and titration method. Available P was determined using Olsen's reagent (0.5 M NaHCO3, pH 8.5) followed by colorimetric analysis of the molybdophosphoric blue complex at 660 NM. Available K in the samples was extracted with neutral normal ammonium acetate solution (pH 7) followed by flame photometer.

III. RESULTS & DISCUSSION

3.1 Bio-manure

The biochemical characteristics of different substrates under both mesophilic and thermophilic conditions are presented in Table 2. The results showed that the bio-manure quality (i.e. organic C and total NPK values are higher) improves in thermophilic conditions.

Table 2. Bio-manure Quality from different substrates under different temperature conditions

Nutrient	DW		MSW		PS		WH		FW		PW	
	Meso	Thermo	Meso	Thermo	Meso	Thermo	Meso	Thermo	Meso	Thermo	Meso	Thermo
Organic C	296.1 ± 14.7	302.4± 11.1	150.3 ± 2.45	167.8± 13.4	423.2 ±12.3	445.1± 6.7	401.6 ±11.9	425.3± 10.3	158.3 ±12.3	178.3± 12.3	305.6 ±11.2	328.1± 9.8
Total N	8.4 ±2.1	8.9±3.1	6.9 ±4.5	7.6±3.2	7.8 ±2.3	8.5±1.2	6.7 ±3.4	7.2±2.3	6.1 ±2.3	6.4 ±3.4	9.5 ±3.4	11.7 ±1.2
Total P	4.8 ±0.23	4.5 ±0.98	3.0 ±0.65	3.8 ±0.5	3.5 ±3.4	4.0 ±1.4	3.2 ±2.3	3.9 ±1.3	2.9 ±1.2	3.3 ±4.3	5.1 ±0.45	6.0 ±0.1
Total K	9.6 ±0.83	11.35 ±1.56	6.7 ±0.34	8.9 ±0.65	8.7±0 .54	9.1 ±0.30	8.1± 0.45	9.5 ±0.23	6.2 ±0.34	7.1 ±0.35	8.4 ±0.78	9.2 ±0.78

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3.1.1 Organic C

From the above table the graph had been plotted, based on the results of bio-manure quality produced from the 20 litres of biogas digester for the values of organic C in mesophilic and thermophilic conditions as shown in Figure 2.

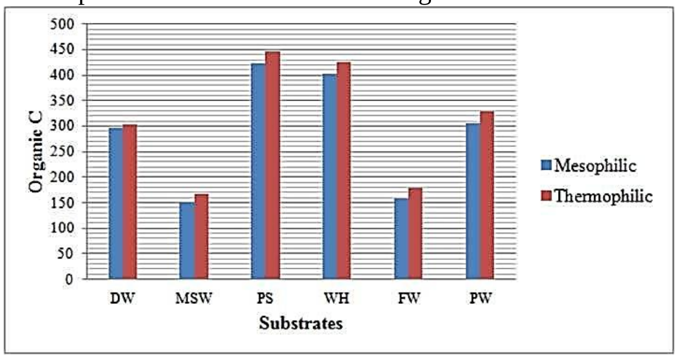

Fig. 2. Organic C for Mesophilic and Thermophilic Zone

Organic carbon (OC) content increased under thermophilic digestion for all substrates; however the amount of change differs in each case. The maximum change was noticed in wheat husk from 401.6 g/kg to 425.3 g/kg which is followed by poultry waste by a change of 22.5 g/kg, paddy straw (21.9 g/kg), food waste (20 g/kg), MSW (17.5 g/kg) and dairy waste (6.3 g/kg). The amount of organic C in biomanure depends on the feedstock and digestion conditions. Hydraulic retention time for any anaerobic digestion process is inversely proportional to temperature i.e. higher the temperature lowers the retention time. However, in case of thermophilic temperature was raised to 52 °C from 37 °C of mesophilic. Thus the retention time of 30 days (in mesophilic case) was reduced to 12 days. That results into higher digestion rate and biogas production. Faster digestion rate ensured the decrease of storage time for bio-slurry that gave less time for the losses of nutrients.

3.1.2 Total N

In most of the cases, the anaerobic digestion process had no affect over nutritional content i.e. NPK values was very less compared to organic C content. Our results were also in agreement to the above statement only with MSW as exception. However, all other substrates showed a very minute change in total N value of biomanure as shown in Figure 3. This is because; the nutritional value of dry feedstock is always higher than the liquid bio-slurry. The liquid bio-slurry was stored or dried with the help of sunlight for 15 days where the loss of N was more in mesophilic conditions compared to thermophilic as the mesophilic digestion retain the bacteria which dies out in thermophilic case. These bacteria led to the microbial digestion of bio-slurry in sunlight as in case of open composting.

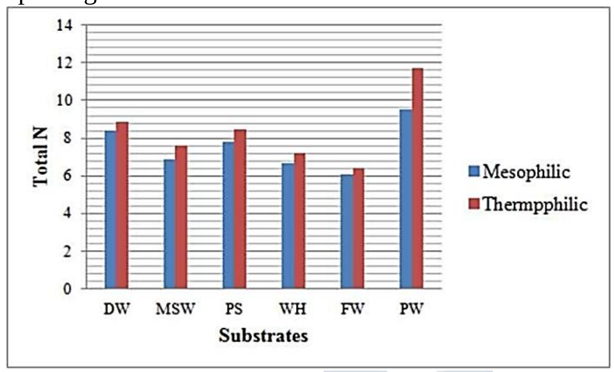

Fig. 3. Organic N for Mesophilic and Thermophilic Zone

3.1.3 Total P and Total K

There was significant increase in the values of total P and total K of thermophilic digestion except total P for dairy waste where a small decrease was noticed. The decrease was because of faster anaerobic digestion rate and high microbial digestion during drying process caused the mineralization and assimilation of unavailable form of potassium and phosphorus as shown in Figures 4 and 5.

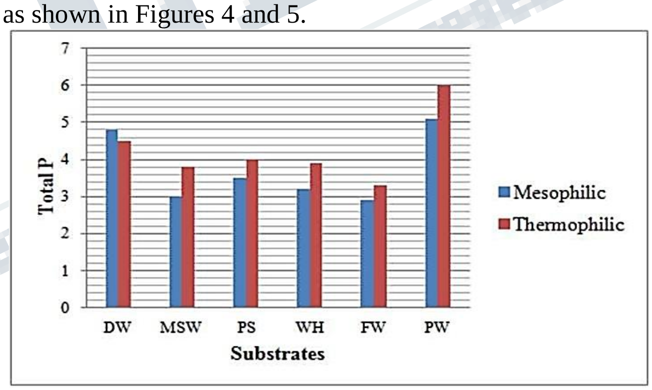

Fig. 4. Total P for Mesophilic and Thermophilic Zone

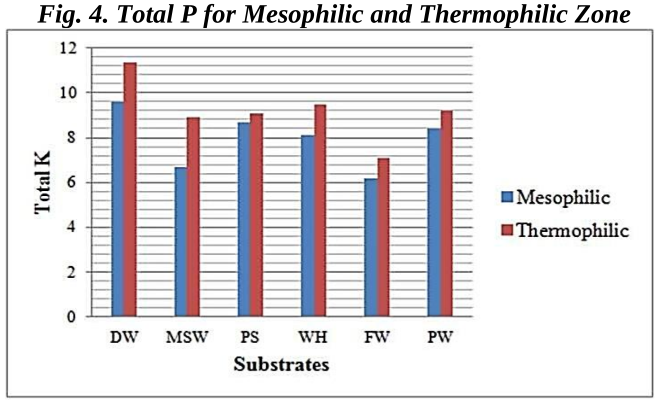

Fig. 5. Total K for Mesophilic and Thermophilic Zone

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3.2 Biogas Quality

The waste was allowed to decompose anaerobically for 15 days in a 20 litres closed digester as shown in methodology. The total gas production was highest for PW i.e. 1639 ml. However, the total gas production form different wastes were 1280 ml for FW, 1368 ml for DW, 1090 ml for MSW, 1001 ml for WH and 1150 ml for PS. Figure 6, shows the graph for biogas produced per day. It also provides the average value of pH for each case i.e. 6.82 for FW, 6.84 for DW, 6.66 for PW, 6.8 for MSW, 6.74 for WH and 6.75 for PS. The optimal range for the growth of bacteria's is from 6.4 to 7.2 i.e. from slightly acidic to slightly basic. Also the decline of pH (below 6) leads to the decrease in rate of methane production.

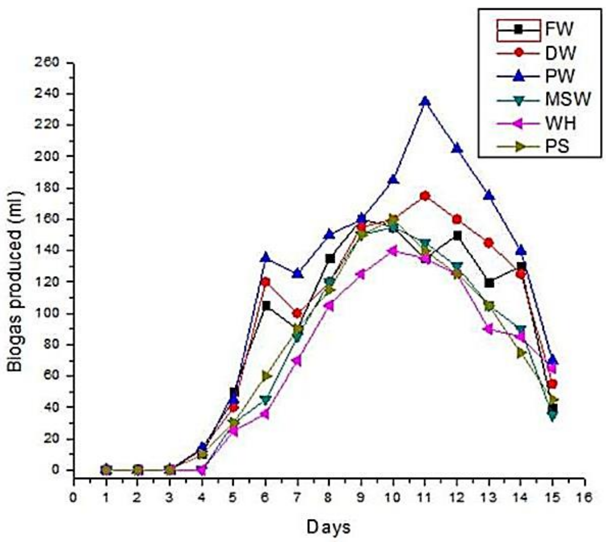

Fig. 6. Biogas Production from different substrates

The experimentation work also concludes that the mixing of some substrates results into lower biogas production rate. Mixing of animal waste with crop residue results in mismatch of the substrate nature as the plant cell contains a cell wall which takes time in decomposition. This results in the mismatch of HRT period and segregation of slurry.

IV. CONCLUSION

Thermophilic digestion converts the raw materials tested here into nutrient-rich substrates, indicating a suitable avenue for disposal of these wastes. Experiment concludes that the NPK values in bio-manure produced from different substrates under thermophilic conditions have increased from mesophilic conditions. Also, the PW produces the best NPK value bio-manure. SRT is the most important factor for bio-manure quality and it is directly proportional to temperature. It also concludes that the mixture of animal and human waste with crop residues decrease the quality of bio-manure.

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