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Enhancement of biogas production from cattle dung using additive

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Abstract
Biogas is a clean, environmental friendly and renewable form of energy generated by anaerobic degradation of organic materials. The biogas production decreases drastically in winter probably due to decrease in temperature, which in turn decreases the dehydrogenase activity as observed in biogas slurry. Thus, it becomes necessity to find out some additive/ stimulant capable of enhancing biogas production. Jaggery is a good source of carbon and energy. It can stimulate the metabolic activity of micro flora. Therefore, in the present investigation jaggery was used as an additive for enhancement of biogas production from cattle dung under batch anaerobic digestion. Cattle dung (3 kg) was mixed with 5, 10, 20, 30, 40, 50 and 60 g jaggery respectively on dry weight basis in different digesters each having 5 litres capacity and digested for nine weeks with temperature varied from 12 to 24ºC. The maximum biogas production (40.0 l/kg), highest volumetric biogas production (0.480 l/l/d) and maximum degradation of TS (27.2%) and VS (30.8%) was observed with supplementation of cattle dung with 40 g jaggery in batch anaerobic digestion.

Keywords: biogas, anaerobic digestion, cattle dung, jaggery, micro flora

Introduction

Waste generation by animals is rapidly increasing and creating enormous waste disposal and management problems. The main cause has been found to be population growth and urbanization. A sustainable waste management system has become an integral part of resource management. Several studies have shown that if the wastes are not properly managed, they will grow to such a level that will prevent human beings from carrying out their daily activities and have adverse effects on human life [1-3]. There are several solid waste management and treatment methods such as sanitary land-fill, incineration, pyrolysis, open dumping and burning, ocean dumping and composting. Each of these methods has its peculiar problems. In many areas the lands for disposal of wastes are no longer available. Waste accumulation in landfills is also the source of odorous emissions to the atmosphere. In other cases like incineration and pyrolysis, air pollution problems are predominant. Government and industries are constantly searching for advance technologies that will allow for more eco friendly and cost-effective waste treatment/management. One technology that can successfully treat the organic fraction of wastes is anaerobic digestion; it has the advantage of producing energy, yielding high quality fertilizer and also preventing transmission of diseases [4].

Anaerobic digestion is an effective decomposition process by which organic matter is decomposed by microorganisms and produces a gaseous by-product often called biogas, which consists mainly of methane and carbon dioxide. The primary benefits of anaerobic digestion are nutrient recycling, waste treatment and odour control. Even the residue processed from the anaerobic digestion has a higher value as a fertilizer than the feedstock. The fertilizer/slurry from a biogas plant contains three times more nitrogen as compared to others. During anaerobic digestion the main plant biomass components proteins, polysaccharides and lipids are initially hydrolysed to more simple amino acids, monosaccharides and free long chain fatty acids and glycerol. The fermentable products are fermented by various bacteria either to volatile fatty acids or to a mixture of carbon dioxide and hydrogen. Acetotrophic and methanogenic bacteria then convert acetic acid and hydrogen into a mixture of methane and carbon dioxide [5].

Anaerobic digestion is applicable for a wide range of material including municipal, agricultural and industrial wastes, and plant residues [6, 7]. Furthermore, this process has some advantages over aerobic process due to a low energy requirement for operation and a low biomass production [8-11] and it is considered as a viable technology in the competent treatment of organic waste and the simultaneous production of a renewable energy [12, 13]. The anaerobic digestion of organic waste is also an environmentally useful technology. The benefits of this process to reduce environmental pollution in two main ways: the sealed environment of the process prevents exit of methane into the atmosphere, while burning of the methane will release carbon–neutral carbon dioxide (no net effect on atmospheric carbon dioxide and other greenhouse gases) [14]. Experiments on biogas technology in India began in 1937. Jashu Bhai Patel designed a floating drum biogas plant popularly known as Gobar Gas Plant in 1956 [15]. The main advantage of anaerobic digestion is the biogas production, which can be used for steam heating, cooking and generation of electricity [16]. However, the biogas production decreases drastically in winter probably due to decrease in temperature, which in turn decreases the dehydrogenase activity as observed in biogas slurry during winter. Thus, it becomes imperative to develop microbial consortia or to adapt the microbial consortia or to find out some additives capable of enhancing biogas production in winter. There are several kinds of microorganisms in anaerobic process, so temperature fluctuations could get advantages for some microbial groups, growth at the same time for other groups of microorganisms are restricted at this temperature range. Each of them has its optimum temperature when best growth and activity is achieved. The growth rate and activity not always rise with temperature [17]. Methanogenic species types and their relative population levels in anaerobic biomass depend on feed substrate as well as operational and/or environmental conditions maintained [18]. In this context, the present research was planned with addition of jaggery as a good source of carbon and energy for enhancement of biogas production. It may stimulate the metabolic activity of microflora. So, jaggery can be used as an additive to increase the production of biogas to overcome the requirement of fuel for growing population.

Materials and Methods

Experimental set-up of digesters

Aspirator bottles (capacity 5 litres each) were stopped with rubber corks fitted with glass tubes and connected with rubber tubing's. The gas collecting bottle was filled with water. The gas produced in digester displaced water in the collecting bottle which was collected in third bottle. The digester provided with an outlet which was used for feeding fresh materials as well as for withdrawing the digested materials. The outlet was closed with a rubber cork (Fig 1). Anaerobic digestion of fresh cattle dung (CD) and jaggery (J) in different ratio was carried out by batch digestion system. In digester-1, along with 3 kg cattle dung 10% inoculum (biogas slurry) was used. The jaggery was mixed with fresh cattle dung in different ratios as mentioned in Table 1.

Analysis of Influent and Effluent Slurry

The influent and effluent slurry was analyzed for various parameters such as pH, total solids, volatile solids, organic carbon content, total volatile fatty acids, cellulose, hemicellulose and lignin contents [19]. The samples were analyzed for nitrogen, phosphorous and potassium content using the standard procedures [20, 22]. The rate of biogas production was estimated by water displacement method.

Table 1: Composition of different digesters for biogas production

Digester	Description
1.	CD (Cattle dung) 3 kg + 10% inoculum (control)
2.	CD 3 kg + double amount of inoculum
3.	CD 3 kg + 5 g jaggery
4.	CD 3 kg + 10 g jaggery
5.	CD 3 kg + 20 g jaggery
6.	CD 3 kg + 30 g jaggery
7.	CD 3 kg + 40 g jaggery
8.	CD 3 kg + 50 g jaggery
9.	CD 3 kg + 60 g jaggery

Fig 1: Experimental Set-up of digesters

Results and Discussion Commented [RA4]: Discussion The aim of this study was to make the use of jaggery along with cattle dung for enhancement of biogas production.

Analysis of fresh substrate

The cattle dung and jaggery were analyzed for various components (Table-2). The cattle dung and jaggery had a pH of 7.5 and 5.9, respectively. Total volatile fatty acids (TVFA) content of cattle dung was higher (1189 mg/kg) than jaggery (420 mg/kg). Cattle dung had total solid (TS) content of 12.5% of which volatile solid (% of TS) content was 81.4%. The jaggery was having TS content of 51.0% and VS (% of TS) of 98.0%. Cattle dung had cellulose, hemicellulose and lignin content of 34.4, 13.9 and 10.4%, respectively. The nitrogen content was higher in cattle dung (1.52%) as compared to jaggery (1.27%). The phosphorus and potassium concentrations were higher in cattle dung (0.64 and 1.28%, respectively) as compared to jaggery (0.04% phosphorus and 0.43% potassium). The jaggery and cattle dung had a C/N ratio of 44.7 and 31.0, respectively.

Table 2: Composition of substrates

Parameter	Cattle dung	Jaggery
pH	7.5	5.9
TVFA (mg/kg)	1189	420
Total solids (TS) (%)	12.5	51.0
Volatile solids (VS) (% of TS)	81.4	98.0
Cellulose (% of TS)	34.4	-
Hemicellulose (% of TS)	13.9	-
Lignin (% of TS)	10.4	-
Nitrogen (% of TS)	1.52	1.27
Phosphorus (% of TS)	0.64	0.04
Potassium (% of TS)	1.28	0.43
Organic carbon (%)	47.2	56.8
C/N ratio	31.0	44.7

Anaerobic batch digestion

Nine digesters were set up with 3 kg material containing different ratios of cattle dung and jaggery as described in material and methods. The digestion was carried out in batch type manner for a period of nine weeks.

Analysis of influent

The influent slurry comprising of different combinations of cattle dung and jaggery were analyzed for various parameters (Table-3). The pH in various digesters varied in a range of 7.0- 7.9. The total volatile fatty acids (TVFA) decreased with the increase in supplementation of jaggery to cattle dung viz. 1189, 1175, 945, 975, 976, 992, 980, 925 and 985 mg/kg in digester 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively. Cellulose and hemicellulose content ranged from 30.4 -34.6 and 13.2-14.9 %, respectively. Lignin content decreased with increase in amount of jaggery supplemented to cattle dung and ranged from 6.68-10.4, respectively. The total solid content ranged from 10.8 to 13.8 %. Volatile solids ranged from 70.1 to 84.6 (% of TS). The Nitrogen content was highest in digester-8 (1.67 %) containing cattle dung supplemented with 50 g jaggery as compared to 1.52, 1.55, 1.56, 1.58, 1.60, 1.63, 1.65 and 1.66 % in digesters 1, 2, 3, 4, 5, 6, 7 and 9, respectively. Total volatile fatty acids, total solids and volatile solids decreased after 8 weeks of digestion. The N, P and K content was increased whereas C/N ratio was found to decrease [23]. The Phosphorus and potassium content were highest in digester - 1 (0.64 and 1.28) containing cattle dung alone (control). The C/N ratio in digester-4 was 38.8 and decreased on increasing supplementation of jaggery to 31.0, 29.9, 26.0, 29.8, 25.3, 29.6, 28.5 and 28.9 in digesters 1, 2, 3, 5, 6, 7, 8 and 9, respectively.

Table 3: Chemical composition and pH of influent for batch digestion

Parameter	Digesters								
	1	2	3	4	5	6	7	8	9
	Cattle Dun G (CD)	CD + DI	CD + 5 g J	CD + 10 g J	CD + 20 g J	CD + 30 g J	CD + 40 g J	CD +50 g J	CD + 60 g J
pH	7.5	7.9	7.9	7.8	7.5	7.2	7.5	7.0	7.0
TVFA (mg/kg)	1189	117	945	975	976	992	980	925	985
Total solids	12.5	5	10.8	11.8	11.7	13.5	12.8	11.1	13.8
Volatile solids	81.4	11.8	70.1	84.2	82.4	72.7	84.6	82.3	82.9
Cellulose (% of TS)	34.4	80.0	34.4	33.5	32.0	30.4	31.2	34.3	33.5
Hemicellulose (%of	13.9	34.6	14.9	14.1	14.2	13.4	13.2	14.4	14.5
TS)	10.4	14.0	7.64	6.68	8.71	9.97	8.01	7.92	9.59
Lignin (% of TS)	1.52	8.63	1.56	1.58	1.60	1.63	1.65	1.67	1.66
Nitrogen (% of TS)	0.64	1.55	0.51	0.49	0.40	0.47	0.46	0.46	0.45
Phosphorus (% of	1.28	0.55	1.22	1.22	1.22	1.23	1.24	1.24	1.26
TS)	47.2	1.27	40.6	48.8	47.8	41.9	48.9	47.7	48.0
Potassium (% of TS)	31.0	46.4	26.0	38.8	29.8	25.3	29.6	28.5	28.9
Organic Carbon (%)		29.9							
C/N ratio									

DI=double inoculum, J=jiggery

Biogas production

The biogas production was recorded for nine weeks in batch digestion (Fig. 2). The temperature ranged from 20 to 24˚C during nine weeks. The biogas production ranged from 0.0 to 26.0 l/week in the digester-1 (control) containing cattle dung alone, 5.5 to 24.8 l/week in digester-2 containing double amount of inoculum as supplement, 2.5 to 22.3 l/week in digester-3 containing the 5 g jaggery as supplement, 2 to 23.6 l/week in digester-4 containing 10 g jaggery as supplement and 7 to 25.2 l/week in digester-5 containing 20 g jaggery as supplement, 3 to 24.6 l/week in digester-6 containing 30 g jaggery as supplement, 1 to 26.6 l/week in digester-7 containing 40 g jaggery as supplement, 0.9 to 22.4 l/week in digester-8 containing 50 g jaggery as supplement, 0.0 to 20.3 l/week in digester- 9 containing 60 g jaggery as supplement. The total biogas production increased in nine weeks of incubation with supplementation of cattle dung with jaggery.

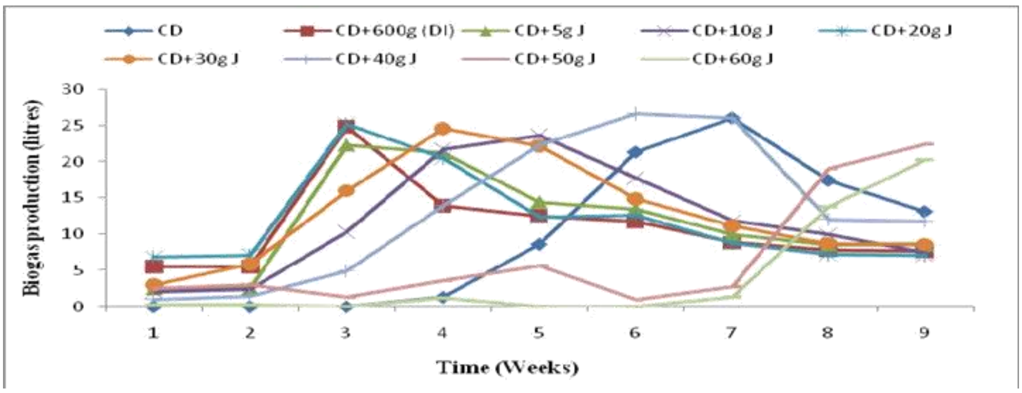

Fig 2: Weekly biogas production from cattle dung supplemented with jaggery during batch digestion

The maximum biogas production was observed in digester –7 (CD + 40 g J) containing cattle dung supplemented with 40 g jaggery and it ranged from 1 to 26.6 l/week (Fig. 2). The cumulative biogas production in cattle dung alone was 87.7 litres in nine weeks which increased to 98.2, 103.2, 106.8, 107.4, 115.5, 120 litres on addition of double inoculum, 5 g, 10 g, 20 g, 30 g and 40 g jaggery which further decreased to 60.9, 37.1 litres on addition of 50 g and 60 g jaggery, respectively (Fig. 3). Highest yield of biogas was observed by addition of piggery feaces (1.07 l/kg), followed by cattle dung (0.71 l/kg) with poultry waste the least (0.42 l/kg) all under direct sunlight [24]. The volumetric biogas production was maximum 0.480 l/l/d in digester –7 (CD + 40 g J) as compared to 0.350 l/l/d (CD), 0.392 l/l/d (CD + DI), 0.412 l/l/d (CD + 5 g J), 0.427 l/l/d (CD + 10 g J), 0.429 l/l/d (CD + 20 g J), 0.460 l/l/d (CD + 30 g J), 0.243 l/l/d (CD + 50 g J), and 0.148 l/l/d (CD + 60 g J) (Table-4). The solid conversion efficiency varied from 0.089-0.312 l/g TS added and 0.107-0.371 l/g VS added in different digesters and were found to be highest in digester-7. Biogas production was measured for a eight weeks and maximum biogas production (32.1 litres) was observed at the end of 4th week on supplementation of cattle dung with kitchen waste @ 5%, compost @ 5%, landfill waste @ 5% and paddy soil @ 5% on dry weight basis in batch anaerobic digestion [25].

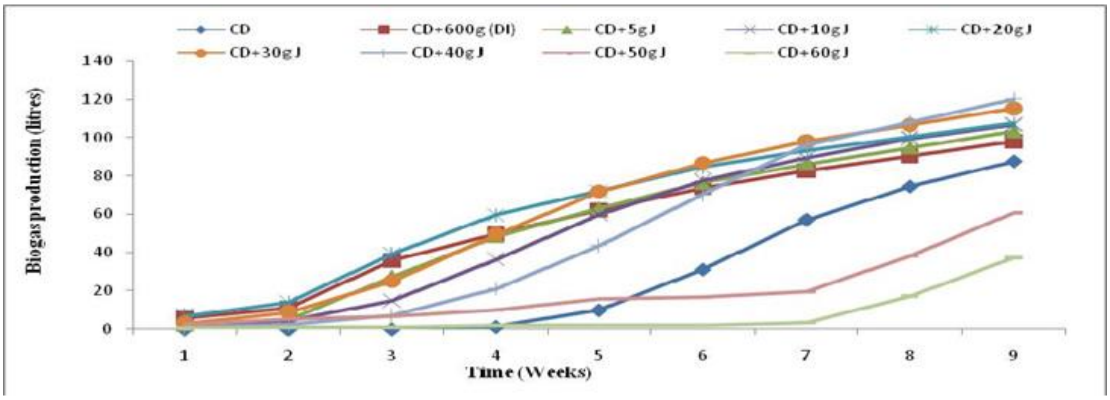

Fig 3: Cumulative biogas production from cattle dung supplemented with jaggery during batch digestion

Table 4: Digestion efficiency of cattle dung supplemented with jaggery during batch digestion for nine weeks

Parameter	Digesters								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	Cattle Dung (CD)	**CD + DI**	**CD + 5 g J**	**CD + 10 g J**	**CD + 20 gJ**	**CD + 30 gJ**	**CD + 40gJ**	**CD + 50 gJ**	**CD + 60 gJ**
Volumetric biogas Production (l/l/d)	0.350	0.392	0.412	0.427	0.429	0.460	0.480	0.243	0.148
Total biogas production (l/kg)	29.2	32.7	34.4	35.6	35.8	38.3	40.0	20.3	12.3
Solid conversion efficiency l/g TS added	0.233	0.277	0.286	0.301	0.305	0.311	0.312	0.182	0.089
l/g VS added	0.286	0.346	0.354	0.358	0.369	0.360	0.371	0.222	0.107

DI=double inoculum, J=jiggery

Analysis of effluent

After completion of batch anaerobic digestion for nine weeks, the samples were withdrawn and analyzed for various parameters (Table-5). The final pH of digesters varied from 5.7 to 7.3. The total volatile fatty acids (TVFA) decreased from 1189 to 1110, 1185 to 1157, 945 to 906, 975 to 911, 976 to 950, 992 to 987, 980 to 970, 925 to 910, 985 to 967 mg/kg in digester 1, 2, 3, 4, 5, 6, 7, 8 and 9 respectively. Decrease in TS and VS (% of TS) was observed in all the digesters. In the digester-1 (control), the TS decreased from 12.5 to 10.7 % while in digester-7 the decrease was from 12.8 to 9.3 %. Maximum reduction of VS (% of TS) was also observed in digester- 7 from 84.6 to 80.9 %. Cellulose decreased from 34.4 to 30.2, 34.6 to 30.5, 34.4 to 29.8, 33.5 to 28.0, 32.0 to 29.6, 30.4 to 28.8, 31.2 to27.3, 34.3 to 30.0 and 33.5 to 28.6% in digesters 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively (Table-5). Lignin content decreased after completion of digestion from 10.4 to 9.2, 8.6 to 7.9, 7.6 to 6.8, 6.6 to 6.1, 8.7 to 8.2, 9.9 to 9.1, 8.0 to 7.5, 7.9 to 7.2 and 9.5 to 8.4 % of total solids in digesters 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively. The nitrogen content was increased from 1.52, 1.55, 1.56, 1.58, 1.60, 1.63, 1.65, 1.67, and 1.66 % to 1.68, 1.70, 1.73, 1.61, 1.72, 1.74, 1.77, 1.78 and 1.81 % in digester 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively. The phosphorus and potassium content after digestion increased in effluent as compared to influent. The maximum degradation (27.2%) of total solids was observed in digester-7 (CD + 40 g J) and minimum degradation

(11.5%) was in digester-9 (CD + 60 g J). The same trend was observed in volatile solids degradation and maximum degradation (30.8%) was observed in digester-7 (CD + 40 g J) as compared to digester-9 (13.3) as shown in Table-6, Fig. 4. Degradation of total solids and volatile solids could be explained due to breakdown of substrates resulting in production of biogas. A similar observation was observed during methanogenesis of poultry waste slurry [26]. The C/N ratio decreased from 31.0 to 27.3, 29.9 to 27.1, 26.0 to 22.5, 38.8 to 28.8, 29.8 to 26.8, 25.3 to 22.6, 29.6 to 26.3, 28.5 to 25.4 and 28.9 to 25.9 in digesters 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively (Table-5, Fig.5). The highest decrease in C/N ratio was observed in digester-4, containing 10 g jaggery, respectively.

Table 5: Chemical composition and pH of effluent after batch digestion

	Digesters								
	1	2	3	4	5	6	7	8	9
Parameter	**Cattle Dung (CD)**	**CD + DI**	**CD + 5 gJ**	**CD + 10 g J**	**CD + 20 g J**	**CD + 30 g J**	**CD + 40 g J**	**CD + 50 g J**	**CD + 60 g J**
pH	7.1	7.3	7.1	7.2	7.0	6.9	6.9	5.9	5.7
TVFA (mg/kg)	1110	1157	906	911	950	987	910	918	967
Total solids	10.70	9.33	8.96	9.94	8.53	9.47	9.32	9.70	12.20
Volatile solids	79.2	79.5	67.3	80.1	79.8	68.9	80.9	78.2	81.1
Cellulose (% of TS)	30.2	30.5	29.8	28.0	29.6	28.8	27.3	30.0	28.6
Hemicellulose (% of TS)	13.5	13.8	14.4	18.5	17.7	13.1	12.9	13.9	14.1
Lignin (% of TS)	9.12	7.93	6.82	6.10	8.29	9.11	7.52	7.23	8.40
Nitrogen (% of TS)	1.68	1.70	1.73	1.61	1.72	1.74	1.77	1.78	1.81
Phosphorus (% of TS)	0.71	0.64	0.62	0.58	0.56	0.59	0.54	0.52	0.55
Potassium (% of TS)	1.32	1.30	1.29	1.27	1.27	1.26	1.29	1.30	1.33
Organic Carbon (%)C/N ratio	45.9	46.1	39.0	46.4	46.2	39.39	46.9	45.3	47.0
DI=double inoculum, J=jaggery	27.3	27.1	22.5	28.8	26.8	22.6	26.3	25.4	25.9

Table 6: Degradation of various constituents after nine weeks of digestion in batch system

	Digester	**Total Solids (%)**			**Volatile Solids (%)**		
		Initial	**Final**	**Degradation**	**Initial**	**Final**	**Degradation**
1	(Control)	12.5	10.7	14.4	81.4	79.2	16.6
2	(CD + DI)	11.8	9.3	20.9	80.0	79.5	21.4
3	(CD + 5 g J)	10.8	8.9	17.0	70.1	67.3	19.8
4	(CD + 10 g J)	11.8	9.9	15.7	84.2	80.1	19.8
5	(CD + 20 g J)	11.7	8.5	27.0	82.4	79.8	29.6
6	(CD + 30 g J)	13.5	9.9	26.1	72.7	68.9	29.9
7	(CD + 40 g J)	12.8	9.3	27.2	84.6	80.9	30.8
8	(CD + 50 g J)	11.1	9.7	12.6	82.3	77.2	17.7
9	(CD + 60 g J)	13.8	12.2	11.5	82.9	81.1	13.3

DI=double inoculum, J=jiggery

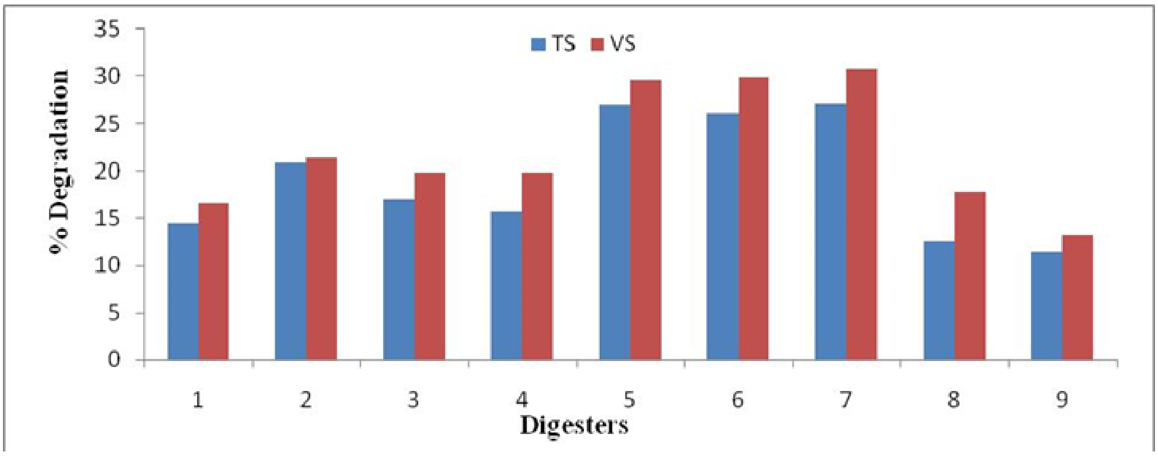

Fig 4: Degradation of total solids and volatile solids after nine weeks of batch digestion

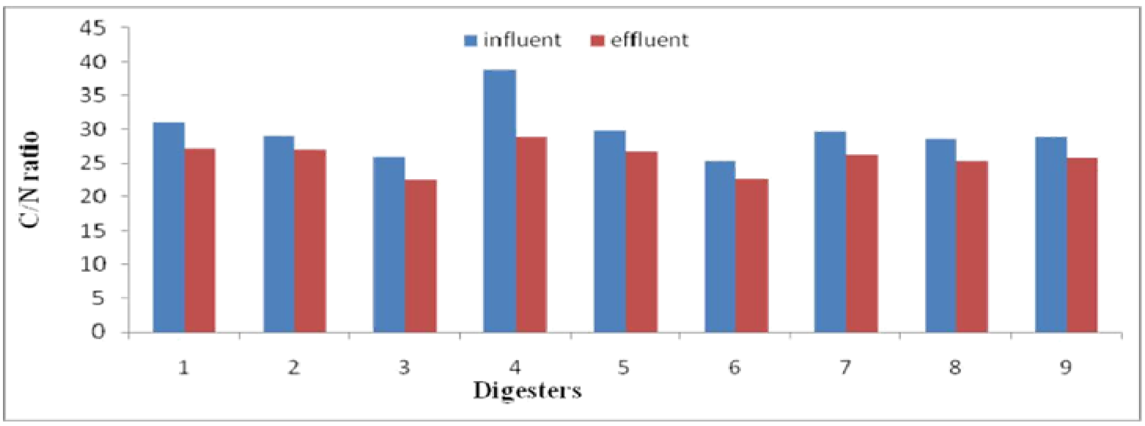

Fig 5: C/N ratio of influent and effluent in batch digestion

Conclusion

Supplementation of cattle dung with 40g jaggery proved to be effective for enhancement of biogas production followed by supplementation of 30g jaggery to cattle dung. Biogas production increased by 36.8% when cattle dung was enriched with 40g jaggery followed by 31.1% increase in cattle dung supplemented with 30g jaggery as compared to control. Thus, it can be used as an additive during anaerobic digestion of cattle dung but higher concentration of jaggery may suppress the biogas production. From the results, it was concluded that jaggery can be supplemented to cattle dung for higher biogas production during winter with temperature range (12 to 24 ºC).

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