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SCREENING OF COMMON PLANT WEEDS FOR THEIR POTENTIAL OF BIOGAS GENERATION ALONE AND IN COMBINATION WITH SOME AGRO-INDUSTRIAL WASTES

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ABSTRACT

The study was made to see the biomethanation potential of 14 commonly present weed plants alone and in combination with some agro-industrial wastes like distillery, sugar, dairy and farmhouse. The plants were used in the original form and after mild alkali treatment to see effect of softening of the tissues. There was a marked increase in biogas production after pretreatment in almost all the plants. The mixing of agro-industrial wastes also enhanced the capability of weeds to produce biogas. In general, *Ipomoea carnea* showed the best results alone as well as in combination with the wastes, especially distillery waste. The use of these plants can be made to supplement the conventional substrates like dung in rural areas to augment the biogas production.

INTRODUCTION

To overcome the present energy crunch, renewable energy resources such as wind, solar, geometrical, tidal and bioenergy have to be tapped in a big way. Of this bioenergy seems to have a great potential because of the ubiquitous presence of plenty of plant biomass, especially in rural areas. This biomass has been serving the mankind since the arrival of Man on the earth in various ways. In fact, the energy which we use today in the form of fossil fuel has also been derived from biomass. However, the bioenergy refers only to renewable biomass, which can be used in a variety of ways to obtain energy such as energy plantation for fuel and fire wood, petroleum plants to obtain liquid biofuels, biomass gasification, alcohol production and gaseous fuels in the form of biogas and hydrogen.

Biogas is a mixture of methane (65-75%) and CO_2 (30-35%) together with other gases like NH_3, H_2S, H_2 and N_2 etc. in trace quantities produced from organic matter by microbial decay under anaerobic conditions. The biogas is highly combustible and can be used for generation of heat, electricity and mechanical energy.

Almost 70% of population of India lives in villages, where the plant and animal biomass in the form of cattle dung, dry leaves, agricultural residues and plant weeds is available in plenty, which can be easily converted into biogas. To meet the daily biogas needs of a family of four persons on an average, twenty five kg/day of dung will be required, which may not be practicable for all. In order to replace dung, search for other resources, commonly present in the rural areas, has to be made to supplement the biogas production (Bose et al. 1983).

A large number of agricultural wastes and residues have been used as supplement to dung in biogas production. Besides agro-residues, a vast amount of foliage of a variety of trees, silage crops and weed plants is also present in rural areas, which has a great potential for biogas production.

While foliage of dry leaves can go for composting or vermicomposting, weed plants cause a great nuisance. Some of the weed plants can invade large agricultural lands and are difficult to be controlled such as *Typha*, *Cynodon*, *Phragmites*, *Lantana* and *Parthenium* etc. Besides, some aquatic weeds like *Eichhornia*, *Salvinia* and *Pistia* also cause much greater problems, especially water pollution and destruction the whole water body.

As these weeds are difficult to be eradicated, some use of them can be made including generation of biogas. Water hyacinth has been extensively researched for biogas production (Gopal & Sharma 1981). As most weeds do not possess a soft tissue, they require an acid or alkali treatment prior to their use as a substrate in biogas production (Chellapandi 2004). Moreover, the microbial consortium required for anaerobic degradation of weeds do not develop easily by simply degrading the weeds anaerobically. These weeds have to be used initially with some other common biogas producing substrate and later the amount of that substrate can be slowly decreased, while at the same time increasing the percentage of weed material. This will enable a proper microbial flora to develop, which can degrade much of the organic matter of the weed at a faster rate.

The present work has been undertaken to study the potential of some common weeds, abundantly found in rural areas, to produce biogas alone and in combination with some agro-industry wastes.

MATERIALS AND METHODS

Weeds: Fourteen common species of plant weeds were taken for screening to see their potential for biogas generation. The names of the plant weeds and their parts used for the study are given in Table 1. Both untreated and alkali treated weed biomass was used for the study. The alkali hydrolysis was made by reacting 25 g of air dried weed biomass with 250 mL of 1% NaOH solution at room temperature for 8 days.

Collection and storage of agro-industrial wastes: The distillery, sugar, dairy and farmhouse wastes were collected as fresh composite samples in disinfected plastic carboys of 5 – 50-L capacity and stored under refrigeration till further use.

Biogas digesters: Preliminary screening studies on biomethanation potential of weeds were carried out in 1-litre capacity glass flasks and plastic carboys. Bench and scale-up studies were performed using locally fabricated (K.V.I.C. design) biogas digesters of 4, 25, 50 and 100-L capacities. The gas collection system used for all the digesters was consisted of an assembly of water displacement method. Analysis of gas was made at Agharkar Research Institute (ARI), Pune by gas chromatography using H_2 as a carrier gas.

Chemical analysis of weed biomass, wastes and digester effluents: Chemical analysis of weed materials, the wastes, digester effluents and sludges was made as per APHA (1985), Trivedy & Goel (1984) and AOAC (1990).

RESULTS AND DISCUSSION

The results of the chemical analysis of different weeds and wastes are presented in Tables 2 and 3 respectively. The material from plants, which was used in the present studies, included entire plant, leaves, twigs and flowers for the biomethanation process. The C:N and BOD:N:P ratios are generally considered critical for biomethanation and should be in the range of 20–30 and 120:5:1 respectively (Payne 1976, Hobson et al. 1981). Chemical analysis of weed materials showed that C:N

Table 1: The plant weeds and their parts used for the study of biomethanation potential. Code names used later in the text are shown in parentheses.

Sr.No.	Weeds		Plant part used
	Common name	Botanical Name (Abbreviation used)	
1	Water hyacinth	*Eichhornia crassipes* (Mart) Solms (Ec)	Entire Plant
2	Besharum	*Ipomoea carnea* Jacq. (Ip) Sub sp. *fistulosa* (Mart, ex Choisy)	Leaves and small twigs
3	Ghaneri	*Lantana camera* Linn. (La)	Leaves, twigs, flowers
4	Gajar gavat	*Parthenium hysterophorus* Linn. (Pa)	Leaves, twigs, Flowers.
5	Pan Kanis	*Typha angustata* Bory (Ty)	Leaves
6	Dub grass (Harali)	*Cynodon dactylon* Pers. (Cp)	Entire plant
7	Blumea	*Blumea lacera* DC. (Bl)	Entire plant
8	Erand	*Ricinus communis* Linn. (Ri)	Entire plant
9	Pivala Dhotara (Maxican Poppy)	*Argemone maxicana* Linn. (Ar)	Leaves and twigs
10	Tambdi Kari-cha gavat	*Striga gesnerioides* (Willd.)Var. gesnerioides (St)	Entire plant
11	Lavala (Nutt grass)	*Cyperus rotundus* Linn. (Cy)	Entire plant
12	Garden spurge (Asthama weed)	*Euphorbia hirta* Linn. Eu)	Entire plant
13	Takala	*Cassia tora* Linn. (Ca)	Leaves and twigs
14	Alu (wild)	*Colocasia antiquorum* Scholt (Co)	Leaves and twigs

ratios of the 14 weed samples ranged from 11.88 for *Parthenium hysterophorus* to 21.03 for *Cynodon dactylon*, while BOD:N:P ratios ranged from 120:6.3:0.46 (*Typha angustata*) to 120:10.6:1.6 (*Argemone mexicana*). This showed that C:N ratios were slightly on the lower side except *Typha angustata* and *Cynodon dactylon*, which were 20.8 and 21.03 respectively. In case of most of the weeds the nitrogen content was significantly higher i.e., ranging from 1840 mg/kg in *Cynodon* to 3110 mg/kg in *Eichhornia*, while phosphorus content was grossly less in comparison to BOD and N with exception of *Parthenium, Ricinus, Argemone, Euphorbia* and *Ipomoea.* It was found that BOD:N:P ratio of *Ipomoea* was comparatively closer to the expected ratio of 120:5:1.

In case of microelements, iron, manganese, zinc and copper levels were studied. In *Eichhornia, Argemone, Blumea, Ricinus, Cassia, Parthenium* and *Lantana*, iron was higher to the level of 420, 410, 390, 380, 370, 360 and 360 mg/kg respectively. Low iron contents of 110, 130, 140, 140, 190 and 190 mg/kg were found in case of *Typha, Euphorbia, Striga, Colocassia, Cyperus* and *Ipomoea* respectively. With respect to manganese levels, it was found that they were low as compared to iron content, in general, where maximum manganese levels of 290 and 230 mg/kg were found in case of *Cassia* and *Lantana* as compared to only 15, 31, 44, 70 and 75 mg/kg in *Cyperus, Blumea, Cynodon, Striga* and *Ipomoea* respectively. There was not much variation with respect to the level of zinc, which ranged from as low as 33, 42, 49 and 49 mg/kg for C*olocassia, Euphorbia, Ipomoea* and *Typha* to the maximum of 95 mg/kg in *Argemone.* The copper levels were low and not much variation was observed among the plants.

Screening of Untreated and Pretreated Weed Biomass for its Biomethanation Potential

The data on biomethanation potential of the untreated and alkali treated weeds are given in Table 4. All the 14 weeds were subjected to 1-L digester level for biomethanation, directly (untreated) and also after pretreatment with dilute alkali. In all the 14 untreated weed biomass samples, the biogas produced was fairly low as compared to pretreated samples, which indicates that untreated weed

Table 2: Chemical analysis of weeds.

Sr.No.	Parameters	Weeds													
		Ec	Ip	La	Pa	Ty	Cp	Bl	Ri	Ar	St	Cy	Eu	Ca	Co
1.	Organic matter, mg/kg	60,400	66,540	62,800	57,020	73,020	73,140	58,500	61,300	57,200	68,500	71,100	70,100	64,600	69,800
2.	Carbon, mg/kg	44,500	49,800	36,420	32,022	42,430	37,690	35,400	38,000	31,800	40,200	38,700	34,500	36,800	40,400
3.	Nitrogen, mg/kg	3110	2980	2450	2700	2040	2180	1980	2950	2320	2200	1840	2550	2510	2220
4.	C : N ratio	14.3	16.7	14.9	11.86	20.8	17.29	17.90	12.88	13.7	18.27	21.03	13.53	14.3	18.2
5.	BOD, mg/kg	37,500	45,950	33,220	32,100	39,110	35,700	32,270	36,440	29,280	38,180	36,320	29,700	34,200	36,220
6.	Phorsphorus, mg/kg	130	560	210	310	150	90	140	330	350	210	120	210	220	160
7.	Potassium, mg/kg	1900	2800	2400	3500	1400	800	1600	1950	1930	1750	1050	1500	1900	1300
8.	Calcium, mg/kg	2570	880	4090	2000	1600	160	2750	4100	3880	2600	180	1800	3500	1800
9.	Magnesium, mg/kg	2050	990	1410	2140	780	390	2250	2300	2160	1780	620	710	1100	950
10.	Iron, ppm	420	190	360	360	110	190	390	380	410	140	230	130	370	140
11.	Manganese, ppm	20	75	230	130	110	15	31	165	168	70	44	95	290	165
12.	Zinc, ppm	71	49	74	75	49	55	60	53	95	68	75	42	80	33
13.	Copper, ppm	5	5	5	5.5	5	5	7	4.8	3.8	4.3	5.3	4.3	3.9	4.55
14.	BOD : N : P ratio	120:9.5 :0.42	120:7.7 :1.46	120:8.8 :0.76	120:10.1 :1.16	120:6.3 : 0.46	120:7.3 : 0.3	120:7.4 :0.52	120:9.7 :1.1	120:10.6 :1.6	120:6.9 :0.66	120:6.1 :0.4	120:10.3 :1.50	120:8.8 :0.8	120:7.4 :0.53

Symbols of weeds as per Table 1.

Table 3: Physico-chemical characteristics of the wastes.

Sr.No.	Parameter	Distillery waste	Sugar Industry	Dairy	Farmhouse waste
1	Colour	Dark brown	Yellowish brown	Dirty white	Brown yellowish
2	Odour	Alcoholic noxious	Unpleasant	Unpleasant	Pungent
3	pH	4.2 -4.5	6.2-6.4	6.3-6.6	5.8-6.0
4	BOD, mg/kg	41290	1150	1350	16500
5	COD, mg/kg	112000	1830	2100	33500
6	Total solids, mg/kg	95000	2200	1320	32000
7	TVS, mg/kg	64000	1950	1200	28400
8	TOC (Carbon), mg/kg	29700	690	810	9900
9	Nitrogen, mg/kg	1550	28	39.5	443.9
10	Phosphorus, mg/kg	950	3	4.6	113.4
11	Potassium, mg/kg	11200	4.5	1.8	6.2
12	Calcium, mg/kg	720	4.0	2.1	31.8
13	Magnesium, mg/kg	290	3.0	1.1	19.3
14	Iron, mg/kg	195	0.5	0.5	2.46
15	Manganese, mg/kg	0.5	0.1	0.15	15
16	Zinc, mg/kg	0.4	BDL	BDL	2.46
17	Copper, mg/kg	0.2	BDL	BDL	BDL
18	C : N ratio	19.16	24.64	20.50	22.30
19	BOD : N : P ratio	120 : 4.5: 2.77	120 : 2.9 : 0.31	120 : 3.5 : 0.4	120 : 3.2 : 0.82

BDL – Below detectable level

biomass, though rich in organics, much of it was not available for biomethanation because of presence of resistant and protective plant components like cellulose, hemicellulose, lignin and pectin. The protective effect of such components in original biomass could be changed to a form, which may be amenable to biomethanation process, by pretreatment of the weeds with a mild alkali. In case of untreated weeds, the maximum amount of daily biogas produced was in *Ipomoea* (310-440 mL/day) with an average of 392.17 mL/day, while all other weeds produced less than half the amount of biogas as compared to it. This indicates that *Ipomoea* was more amenable, even in untreated form, to the biomethanating bacterial population than other weeds.

More biogas production in case of *Ipomoea* could be because of its soft biomass and C:N and BOD:N:P ratios, which were close to the desired values for biomethanation. For *Ipomoea* these ratios were found to be 16.7 and 120:7.7:1.46 respectively. *Ipomoea* also has nitrogen and phosphorus levels slightly at the higher side, which showed that if its biomass is admixed with a substrate containing more BOD and comparatively low nitrogen and phosphorus contents, it would be a suitable combination for biomethanation, because C:N and BOD:N:P ratios of this admixture will come still closer to the desired levels for biomethanation. In case of *Parthenium, Ricinus, Argemone* and *Euphorbia*, BOD:N:P ratios were higher at 120:10.1:1.16, 120:9.7:1.1, 120:10.6:1.6 and 120: 10.3:1.50 respectively, hinting at possible admixing with substrates containing more BOD to improve suitability for biomethanation. C:N ratios of these plants were lower than the required for biomethanation *viz.,* 11.86, 12.88, 13.7 and 13.53. The phosphorus contents were enough for biomethanation process. In the present studies the biogas volumes per day obtained for all the above four weeds in the untreated and pretreated conditions were low because of unsuitable C:N and BOD:N:P ratios as compared to *Ipomoea,* while for remaining weeds lower biogas production could also be because of unsuitable C:N and BOD:N:P ratios as well as less amenable biomass in untreated forms.

Table 4: Screening of untreated and treated weed samples with different agro-industrial wastes for biomethanation potential.

Type	Parameters	Ec	Ip	La	Pa	Ty	Cy	Bl	Ri	Ar	St	Cp	Eu	Ca	Co
							Untreated Weeds								
Untreated Weed	Biogas (mL)	70-120	310-440	80-130	80-160	60-100	90-190	144-170	55-95	50-80	110-180	90-160	70-140	70-170	130-170
	Av. Biogas mL/day	102.17	392.17	108.00	128.50	82.67	148.50	156.57	80.33	67.70	145.17	128.70	108.17	75.67	151.00
	Std. Deviation	12.15	39.51	16.38	26.62	13.24	33.09	12.91	8.50	10.95	26.24	22.75	22.80	11.57	15.10
Weed + Distillery waste	Biogas (mL)	300-520	450-750	280-390	200-290	190-340	180-410	270-330	130-220	95-120	180-390	240-460	160-270	125-205	200-260
	Av. Biogas mL/day	424.33	677.83	324.83	254.17	275.00	322.00	297.67	182.17	111.67	303.50	373.17	220.53	174.53	232.33
	Std. Deviation	69.60	71.01	36.21	27.73	51.49	75.67	19.508	27.62	30.77	65.05	67.52	33.47	26.55	19.42
Weed + Sugar waste	Biogas (mL)	150-320	390-510	250-400	180-260	130-200	160-250	170-200	120-180	90-180	150-240	160-260	110-160	80-120	160-240
	Av. Biogas mL/day	185.03	466.17	310.33	218.67	169.50	208.00	181.67	152.33	136.00	194.50	224.00	134.00	100.67	206.17
	Std. Deviation	20.56	47.30	74.25	27.00	22.26	28.45	10.03	22.12	31.96	31.41	30.12	16.21	14.60	24.06
Weed + Dairy waste	Biogas (mL)	140-210	350-500	260-390	160-240	110-140	130-240	160-240	100-150	70-110	135-220	130-220	85-150	70-100	150-200
	Av. Biogas mL/day	168.70	435.67	317.83	200.83	121.00	175.33	176.83	163.33	91.67	182.67	170.73	117.00	84.00	175.00
	Std. Deviation	35.26	52.63	45.52	26.91	13.98	35.55	12.63	206.89	14.16	30.33	27.94	21.36	10.70	17.22
Weed + Farmhouse waste	Biogas (mL)	210-420	370-590	240-390	170-240	170-290	150-360	230-310	135-180	90-115	165-360	230-390	110-220	100-180	200-405
	Av. Biogas mL/day	313.33	473.67	302.33	208.67	235.17	285.50	276.67	152.77	102.00	274.00	327.67	175.17	148.50	322.00
	Std. Deviation	67.74	70.73	65.29	21.73	38.74	68.48	23.72	14.77	9.15	61.90	48.26	35.24	25.36	59.94
							Alkali Pretreated Weeds								
Pretreated Weed	Biogas (mL)	125-200	350-490	100-200	125-210	100-190	130-340	210-320	100-170	80-130	160-260	170-280	90-160	70-170	170-320
	Av. Biogas mL/day	167.83	427.00	134.50	166.17	138.67	233.83	268.00	137.50	102.50	221.13	232.33	117.00	112.33	248.50
	Std. Deviation	22.07	40.01	27.30	29.93	21.09	52.48	28.33	18.88	17.26	29.63	31.37	21.92	27.31	42.22
Weed + Distillery waste	Biogas (mL)	390-600	470-820	310-440	220-350	270-380	220-490	305-480	180-390	120-200	220-400	300-575	120-305	160-280	210-480
	Av. Biogas mL/day	516.33	698.67	336.37	285.67	319.00	360.67	401.50	303.03	153.90	365.00	454.67	226.17	220.33	373.67
	Std. Deviation	86.64	88.33	34.52	45.37	40.37	96.91	56.844	60.33	35.02	73.47	73.105	96.26	42.85	78.10
Sugar industry waste	Biogas (mL)	180-270	420-650	300-490	210-310	140-250	230-380	250-390	170-250	180-240	200-310	230-320	140-270	135-200	200-390
	Av. Biogas mL/day	222.00	567.67	375.87	263.50	187.40	307.33	318.50	212.33	207.00	258.18	277.33	199.17	167.17	294.50
	Std. Deviation	33.26	75.43	48.26	37.00	47.18	48.47	43.93	26.09	21.07	60.68	28.27	41.48	32.42	58.64
Dairy industry waste	Biogas (mL)	170-240	400-550	280-430	190-270	125-210	210-370	230-370	140-210	160-210	170-280	200-310	95-260	110-180	180-350
	Av. Biogas mL/day	322.03	468.17	369.33	236.33	176.50	298.83	309.00	180.17	184.67	220.33	359.00	173.50	145.87	257.00
	Std. Deviation	444.66	70.35	51.85	27.26	28.41	52.12	42.23	22.53	16.50	38.009	500.00	48.62	21.22	52.60
Farmhouse waste	Biogas (mL)	290-580	410-680	280-400	190-300	250-350	180-400	260-350	170-330	110-190	190-400	270-480	120-295	145-275	210-435
	Av. Biogas mL/day	437.00	560.33	352.67	253.00	301.17	290.00	300.33	267.00	157.83	282.00	393.17	217.83	217.33	491.77
	Std. Deviation (SD)	90.14	127.83	39.73	38.96	33.520	67.77	32.53	46.54	27.63	96.54	69.81	58.32	45.40	898.83

Although, there was an increase in the biogas production after pretreatment in case of *Ipomoea*, the amount of increase was not very large. The increase in the quantities of daily biogas was not much significant if we take into account the requirement of time and alkali for pretreatment, which could add to the cost of overall biomethanation process, and hence, it hints at the use of untreated weed biomass for biomethanation, especially *Ipomoea*.

Biomethanation Potential Studies on Admixtures of Untreated and Pretreated Biomass with Agro-industrial Wastes

The 14 weeds were used in combination with various agro-industrial wastes in the proportion of 75% weed and 25 % waste with a retention time of 30 days. It was found that all the 14 weeds after admixing with distillery waste, showed expected increase in the biogas volumes. The distillery waste is a well known substrate for biomethanation, which is proved in the present study and also by many other workers (Gadre 1982). The chemical characteristics of distillery waste in the present studies showed that it has high level of TVS (64,000 mg/kg) and more organic carbon as compared to N and P, and hence, if it is admixed with substrates containing higher levels of N and P, the biomethanation can be improved. It has been observed in the present study that amount of biogas increases when weeds were admixed with distillery waste.

The maximum amount of biogas was produced in case of *Ipomoea* (677.83 mL/day), and the minimum in case of *Argemone* (111.67 mL/day). *Ipomoea* and *Argemone*, when used alone as biomethanation substrates they produced an average of only 392.17 and 67.7 mL/day of biogas respectively. This indicates that almost double amount of biogas was produced after mixing them with distillery waste. The similar pattern of increase in the volumes of biogas was observed in remaining weeds also after mixing them with distillery waste.

Like distillery waste, sugar factory waste also increased the gas production when mixed with the weed biomass. Untreated weed biomass, when used as a substrate for biomethanation, produced on an average of minimum 67.70 mL/day in case of *Argemone* to maximum of 392.17 mL/day in *Ipomoea*, but when admixed with sugar industry waste, it produced average minimum of 100.67 mL/day in case of *Cassia* to average maximum of 466.17 mL/day in *Ipomoea*. In case of admixture of pretreated weed biomass and sugar industry waste, average minimum biogas of 167.17 mL/day was produced in case of *Cassia* to an average maximum of 567.67 mL/day in *Ipomoea*, which was quite higher than the gas production in pure biomass. It was evident from the chemical analysis of sugar industry waste that it contains more BOD but less N and P, while weeds contain comparatively more N and P, which caused improvement in BOD:N:P ratios.

The dairy industry waste contained more BOD and TVS but comparatively low N and P, hence alone it was not much suitable for biomethanation. It was found that when untreated or pretreated weed biomass was admixed with dairy waste and used as substrates for biomethanation, it improved the biomethanation efficiency as compared to the weed biomass alone. Weed biomass after mixing with dairy waste produced average minimum of 84 mL/day in case of *Cassia* to maximum of average 435.67 mL/day in case of *Ipomoea* showing a substantial increase. Similar results were also obtained with the pretreated biomass of weeds.

It was found that the farmhouse waste consisted of large amount of bioamenable organics and TVS but insufficient N and P contents. When this waste was admixed with untreated as well as treated weeds, the biomethanation efficiency was increased significantly over the weed biomass alone.

CONCLUSIONS

1. Untreated weed biomass was proved comparatively a poor substrate for biomethanation than pretreated (with dilute alkali) weed biomass.
2. Weed biomass alone was not found to be good substrate for biomethanation but when admixed with industrial and agro-industry based wastes like distillery, sugar, dairy and farmhouse wastes, its biomethanation potential was increased.
3. Amongst 14 different selected common weeds and four waste combinations as a substrate for biomethanation, untreated *Ipomoea* biomass and distillery waste admixture was found to the best one amongst all.
4. Though untreated *Ipomoea* biomass and distillery waste in combination proved to be the best amongst all for biomethanation in the present study, other weeds and organic wastes, available in plenty in rural areas, should also be tried for biomethanation.

REFERENCES

AOAC 1990. Official Methods of Analysis of Association of Official Agricultural Chemists, 15th edition, Published by A.O.A.C. Inc., Wilson Bodevard Arlington, Virginia, 22201, USA.

APHA 1985. Standard Methods for Examination of Water and Waste Water, 15th Edition, American Public Health Association, Washington DC.

Bose P.R., Vashist U.N. and Gupta B.M. 1983. Viability of biomass as an alternative source of energy in India. Research and Industry, 98(9): 195.

Chellapandi, P. 2004. Enzymes and microbiological pretreatments of oil industry wastes for biogas production in batch digesters. In: G.R. Pathade and P.K. Goel (Eds.) Biotechnology in Environmental Management, ABD Publishers, Jaipur.

Gadre R.V. 1982. Studies on the microbial degradation of distillery waste (spent wash), Ph. D. Thesis, University of Poona, Pune, India.

Gopal, B. and Sharma K. P. 1981. Water hyacinth - Most Troublesome Weed of the World, Hindasia Publishers, Delhi.

Hobson P. N., Bousfield, S. and Summens 1981. Methane Production from Agricultural and Domestic Waste. Applied Science Publishers Ltd., London.

Payne, J. 1976. Energy recovery from refuse : State of the art. Journal of Environmental Engineering Div, ASCE 102 (EE2).

Trivedy, R. K. and Goel, P. K. 1984. Chemical and Biological Methods for Water Pollution Studies. Environmental Publications, Karad, India.