CHAPTER - 3

CHARACTERIZATION OF BIOMASS

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3.1 INTRODUCTION

The term biomass refers to all the earth's vegetation and many products that come from it. Biomass covers all kinds of organic matters from fuel wood to marine vegetation. Biomass has high energy content, infact the energy content of dry biomass ranges from 3888 kcal/kg to 4720 kcal/kg [64] for wood. Bio-mass energy utilizes the energy content of such items as agricultural residue e.g. bagasse from sugarcane, corn fibers, rice straw and hulls, nut shell, urban yard clippings in municipal waste, energy crops. It is renewable as long it is grown or cultivated at a rate of equal to the rate of its consumption. On the other hand the principal organic matter in all plants constituting the major forms of biomass renews naturally and adds to itself in a very short span of time. This is a significant factor, which has classified Biomass as renewable source of energy [65].

Principal organic matter in the plants constituting the major form of biomass renews naturally. Thus all form of biomass has been classified as a renewable source of energy.

Sources of bio-mass

Biomass can be obtained from different sources comprising

(i) Organic waste, which accumulate at specific location such as municipal solid waste (M.S.W.) sewage sludge.

(ii) Residues left as plants materials in the field or during the post harvest period of agricultural crops or timber.

(iii) Bio-mass plantation like (a) Food crops with sugar cane, maize, cassova, sweet sorghum and potatoes, (b) Grasses, shrubs and particularly fast growing tree species such as eucalyptus and leguminous plants (ku-babul), (c) Some hydro-carbons producing plants such as *Euphorbia athyris and Euthorbia tirucolli,* crops like sunflower, rap seeds, soyabeans and ground nuts which are rich in vegetable oil.

About 370 million tons of agro wastes are generated every year, if fully utilized can generate 6000 MW of power yearly [66].

About 45 Million tons of solid waste and about 4500 million tons of liquid waste is generated every year in the urban areas of our country. This corresponds to an estimated potential of generatin about 1000MW of power from urban waste and about 700MW from Industrial waste generated by sugar mills, pulp and paper mills, etc [67].

3.2 PHYSICAL PROPERTIES

All biomass are mixture of major compound of carbon, hydrogen, oxygen and nitrogen. The Stoichiometric formula of biomass is $CH_{1.4}O_{0.6}$. Moisture content and specific gravity are the important physical properties, which influence the reaction pathways. Energy content of the biomass can be enhanced by removing the moisture [68]. The moisture content in the biomass greatly influences the reaction rate and also the hydraulic retention time. Proper particle size of processed biomass for conversion is also very important because a smaller size of it reduces the storage volume and facilitates handling of the material. The reduced sizes of particle also facilitate the easy movement of the slurry mixture. The particle size of biomass affects the conversion process in the bio-digester. Retention time for digestion is also a function of the density, which influences the biogas production. Retention time for the digestion will increase with the increase of density. The cost of shredding the biomass will also increase with the increase of density.

Biogas is about 20% lighter than air and has ignition temperature in the range of 650°C-750°C. It is an odourless and colourless gas that burns with clear blue flame similar to that of LPG gas [69]. Its calorific value is 20 Mega Joules (MJ) per m^3 (4700 Kcal/m^3) [70] and burns with 60% efficiency in a conventional Biogas stoves. The gas is useful as a fuel substitute for firewood, dung, agricultural residues, petrol, diesel, and electricity, depending on the nature of use, local supply conditions and constraints [71].

3.3 CHEMICAL PROPERTIES

Chemical properties govern in general the volatility, heat content, chemical reaction and characteristics of biomass. The volatility of biomass materials can be evaluated from proximate analysis. This is a function of the chemical composition as evidenced by the molecular arrangements. Calorific value is also an important chemical parameter determining its suitability to use as a fuel. About 70% of the terrestrial bio mass are obtained from forest [72-74]. The structural components of wood are shown in table 3.3 [75,76]. The woody tissues are mainly composed of cellulose, hemicelluloses in particular pattern with other compounds such as lipids, hydrocarbons, etc. Chemical analysis shows that wood contain 50% carbon. The second major component of wood is oxygen (44%). The amount of hydrogen (6%), nitrogen (1%) and ash is supposed to be negligible [77]. The wood, like coal, can be gasified to carbon monoxide and hydrogen and it may also be liquefied and pyrolysed to yield ammonia, carbon, methanol, hydrocarbon etc. Biomasses are oxygenated complex compound as it is composed of cellulose, hemi-cellulose and lignin. The contents like carbon, hydrogen, nitrogen, oxygen, sulphur is to be analysed accurately for understanding their conversion to bio-fuel.

Table No. 3.3 Chemical composition of different woods

Wood	Cellulose	Hemi-cellulose	Lignin
Trembling Aspen	56.6		16.3
Beech	5.8	32.7	22.1
White Birch	44.5	36.6	18.9
Red Maple	44.8	31.2	24
Jack Pine	45	26.4	28.6
White Spruce	48.5	21.4	27.1
Eastern White Cedar	48.9	20.4	30.7
Eastern Hemlock	45.2	22.3	32.5
Oak Wood	44	20	26
Sycamore Wood	46	14	22
Grasses (Palums, bamboos, sugar, cane,)	25.4	25.5	10.3
Soft Wood (pine etc.)	42	27	28

Source: Green Energy (Biomass Processing and Technology), 2003, Capital Publishing Company, New Delhi, p 26.

3.3.1 Carbon / Nitrogen (C / N) Ratio

The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon / Nitrogen (C/N) ratio. A Carbon/Nitrogen ratio ranging from 20 to 30 is considered optimum for anaerobic digestion [78].

It is important that the bacterial elements present in the waste uses up carbon 30 times faster than they use up nitrogen. This is why the fixation of carbon to nitrogen ratio in the right proportion is essential along with monitoring of temperature, pH, etc. Considering the optimum values of pH, temperature etc. a Carbon to Nitrogen (C/N) ratio of 30:1 is maintained for obtaining optimum digestion rate [79].

If the C/N ratio is very high the nitrogen will be consumed rapidly by methanogen for meeting their protein requirements and will no longer react with the left over carbon content of the material. As a result gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH_4) [80]. Ammonia will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing toxic effect on methanogen population [81]

Animal waste, particularly cattle dung, has an average C/N ratio of about 24. The plant materials such as straw and sawdust contain a higher percentage of carbon. The human excreta have a C/N ratio as low as 8.

C/N ratio of some of the commonly used materials is presented in table no. 3.3.1.1 [82].

Table No.3.3.1.1 C/N ratio of some organic materials is mentioned below:

Raw Materials	C/N Ratio
Duck dung	8
Human excreta	8
Chicken dung	10
Goat dung	12
Pig dung	18
Sheep dung	19
Cow/ buffalo dung	24
Water hyacinth	25
Elephant dung	43
Straw (maize)	60
Straw (rice)	70
Straw (wheat)	90
Saw dust	Above 200

Source: " Bio-gas technology: a training manual for extension", (FAO/CMS, 1996).

The general quality of biogas can be estimated from the C/N ratio of the raw materials as mentioned in the table no.3.3.1.1.

Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite input to a desirable level. Infact, as means to balance C/N ratio, it is customary to load rice straw at the bottom of the digester upon which latrine waste is discharged.

Table No. 3.3.1.2 Gas Productions according to C/N Ratio of various waste

	Wastes	CH_4	CO_2	H_2	N_2
C/N Low (High Nitrogen)	Blood, urine	Low	High	Low	High
C/N High (low nitrogen)	Saw dust, straw, sugar and starches such as potatoes, corn, sugar beet wastes	Low	High	High	Low
C/N Balanced (C/N = near 30)	Manures, garbage	High	Some	Low	Low

Source: Fry L.John, 19, Methane Digester for Fuel Gas and Fertilizer, 2004.

3.3.2 pH value of slurry mixture

The optimum biogas production is achieved when the pH value of the input mixture in the digester is between 6 and 7. The pH in a bio-digester is also a function of the retention time. In the initial period of fermentation as large amount of organic acids are produced by acidogenic bacteria, the pH inside the digester can decrease to below 5. Low pH inhibits the growth of the methanogen bacteria and hence gas generation is often the result of over loading [84]. Acetate and fatty acids produced during digestion tends to lower the pH of digester liquor [85]. Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5. Later, as the digestion process continues, the concentration of ammonia increases due to digestion of nitrogen, which can increase the pH value to above 8. When the methane production level is stabilized the pH range remains buffered between 7.2 to 8.2 (FAO/CMS, 1996b) [86]. A pH higher than 8.5 will start showing toxic effect on methanogen population. Hansen et al. (1998) states that acetate - utilizing methanogens are responsible for 70% of the methane produced in biogas reactors) [87].

3.3.3 B.O.D. and C.O.D. ratio

BOD is a measure of the amount of O_2 required for the Biological oxidation of the organic matter under aerobic condition at 20°C and for a period of 5 days. Microorganism consumes biodegradable materials and amount of material consumed is proportional to the amount of oxygen present in the stream. In anaerobic digestion no oxidizing agents are added and hence amount of BOD resume is proportional to methane produced [88]. The rate of BOD reaction depends on the type of waste present and temperature and is assumed to vary indirectly with the amount of organic matter (Organic Carbon) present.

Chemical Oxygen demand is a measure if any kind of oxidisable impurities present in the organic compounds [89], most of the organic matter are completely oxidized by a boiling mixture of chromic acid and H_2SO_4 to produce CO_2 and H_2O.and the results are on a mass basis in term of the amount of O_2 that would be required if it were electron acceptor.

Expected BOD /COD ratio is always greater than 0.5 to ensure proper biodegradability during anaerobic digestion. Anaerobic digestion is not preferred if BOD/ COD is < 0.33. The BOD for kitchen waste observed was 44000 mg/lit. and COD 57000 mg/lit [90].

3.4 RELATIONSHIP OF BIOMASS PROPERTIES AND CONVERSION PROCESS

Exploitation of biomass as an energy source will not to be to its fullest extent if used as a fuel for cooking. However, converting into combustible gasses by biotechnological mean [91-94], it has wider application and can be used as an alternative fuel for cooking, generating Electricity by driving an Engine.

The biomass conversion techniques mainly of three fundamental types namely combustion process, dry chemical process and aqueous process and the choice depends on the biomass water contents. The principal routes and product involved in these techniques are given in fig. nos. 3.4.1.and 3.4.2.

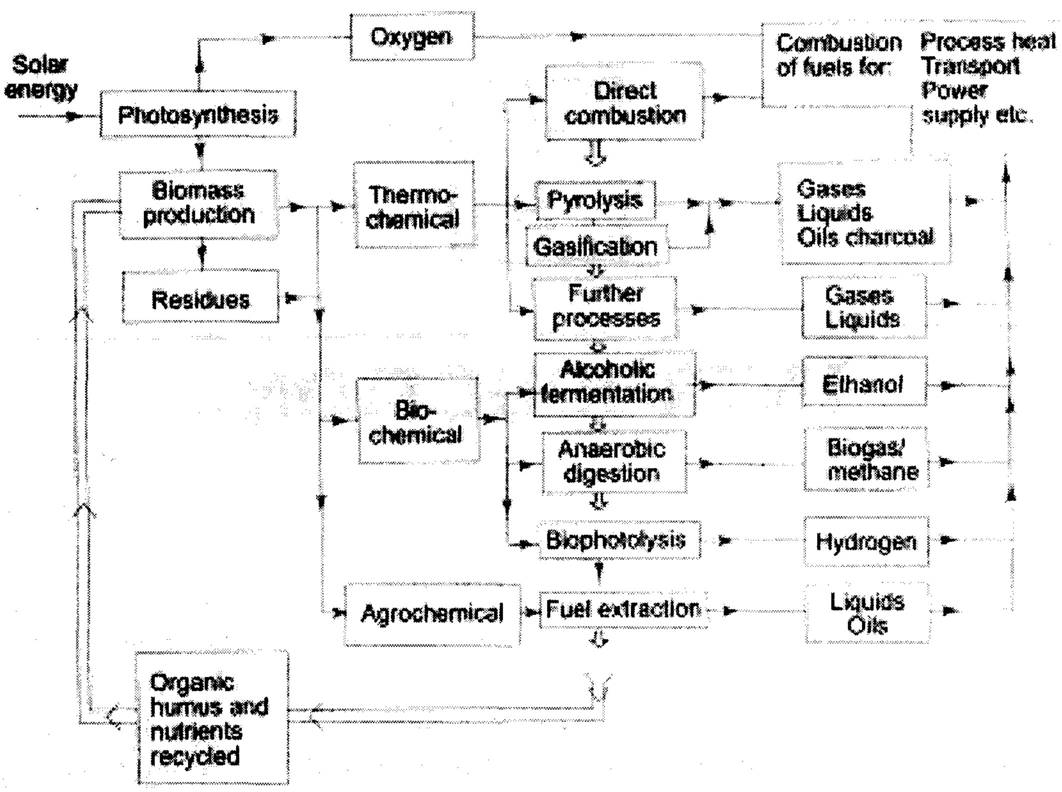

Fig. No. 3.4.1: Biomass Conversion Route to Bio fuel

Source: Nijaguna, B.T., "Biogas Technology", Published by New Age International (P), 2002, p 2

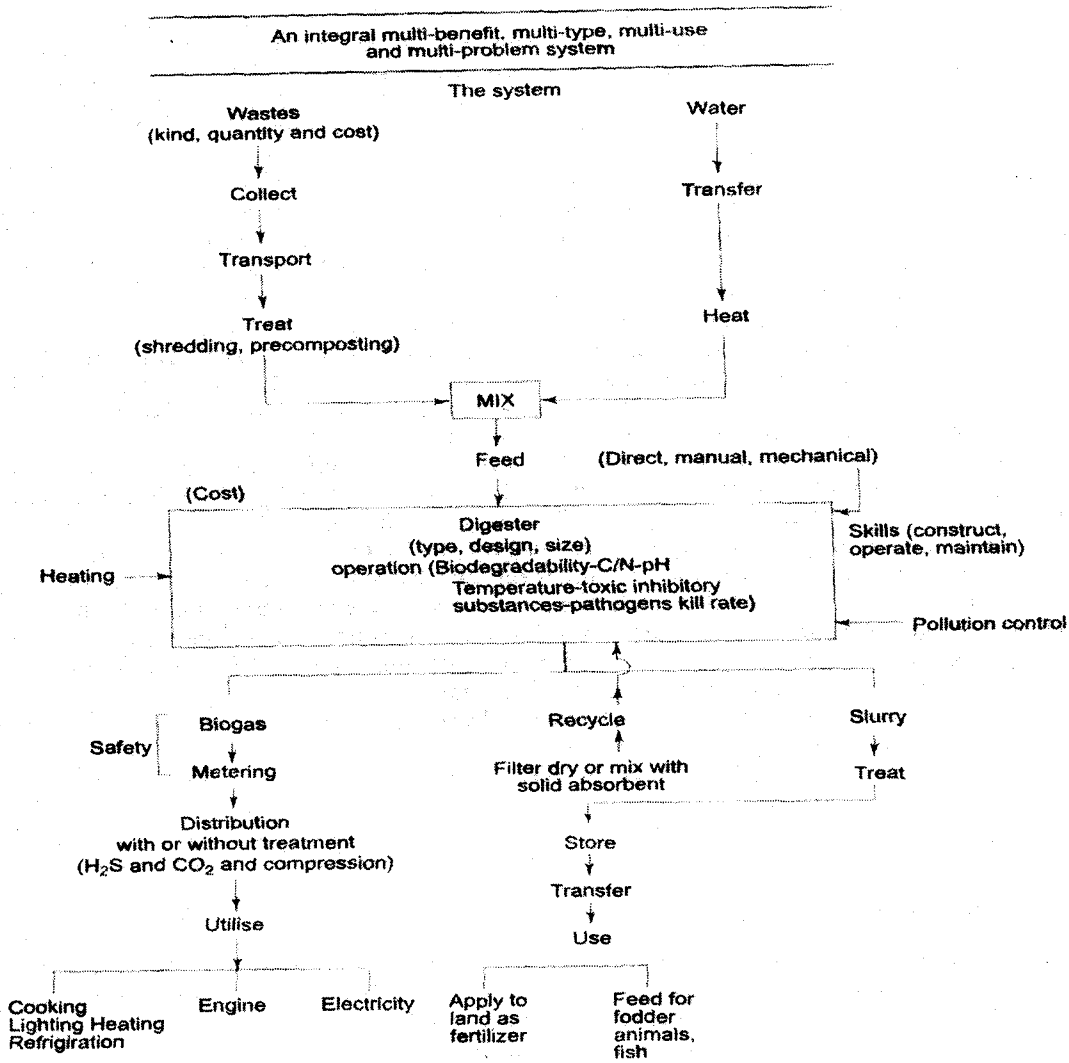

Fig. no. 3.4.2. The Biogas/ Biomethanation System

Source: Nijaguna, B.T. , "Biogas Technology" , Published by International (P), 2002, p 3

Based on the above conversion process -Biomass can be converted into energy, either in the form of liquid fuel or gaseous fuel by means of suitable microbes.

3.5 BIOMASS ENERGY CONVERSION TECHNOLOGY

Biomass has been used for many thousand years as a source of energy. Direct combustion of biomass considered as a source of fuel throughout the history of human civilization. The process of direct use of biomass as a fuel for cooking and heating purpose rather inefficient. But conversion to combustible gas by bio technological means will have wider application purpose. Biomass conversion techniques, mainly of three fundamental types i.e. (i) combustion, (ii) dry chemical process, (iii) aqueous process are chiefly used depending on the biomass water contents [95].

The principal routes and product involved in these techniques are given in fig. no. 3.5.

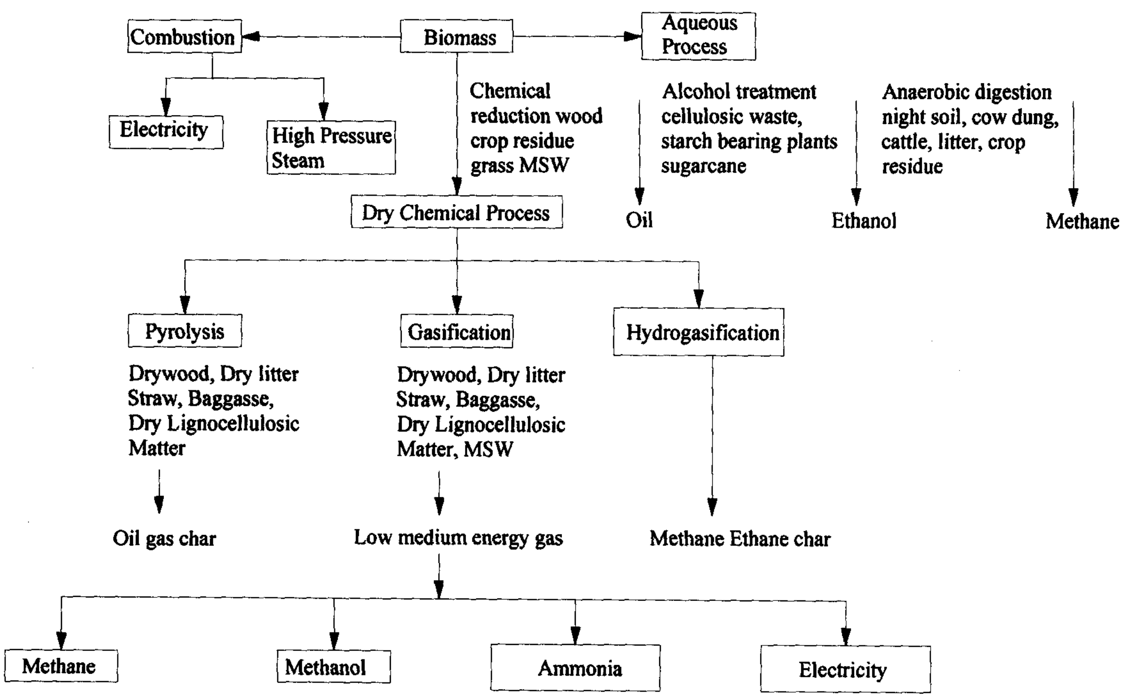

Fig. No. 3.5: Biomass Energy Conversion Technology

Source: Green Energy (Biomass Processing and Technology), 2003,Capital Publishing Company, P 103.

Biomass that contains high percentage of moisture and for this reason thermal gasification or pyrolysis of the feed is not recommended. On the other hand, it is very much suitable to follow the anaerobic digestion of the feedstock where moisture removal is not necessary. So the conversion process should be considered depending on the characteristic of the feedstock.

3.5.1 Advantage of methane

Biomass can be converted to a variety of energy forms including heat (via burning), steam, electricity, hydrogen, ethanol, methanol, and methane. Selection of a product for conversion is dependent upon a number of factors, including need for direct heat or steam, conversion efficiencies, energy transport, conversion and use of hardware, economics of scale, and environmental impact of conversion process of waste and product use. Under most circumstances methane is an ideal fuel.

Compared to other fossil fuels, methane produces few atmospheric pollutants and generates less carbon dioxide per unit energy. Because methane is comparatively a clean fuel, the trend is toward its increased use for appliances like vehicle, industrial applications, and power generation. Other fuels such as methanol and hydrogen are not well developed commercially for production and use are more difficult to produce from biomass.

3.5.2 The benefits of anaerobic digestion

The benefits of anaerobic digestion include the following such as odour reduction, reduction in the biological oxygen demand of treated effluent by up to 90%, reducing the risk for water contamination, Improved nutrient application control, because up to 70% of the nitrogen in the waste is converted to ammonia, the primary nitrogen constituent of fertilizer, reduced pathogens, viruses, protozoa and other disease- causing organisms in lagoon water, resulting in improved mainly health and possible reduced water requirements, and potential to generate electricity and process heat.

Laboratory and pilot studies have been carried out at different places in India to convert various biomass feed stocks to biogas, notably with water weeds such as water- hyacinth (*Eichhornia* sp.) and salvia [96]. These feedstock was simply fed to the pulverizer in order to obtain small particles and render them into slurry [Hobson et al.1981] and feed them to the conventional type of biogas plant. Similar efforts have been made with kitchen waste [97], crops residues such as rice straw [98].

3.6 ANAEROBIC DIGESTION OF VARIOUS ORGANIC WASTE

The people throughout the world in recent years are very much concerned about the environmental pollution caused by the large quantity of garbage and waste materials, which are generated in urban areas, and also by the industrials sectors. The generated waste materials thus needs scientific treatment in order to maintain the pollution control levels and also recovering the huge energy potential from them. The quantity generated every year in class-1 cities in our country is estimated to be about 30 million tones of municipal solid waste and about 440 million cubic meters of sewage [99]. In addition to these large quantities of waste are also produced by manufacturing and other processing industries like sugar mills, distilleries, pulp and paper mills, dairies, slaughter houses, tanneries, pharmaceutical units, etc. These waste have energy potential equivalent to 1700 MW (1000 MW from urban waste and about 700 MW from industrial waste) [100].

Treatment of these waste are mostly organic in composition and have the potential of energy recovery with multiple benefit such as abatement of environmental pollution.

In view of the above, the ministry has implemented projects throughout the country. One such program with the help of UNDP/GEF have been stabilized on development of high rate bio-methanation process to reduce the emission of green house gases. The National Environmental Engineering Research Institute (NERI) has taken of a pilot project for de-sulfurization of biogas as R&D projects at M/S Vam Organic Chemical Ltd., Gajraula (UP), and Nagpur sponsored by the MNES. [101].

3.6.1 Biomethanation of Industrial Effluents

Indian Renewable Energy Development Agency Limited (IREDA), was established under ministry of non-conventional energy sources (MNES), Govt. of India with the following objectives:

(i) To promote renewable sources of energy,

(ii) To provide financial support to manufactures and users,

(ii) To assist in rapid commercialisation,

(iv)To provide consultancy.

The Process:

The process called anaerobic fermentation of the organic waste generates biogas. Anaerobic digestion or bio methanation is a complete process carried out by a number of species of bacteria with varied characteristics. The anaerobic digestion takes place in two different bio-chemical stages. First the acid forming bacteria act and degrade long chain organic compounds effluents to acetic, propionic and butyric acids and in the second phase the methanogenic bacteria act to generate biogas comprising methane, carbon dioxide and hydrogen sulphide. The bacteria feed upon the BOD contributors of the effluents and convert them into methane gas [Source: IREDA, Energy forever].

3.6.2 Methane production by anaerobic digestion using Water-Hyacinth_(*Eichhomia crassipas*).

Water hyacinth a native of South America is abundantly found in India, Bangladesh, South East Asia and in Philippines Island. Under favourable conditions a growth rate as high as 17.5 metric tones of water hyacinth per hector per day has been reported. [102-104].

Water hyacinth is a wetland plant and aquatic biomass species and grows submerged in water and show various adaptation to this habitat (Visual dictionary, page 158) [105]. It has been suggested that this plant is a strong candidate for producing methane by anaerobic digestion method. The study was carried out in a batch fed digester (fixed dome type), [106].

Water hyacinth is chopped and mixed with plant sludge for obtaining rich compost, which can be utilized in sugarcane cultivation. The entire process was developed as a natural and inexpensive technique of recycling liquid waste [107]. Attempts have been made to reach at an optimum condition for the production of maximum amount of gas by the addition of lower volatile fatty acids, cow dung and inoculums. Addition of cow dung increases the gas production as well as it lowers the retention period. This has been observed that the total volatile solid content of the system increases with the increase amount of cow dung. The lowering of the retention period in the case of cow dung +water hyacinth system is due to the fact that the bacteria responsible for the degradation of biomass is facilitated by the addition of cow dung [108]. After digestion of water hyacinth inoculums can be used as good manure for soil fertility, which is free from harmful chemicals and is a boon for sustainable practices [109].

It has been observed that a blend of water hyacinth cow dung in the ratio of 2:3 by weight is most suitable for biogas production. But rate of production of biogas from water hyacinth is higher as compared to cow dung slurry. The digested slurry can be used as useful chemical free eco- friendly manure [110].

3.6.3 Biogas from slaughter house wastes

Study reveals that huge quantity of waste generated from the slaughter houses is about 3600 tones per day in India which consists of: floor washings, stomach contents, small bone and meat pieces. Floor washings mostly contain blood, small meat and bone pieces, which is collected in a pit and dumped to the dumping sites.

All the above waste is biological in nature and hence bio-methanation is the real solution for generating biogas from these wastes and also to reduce the pollution load.

Multiple models of anaerobic decomposition for the production of methane rich biogas from slaughterhouse waste had been designed and developed by G.D. Lindaur and their co-workers [111]. In these types of models two numbers of tanks were made, one for storing the half of daily amount of substrates as a first batch. After storing the same is heated and stirred in a pasteurisation tank. Once the pasteurised temperature reached, the substrate is stored until the other half of the substrate is fed into the other pasteurised tank. The pasteurised substrate is cooled by circulation and the heat, which it gives off, is used to heat the second amount of substrate. The substrate is cooled to 37^0 C in the decomposition tank and injected into the agitation process. The substrate in the pasteurised tank is agitated by a motorized stirrer and thus produces two types of circulation by which creation of any scum in the top surface is eliminated. The decomposed substrate than passes to a tank for dehydration process. The dehydrated residue is then transported to the land as fertilizer.

3.6.4 Biomethanation of Tannery waste

Biomethanation of tannery waste was first developed by the Centre for Leather for Leather Technology, CTC, Lyons, France.

It has been studied from the recent literature that the daily solid waste generated from leather processing units in Kolkata is approximately 175- 180 metric tones having an energy potential of 2.3 x 10^6 MJ which once again is equivalent to about 80 metric tones of coal [112]. Hides and skins are very rich in organic carbon content to the extent of about 50% on dry weight basis. The hydrogen content of the collagen is about 6.7% on dry weight basis. Another important feature is about 16 – 17% on dry weight basis presence of nitrogen. This is responsible for 30% of the digested solid waste remaining as residue after energy recovery which is a nitrogen rich manure. It has been observed that bio-gas generated from tanneries contain 70- 80% methane as compared to collection from cow dung, piggery waste etc which is only in the range of 50-55%. [113].

3.6.5 Bio-gas produced from kitchen waste

Kitchen waste has a good potential for generation of power and fertilizer. In big kitchen in the hostel, restaurant, hotel, there is large quantity of remnants of vegetable, fruit peel and other residues are generated. Disposal of these waste in the open area create problems of pollution. To solve this problem, one of the solutions is bio-methanation of this waste [114].

Yeole et al., [115] reported the feasibility of using the canteen waste as a feedstock in biogas digester. They suggested reduction in particle size of the waste below 2 cm, for successful operation of the biogas plant. After study it further revealed that biogas could be generated to 60 m^3 per day from the generated kitchen waste of 600 kg/day. This biogas can be used for cooking in the kitchen and can replace L.P.G. of 30 kg/day approximately. Wastewater generated from the kitchen waste plant (KWP) can be used for gardening purpose. A typical kitchen waste to energy plant scheme is shown in fig. no. 3.6.5.

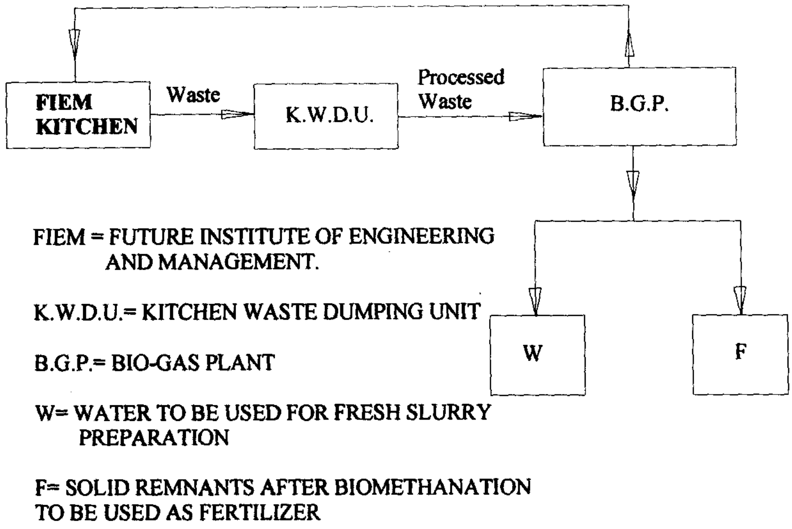

Fig. No. 3.6.5: Biogas production from Kitchen waste

It is estimated that 10- 15 % fuel requirement of a kitchen can be met with biogas obtained from kitchen waste. Kitchen waste based biogas plant set up by Bhava Atomic Research Center (BARC) at Trombay. The plant produces biogas from kitchen waste by using thermophillic microorganism that flourish in extreme environment. A kitchen waste based biogas plant has been installed at nursery site for environmental friendly disposal of the waste generated in kitchens of various canteens in BARC premises. The waste generated in kitchen in the form of vegetables refuge, cooked and uncooked food extracted tealeaves, and waste milk and milk products can all be processed in this plant. They designed and developed mixed manure by a 5 HP motor to process the waste in the form of slurry, which would be far more accessible for the microbial action. The waste is converted in slurry by mixing with water (1: 1) in this mixing tank. Sarder Patel Renewable Energy Research Institute (SPRERI),Vallabh Bidhyanagar, Gujrat, conducted experiments on generation of biogas from kitchen waste. Based on the data obtained, a prototype of a 10m^3 biogas plant was designed. To such plants were installed at two-community kitchen serving food to the students in Vallabh Vidyanagar.

3.6.6 Biomathanation of market waste

In our country there are about 400 districts with about 4000 towns and bazaar places having large vegetable market. The vegetable waste generated from these markets to be around 50000 tones per day. These vegetable wastes have the potential to generate 4million m^3 of biogas per day. Moisture content of this waste is around 70% [116]. This material is usually high in fibrous content.

To eliminate the transportation cost for transporting this waste to the site of biogas plant, it will be beneficial to set up bio-methanation plant nearby the market area. By bio-methanation process of this waste, biogas can be generated and the effluent can be used as good fertilizer. In addition the process would be environment friendly, hence improve sanitation. If such waste is recycled in biogas plant it will be a source of energy, health and wealth [117]. Because of the high content of moisture in the waste, it is not recommended for incineration, bio-methanation is most suitable for decomposition of this waste. A biogas plant was commissioned in November 1992, in Pune, India for producing biogas using market waste. Digester is floating type gasholder with water sealed type. The methane content observed is around 70% [118].

3.6.7 Biogas from Paper Mill Waste

The growing environmental concern and stringent government legislation have brought biological treatment system into spot light as means of treating pulp and paper with effluents

Pulp and Paper Mill effluent is a potential source for conversion of waste to energy. Treatment of paper mill waste through UASB not only helps in environmental preservation but also produces energy by converting waste to energy. The additional advantage is that the biogas produced from the anaerobic treatment plant is used as a fuel in the boilers and meets up to 18 % of the thermal energy required for cooking the meals.

A biogas plant was set by nuclear fuel complex in Hyderabad, India, July 1991 to utilize the paper waste in order to get methane [119]. The waste paper fed initially to a shredder for size reduction then mixed with water to produce slurry at about 5- 10 % consistency. The slurry mixture is than dropped through screen to the preliminary digester where the previously weighted food waste is added. The waste then mixed with the help of mechanical agitator for an hour to form pulper. This mixture is finally transferred to pre- digester. Sometime a measured quantity of urea and caustic soda is added for faster process in the digester. After 24 hours of reaction time, the mixture is transferred to first anaerobic digester for acid formation and finally it is fed to the second anaerobic digester for methanation. It was found satisfactory production of biogas from the plant.

3.6.8 Bio-gas production from cow dung

Dr. Ram Bux Singh and his co-workers have designed and set up a biogas plant in the name of Gobar Gas Research Station at Ajitmal [120] in India in 1960 having capacity of 100 to 9000 cubic feet of methane per day. They have experimented with different mixture of manure and vegetable waste.

Cow dung gas having 55- 65% methane, 30- 35% carbon dioxide with some hydrogen, nitrogen and other traces. Its heat value is about 600 BTU per cubic feet. Gobar gas may be improved by passing it through limewater to reduce CO_2, iron fillings to absorb hydrogen sulphides and calcium chloride to extract water vapour. It has been observed that after degradation, the cow dung slurry is composed of (1.8- 2.4) % nitrogen, 1.0- 1.2% of phosphorous (P_2O_5), 0.6- 0.8% potassium dioxide (K_2O) and 50- 75% organic manure [121].

S.Singh and S.K. Singh has produced approximately 22% more bio-gas from the cow dung as compared to the normal decomposition by adding cupric nitrate {Cu $(No_3)_2$} as an accelerator in the digester and in the process gas production is increased by about 22% [122].

Punjab Energy Development Agency (PEDA) has developed non-conventional sources by utilizing the cow dung originating from the dairy units in the Haebowal complex in Ludhiana for the production of electricity, [123]. Biogas technology has been commercially introduced in Nepal since the establishment of a unit by Gobar Gas Tatha Krishi Jantra Vikas (P) Ltd in the year of 1977.

3.6.9 Biogas production from cotton waste

It has been observed that cotton textile dust is a good raw material for the purpose of anaerobic fermentation and could be economically converted into biogas and manure. One kg of micro-dust can generate about 200 m^3 of biogas in 50 days.

At present there is no use of this cotton waste except to some extent it is composed for cultivating vegetables, this can be a good source of generating thermal energy through biomethanation.. The country can generate useful fuel from the available cotton waste, equivalent to 30 lacs liter of petrol or 18,26,086 kg LPG [124].

3.6.10 Biogas production from human excreta (night soil)

Originally, it was envisioned that the waste of the latrine would be collected into a settling tank and the excess of liquid would be drained into a soaking pit. The settling tank, which was conceived as a manhole chamber substituted pre-storage tank. Thus, the faecal raw sludge from the latrine is first collected into this manhole compartment from where it is led into the bio digester. Excess of urine can create toxicity to the methanogenic bacteria for which a provision was made to drain it into a soak pit particularly from the urinals constructed in the male section of the latrines. The concept of the integrated production and use of biogas and stabilized manure from the community latrine-cum biogas plant has been shown in the figure no.3.6.10

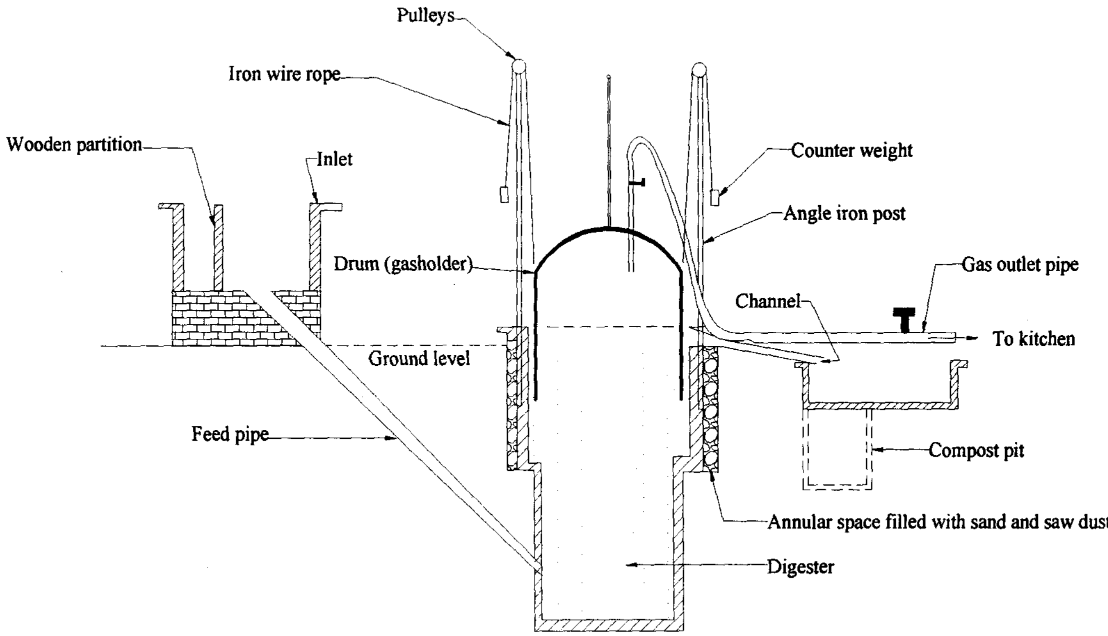

Fig No. 3.6.10: Biogas Plant based on human excreta

Chinese are the first front in using human excreta at mass scale level [125,126].

A fixed dome Chinese type Gobar gas plant of 15 m^3 capacity was installed by Agricultural Equipment Development Company as approved by biogas support program of the Netherlands development organization (SNV/ Nepal) was installed to produce bio-gas and stabilized manure Human excreta is also an excellent feed material for anaerobic fermentation. On an average 85% volatile solids are present in human excreta and the carbon to nitrogen (C/N) ratio is low [127-132]. The excess of ammonia present/ produced during digestion is generally neutralized by volatile fatty acids accumulated in the digester, due to over loading. Besides this night soil is rich in organic content, nutrients are easily susceptible for microbial digestion. For these reasons it is often responsible for environmental pollution and a host of diseases. With proper technique of microbial treatment night soil can be processed production of value added gases and low cost fertilizer. This means bio-methanation of human excreta has two important aspects; environmental sanitation and energy generation. In India, utilization of night soil in biogas plant was first initiated by "Appa Saheb, Patwardhan of Maharastra Gandhi Smarak Nidhi, Pune, in the year of 1953." The biogas generated from such plant is used for cooking, lighting and generation of electricity [133-134]. Estimated Human excreta and animal wastes available in Indian conditions are mentioned in the table no. 3.6.10

Table No. 3.6.10

Source (Waste)	Total Waste (Kg./day/head)	Collectable Kg./day/head
(a) Cattle	10-15	5-8
(b) Pigs	1.3	0.3
(c) Sheep	0.75	0.25
(d) Man /person	0.75	0.75
(e) Kitchen Waste/ person	0.25	0.25
(f) poultry	0.06	0.06

Source: Nijaguna, B.T., " Biogas Technology", New Age International Publishers (P) Ltd, page 28.

It has been observed that addition of inoculums from an operating digester and a little amount of molasses to a fresh digester reduces time of gas production [135].

3.6.11 Biogas generation by plug flow type of digestion using pig manure.

The first effort to produce biogas in a controlled way and in quantity was done by a South African pig farmer, L. John Fry, R.A.F. Retired [136]. Mr. Fry built the first "continuous – feed displacement digester"- A closed concrete tank, 50 ft. long, 11 ft. wide and 5 ft. deep. A few sealed hatches were left for access points and a pipe led to a huge gas storage tank. Raw manure from 500 pigs was mixed with water poured into a loading pit, and pumped into a digester. In every 24 hour, the mixed daily load in the digester transferred to the adjoining digester by injecting fresh material at the input end. The mixed slurry was retained in the digester for 30 days.

The sludge was odourless, entirely free from harmful bacteria and much richer in nitrogen than manure composted in an open-air heap. About 3000 cubic feet of biogas per day was generated continuously. Part of the gas was used for heating and cooking; the rest was used for generating electricity.

3.6.12 Metals supplementation enhances biogas generation.

Heavy metals such as copper, nickel, chromium, zinc, lead, etc. in small quantities are essential for the growth of bacteria. But their higher concentration has toxic effects. Mineral ions, heavy metals and the detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digester. Small quantity of minerals ions also stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effects. The inhibiting levels of some major substrates that produce toxicity on bacterial growth are given in table no.3.6.12

Table No. 3.6.12 Toxic level of various inhibitors

Inhibitors	Inhibiting Concentration
Sulphate (SO_4^{2-})	5000 p.p.m.
Sodium Chloride or Common salt (NaCl)	40000 p.p.m.
Nitrate (calculated as N)	0.05 mg/ml
Copper (Cu^{2+})	100mg/l
Chromium (Cr^{3+})	200mg/l
Nickel (Ni^{3+})	300-500mg/l
Sodium (Na^{+})	3500-5500mg/l
Potassium (K^{+})	2500-4500mg/l
Calcium (Ca^{2+})	2500-4500mg/l
Magnesium (Mg^{2+})	1000-1500mg/l
Manganese (Mn^{2+})	Above 1500mg/l

Source : Biogas Technology in China, BRTC, China (1989)

3.6.13 Bio-methanation potential of municipal waste water

Municipal wastewater is a potential feedstock for bio-methanation. It reveals from Literature Survey that thousand gallons of municipal wastewater yield about 0.25 m^3 of biogas. It is anticipated that about 46000 NM^3 of biogas can be produced per day from 340 million litres daily from municipal wastewater. There is a possibility to generate 99450 kwh. per day of electrical energy from the installed biogas plant in 21 cities under Ganga Action Plan [137].

Apart from municipal wastewater, the other waste generated from industries like dairies, distilleries, tanneries, paper and pulp industries, has the potential to generate nearly 700 MW of power [138].

3.6.14 Bio-methanation of market organic waste

Large vegetable and fruit markets in big cities contribute much to the accumulation of this waste which is disposed –off by composting, spreading on the land or some times as an animal feed [139, 140]. Over 600 tonnes of fruits vegetables are produced annually in India, of which only one percents processed in fruit and vegetable processing industry [141]. Market waste consists of mainly seasonal vegetables waste; fruit waste, packing materials, plastic, etc. Types of these waste has been shown in the fig. no.3.6.14.1

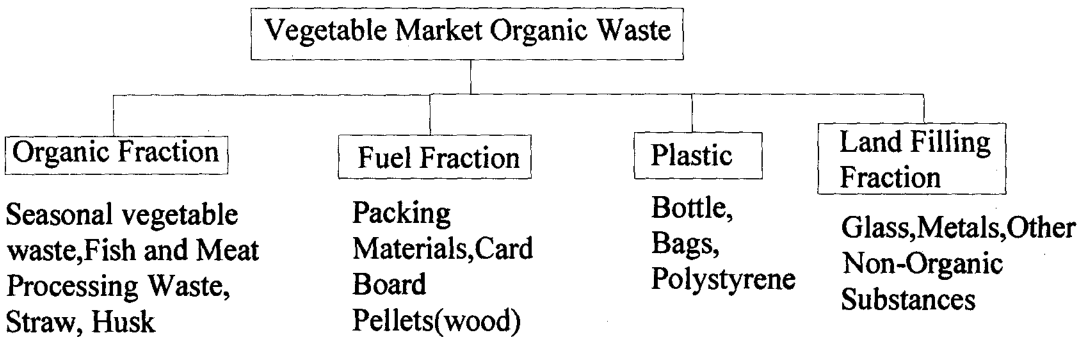

Fig.No.3.6.14.1: A schematic diagram of vegetable market organic waste (Based on general appearance)

Composition of typical organic waste from vegetable market is given in Fig. no.3.6.14.2

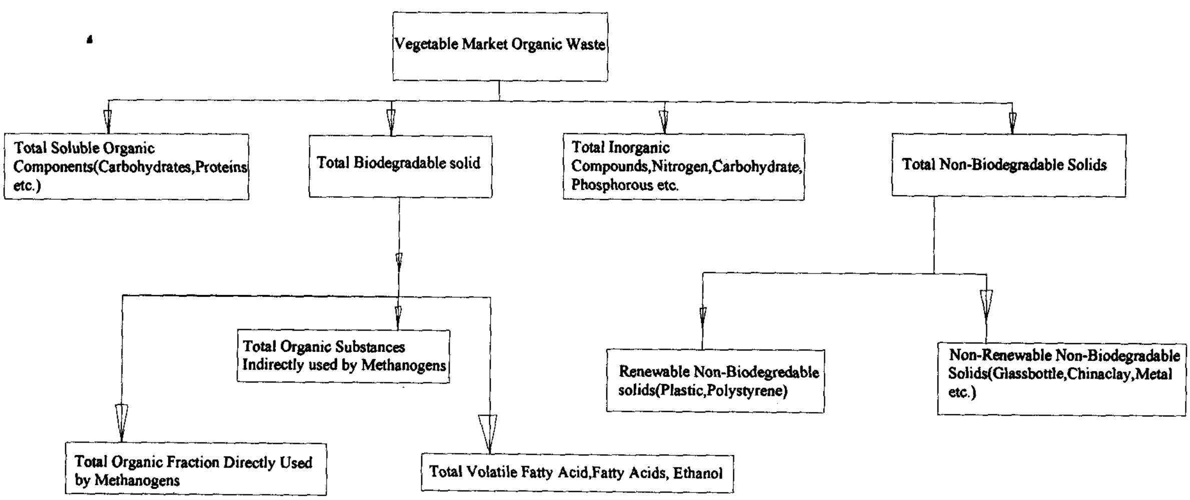

Fig No.3.6.14.2: Composition of Market Organic Wastes

Production of biogas from market organic waste (M.O.W.), depends on the composition of seasonal vegetables and other organic waste present. It has been observed that the total carbon content in market organic waste is 40% and nitrogen is in the wide range of 21.32 – 76.5 [142].

In order to get maximum biogas the ratio of C/N is generally maintained between 20-30.

However in case of paper and sewage waste maximum yield of biogas has been noticed at C/N ratio of 52. [143]

3.6.15 Biogas from Banana Stems

Banana stems are fibrous and has very high moisture content; 83% of its local solids are volatile which offer potential for anaerobic digestion. Its C/N ratio is 25 and cellulose content is 17% of dry weight, both of which are good for anaerobes. From extensive studies at laboratory and pilot scales, the following observations are reported:

i. One Kg of fresh banana stems (moisture content 95%) generates 25- 30 litres of biogas. One Kg of sun dried banana stems (moisture content) generates 330- 350 litres of biogas [144].

ii. Methane content in biogas generated from banana stems is in the range of 60- 70% compared to 50- 55% in the biogas produced from cattle dung. Hence, the biogas produced from banana has higher calorific value.

iii. The retention period for the degradation of banana is 40 days compared to 30- 35 days for cattle dung. Specific gravity of banana stems is 0.5 compared to 1.01 for cattle dung. The substrate to water ratio for the degradation of banana stems is 1:2 compared to 1:1 for cattle dung. Hence, the degradation for banana stems requires more volume than that of cattle dung degradation.

iv. Behaviour of banana stems under anaerobic digestion is different from that of cattle dung. Fresh banana stems float over the water surface and digested material sinks to bottom.

Fully digested material is in the form of powder.

v. The fresh and floating material forms a mat over the water surface and sticks to the vertical sides of the floating gasholder.

vi. As the behaviour of banana stems mentioned above is different from cattle dung, the traditional designs of biogas plant (KVIC, Janata) are not suitable for banana stems.

This plant has the following features:

i. Input material is provided through a masonry wall near the top of the digester and the output chamber is connected to the bottom of the digester to facilitate the feeding of fresh material and discharging the digested slurry.

ii. Hopper bottom is provided to prevent accumulation of digested material.

iii. A stirrer is fitted centrally to the digester having the horizontal and vertical bars so that the slurry material inside the digester being stirred throughout the depth of the slurry and also to break the scum appeared over the top surface of the slurry.

3.6.16 Biomethanation of Municipal Solid Waste (MSW)

Anaerobic digestion systems for digesting Municipal Solid Waste are now widely used through out the world. The majority of plants are large scale, processing over 2,500 tonnes of waste per day and thus involve complex plant design including the handling system of the voluminous waste. Most of the technology is based in Europe, with Germany and Denmark leading the field in technology and in the number of successful plants in operation. [145].

In municipal solid waste, acetic and lactic acids are produced during storage, and in source-separated organic waste, these acids can reduce the pH value to 4-5 [146]. The initial period of low pH can be significantly reduced if the temperature in compost stays below 40^0C

until pH rises [147].

To increase the rate of digestion and biogas production multi-stage processes are often used. Most of the larger scale, industrial systems process MSW alone, however the simpler, smaller scale systems are more successful when co-digestion with animal manure is used.

Breakdown of facility by the different country is shown in table no. 3.6.16

Table No.3.6.16 Breakdown by various countries of Anaerobic Digestion Plants (capacity of 2500 Tonnes per year).

Country	No. of plants in operation	No. of plants under construction
Austria	10	0
Belgium	1	2
China	0	1
Denmark	21	1
Finland	1	0
France	1	0
Germany	30	9
India	0	4
Italy	4	2
Japan	0	1
Netherlands	4	0
Poland	0	1
Spain	0	1
Sweden	7	2
Switzerland	9	1
Thailand	0	1
U.K.	0	1
Ukraine	1	0
U.S.A.	1	2

Source:IEA Bio Energy Report 1997-System and Market Overview of Anaerobic Digestion.

The following sequences are being followed of Anaerobic Digestion of MSW

(i) Digester Material

Only Waste of organic origin can be processed in an anaerobic digestion about 30-60% of household waste there is a considerable benefits in diverting this waste from landfill, MSW is composed of: -

a) Digestible organic fraction-readily biodegradable organic matter, eg. Kitchen waste, Food residue, Vegetable waste, Grass cutting etc.

b) Combustible fraction-Slowly digestible organic matter such as coarser wood, papers, cardboard.

c) Inert fraction-Stones, glass, sand, metal etc. Some of these products are suitable for recycling, the reminder can be land filled

(ii) Separation

Source separation: Recyclable materials separated from organic waste in the source. The production obtained is more contaminated which will affect the heavy metal and plastic content of the final digested composting product.

(iii) Pre-Treatment

Having separated any recyclable or unwanted material from the waste, the organic material must be chopped / shredded before it is fed into digester.

(iv) Anaerobic digestion

The process of digestion follows three stage,

(a) Hydrolysis or liquification

(b) Acetogenesis/Fermentation

(c) Methanogenesis

(v) Final Product

The gas produced through anaerobic digestion is methane, carbon-dioxide, hydrogen sulphide.

(vi) Up gradation

The generated gas should be upgraded by eliminating CO_2, H_2S and water vapour so that the up graded gas can be used for cooking, as an alternative fuel for I.C. engines.

(vii) Composting

Drying of the substrate is often a key objective of composting [148,149]. In household waste composting, the waste normally has as solids contents of 30-60 % and the concentration of readily available substrate is high. This makes the compost susceptible to high temperatures and excessive drying. In fact, water addition can often speed up the composting process [150].

Advantages of MSW anaerobic digestion

Following advantages can be noticed by anaerobic digestion of MSW:-

(i) Makes land fills easier to manage by removing problematic organic waste material

(ii) An end product can be used as a soil conditioner is produced.

Anaerobic digestion for solid waste can be processed through one stage dry system and the same has been inspired for digestion of organic waste, during the 80`s.

Later the conversion technology is mediated by two stage systems that lead to large overall reaction rate of biogas yield.