# CHAPTER 16

# EMERGING PROCESSING TECHNOLOGIES

## 16.1 INTRODUCTION

Besides the established techniques such as composting, incineration, etc. (chapters 14 & 15), various new methods are being developed for processing of municipal solid waste. All these methods reduce the pollution potential & quantity of solid waste requiring to be disposed off and also sometimes result in recovery of some by products having potential use.

These processes commonly follow either the biological or the thermal route. However, a few methods use a combination of these routes while others which treat the waste as an ore etc. have been developed in the developed countries but their suitability for the Indian municipal solid waste has not yet been established are discussed in this chapter.

## 16.2 VERMICOMPOSTING

Vermicomposting involves the stabilisation of organic solid waste through earthworm consumption which converts the material into worm castings. Vermicomposting is the result of combined activity of microorganisms and earthworms. Microbial decomposition of biodegradable organic matter occurs through extracellular enzymatic activities (primary decomposition) whereas decomposition in earthworm occurs in alimentary tract by microorganisms inhabiting the gut (secondary decomposition). Microbes such as fungi, actinomycetes, protozoa etc. are reported to inhabit the gut of earthworms. Ingested feed substrates are subjected to grinding in the anterior part of the worms gut (gizzard) resulting in particle size reduction. Vermitechnology, a tripartite system which involves biomass, microbes and earthworms in influenced by the abiotic factors such as temperature, moisture, aeration etc. Microbial ecology changes according to change of abiotic factors in the biomass but decomposition never ceases. Conditions unfavourable to aerobic decomposition result in mortality of earthworms and subsequently no vermicomposting occurs. Hence, preprocessing of the waste as well as providing favourable environmental condition is necessary for vermicomposting.

The vermicompost is relatively more stabilised and harmonises with soil system without any ill effects. Unfavourable conditions such as particle size of biomass and extent of its decomposition, very large temperature increase, anaerobic condition, toxicity of decomposition products etc. influence activity of worms.

This technology has been used for agricultural waste and its adoption to municipal solid waste is of recent origin.

The worm species that are commonly considered are **Pheretima sp, Eisenia sp & Perionyx excavatus sp.** These worms are known to survive in the moisture range of 20-80% and the temperature range of 20-40$^{o}$C. The worms do not survive in pure organic substrates containing more that 40% fermentable organic substances. Hence fresh waste is commonly mixed with partially or fully stabilised waste before it is subjected to vermicomposting. The worms are also known to be adversely affected by high concentrations of such heavy metals, as Cd (Cadmium), Cr (Chromium), Pb(Lead) & Zn(Zinc). Due to the constraints of the temperature, moisture, Fermentable Organic Substances (FOS) and heavy metals use of vermicomposting on municipal scale has not been successful. However, use of this method for wastes from individual houses, housing colonies etc. where the waste is mainly organic in nature and where the quantities are less and can be manually handled is common.

Table 16.1 indicates the chemical analysis of earthworm casting from soil and soil mixed with cowdung.

**Table 16.1 Chemical analysis of earthworm casting**

| Casting Source | Total Nitrogen (%) | Nitrate | Total Phosphorus (P) | Water Soluble (P) | Total Potassium | Water Soluble Potassium |
|---|---|---|---|---|---|---|
| Soil | 0.18 | 0.40 | 732 | 6.00 | 84.00 | 4.0 |
| Cowdung + Soil | 0.38 | 25.00 | 521 | 2.00 | 37.21 | 88.0 |

Values, except total nitrogen are in milligram (mg)/100 gram (gm).

## 16.3 BIOGAS FROM MUNICIPAL SOLID WASTES

When municipal solid wastes with a large proportion of organic matter is subjected to anaerobic decomposition, a gaseous mixture of Methane & Carbon di-oxide ( $CH_4$ & $CO_2$ ) known as biogas could be produced under favourable conditions. The process is quite stable and upsets do not easily occur. The gas production ranges from 0.29 $m^3$ /kg of VS added/day to 0.16 cubic metre ($m^3$ )/kilogram of VS added/day in different seasons. The pH (Hydrogen Ion Concentration) of the digesting mixture remains around 6.8 $\pm$ 0.20.

The volatile solids destruction ranges from 40 to 55%. The sludge has good manurial value of Nitrogen, Phosphorous, Potassium (NPK :: 1.6 : 0.85 : 0.93) and is observed to drain easily. The process gives a good performance at a detention time of 25 days.

A large number of plants to stabilise organic waste from vegetable market solid waste to biogas have been operating in Europe and United States of America. These plants mainly use low solids digestion or high solids digestion in single stage or multistage processes. The Steinmuller Valorga process and Dranco process are reported to have a favourable cost benefit ratio. (Additional details of these plants are provided in Chapter 15).

Presently no such plants exist in India. However, proposals to construct two such plants with Ministry of Non Conventional Energy Sources funding, to process market waste are in an advanced stage of consideration.

## 16.4 CONVERSION OF SOLID WASTES TO PROTEIN

Laboratory investigations conducted at Louisana State University, USA showed that under aerobic conditions, it is possible to convert the insoluble cellulose contained in municipal waste by a cellulytic bacteria. The bacteria are then harvested from the media for use as protein. Studies were conducted using waste bagasse as the sole carbon source. The process involves size reduction followed by a mild alkaline oxidation treatment before aerobic oxidation. The bagasse is slurried in water, mixed with simple nutrient salts mixture and then fed to the reactor from where it is harvested. The single cell protein produced has a crude protein content of 50 to 60%. It has a good amino acid pattern and has been successfully tested on animals. The process has yet to be tested on a full scale basis, but shows promise, especially due to its high efficiency of protein production. It has been shown that a 450 kg bullock can synthesize 0.4 kg of protein in every 24 hours (hrs) whereas 450 kg of soyabean synthesizes 36 kgs protein in 24 hrs and 450 kg of yeast can synthesize more than 50 tonnes of protein in 24 hrs.

## 16.5 ALCOHOL FERMENTATION

This is a developing technology applicable to cellulosic biomass. It involves anaerobic decomposition of cellulosic organic matter by Ethanologic bacteria to produce mainly Ethanol.

More than 95% of the Ethanol produced world-wide is through fermentation by yeast of molasses or starch (sugar or starch substances) which are in short supply and are required for alternative uses. Ethanol production utilising less expensive, abundant and renewable feed-stock such as cellulosic bio-mass (lignocellulosics) is, therefore, desirable. Yeasts, however, are currently unable to degrade cellulose. Acid/Alkali treatment of ligno-cellulosics removes lignin & other inhibitory materials and renders the biopolymers accessible to enzymatic degradation and Ethanol production. This is, however, an extra cost factor.

Bacterial strains have been developed in recent years which yield high substrate conversion efficiencies and Ethanol tolerance. Some of these bacteria also have the ability to ferment both cellulose and hemi-cellulose leading to complete utilisation of cellulosic bio-mass. Such production of Ethanol has a great potential and is one of the best eco-friendly technologies for energy recovery from fibrous wastes. Ethanol can be used as a fuel, a fuel additive, or as a chemical feed stock.

## 16.6 PYROLYSIS

Pyrolysis involves an irreversible chemical change brought about by the action of heat in an atmosphere devoid of oxygen. Synonymous terms are thermal decomposition, destructive distillation and carbonisation. In partial combustion, oxygen is present in insufficient quantities to cause complete combustion (i.e., less than SOR). Normal combustion, as in conventional incineration requires the presence of sufficient amount of oxygen which will ensure complete oxidation of organic matter. Using cellulose ($C^6 H^{10} O^5$) to represent organic matter, the reaction is

$$C_6 H_{10} O_5 + 6O_2 \longrightarrow 6CO_2 + 5H_2 O + \text{heat} \quad (H_2 O : \text{Water})$$

$$(CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2 O + \text{heat})$$

To ensure complete combustion and to remove the heat produced during the reaction, excess air is supplied during incineration which leads to air pollution problems.

In the case of partial combustion, the reaction would be

$2\ CH_4 + O_2 \longrightarrow 2CO + 4H_2$ (CO : Carbon Monoxide
$H_2$ : Hydrogen)

$CO + H_2 \longrightarrow$ HCHO (formaldehyde)

$CO + 2H_2 \longrightarrow CH_3\ OH$ (methanol)

Thus even the simplest of hydrocarbons will yield a variety of products under conditions of partial combustion. As the complexity of fuel increases the variety of possible products also increases. Pyrolysis, unlike incineration is an endothermic reaction and heat must be applied to the waste to distill off volatile components.

When the waste is predominantly cellulose under slow heating at a moderate temperature, the destruction of bonds is selective (the weakest breaking first) and the products are primarily a non-combustible gas and a non-reactive char. On the other hand, when the waste is rapidly heated to a high temperature, complete destruction of the molecule is likely to take place. Under intermediate conditions, the system would yield more liquid of complex chemical composition. Normally these two processes are referred to as **low temperature and high temperature pyrolysis respectively**. Pyrolysis is carried out at temperature between 500 and $1000^{O}C$ to produce three component streams.

i) Gas : It is a mixture of combustible gases such as hydrogen, carbon monoxide, methane, carbon dioxide and some hydrocarbons.

ii) Liquid : It contains tar, pitch, light oil and low boiling organic chemicals like acetic acid, acetone, methanol, etc.

iii) Char : It consists of elemental carbon along with the inert materials in the waste feed.

The char, liquids and gas have a large calorific value. This calorific value should be utilised by combustion. Part of the heat obtained by combustion of either char or gas is often used as process heat for the endothermic pyrolysis reaction. It has been observed that even after supplying the heat necessary for pyrolysis, certain amount of excess heat still remains which can be commercially exploited. Though a number of laboratory & pilot investigations have been made, only a few have led to full scale plants. Details of such plants are given in Chapter 15.

### 16.6.1 Plasma Arc Technology/Plasma Pyrolysis Vitrification (PPV)

This is an emerging technology for energy/resources recovery from organic wastes. The system basically uses a Plasma Reactor which houses one or more Plasma Arc Torches which generate, by application of high voltage between two electrodes, a high voltage discharge and consequently an extremely high temperature environment (between 5000-14,000$^o$) approximating the temperature of the Sun. This hot plasma zone dissociates the molecules in any organic material into the individual elemental atoms while all the inorganic materials are simultaneously melted into a molten lava.

The waste material is directly loaded into vacuum in a holding tank, pre-heated and fed to a furnace where the volatile matter is gasified and fed directly into the plasma arc generator where it is pre-heated electrically and then passed through the plasma arc dissociating it into elemental stages. The gas output after scrubbing comprise mainly of CO and $H_2$. The liquefied produce is mainly methanol.

The entire process is claimed to safely treat any type of hazardous or non-hazardous materials. It has the advantage that the oxides of Nitrogen (Nox) and oxides of Sulphur (Sox) gaseous emissions do not occur in normal operation due to the lack of oxygen in the system.

Some United States companies offering PPV technology are Quantum Tech LLC and Global Plasma Systems, who are reported to be setting up some demonstration units based on this technology in Malaysia and Singapore.

## 16.7 REFUSE DERIVED FUEL

The process of conversion of garbage into fuel pellets involves primarily drying, separation of combustibles from garbage, size reduction and pelletisation after mixing with binder and/or additives as required.

The MSW collected for disposal is tested for its moisture content and when the moisture content is more than 35- 40%, it requires drying to produce fuel pellets with reasonable heating values. The reduction in moisture can be done artificially or by natural sun drying. Sun drying is preferred when adequate land is readily available. However, during periods of heavy rainfall, alternate arrangements for drying will have to be made. The moisture level of waste is brought down to around 35-40% by uniformly spreading it on an open, paved area and allowing it to sun dry. The duration of sun drying varies from 1 to 2 days depending upon the garbage quality. In the process of spreading the garbage, manual inspection is carried out to remove large debris, tree cuttings, tyres etc., which are harmful to the downstream process equipment.

The sun dried garbage is then uniformly fed into a rotary drying system i.e. Hot Air Generation burning oversize garbage or other fuel to further bring down the moisture level to about 10-12%. It is reported as well as proved that 10-12% moisture content is desirable to be maintained in the garbage for densifying into fuel pellets.

After drying is over, the garbage is passed through a screening equipment to separate sand/grit (below 8mm), heavier combustibles & ferrous materials which are abrasive in nature and may cause harm to process equipment. This fine fraction having organic matter in it is already proved to be useful as garden manure.

The dried and screened garbage is then passed through an Air-Classifier (Density Separator) in which the light combustibles and dense fractions (e.g. stones, glass etc.) are separated over an air barrier. At the same time, the garbage is passed over a magnetic separation unit to remove magnetic materials. The light combustibles are ground to 10/15mm particle size. The binder and/or additives are mixed with ground garbage in mixer/conditioner before pelletising. The pellets coming out of pelletiser are cooled and stored in the pellet storage yard for despatch. The pellets so produced can be used in industrial boilers and thermal power plants as fuel. A typical process flow diagram of a RDF plant is shown in Fig.16.1.

Studies were carried out in India on a plant to process 150 tonnes per day (t.p.d.) Municipal Solid Waste (MSW) to 80 t.p.d. pellets. The plant was funded by Department of Science & Technology (DST) and was set up in Mumbai in 1991. It was operated for sometime as a pilot plant but was closed down for various reasons. Based on this technology, a 350 t.p.d. plant to produce 100 t.p.d. pellets has been installed at Hyderabad through private sector participation.

## 16.8 HYDROPULPING

Due to high paper content in the waste from developed countries, a method has been developed to hydropulp the waste and recover paper fibre from refuse. The method is being used in a full scale plant of 150 tpd capacity operating at Franklin, Ohio, USA (Fig.16.2). The method is suitable for processing of paper waste. However, no such plant has yet been installed in India.

## 16.9 SLURRY CARB PROCESS

This process has been developed in USA by M/s Enertech Environmental Inc., USA to convert municipal solid waste into "Energy Fuel" (E-fuel) which is suitable for combustion in industrial and utility coal boilers. It is used in conjunction with a wet resources recovery process to separate out the recyclables. The waste slurry is then subjected to high pressure and temperature and undergoes thermal decomposition/carbonisation to "E-fuel". The received waste is first shredded and then placed in an industrial pulper. The heavier, more dense inorganic material sinks to the bottom of the water-filled pulper where it is easily removed. The organic fraction which remains, is subjected to violent pulping action which further reduces its particle size. The pulped organic waste is then subjected to a combination of temperature and pressure causing the waste to "carbonise" (a process which is similar to the natural formation of coal).

The process is claimed to lead to virtually 100% chlorine extraction, no dust or no net green house gases, no dioxin, furan and any heavy metals like mercury. The ash by product is claimed to be non-hazardous and can be used as base material for roads. The capital and recurring costs are claimed to be 20-50% less and the revenue as much as 40% more than in case of comparable incinerators.

## 16.10 TREATMENT FOR RECOVERY OF USEFUL PRODUCTS

Solid waste is a heterogenous mixture which contains various ingredients, some of which have a large resale/reuse potential. Solid waste in developed countries contains glass and ferrous as well as non-ferrous metals in large proportion. The energy required and the pollution caused to obtain a product from virgin material is more than that required for obtaining it from secondary sources as from MSW. Hence research efforts have been concentrated in this area. In India much of the useful constituents seldom reach the waste stream, though in industrial and commercial areas and in high income group areas such conditions may be encountered. Before any reusable components can be removed from MSW, size reduction is necessary to make it suitable for handling. It can then be

subjected to either incineration or pyrolysis followed by separation of usable constituents from the processed waste or to a detailed physical separation process.

Residue after incineration is smaller in volume, relatively pollution free and innocuous. However, it alters the form of many constituents which cannot be easily reused. Glass tends to melt to an intractable lump. Most of the plastics burn away and some of them like Poly Vinyl Chloride (PVC) while burning release halides resulting in chemical reactions that impair metal recovery. Metals may melt, get oxidised or converted to halide compounds and get lost in the gaseous effluents. Thus the recovered metals from incinerator residue will not be of very good quality. During pyrolysis, on the other hand, oxidation of metal components does not occur. The final product is in the form of a friable char which unlike incinerator residue does not require crushing to release values.

Shredded raw MSW can also be regarded as a multivalue ore and treated by mineral engineering methods into products which can serve as a potentially useful material. A number of organisations have come forward with flow sheets for recovery of various ingredients like glass, metals, etc. such as the one by U.S. Bureau of Mines (Fig. 16.3). In this process, the material is initially subjected to coarse shredding in a machine which breaks plastic and paper bags and boxes without damaging metal object. Glass is broken into pieces but not in fines. The material then passes under a magnetic separator where it is subjected to a vertical air classifier when the heavy objects fall through the vertical air stream while the lighter objects (paper, plastics, etc.) are carried away to a cyclone separator. The heavier particles are passed through a trommel screen of 57 mm (2.25") size. The fines are subjected to elutriation by water which helps separate glass from organic waste containing soil and glass. Oversize is processed by an optical color sorter into white and colored glass and oversize from the trommel is subjected to further shredding to 25-75 mm (1-3") followed by secondary air classification and water elutriation. Light material (paper and plastics) from the secondary cyclone is separated by the use of high tension electro-dynamic technique when paper is drawn to the electrode while plastic sticks to the drum and gets separated. The heavies from the secondary water elutriator mainly comprise of organic wastes and metallic aluminium. A similar flow-sheet has been developed by Warren Springs Laboratory, United Kingdom.

## 16.11 SUMMARY

Various processes have been developed and used in the developed countries. These are suitable for specific types of waste and a comparison is provided in Table 16.2.

**Table 16.2 – Summary of basic principles for adoption of emerging technologies**

| S. No | Method | Basic principle | Suitability for Waste | Stage of development |
|---|---|---|---|---|
| 1. | Vermicomposting | Decomposition through microbes such as fungi, actinomycetes, protozoa in the gut of earthworms | Organic waste with low organic & moisture content | Developed and adopted extensively |
| 2. | Biogas from MSW | Anaerobic decomposition of organic matter | Organic matter | Developed & widely used in developed countries |
| 3. | Conversion of solid waste to protein | Bacterial conversion | Cellulosic waste | Lab-scale in India well as in developed countries * |
| 4. | Alcohol fermentation | Anaerobic decomposition | Cellulosic waste | Lab-scale |
| 5. | Pyrolysis (including plasma arc technology) | Destructive distillation | Cellulosic waste | Used in Developed Countries |
| 6. | Refuse derived fuel | Separation | High Cellulosic waste | Used in Developed Countries |
| 7. | Hydropulping | Hydropulping | Paper waste | Used in Developed Countries |
| 8. | Slurry carb process | Slurry formation followed by carbonisation | Paper waste | Used in Developed Countries |
| 9. | Recovery of useful products | Separation | Low ash waste | Used in Developed Countries |

* Commercial viability yet to be established.