CHAPTER 1

INTRODUCTION

1.1. GENERAL

With increasing population and income, the life style of urban residents is also changing. Urban India is thus becoming a "throwaway society". In larger cities, the composition of wastes is changing with rapid increase of paper, plastic, metal and hazardous materials. Scavengers and rag pickers collect wastes from households and garbage dumps for recycling. This activity reduces the burden on the municipal system and provides employment and income to a large number of people. Their working conditions are appalling and the manner in which recycling of plastics and metals takes place is also harmful to their health.

Collection techniques and procedures used by waste management authorities are often inappropriate and inconvenient. In many states of India, by law, local governments are required to remove garbage only from public places. Provision of number of waste bins at all places are also not possible for several reasons. As a result garbage is strewn all around the streets. The waste from households is also thrown onto the street. These wastes often block surface and underground drains causing diseases and flooding all over.

The problem of sanitary disposal of refuse is thus becoming very serious in many developing countries. In spite of the regular publicity in the mass media and the constant political statements and actions made by highly placed persons in authority, refuse remains a permanent feature along urban roads. The emphasis on the enforcement of sanitary laws and regulations also may not yield results to our satisfaction. Rapid urbanization rate, heterogeneous nature of the cities, poor finances of the local authorities and the managerial capabilities are the major causes of the refuse disposal crisis which exists in all the urban centres of India. Biogas
technology (BGT) is a viable option in India for the mitigation of some of these pressing problems; such of step will have a positive impact on energy, public health and agricultural productivity. The techniques is proven. The everyday operation can be made to work fairly efficiently. The benefits are plenty and the need for fuel is beyond any doubt. But putting the package together and keeping it so, is a taller order than a casual look would indicate (1).

1.2. POLLUTION DUE TO SOLID WASTE

Unlike other waste products such as untreated waste water or excessive air contaminant emissions from industries, there is no particular awareness of a strong relationship between solid waste and public and environmental health. Indeed solid waste has come to be regarded more as a nuisance than as a health hazard. There are certain inherent risks in solid waste handling which can become chronic problems if reasonable sanitation precautions are not taken. Flies, rats and other vectors can live and breed in refuse which is improperly stored or disposed. Vectors can in turn transmit certain diseases, although the likelihood of such an occurrence reaching serious proportions is small. It took the scare of the Black Death, the pneumonic plague which hit Surat, India, in Sept, 1994, to finally make people wake up to the connection between waste and health. The unfortunate symbol of modern urban India today is a pile of rotting garbage. Refuse burning can impair air quality but this problem is being greatly reduced by open burning restrictions and higher emission standards applied to incinerators.

1.3. CHARACTERISTICS OF SOLID WASTE

It is universally accepted that the quantity and characteristics composition of refuse vary mainly according to the socio economic status; the food habits, local customs, geographical locations, occupations and climatic conditions (2). However, the variations within most of the communities in India are more dramatic. The gap between the rich and the poor is very wide. These
variations are much reflected in the refuse quality and quantity. Seasonal variations in the quality and quantity of waste are also very wide. The rate at which the characteristics of refuse change in India are higher than those normally experienced in the developed countries.

1.4. HOUSEHOLD STORAGE OF SOLID WASTE

In the developed countries, the standard household dustbins are common and familiar to everybody. Such dustbin comply with certain standards which enable them to function efficiently. In most of the cities of India, the majority of the people do not have dustbins. The few people that have, make use of all sorts of containers which do not ensure sanitary storage of refuse in the premises of the household. In many areas, there are no regulations or byelaws on household dustbins. Where such laws exist, they are never enforced.

Another aspect of refuse storage problem is sanitary storage of solid waste generated in the shops and market stalls - the commercial refuse. Normally the traders do not have dustbins. They and their customers litter the markets and the shopping centres, thereby making sanitary refuse collection difficult for the disposal authority.

1.5. SOLID WASTE COLLECTION

"Get mobilized, pay attention to hygiene, reduce diseases, improve the health conditions." (Mao Tse-Tung) (3).

The above statement of the great Chinese leader is relevant when discussing how to improve solid waste collection in India. In many areas, refuse collection is so poorly organised and executed that less than 25% of the refuse produced is actually collected for disposal. The remaining 75% is allowed to remain and cause nuisance and pollution of the urban environment.
To have an efficient refuse collection programme the following approaches must be efficiently employed in different situations.

1.5.1. Effective house to house collection

It is the most convenient method for refuse collection. If properly organised, it will enable disposal authorities to derive revenue direct from solid waste management. To succeed in India, there must be regular and effective health education of the public. The authorities must have an adequate number of suitable refuse collection vehicles to achieve this efficient maintenance workshops and a regular supply of spare parts.

1.5.2. Depot method

This method is suitable for those areas where the houses are not accessible by roads. Depots are necessary in market places and other commercial centres.

1.5.3. Chinese collection practice

Chinese employ the principle of mass participation for both refuse and night soil collection. This reduces collection costs and time. The refuse vehicles visit at specific times of the day and familiar noise is made to collect dustbins or night soil containers. If backed up with proper health education of the public, it works out well in metro cities.

1.5.4. Modified Garchey technique

In this method, the household refuse is flushed with water through 20 cm diameter pipes into the tanks provided in the ground of multistorey blocks of flats. This is too sophisticated and expensive, as most of the areas in India have inadequate supply of water.
1.6. TRANSPORTATION OF SOLID WASTE

The importance of regular and efficient transportation can not be over-emphasized as the majority of the people normally empty their dustbins into roadside depots. If these depots are not emptied regularly due to insufficient number of vehicles, the failure of disposal programme is easily perceived. Many factors like the nature of the refuse, the traffic situation, inadequate number of refuse vehicles, shortage of funds and haulage distance make efficient refuse transportation difficult in India.

1.7. COMMON DISPOSAL METHODS

1.7.1. Tipping

In most of the areas of India, the most common method of disposal of solid waste is crude controlled tipping or semi-controlled tipping. It should be always borne in mind that the tipping sites can pollute ground water and those who live near tipping sites must be warned about this danger.

1.7.2. Composting

Composting is normally considered to be an aerobic process accomplished either by mixing or forced aeration methods. Technically, however, the term composting addresses the fact that biological stabilization process has occurred, resulting in a product, that has properties which make it valuable as a soil amendment.

1.7.3. Incineration

Incineration is a proven method of disposing solid waste with considerable recovery. The feasibility of energy recovery through incineration depends primarily on the properties of the solid wastes. The process becomes economical if the combustion is autothermic i.e., if the waste can itself sustain combustion without addition of auxiliary fuel (4).
1.7.4. Pyrolysis

It is a process of physical and chemical decomposition of organic matter present in the solid waste brought about by the action of heat in the absence of oxygen. The energy produced by the pyrolysis process generally varies according to operating characteristics of a particular system. The efficiency varies between 50% and 80%.

1.7.5. Recycling

Solid waste management, and in particular, the disposal of used packaging is currently the subject of much topical debate. This is driven by both consumer and legislative pressures. Consumers see used packaging as a highly visible element of municipal solid waste, complaining of excessive packaging and low levels of recycling.

1.7.6. Landfill

Land disposal of solid wastes in the form of sanitary landfill has been proven to be the most economically and environmentally acceptable method where sufficient land is available. The process has got some drawbacks such as leachate contamination of ground water. But through proper planning, analysis and design of modern landfill systems which involve the application of a variety of scientific, engineering and economic principles, the process can recover significant amounts of methane gas for energy production (5).

1.8. ANAEROBIC DIGESTION

The decomposition of organic matter and subsequent formation of methane gas by micro-organisms is indigenous to nature. Anaerobic micro-organisms have been essential to the digestion of vegetative foodstuffs in the alimentary tracts of herbivores throughout the evolutionary history. Anaerobic microbial metabolism takes place whenever the ingress of oxygen is stopped completely or limited to such an extent that microbes remove the oxygen. When environmental conditions are
suitable for the growth of methanogenic bacteria, methane gas is produced. Of all the biological conversion processes, the anaerobic digestion process has been proved to be very effective and economically attractive for producing energy (alcohols, methane gas etc.,) and other useful by-products from solid waste.

Today research is underway to optimize the anaerobic fermentation process for treatment of a wide array of organic substances with an emphasis on maximizing methane gas production.

Due to variation in physical and chemical composition of substrates, a variety of anaerobic digestion concepts have been developed ranging from simple to highly complex processes.

1.8.1. Single-stage Process

1.8.1.1. Lagoon

It is merely a pond lined with concrete or water proof material and open to atmosphere. Aerobic metabolism takes place in the top layers of the liquid, but in the liquid and solids below, anaerobic microorganisms break down and stabilize organic matter. The major problem is bad odour produced by animal waste disposal in lagoons.

1.8.1.2. Landfill

It is a method of disposing refuse on land without creating nuisance by utilizing the engineering principles to confine the refuse to the smallest practical volume and to cover it with a layer of earth at the conclusion of each day's operation. Lack of control of production of gases and leachates result in fires, suffocation and ground water degradation.
1.8.1.3. Septic tank

It is the oldest and simplest enclosed anaerobic digester for treating domestic sewage. Today these are used primarily for household wastewater, although some storage pits for farm wastes of a similar design are used in some places.

1.8.1.4. Conventional single-stage tank digester

It is merely a holding tank for wastes in which both biological stabilization and solid and liquid separation takes place. Substrates composed of animal dung, night soil, garbage, wastewater, vegetation are sealed in insulated containers and left to decompose. This system will only perform with low loading rates and is particularly sensitive to temperature fluctuations.

1.8.1.5. Bag-type digesters

These are known for their low cost, mass production capabilities and easy transportability. These are reported to have originated in Taiwan. Light weight compact plastic digesters have been designed for field and laboratory use. This system lends itself readily to compact storage, quick assembly and ease of operation and is also disposable after use.

1.8.1.6. High-rate digesters

A high rate process requires complete mixing of the digester contents by either a continuous or periodic system to maintain a homogeneous mixed liquor stage in all parts of the tank.

1.8.2. Two-stage digester

It is a basic combination of high rate digestion and conventional unmixed digestion used currently for sludge stabilization and for gas production from low solids organic materials. The control of the rate of organic assimilation is limited to first stage. Most important is the reduction in the retention time from a 30-
60-day range as used in the single stage digester to a 10- to 20-day range in the two stage digester.

1.8.3. Two-phase digesters

In two phase digestion, assimilation takes place in both stages. Acid forming bacteria and methane forming bacteria are physically separated to provide optimum conditions of each, thus increasing waste stabilization and methane production rates.

1.8.4. Biomethanation

It is an anaerobic fermentation process in which carbon monoxide, carbon dioxide, and hydrogen are converted to methane. When carbon dioxide and hydrogen, the only carbon and energy sources are fed to fermenter, the rate of methane production is extremely rapid.

1.9. OPERATIONAL FACTORS AFFECTING THE ANAEROBIC DIGESTION PROCESS

1.9.1. Seeding

Seeding in actual practice is done by mixing the raw waste with well digested sludge. The raw waste at 37°C could be digested in about 10 days if the ratio of digested sludge to raw waste is maintained at 1:1 (6).

1.9.2. Biodegradability

For organic wastes such as industrial, municipal and animal wastes, chemical oxygen demand (COD) or volatile solids (VS) are used as gross substrate for anaerobic digestion process. Methane production correlates directly with COD reduction. Since no oxidizing agent is added, the only way COD reduction can occur is through the removal of organic material from waste by the evolution of methane and carbon dioxide. The other avenues of COD reduction, is evolution of hydrogen sulphide and hydrogen gas which is insignificant.
1.9.3. Temperature

Faster rates of digestion and minimization of bacterial and viral pathogens are benefits obtained with high digestion temperatures. The response to methanogenesis to temperature is immediate as temperature affects the enzyme catalyzed reactions. Accurate thermostatic control of medium temperature is essential and digestion vessels are normally insulated to keep the heat losses to a minimum. At 35°C, no appreciable increase in performance is noted once solids retention time (θc)(SRT) is greater than 10 days. However operation of larger values of SRT does afford the operator a margin of safety if system temperature drops.

1.9.4. Hydraulic retention time

It is the theoretical time that a particle or volume of liquid added to a digester would remain in the digester. It is expressed as the volume of the digester divided by the volume added per day and is expressed in days. The ratio of the total cell mass in the digester to the cell mass in the effluent is the solids retention time θc and for a completely mixed system without solids recycling - θc is identical to θ.

1.9.5. Organic loading rate

The rate at which biomass is supplied to the digester is referred to as the volumetric organic loading rate and is commonly expressed in terms of kilograms of volatile solids per m³ of digester capacity per day.(kgVs m⁻³ d⁻¹). Different loading rates can be obtained by either changing the concentration of the solids in the influent or by varying the flow through the digester.

1.9.6. Concentration of the feed stock

Gas production is a function of solid materials and their biodegradability in the digester. The more concentrated the solids, the smaller the digester and lower the cost of the system.
1.9.7. pH

Maintenance of system pH in the proper range is required for efficient anaerobic digestion. The generally accepted range for a good and proper efficiency is 6.5 - 7.6. A common misconception is that if the pH drops below 6.0, the system is effectively dead. An increase in pH to 9 may also result in cessation of methane production.

1.9.8. Shredding

It is found that the more surface area of the particles fed into the digester, the more is the digestion resulting in good volume of biogas production. Shredding of refuse before deposition promotes movement of moisture throughout the landfill, increasing the gas production. Either fine grinding or ball milling is the most effective treatment for increasing digestibility of wood and other cellulosic material as on date.

1.9.9 Degree of mixing

Mixing in digesters offers an advantage that the substrate is kept in contact with the microbes and the temperature is kept uniformly distributed eliminating undesirable stagnant pockets. Mixing has been shown to produce a 26 per cent increase in gas production.

If the digester has mixing facilities and raw sludge is pre thickened there is not much likelihood of any separation of supernatent. If raw sludge is not prethickened and the digester contents are not mixed, it is common practice to remove the supernatent. If raw sludge is not prethickened, but the digester contents are mixed, then the supernatent is removed in an untreated and unmixed secondary digester (6).
1.9.10. Methane production

There is confusion between total gas production and methane production as a measure of process performance. Methane production is the most important measure of performance and is related to total gas production by the percentage of carbon dioxide in the gas phase. Carbon dioxide is affected by conditions such as temperature, pressure and the oxidation state of the carbon in the feed stock. Based on total gas production, design innovation, such as a gas cover with a negative pressure has been found to increase performance.

1.9.11. Volatile fatty acids (VFA)

In the digestion process, acetogenesis provides short chain fatty acids expressed as concentration of acetic acid, being the major constituent. Values of 200 mg L\(^{-1}\) are ideal for healthy digestion but no true ranges can be set due to immense buffering capacity of certain wastes. Most biogas plants are therefore monitored by establishing the VFA level as constant; sudden rise in VFA content would indicate potential souring of the process.

1.9.12. Carbon-Nitrogen ratio

The carbon to nitrogen ratio in a substrate is important because high nitrogen levels (greater than 80 mg L\(^{-1}\) as undissociated ammonia) with low C/N ratios can cause toxicity and low levels (high C/N ratios) can inhibit the digestion rate. The most critical factor in feedstocks, however, is the available C/N ratio and this depends on such factors as percentage biodegradability of the substrate which is the fraction of nitrogen released during digestion and the yield of cell mass from the biodegradable fraction. Assessing C/N context is a fairly complex undertaking, a more empirical approach is possible by monitoring soluble ammonical concentrations in the effluent. It is possible to ensure that the digester will operate under optimal conditions.
1.9.13. Nutrients

The major nutrients required by the bacteria in the digestion are carbon, hydrogen, oxygen, nitrogen, phosphorous and sulphur. Of these nutrients, nitrogen and phosphorous are always in short supply and therefore to maintain proper balance of nutrients, an extra feed stock rich in phosphorous and nitrogen should be added along with the organic wastes, if required.

1.9.14. Toxicity

Biological systems need some trace elements like calcium, magnesium, potassium etc. Production of biogas is reduced when these elements are present in higher concentrations. So care should be taken to remove them at frequent intervals.

1.9.15. Substrate

Early research (in the 1930s) demonstrated that the garbage (food waste) component of solid waste was amenable to conversion as methane gas by an anaerobic fermentation process. Research in the early 1970s developed a technical base for the conceptual design of a process for the production of a substitute natural gas from urban refuse.

1.10. PROCESS KINETICS

Process kinetics play a central role in the development and operation of anaerobic treatment systems. Based on the biochemistry and microbiology of the anaerobic process, kinetics provide a rational basis for process analysis, control and design. In addition to the quantitative description of the rates of waste utilization, process kinetics also deal with operational and environmental factors affecting these rates. A sound knowledge of kinetics allows for the optimization of performance, a more stable operation as well as better control of the process.
1.10.1. Growth rate

In the anaerobic digestion process, the product formation is a result of bacterial cell growth and substrate metabolism. The rate of microbial growth can be expressed by autocatalytic equation.

\[
\frac{dX}{dt} = \mu X \tag{1.1}
\]

where \( X = \) microorganism concentration (kg m\(^{-3}\))

\( t = \) time (d)

\( \mu = \) specific growth rate (d\(^{-1}\))

1.10.2. Growth yield and substrate utilization rate

The relationship between the rates of microbial growth and utilization is as follows:

\[
\frac{dS}{dt} = -\frac{dX}{Y} \quad \text{or} \quad \frac{dS}{dt} = -\frac{\mu X}{Y} \tag{1.2}
\]

where \( Y = \) growth yield coefficient (kg kg\(^{-1}\)). Using the definition of \( \mu \), the following equation is obtained.

\[
\frac{1}{X} \frac{dS}{dt} = \frac{\mu}{Y} = U \tag{1.3}
\]

where \( U = \) specific substrate utilization rate (kg kg\(^{-1}\) d\(^{-1}\)).

when \( \mu = \mu_m = \) maximum specific growth rate, then

\( \frac{\mu_m}{Y} = U_m \)

\( U_m = K = \) maximum specific substrate utilization rate (kg kg\(^{-1}\) d\(^{-1}\))
1.10.3. Effect of substrate concentration on the microbial growth rate

The effect of growth-limiting substrate (ie., essential nutrients) concentration on the rate of microbial growth has been described by various mathematical models. However, the most widely used kinetic model is that of Monod (7).

\[
\mu = \frac{\mu_m S}{K_S + S}
\]  \hspace{1cm} (1.5)

\(\mu_m\) = maximum specific growth rate (d\(^{-1}\))

\(S\) = concentration of the growth limiting substrate (kg m\(^{-3}\))

\(K_S\) = half velocity coefficient (ie. substrate concentration at one half maximum specific growth rate (kg m\(^{-3}\)).

Substituting eqn. (1.5) in eqn. (1.1), the relationship between the reaction rate (\(-r_s\)) and substrate concentration can be developed:

\[
\frac{dX}{dt} = \frac{X \mu_m S}{K_S + S}
= -r_s
\]  \hspace{1cm} (1.6)

Application of eqn (1.6) is impractical for description of anaerobic digestion of particulate feed because measurement of the cell mass concentration, \(X_c\), is difficult in the presence of non-bacterial particulates. Many modifications of this equation have been proposed by researchers to accommodate complex organic substrates and mixed cultures and these are dealt in the next chapter.

1.10.4. Kinetic equations for methane production

It is accepted that the anaerobic digestion of organic wastes is a complex multi-stage process. Various steps are completed by four physiologically different groups of bacteria. In the anaerobic digestion process, all steps are taking place simultaneously.
The multi-stage approach requires the understanding of the major steps involved such as rate-limiting step, so that physical separation of the process into a two or multistage system is possible and it is dealt in the next chapter.

1.11. SCOPE OF THE PRESENT STUDY

The major problem related to municipal solid waste treatment is caused by its heterogeneity. A good separation of the various recyclable fraction has serious economic and technological difficulties even when very sophisticated sorting facilities are used in industrialised countries. Separate garbage collection and/or source sorted waste programmes undoubtedly give better results in municipal solid waste (MSW) management. In this way, the most important biodegradable components from the whole urban waste (putrescible fraction, paper, etc) can be kept uncontaminated by the potentially toxic materials (medicals, batteries etc.).

Many middle sized towns like Coimbatore could easily recover the putrescible organic fractions of municipal solid wastes (OFMSW) with very few modifications in collection services. This would require collecting the wastes coming from garden-produce markets, super markets, restaurants, etc, which constitute a significant portion of the fermentable components of MSW. Upto now and in the near future, however, the collection of putrescible organic matter source-sorted by families, appears to be very difficult. In fact the achievement of such a goal would require a real revolution in conventional refuse management. Management of solid wastes in a cost effective and environmentally sensitive manner has become one of the most challenging infrastructure issues facing a municipality today.

1.12. PURPOSE AND OBJECTIVES OF THE PRESENT STUDY

With increasing population and income, the life style of urban residents of Coimbatore city is also changing, thus becoming a "throw away society". The prime responsibility of waste disposal authorities is to dispose of MSW in a manner which
preserves the environment and protects the public health at the least possible cost. Converting the waste into wealth was only the first foray into uncharted territory. Hence a study on characterization and treatment of MSW generated in Coimbatore City has become a necessity. Due to a great need of generation of nonconventional energy, much emphasis is to be laid in the generation of biogas from the abundant waste generated.

Normally in anaerobic digestion of MSW, the feed is prepared with OFMSW plus tap water in order to obtain volatile solids concentration for the organic loading rate. Due to scarcity of tapwater and due to economical constraints in India, an attempt has been made to use domestic sewage instead of tap water to obtain volatile solids concentration needed for the organic loading rate. From the laboratory studies the steady state is obtained in much lesser days than the work with tap water. Hence, in this study, an attempt has been made on an engineered anaerobic digestion of OFMSW in conjunction with domestic sewage and an assessment of biochemical methane potential of individual components of OFMSW with specific objectives as follows.

- determination of characteristics of municipal solid waste (MSW) of Coimbatore city
- determination of characteristics of garbage, fruit waste, yard waste, kitchen refuse and source-sorted organic fractions of municipal solid waste (SSOFMSW)
- anaerobic digestion studies on individual components of OFMSW in conjunction with domestic sewage
- use of biochemical methane potential for estimating methane yields and associated conversion rates of MSW component samples.
- determination of kinetic parameters for anaerobic digestion of OFMSW, kitchen refuse, garbage, fruit waste, yard waste using first order kinetics (8).
• determination of kinetic parameters for SSOFMSW using first order kinetics and Chen and Hashimoto model (9) and application of kinetic model to predict the effect of digestion studies and operating conditions on methane yield.

1.13. APPROACH

Urban waste has been traditionally looked at as solid and liquid waste. But in the Indian context, characterised by widespread prevalence of open defecation and the practice of manual scavenging, the problem of human waste clearly presents a case for special attention. It is a serious and persuasive contributor to environmental deterioration affecting a variety of settlements across the country.

The nonchalant attitude towards the public cleanliness appears to cut across all distinctions. Households, commercial establishments, Government institutions and industrial units, to name a few; but all sectors are guilty of indiscriminate dumping of waste. Even nursing homes and hospitals which are supposed to have greater awareness about the effects of a filthy environment, are no exceptions. The effluents from medical institutions include human tissues, animal carcasses, organs and other pathological matter.

The samples analysed included MSW samples from five subyards reaching the main disposal yard, Sanganurpallam. Components studied represented four broad classes of MSW components, including kitchen refuse, garbage, yardwaste and fruit waste.

Kitchen refuse derived from the kitchens of households, restaurants and institutions are estimated to account for as much as 15% of the nation's MSW (10) but this does not apply to India as this waste does not reach the MSW stream as such, but reaches as residue. Hence, in this study, it is suggested that the kitchen refuse arising from hostels, restaurants etc., can be disposed by biofermentation and utilised at the source itself.
Yard waste which can contribute up to 20% of MSW streams destined for final disposal (11) also does not apply to Indian conditions as this waste is disposed of either by open-air burning or vermi-composting at the source itself.

Garbage from vegetable markets and commercial establishments reaches the MSW stream and can contribute up to 30 - 50% of the MSW, and is normally the largest component.

Fruit waste from all fruit stalls of Coimbatore also does not reach fully into MSW stream and can contribute to 10% as rubbish. Paper waste is less than 10% of MSW stream as recycling facility is available and does not fully reach the MSW stream.

The estimates of methane yields and rates for these major samples represent a cross section of MSW components. The results of biochemical methane potential assays can direct the focus of further assays of components which might have large variabilities in yields and rates, or which do not fall into the categories tested.

Domestic sewage is used instead of water to obtain volatile solids concentration needed for the organic loading rate due to scarcity of water and availability of sewage is inevitable at each sources of the MSW components. OFMSW, in conjunction with domestic sewage is economical and in a combined treatment of any biomass with domestic sewage, more than 70% is biodegradable. (12). Future waste disposal strategy is based on the introduction of source separation of household waste into two fractions - an organic fraction (biowaste) and a second fraction containing all other waste (residual waste) (13). Hence, a study on source-sorted organic fractions of MSW (SSOFMSW) was also undertaken.

For process kinetics, in determination of kinetic parameters, first order kinetic model and Chen and Hashimoto model were used.