CHAPTER 1

INTRODUCTION

1.1 MOTIVATION AND GOAL

Recent Industrial boom and population growth in India has led to the migration of people from villages to cities, which generate thousands of tons of MSW daily. Municipal solid waste management (MSWM) is one of the prominent environmental issues in most of the Indian cities. Improper management of municipal solid waste (MSW) causes hazards to inhabitants. Several studies reveal that around 90% of MSW is disposed of non-technically in open dumps and landfills, causing problems to both human health and environment. In the present study, various proven techniques like land-filling, Composting and Anaerobic digestion of solid waste has been focused.

Various Physico-Chemical Properties had been taken into consideration of studies. In the recent years, anaerobic digestion process is most widely preferable owing to its more eco-friendly and in this thesis efforts have been made to design and fabricate of a horizontal continuous mode anaerobic digestion reactor with additional studies on the factors influencing the anaerobic digestion process such as Nutrient analysis, Heavy metals analysis, Leachate characteristics, Biogas analysis & BMP analysis in the lab scale.
1.2 OBJECTIVE

1. Identifying the eco-friendly methods like land filling, composting and anaerobic digestion process for the treatment of Municipal Solid waste.

2. Studies on the land filling method and key parameters controlling degradation like refuse composition, moisture content, temperature, pH & heavy metals.

3. Studies on factors affect composting processes, including temperature, moisture & other physical, chemical and biological variables.

4. Design and fabrication of a continuous horizontal type anaerobic digestion bioreactor and studies on the performance of anaerobic digestor.

5. Parametric studies on the factors affecting the AD process such as Nutrient analysis, Heavy metals analysis, Leachate characteristics, Biogas analysis & BMP analysis in the lab scale.

1.3 BACKGROUND

Solid waste management is a difficult issue for the authorities in major cities of developing countries like India mainly due to the increasing generation of waste. High budget is being allocated towards the municipal solid waste management in addition to which the lack of understanding over a diversity of factors that affect the various stages of waste management and to enable the entire handling system functioning. Rapid population growth, increasing economy, fast urbanization and the escalating community living
standards have greatly shoted-up the municipal solid waste generation rate in developing countries.

Corporation and municipalities are responsible for waste management in the urban and rural areas, have the task to allocate an effective and efficient system to the living community. However, they use to overcome with problems beyond the capability of the municipal authority to embark on mainly due to lack of involvement, financial commitment and inadequate system. In the recent years, a huge number of research studies have been undertaken to find out the predominant factors influencing waste management systems in major cities of India.

Land filling is one of the effective methods for the disposal of municipal solid waste [MSW]. The significant benefits of landfills include energy generation from landfill biogas and a usage of landfill area. The recent trends of developed countries are to limit the microbial nitrogen fixation at landfill sites because of rising paper as well as plastic content and more of C/N ratio. Determination of parameters such as moisture, volatile solids, biochemical methane potential, pH and inorganic nutrients as metals are considered for the stability of reuse in waste materials. Development of a Landfill Bioreactor along with recovery of methane is a demanding profit for waste degradation. In the present study, the objective is to use a simulated landfill bioreactor and to study waste characteristics.

Composting is a method of organic matter decomposition to get a end product “compost”. The same had been used to recover organic waste in municipal solid waste management. Organic waste composting is recognized as an efficient method to produce useful end products such as “Bio-fertilizer”. The sustainable agriculture needs the compost materials as an effective tool to promote the soil fertility as well to maintain organic farming for the healthier society. Some of the significant factors that can affect
composting processes are temperature, moisture, pH along with other physical, chemical and biological variables.

Several methods are available for the organic fraction pretreatment of municipal solid wastes before disposal like physical, chemical, and biological processes. In addition to above the selection of any treatment method always has its own positive and negative aspects and it depends on waste compositions, financial and institutional framework or country policies, and waste quantities. Biological processes; which comprise of aerobic composting and Anaerobic Digestion (AD), provide advantages due to its natural treatment processes over other technologies. Treating organic wastes by AD is an attractive method for stabilization of organic wastes into methane (CH$_4$) and compost. It is the method which is used by nature under anoxic conditions. Therefore, it is placed in the context of end product, energy use, recycling and environmental aspects in term of greenhouse reduction in general.

AD also showed an excellent Life Cycle Analysis (LCA) performance as compared to other treatment methods as it can improve the energy balance. Biogas is a desirable energy product which can be used directly as the source of energy. In addition, the residues are stable and serve as excellent compost for the agricultural purpose as well as reduce pathogenic bacteria and then decrease the possibilities of disease transmission.

The present thesis is intended to study the municipal solid waste by land filling method and key parameters controlling degradation like refuse composition, moisture content, temperature, pH & heavy metals. The work mainly involves in determining the composting processes, including temperature, moisture & other physical, chemical and biological variables. In addition to this, Design and fabrication of a continuous horizontal type anaerobic digestion bioreactor was made and performance of anaerobic
digestion reactor studies was also made. Also, factors affecting the AD process such as Nutrient analysis, Heavy metals analysis, Leachate characteristics, Biogas analysis & BMP analysis in the lab scale were also performed.

1.4 ORGANIZATION OF THE THESIS

Chapter 1 gives the introduction and gives a detail literature background on the research that has been carried out in different types of municipal solid waste treatment techniques and also an overview of the current research that has been presented in this thesis.

Chapter 2 deals with the materials taken for this research work and methodology adopted especially on the design of continuous mode horizontal type anaerobic digestion reactor, characterization methods and sample analytical studies that have been carried out.

Chapter 3 deals with the results and discussion of the performance of landfill bioreactors, Composting process and anaerobic digestion process along with the details of various factors affecting each process towards treatment of Municipal Solid Waste (MSW).

Chapter 4 is dedicated to conclusion of the thesis.

1.5 THESIS CONTRIBUTION

a) Three different techniques like Land filling, Composting and Anaerobic Digestion processes of municipal solid waste were studies instead of restricting on only one method.

b) Design and fabrication of a continuous horizontal type anaerobic digestion reactor is made.
c) Analysis of municipal solid waste was performed after treatment in addition to raw waste characteristics.

d) Biogas analysis & BMP analysis is made in lab scale.

1.6 LITERATURE REVIEW

1.6.1 Municipal Solid Waste Method

In recent years, managing Municipal solid waste (MSW) is one of the key environmental problems of Indian cities. Several literature studies shows that around 90% of MSW is disposed of unscientifically in open dumps and landfills makes problems to society and the environment. Recently, biological waste treatment methods have prepared the way for recycling the organic compounds and other nutrients from the organic fraction of MSW.

1.6.2 Land Filling

Development of a Bioreactor Landfill with methane recovery is an attractive incentive for rapid and managed waste degradation since the landfill gas has a heating value of about 500 Btu/scf. In leachate recirculating landfills both acid formation and methane fermentation phases are reduced in duration and stabilization is sped up (Pohland & Kim 1999). The impact of recirculation also results in either rapid formation of VFA.s, which tend to be retained more than those in conventional fills or more gas recovery with more stable leachate subsequently. The optimal recirculation of leachate implies that the landfill shall be divided into cells such that leachate from fresh cells having high organic load can be recirculated into old stabilized cells, where methanogenic conditions prevail and the land fill gas (LFG) extracted from old cells.
Leachate management from process control consideration implies storage of leachate during the acid formation phase to avoid inhibition of fermentation, facilitate pH control and its subsequent release in the waste during methanogenesis. Studies indicate that about 60% of the total solids are cellulose and hemicellulose and they generate about 90% of methane in a landfill (Barlaz et al 1990). In conventional landfills, metal removal is by washout and chemical precipitation. For leachate recirculating landfills, the primary metal removal mechanism appears as precipitation in the form of sulfides and hydroxides. (Reinhart & Al-Yousfi 1995).

In general, metal solubility is higher at low pH during acid formation phase restricted by ligands both organic and inorganic. The solubility drops during fermentative phase due to rise in pH and formation of insoluble precipitates. In older stabilized fills, moderate to high molecular weight humic-like substances are formed from waste organic which tend to form strong complexes with heavy metals. Potentially remobilization of precipitated metals can occur from such complexation, once the organic content has been stabilized and oxic conditions get re-established.

Reinhart (1996) suggests a storage volume in excess of 700m³/ha to manage leachate. It was reported that leachate generated exceeds leachate recirculated thus implying leachate holding/treatment facility during some stage before closure of landfill.

Potential benefits of Bioreactor landfills are the increased gas yield, whereas greenhouse gas emissions would be reduced due to more efficient degradation. Almost, all of the rapid and moderately decomposable organic constituents are degraded within 5 to 10 years of closure. Bioreactor landfills also offer low cost partial treatment of leachate within the active life of a fill and improved leachate quality & stabilization within 3 to 10 years after closure along with subsequent reduced leachate disposal costs.
The enhanced biodegradation enables rapid settlement, rapid volumetric reduction resulting in more disposals within the landfill volume, early landfill closure and subsequent land use. Other benefits include reduced operation and maintenance activities and reduced risk of gas migration. At landfills, where leachate recirculation is practiced, leachate ammonia concentrations may accumulate to much higher levels than during conventional single pass leaching, thereby creating a leachate discharge problem (Onay 1998).

Disposal of leachates high in nitrogenous constituents has damaging impacts due to a reduction in chlorine disinfection efficiency, increase in the DO reduction in receiving waters, adverse public health effects, and a decrease in appropriateness for reprocess (De Renzo 1978). Landfill leachate from mature sites are usually highly contaminated with NH$_3$ resulting from the process of hydrolysis and fermentation of N$_2$ containing fractions of biodegradable refuse (Knox 1985) and (Carley & Mavinic 1991) and may contain 400-800 mg/l of ammonia nitrogen (Welander et al 1998). Another aspect is that the low refuse hydraulic conductivity at the bottom of the landfill interferes with progress of the leachate moving towards the leachate collection system (LCS), and potentially a leachate mound can form in the refuse above an operating LCS.

A leachate mound has the potential to cause leachate side seeps and could interfere with the landfill gas collection system. However, a leachate mound within the refuse is not necessarily indicative of the head on the liner. Hence the strain due to settlement results in reduced refuse permeability and along with chemical precipitation and biological clogging significant reductions in refuse permeability may occur and in turn contribute to the formation of a leachate mound within the refuse. The increased water content of the refuse will lead to an increased rate of biodegradation and gas
production. Additionally, the higher densities result in higher gas production per unit volume. Due to reduced refuse permeability, the gas hydraulic conductivity is reduced since void space is occupied by leachate, and gas collection apertures are reduced in magnitude due to submergence. This leads to a reduction in the radius of influence for gas collection wells and trenches and thus a decrease in the efficiency of the landfill gas recovery system (Bleiker 1995).

Other important factors to consider are the pathways to relieve the excess pore pressure. Leachate production is observed to follow precipitation and leachate recirculation events due to such preferential flow pathways in a refuse mould. Potential pathways are flow into gas collection devices, flow to the leachate collection system and migration through the liner due to increased head on the liner.

David Laner et al (2012) made a review on approaches for the long-term management of municipal solid waste landfills and Different approaches have been suggested for long-term landfill management and evaluation of aftercare completion. Approaches to aftercare were categorized as (i) target values, (ii) impact/risk assessment, and (iii) performance based. It was concluded that to assess the practicality of evaluation methodologies for aftercare, well-documented case studies including regulatory review and acceptance are needed.

Sunil Kumar & Mudoo (2011) made a thorough review over bioreactor landfill technology in municipal solid waste treatment in addition to which leachate recirculation and stabilization, nitrogen transformation and corresponding extensive laboratory and pilot-scale research, the bioreactor landfill concept, the benefits to be derived from this bioreactor landfill technology, and the design and operational issues and research trends that form the basis of applied landfill research was done and suggested that
implementation of landfill technology are gaining momentum in landfill research and development activities.

Cheng-Ran Fang et al (2010) studied on Di-butyl phthalate degradation using Enterobacter sp. T5 isolated from municipal solid waste in landfill bioreactor. Optimal pH and temperature for biodegradation were maintained at 7.0 and 35 °C, respectively. The effect of initial DBP concentrations on the degradation was investigated between 100 and 1500 mg l\(^{-1}\). It was concluded that the degradation fit a first-order kinetic model, and the degradation half-life was about 20.9 h when the concentration of DBP was lower than 1000 mg l\(^{-1}\).

Ana-Maria Schiopu & Maria Gavrilescu (2010) reviewed on the current status of landfill problems and operation as an ultimate alternative for waste management, together with future landfilling trends and reported that understanding of leachate composition is critical for making projections on the long-term impact of landfills.

Chen et al (2010) studied on biodegradation behavior and the compression of municipal solid wastes. Experiments were performed both with and without optimal biodegradation for comparative purposes. They conclude that settlement resulting from creep was relatively insignificant when the biodegradation process was inhibited. Compression due to decomposition under optimal biodegradation conditions was found to be much larger than compression associated with creep. The biodegradation process was significantly influenced by the operational temperature. Model was developed to accommodate the calculation of settlement in landfills when a multistep filling procedure was used. They also reported that simulations of the physical processes enhancing solid waste biodegradation during the filling stage can considerably increase the capacity of the landfill and reduce post closure settlements.
Sivakumar Babu et al (2010) proposed a generalized constitutive model for municipal solid waste, based on the framework derived from critical state concepts and incorporating the effects of mechanical creep and time-dependent biodegradation, to predict total landfill compression under incremental loading and with time. They proposed a model to predict the total settlement considering all three components (mechanical, creep, and biodegradation) of the settlement.

Halil Hasar et al (2009) developed a configuration for the complete treatment of landfill leachate with high organic and ammonium concentrations. It was reported that by coagulation–flocculation process, COD and suspended solids (SS) were removed 36 and 46%, respectively. After pretreatment, an aerobic/anoxic membrane bioreactor (Aer/An MBR) accomplished the COD and total inorganic nitrogen (total-$N_i$) removals above 90 and 92%, respectively, at SRT of 30 days. Concentrations of COD and total-$N_i$ (not considering organic nitrogen) in the Aer/An MBR effluent decreased to 450 and 40 mg/l, respectively, by significant organic oxidation and nitrification/denitrification processes. Reverse osmosis provided high quality effluent by reducing the effluent COD from MBR to less than 4.0 mg/l at SRT of 30 days.

De Gioannis (2009) studied on mechanical biological treatment (MBT) of residual municipal solid waste (RMSW) was with respect to landfill gas generation. Mechanically treated RMSW was sampled at a full-scale plant and aerobically stabilized for 8 and 15 weeks. It was reported that MBT allowed for a reduction of the non-methanogenic phase and of the landfill gas generation potential by, respectively, 67% and 83% (8 weeks treatment), 82% and 91% (15 weeks treatment), compared to the raw waste. The amount of gasified organic carbon after 8 weeks and 15 weeks of treatment was equal to $11.01 \pm 1.25$ kg $C/t_{MBTW}$ and $4.54 \pm 0.87$ kg $C/t_{MBTW}$, respectively, that is 81%
and 93% less than the amount gasified from the raw waste. They also conclude that gas production from MBTW landfills is well-suited to a passive management strategy.

Valencia et al (2009) studied on “final storage quality” of municipal solid waste using a pilot scale bioreactor landfills. It was concluded that the bioreactor landfill simulator was capable of practically achieving biological stabilization after 2 years of operation, with approximately 45% of the total available (organic and inorganic) carbon and nitrogen into the liquid and gas phases.

Kai Sormunen et al (2008) studied on leachate quality in a municipal solid waste landfill. The leachate was monitored for COD, BOD, TKN, NH₄–N, Cl, pH and electric conductivity. It was reported that high horizontal and vertical variability in leachate quality between monitoring wells, indicating that age and properties of waste, local conditions (e.g., water table) in addition to that degradation and dilution processes have a marked effect on local leachate quality. Finally it was concluded that the mean COD values (642–8037 mg/l) and mean BOD/COD ratios (0.08–0.17) from the different monitoring wells were typical of landfills in the methanogenic phase of degradation.

Sherien Elagroudy et al (2008) studied on a biodegradation–induced settlement model. It was concluded that the rate of initial settlement occurring under aerobic conditions has been greater than that under anaerobic conditions. Parameters increased with the increase in the concentration of enzymes and with the presence of sludge in both aerobic and anaerobic stages. Also, it was reported that increasing organic content of MSW has resulted in the enhancement of the biodegradation rate and settlement.
Hanson et al (2008) made a parametric study on Spatial And Temporal Temperature Distributions In Municipal Solid Waste Landfills and reported that use of insulating materials over covers decreased temperature variations compared to uninsulated conditions for prevention of frost penetration or desiccation and for optimum methane oxidation. Hence the thermal regime of landfills is controlled by climatic and operational conditions.

Renou et al (2008) made a thorough study on Landfill leachate treatment. Various treatments were reported under the items: (a) leachate transfer, (b) biodegradation, (c) chemical and physical methods and (d) membrane processes. They suggested that new technologies like membrane technologies or reverse osmosis need to be developed and tried to be financially attractive.

Bulent Mertoglu et al (2006) studied on in situ ammonia removal in an aerated landfill bioreactor operated at various ORP levels (−400 to 150 mV). They reported that BOD$_5$ decreased faster than TOC and dropped below 10 mg/l after day 120. Subsequently, it remained quite constant until the end of the operational period. This rapid BOD$_5$ degradation in the aerated landfill bioreactor increased the possibility of nitrification by promoting nitrifying bacteria having high oxygen affinities.

Jain et al (2005) studied on the permeability of compacted municipal solid waste in a landfill with respect to air or gas flow using a short-term air injection test. It was suggested that multiple wells screened at different depths provide greater control of air distribution within the landfill and the waste exposed to leachate recirculation was found to be significantly less permeable to air.
Yesiller (2005) studied on the thermal aspects of municipal solid waste landfills as a function of operational conditions and climatic region. Heat content (HC) of wastes was determined as the difference between measured waste mass temperatures and unheated baseline waste temperatures at equivalent depths. Heat generation was determined based on HC using 1D heat transfer analysis. It was reported that the heat energy from 23 to 77 MJ/m$^3$ values were obtained without losses and it was significantly higher than biochemical prediction models.

Osman Nuri Ağdağ & Delia Teresa Sponza (2005) investigated the effects of alkalinity on the anaerobic treatment of the organic solid wastes collected from the kitchen and the leachate characteristics treated in three simulated landfill anaerobic bioreactors. It was observed that the chemical oxygen demand (COD), volatile fatty acids (VFA) concentrations, and biochemical oxygen demand to chemical oxygen demand (BOD/COD) ratios in the leachate samples produced from the alkalinity added reactors were lower than the control reactor while the pH values were higher than the control reactor. Alkalinity addition reduced the waste quantity, the organic content of the solid waste and the biodegradation time.

Shi Lei (2005) studied on control measures of odor pollution in different areas of sanitary landfill. It was found that microbial deodorization techniques are suitable for waste gas treatment in all kinds of environmental sanitation facilities, such as MSW collecting stations, MSW transfer stations, incineration plants, composting plants and night soil treatment plants.

Wang et al (2003) made a review on the application of advanced oxidation methods for landfill leachate treatment. The characteristics of landfill leachate and the mechanisms of O$_3$, O$_3$/H$_2$O$_2$, O$_3$/UV, H$_2$O$_2$/UV, H$_2$O$_2$/Fe$^{2+}$, and H$_2$O$_2$/Fe$^{2+}$/UV oxidation processes and their applications for landfill leachate treatment were studied. It was reported that the ammonia
nitrogen (NH$_3$-N), pH, and alkalinity had influence on the advanced oxidation processes.

Mostafa (2002) made an experimental study to determine the effect of solid waste size, leachate recirculation and nutrient balance on the rate of municipal solid waste (MSW) biodegradation. The study indicated that the smaller the size of the MSW the faster the biodegradation rate of the waste. The average pH of the leachate in the early stages of recirculation was on the acidic range. The concentration of chloride remained fairly constant during the leachate recirculation period. A decreasing trend of the organic load, measured as biological oxygen demand and chemical oxygen demand was reported.

Hyun Park (2002) studied on the long-term settlement characteristics by applying a number of prediction methods to fresh MSW sites. It was witnessed that most of the proposed methods, excluding the power creep law, successfully predicted long-term settlement only if accelerated logarithmic compression due to decomposition of biodegradable MSW was included in the settlement prediction.

Ling et al (1998) studied the validity of functions based on published settlement results from three landfill sites. A hyperbolic function was proposed as an improved tool to simulate the settlement-time relationships, as well as to detect final settlement. The relationships between the parameters of these empirical functions and water content are reported.

Basel AI Yousfi & Frederick Pohland (1998) studied on strategies for modeling, designing, and operating landfills with leachate recirculation. A numerical model capable of predicting leachate quantity and quality, as well as biogas generation at solid wastes was reported for both single-pass leaching and leachate recirculation. Finally, the microbial mediated processes
of solid waste decomposition in landfills were simulated in terms of solublization of solid organic constituents (hydrolysis), acid formation (acidogenesis), and methane fermentation (methanogenesis).

Dean Wall (1995) studied the ability of biological enhancement to reduce the time to reach biological stabilization of the waste to non-degradable matter, and to determine the effects of biodegradation on settlement using six landfill test cells. It was concluded that secondary settlement is linear with the logarithm of time and decomposition followed first-order model. It was also reported that there is no significant increase in the settlement rate due to biodegradation; however, in the long term the settlement rate will increase as the effects of decomposition become more significant.

1.6.3 Compositing

Aerobic composting is called an energy consuming process, because around 30-35kWh is consumed by one ton of feedstock (Hartmann & Ahring, 2006). Composting is the natural biological process in which degradable part of waste is transformed to a steady material with exceptional characteristics for use on soils (Pathak et al 2011).

Composting is the decomposition of biological and organic substrates stabilization under conditions which allow development of thermophilic temperatures as a consequence of biologically induced heat, with a final product sufficiently steady for storage and usage to land without undesirable environmental effects (Haug 1993). The popularity of composting has increased in the past decade due to numerous environmental settlement such as rapid conversion of the organic solid waste to a biologically stable end product, effective hygienization of pathogenic bacteria present in the organic waste, stabilization and degree reduction of the waste materials.
preceding to eco-friendly final disposal in landfills, cheap and effective solid waste treatment method (Bertoldi et al 1988).

Different composting technologies depend on the quality of the initial substrate, processing time and process control. The length of composting cycle depends on the nature of the waste used (Saidi et al 2008). The efficiency of composting processes would be enhanced and aeration requirements shall be reduced by controlling the oxygen concentration in the exhaust air within a proper range (Xi et al 2005). The main technologies are forced aeration, reactor having a mechanism of mechanical turnover or by means of windrow composting pile. The reactors could be static or slowly rotating and the windrow could be formed in an open area or in a closed shelter. Also, the process could be batch or continuous; however, the batch process is usually applied to large-scale composting methodology (Benedict et al 1986; Epstein et al 1983; Sikora et al 1983).

The composting has been practiced for many years and numerous guidelines are available for the design of effective plants (Epstein 1997; Haug 1993; Nakasaki et al 1987; Finstein 1985; Kuter et al 1985). Most of these guidelines deal with municipal solid waste or sewage sludge.

Many advancement have been made in the area of composting since the 1970s because of the demise of the open dump (Golueke & Diaz 1987, Kuter 1985). The efficiency of composting stages depends on a variety of parameters, including aeration, temperature, content of moisture in the compost, pH, methods of composting and composition of the mixture to be composted. Of prime importance, however, are the microorganism species involved and the activity thereof (Neklyudov et al 2008).

The process of composting involves the interaction between organic waste, microorganisms, moisture and oxygen. The organic material
will usually have an inherited mixture of microorganisms derived from the atmosphere, water and soil. There is an increase in microbial activity under favorable conditions of moisture and aeration. The rapid assimilation of organic matter results in the production of CO$_2$, water, organic products and energy. Energy is utilized for microbial metabolism and reminder is given off as heat.

Wastes treatable by composting vary from the heterogeneous organic and inorganic mixture in municipal solid waste (Deportes et al 1998; Glenn 1997; Goldstein et al 1996) to the more homogeneous animal manure (Singley et al 1975), crop residues, fisheries waste biomass (Martin 1999); pulp and paper residues (Provenzano et al 1998); and primary and secondary sewage sludges (Bernal et al 1993; Golueke 1987). During the composting process with the availability of sufficient oxygen, the organic materials are converted to more stable products such as humic acids and carbon dioxide and water is evolved. The composting is therefore simply a means of converting raw organic matter into usable humus (Gray et al 1971).

Organic wastes originating from agricultural or industrial origin, e.g. food industry, meat industry (Oostrom et al 1991; Keeley and Skipper 1988), or municipalities (Fang et al 1999; Moreno et al 1997, 1998) are mixtures of sugars, proteins, fats, hemicelluloses, celluloses, lignin, minerals and other compounds in a wide variety of concentrations. These may serve as starting material for composting (Zucconi & Bertoldi 1987; Genevini & Negri 1986). Various studies of spent pig manure (Tiquia et al 1997, 1996) and sewage sludge composting have shown that temperatures between 40°C to 60°C favour microbial activity and decomposition (Neto et al 1986; Finstein et al 1985; Kuter et al 1985; Hoitink et al 1984; McKinley & Vestal 1984). The beneficial or detrimental effect of the application of these composted
materials on land has also been studied extensively over the past few years (Houot et al. 1998; Marull et al. 1997; Diazmarcote 1995).

Although this biological decomposition can take place under aerobic or anaerobic conditions, composting is mainly considered as an aerobic process (Schulze 1962). Furthermore, most practiced and controlled composting processes are aerobic (Martin 1999). Anaerobic composting is the digestion or fermentation of organic matter under anaerobic conditions (Tchobanoglous et al. 1977, Epstein 1997) and is generally applied for the production of biogas, mainly methane (Bertoldi et al. 1988).

Anaerobic composting has higher odour potential because of the nature of many intermediate metabolites (Haug 1993), whereas aerobic composting minimizes the impending of irritant odors (Metcalf and Eddy 1991). The decomposition rate in anaerobic composting is also very slow. Eyras et al. (1998) investigated the quality of seaweed compost which was limited by excessive amounts of sand and low nitrogen content but proved to be a good amendment that improved both physical and nutritional characteristics of loam soils used in intensive horticulture.

Mohajer (2008) investigated the microbial oxygen uptake rate in sixteen sludge waste recipes. The cumulative oxygen consumption after 14 and 28 days was found to be significantly influenced by moisture content, waste/bulking agent ratio and particle size. Peters et al. (2000) conducted experiments on succession of microbial communities during hot composting and found that community single-strand-conformation polymorphism profiles can be highly useful for the monitoring of bacterial diversity and community successions in a biotechnologically relevant process.

Xiaosong He et al. (2011) studied on spectroscopic characterization water extractable organic matter (WEOM) during the composting of
municipal solid waste (MSW), and investigated the correlation between maturity and WEOM characteristics. WEOM was extracted at different stages of MSW composting (0, 7, 14, 21, and 51 d) and characterized by FTIR, UV-Vis, and fluorescence spectroscopy. It was reported that the composting process decreased aliphatics, alcohols, polysaccharides, as well as protein-like materials, and increased aromatic polycondensation, humification, oxygen-containing functional groups, molecular weight, and humic-like materials.

Hultman et al (2010) studied on fungal succession during municipal solid waste composting using a cloning-based analysis. The microbiota at industrial full-scale composting plants has earlier been fragmentarily studied with molecular methods. Fungal communities from different stages of a full-scale and a pilot-scale composting reactors were studied. It was reported that the portion of fungal biomass, determined using phospholipid fatty acid analysis, varied between 6.3% and 38.5% in different composting phases.

Farrell & Jones (2009) assessed the potential end uses and sustainable markets for organic residue obtained by Municipal Solid Waste Composting. Critical evaluation revealed that the best option for using this organic resource is in land remediation and restoration schemes. For example, application of MSW-derived composts at acidic heavy metal contaminated sites has ameliorated soil pollution with minimal risk. Also it was concluded that although MSW-derived composts are of low value, they still represent a valuable resource particularly for use in post-industrial environments.

Smith (2009) studied on the impacts of heavy metals in municipal solid waste composts and compared the sewage sludge metal contents of source-segregated MSW or greenwaste compost with mechanically-sorted MSW-compost. It was reported that risks to the environment, human health, crop quality and yield, and soil fertility, from heavy metals in source-segregated MSW or greenwaste-compost are minimal. Further, composts
produced from mechanically-segregated MSW generally contain fewer metals than sewage sludge used as an agricultural soil improver under controlled conditions. Also, the metal content of mechanically-segregated MSW-compost does not represent a barrier to end-use of the product.

Paola Castaldi (2008) studied assessment of compost from municipal solid waste through the study of enzyme activities and water-soluble fractions. Municipal solid wastes composting were studied to evaluate their suitability as tools for compost characterization. It was reported that the hydrolytic activities and the water-soluble fractions did not vary statistically during the last month of composting. Significant correlations between the enzymatic activities, as well as between enzyme activities and water-soluble fractions, was reported.

Hargreaves & Warman (2008) studied the potential use of composted municipal solid waste in agriculture. A review of relevant agricultural studies was presented as well as recommendations for improving MSW compost quality was provided.

Weber (2007) studied the effect of municipal solid waste composts sandy soil towards agricultural and ecological applications. Sandy soil were examined after amending the soil with two different composts produced from municipal solid wastes. Triticale (XTriticosecale), cultivated in a 3-y monoculture, was used as a test plant. A large increase of plant-available P, K, and magnesium (Mg), which was observed during the entire period of the experiment. Beneficial changes were also observed in soil humic substances composition. It was concluded that Soil cation exchange capacity and base saturation increased was observed 1 year after compost application, while it remained significant only at the highest compost rates in third year. Compost originating from industrial areas, even if applied in low amounts, caused a significant increase in total concentration of soil heavy metals.
Madrid & Cabera (2007) studied the metal accumulation and DTPA-extractability in a sandy soil with three successive applications of municipal solid waste compost (MSWC) under intensive farming conditions. It was concluded that after the second and third application of compost, increases in the DTPA-extractable concentrations of metal contents Cu and Ni contents were also increased. The increases in the available fraction of the metal after MSWC application, the sandy characteristics of the soil, and the high irrigation rate would favour metal leaching through the soil profile.

Komilis (2006) performed a kinetic analysis study on waste composting at optimal conditions. Six municipal solid waste (MSW) and yard waste components (food waste, mixed paper, yard waste, leaves, branches, grass clippings) was considered for studies. An aerobic biodegradation conceptual model was presented for solid waste composting with the assumption that solids hydrolysis is the rate-limiting step. It was concluded that food waste had the largest readily hydrolysable carbon fraction and produces the highest amount of CO₂ among all substrates.

Komalis et al (2004) studied on the emission of volatile and semi-volatile organic compounds (VOCs) produced during composting of the organic fraction of municipal solid wastes (MSW). A laboratory experiment was conducted using organic components of MSW that were decomposed under controlled aerobic conditions. It was reported unseeded mixed paper, seeded mixed paper, seeded yard wastes, unseeded yard wastes, seeded food wastes and unseeded food wastes produced approximately 6.5, 6.1, 2.1, 0.83, 2.5 and 0.33 mg of 13 volatile and semi-volatile aromatic organic compounds combined, respectively, per dry kg. All VOCs were emitted early during the composting process and their production rates decreased with time at thermophilic temperatures.
Tuomela et al (2000) made a review on biodegradation of lignin in a compost environment. It summarized that efficient degradation of papers in composting plants was due to biodegradation of lignin by white-rot fungi. Organic material would be converted to carbon dioxide, humus, and heat by compost microorganisms. Elevated temperatures during the thermophilic phase was essential for rapid degradation of lignocellulose. Complex organic compounds like lignin are mainly degraded by thermophilic microfungi and actinomycetes. It was reported that the optimum temperature for thermophilic fungi is 40–50°C which is also the optimum temperature for lignin degradation in compost.

Das & Keener (1997) studied about effect of initial moisture content and compressive loads on the compactability and air permeability of compost mixes. The relationship between air permeability and total air-filled porosity using the Kozeny-Carman flow model at different moisture levels was reported. It was concluded that biosolids showed significant compressive behavior and lower permeabilities with increasing moisture content (42–57%) and Cow manure had a high moisture-retaining capacity and the differences in compaction behavior and air permeabilities were small when moisture levels were varied (57–73%). The model described the relationship between air permeability and effective free air space with a high level of accuracy ($R^2 > 0.95$) at all moisture levels and compacted state.

Claire Serra-Wittling et al (1996) studied about the suppressiveness of a loamy soil amended with municipal solid waste compost to Fusarium wilt of flax (caused by *Fusarium oxysporum* f. sp. *lini*). The soil was reasonably conducive to the disease, with an estimated half life time (HLT) of the flax population of 41 days with the help of hat-treatment. The suppressiveness of the control soil was increased because of compost addition proportionally to the application rate (10, 20 and 30%). Both microflora of soil and compost
were involved in the suppressiveness and mainly acted through nutrient and space competition towards the population of the pathogen.

Anna Palmisano et al (1993) developed a bioreactor with the capacity of 19L to simulate municipal solid waste composting. The bioreactor utilized a defined waste mixture consisting of rabbit chow with alfalfa and shredded newspaper inoculated with an equal quantity of leaf compost, garden soil, and cow manure to minimize variation in feed stock. During the first 24 h, the mixture self-heated from 37°C with the result of Bacillus-like bacteria dominated the composting mass. All the parameters increased initially and remained high throughout a 28 day incubation period. After 28 days, volatile solids and carbon nitrogen ratios had decreased appreciably. It was concluded that under moist, aerobic conditions, simulated solid waste can undergo changes comparable to those reported for municipal solid waste in full-scale composting systems.

Epstein et al (1992) evaluated the data on heavy metals from mixed MSW and source separated MSW (SOW) for the United States and European facilities in his studies. The levels of heavy metals in mixed MSW-compost were considerably lower than levels in sewage sludge and sludge compost that the U.S. EPA has determined to be safe for land application. Although concentrations of heavy metals in SOW are somewhat lower than in mixed MSW compost, there is no evidence that either type poses a risk to human health or the environment. The risk analysis showed that the potential health risk even in the worse cases is extremely low.

James Gillett (1992) discussed in his research studies about the various issues in risk assessment of composting from Municipal Solid Waste. He analyzed various occupational health and safety, public health and environmental issues with respect to composting of MSW.
Tom Richard & Peter Woodbury (1992) made a complete study on the impact of separation on heavy metals in Municipal Solid Waste. Various separation strategies were considered to separate the metals like prior to collection from the sources, wet and dry collection method, and manual or mechanical separation method at the centralized facility. It was concluded that centralized separation can be more suitable than other methods to separate the metals moderately.

Richard (1992) studied elaborately about the various methods like separation processes, size reduction and biological processing available for the composting of municipal solid waste. Many of these technologies were originally developed for other purposes, and are being adapted for different functions with new feedstocks. Separation systems traditionally were designed to recover recyclable material, but are now also used to reduce inert and chemical contaminants. Size reduction can be coordinated with separation equipment to enhance materials recovery and contaminant reduction. Biological processing methods combine process control with materials handling to manage a complex microbial ecosystem. Linked with an MSW collection program, these technologies must act as a coordinated system to transform incoming waste materials to a marketable end product.

Senesi (1989) studied in his review about the composting into three sections. The first section briefly discusses on input, transformation and loss of native and added organic matter in soil and on principal effects of fresh organic matter addition on soil properties. The subject of the second section focuses on organic compost. The third section discusses extensively on the most commonly used waste composting process, substrate materials and products of compostation, i.e. criteria and parameters for the evaluation of compost quality as organic fertilizers, including various proposed
“humification degree” indexes and compositional, structural and functional properties of humic-like substances in compost.

Emeterio Iglesias Jiménez & Victor Perez García (1989) reviewed the evaluation of the maturity of domestic refuse compost has been widely recognized as one of the most important problems concerning the composting process and the application of the product to the land. The conditions or characteristics which the compost must meet to assure an acceptable degree of maturity were analyzed.

Gallardo-Lara & Nogales (1987) reviewed the effect of the application of town refuse compost on the soil plant system as probable fertilizer. It has been demonstrated that the application of compost to soil improves some physical properties such as porosity, water-holding capacity and bulk density. Compost application to soil has a positive effect on the microbial population and rhizosphere microorganisms and also contributes to the reduction of nematode populations in plants. However, when big doses of compost are used, an inhibitory effect on seed germination may appear. The nitrogen availability of the municipal compost is closely related to the maturity of this material. A wide range of results has been obtained from different studies performed to evaluate the efficiency of compost as a source of phosphorus, sulphur, calcium and magnesium for plants. The incorporation of municipal compost constitutes a valuable resource for supplying potassium and some micronutrients (i.e. boron and zinc), but also presents potential pollution hazards associated with some heavy metals.

1.6.4 Anaerobic Digestion

Anaerobic Digestion (AD) is the most cost effective having high energy recovery with limited environmental impacts, especially considering its limited greenhouse gases effect. AD can be the attractive method for both
energy generation and waste disposal (Rao & Singh 2004). AD will become much more important in the future for ecological reasons (Siddarth Jain et al 2015). The composition of MSW at generation sources and collection points was estimated on a wet weight basis and it consists mainly of a large organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%) and plastic, glass and metals (each less than 1%). According to a statistics, the physical characteristics of MSW in Coimbatore city are as follows: Paper: 5%, Textile: 9.0%, Plastic: 1%, Ash, fine earth, etc.: 50% and finally, Compostable matter: 35% (Sharholy et al, 2008).

Benjamin Wirth et al (2015) investigated the use of process liquor from hydrothermal carbonization (HTC) of sewage sludge as sole substrate for anaerobic digestion (AD). Increased temperature had no effect on the steady-state COD removal efficiency with reactors stabilized at 68–75%. Methanogenesis was identified as the speed-limiting step in anaerobic digestion of HTC liquor. Hydrolysis was of an order of magnitude faster than methanogenesis.

Matthew Uke et al (2013) observed the Poor performance of leach bed reactors (LBRs) is attributed to channeling, compaction from waste loading, unidirectional water addition and leachate flow causing reduced hydraulic conductivity and leachate flow blockage. Performance enhancement was evaluated in three LBRs M, D and U. The strategy adopted in U led to more water addition (30.3%), leachate production (33%) and chemical oxygen demand (COD) solubilisation (33%; 1609 g against 1210 g) compared to D (control).

Ajay Kumar Jha1 et al (2011) studied the dry anaerobic digestion process to treat high-solid content bio-wastes. This can be done without dilution with water by microbial consortia in an oxygen free environment to
recover potential renewable energy and nutrient-rich fertilizer for sustainable solid waste management.

Lucia Martín-Gonzále et al (2011) observed the thermophilic conditions instead of mesophilic, and also the addition of a co-substrate, are both the ways to intend to improve the anaerobic digestion of the source-collected organic fraction of municipal solid wastes (SC-OFMSW). Addition of sewage treatment plant fat, oil and grease wastes (STP-FOGW) is used to recover a wasted methane potential and to improve the whole process. During the co-digestion period enhancements in biogas production (52%) and methane yield (36%) were achieved.

Baoning Zhu et al (2009) observed the characteristics and biogas production potential of organic materials separated from municipal solid wastes using a rotary drum reactor (RDR) process. After 20 d of thermophilic digestion (50 ± 1 C), it was found that the biogas yields of the above materials were in the range of 457–557 mL g VS⁻¹ and the biogas contained 57.3–60.6% methane.

Poh et al (2009) studied the various anaerobic treatments of Palm oil mill effluent (POME) and factors that influence the operation of anaerobic treatment. The POME treatment at both mesophilic and thermophilic temperature ranges are also analyzed.

Panyue Zhanga et al (2008) observed the co-digestion of biosolids and organic fraction of municipal solid waste was compared with the direct digestion of biosolids. The biogas yield rate was increased by the mixed feed stock, the biogas yield peak was observed for about 10 days and the maximum biogas yield rate was reduced.
Annop Nopharatana et al (2007) investigated a series of batch, slurry anaerobic digestion experiments. In which soluble and insoluble fractions, and unwashed MSW were separately digested in a 200 L stirred stainless steel vessel at a pH of 7.2 and a temperature of 38°C. The minimum time of 20 days is required to convert 95% of the degradable fraction to biogas. The lag phase for the degradation of insoluble fraction of MSW can be overcome by acclimatizing the culture with the soluble fraction. The rate of digestion and the methane yield was not affected by particle size (within the range of 2–50 mm). The kinetics for hydrolysis of insoluble fraction could be adequately described by a Contois equation and the kinetics of acidogenesis, and aceticlastic and hydrogen utilizing methanogenesis by Monod equations.

Anna Fernandez et al (2005) studied the potential of mesophilic anaerobic digestion for the treatment of fats of different origin through co-digestion with the organic fraction of municipal solid wastes (OFMSW). The anaerobic co-digestion of OFMSW and fat wastes appears to be a suitable technology to treat such wastes, obtaining a renewable source of energy from biogas.

Hinrich Hartmann et al (2005) studied the configuration of anaerobic digestion (AD) of the organic fraction of municipal solid waste (OFMSW). To enhance hydrolysis of recalcitrant organic matter, an anaerobic hyperthermophilic (688°C) reactor R68 was implemented as a post-treatment. The Volatile Solid(VS) reduction and biogas yield of the combined system was 78–89% and 640–790 mL/g VS, which is higher than the single stage treatment. Removal of pathogens was enhanced by the hyper-thermophilic post-treatment.

Wilton Silva Lopes et al (2004) observed the influence of bovine rumen fluid inoculum during anaerobic treatment of the organic fraction of
municipal solid waste (MSW). The proportions between MSW/inoculum loaded in the reactors were Reactor A (100%/0%), Reactor B (95%/5%), Reactor C (90%/10%) and Reactor D (85%/15%). The methane concentration in the biogas produced was 3.6%, 13.0%, 25.0% and 42.6% for Reactors A, B, C and D, respectively. It confirms that the inoculum used in MSW substantially improved the performance of the process.

Delia Teresa Sponza et al (2004) investigated the effects of leachate recirculation and the recirculation rate on the anaerobic treatment of domestic solid waste in three simulated landfill anaerobic bioreactors. A single pass reactor was operated without leachate recirculation while the other two reactors (Reactor 9, Reactor 21) were operated with leachate recirculation. After 220 days of anaerobic incubation, it was observed that the pH, COD, VFA concentrations, methane gas productions and methane percentages in Reactor 9 (recirculation rate was 9 l/day) were better than the single pass reactor and Reactor 21 (recirculation rate was 21 l/day). Leachate recirculation reduced the waste stabilization time and was effective in enhancing methane gas production and improving leachate. However, leachate recirculation was not effective in removing ammonia from the leachate.

Sosnowski et al (2003) investigated the methane fermentation of sewage sludge and organic fraction of municipal solid wastes (OFMSW) as well as the co fermentation of both substrates under thermophilic and mesophilic conditions. Totally five experiments were conducted using different mixture of substrate. The first and second experiments were conducted in bioreactor at thermophilically, while other three experiments (III and IV, V) in the continuous stirred tank bioreactor at thermophilic conditions (56°C) and mesophilic methane fermentation (36°C). Methane concentration
in the biogas was above 60% in all cases. Biogas productivity varied between 0.4 and 0.6 dm yg VSS depending on substrate added to the digester.

Annop Nopharatana et al (2003) studied a mathematical model that describes the operation of a sequential leach bed process for anaerobic digestion of organic fraction of municipal solid waste (MSW). The model was validated using data from leach bed digestion experiments in which a leachate volume equal to 10% of the fresh waste bed volume was sequenced.

Largus et al (2002) observed the Changes in methanogenic population levels in full-scale, farm-based anaerobic sequencing batch reactor (ASBR) and this changes were related to operational and performance data. Methane production and reactor performance were not affected as the 16S rRNA levels of the hydrogen-utilizing methanogens of the order Methanomicrobiales increased from 2.3% to 7.0%. During high ammonia level conditions, the major route of methane production is through a syntrophic relationship between acetate-oxidizing bacteria and hydrogen-utilizing methanogens.

Peter Stroot et al (2001) studied the feasibility of codigestion of the organic fraction of municipal solid waste, primary sludge and activated sludge in mesophilic, laboratory scale digester. The experiments were conducted under continuous and minimally mixed conditions, the results demonstrated that reducing the level of mixing improved digester performance and also it stabilize the unstable digester.

Mata-Alvarez et al (2000) investigated the fundamentals, process aspects, digestion enhancement, co-digestion with other substrates and its relation to composting technology. It also describes the anaerobic digestion in limiting the emission of greenhouse gases.
Pavan et al (2000) investigated the a two-phase system operated in different conditions, treating the source-sorted organic fraction of municipal solid waste (SS-OFMSW), coming mainly from fruit and vegetable market. Specific gas production (SGP) in these conditions is around 0.6 m$^3$/kgTVS. It shows that the two-phase system is much more appropriate for the digestion of this kind of highly biodegradable substrate in thermophilic conditions, when compared to the one-phase system.

Negri et al (1993) studied a mathematical model of a plug-flow reactor with a fluid recycle to simulate the VFA production process treating the organic fraction of the municipal solid waste. It is found that the reactor production is very sensitive to the system pH. For the system analyzed, the pH is a critical parameter and a plug-flow arrangement (without recycle) seems to be the more reasonable.

In the present work, it is intended to study on different conventional, viable and eco-friendly methods like land filling, composting and anaerobic digestion towards municipal solid waste treatment in Coimbatore city. It is also proposed to study the factors like pH, temperature, moisture content and other factors that affects the land filling strategy. It is also proposed to study composting method of MSW and its characteristics analysis. Further, it is proposed to design and fabricate a continuous horizontal anaerobic digester for studying the organic material decomposition in an oxygen depleted environment along with analysis of waste composition, controlling parameters, nutrients, metals, leachate and biogas potential under lab scale environment.