IN-VESSEL COMPOSTING OF FOOD WASTE: A NOVEL APPROACH

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By

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Certificate

This is to certify that the thesis entitled **“In-Vessel Composting of Food Waste: A Novel Approach”** is a report of the original work carried out by **Mr. Anand M.** under our supervision and guidance in the School of Environmental Studies, Cochin University of Science and Technology, Kochi-22. No part of the work reported in this thesis has been presented for any other degree from any other institution. All the relevant corrections and modifications suggested by the audience during the pre-synopsis seminar and recommended by the Doctoral committee have been incorporated in the thesis.

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Declaration

I hereby declare that the thesis entitled, **"In-Vessel Composting of Food Waste: A Novel Approach"**, is the original research work carried out by me under the joint guidance and supervision of Dr. M.V. Harindranathan Nair, Associate Professor (Rtd.), School of Environmental Studies, Cochin University of Science and Technology, Kochi – 682 022 and Dr. I.S. Bright Singh, UGC- BSR Faculty, NCAAH, Cochin University of Science and Technology, Kochi-682 022. No part of this thesis has been presented for any other degree from any other institution.

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Executive Summary

This study is to develop a device for converting organic waste into resource and a decentralized approach to waste composting. The system is developed based on real ground level experience of food waste concern, faced by people at households, apartments and community levels in urban centers. This study serves to create and contribute towards an environment which can strengthen decentralized composting.

The physical composition of municipal solid waste in India consists mostly of organic matter, which is biodegradable. Inadequate collection and disposal of these wastes poses a serious health risk to the population through rodent and other vector related pestilences and is an obvious cause of environmental degradation in most of the cities in India. When organic waste remains uncollected in the streets, drains or when disposed in open crude dump sites, it poses three major environmental problems: firstly, ground and surface water pollution through leachates including drainage bottlenecks; secondly, spread of disease vectors from open and uncovered waste dumped in crude dump sites; and thirdly, emission of methane which is a major greenhouse gas due to anaerobic condition in the dump sites. With growing public pressure and environmental legislations, the waste management experts are being called upon to develop more sustainable methods of dealing with municipal waste. One step in improving the current solid waste situation is by enhancing resource recovery activities; mainly by the so called rag pickers. Recycling inorganic materials from municipal solid waste is often well developed by the activities of the informal sector in India. Reuse of organic waste material however, often contributing to more than 50% of the total waste amount, is still fairly limited but has interesting recovery potential. Approaches to reduce reliance on landfill as a disposal route, biological treatment is increasingly becoming adopted as a standard requirement for the vast majority of biodegradable wastes. In order to avoid the solid waste - triggered environmental hazards, use of compost needs to be

promoted. One of the sustainable approaches is to look at waste as a resource, not as a problem. The existing physical plan, waste stream, tropical climate, and socio-economic situation of many cities in India strongly favor the implementation of decentralized composting systems.

The main objective of this study is to find different ways in which the enormous quantity of solid wastes currently disposed of on landfills can be reduced by recovering the organic portion and recycling it, in a cost effective and environmental friendly manner. The focus of this work is on the development of appropriate in-vessel composting technology for the treatment of food waste onsite, appropriate to the local conditions and feasible from a technical, environmental, social, economic, financial, institutional and political perspective.

Pilot scale 75 liter, insulated, twin chambered composter has been fabricated to perform closely monitored composting studies. This fully enclosed, logic controlled, pilot scale reactor hold about 55 Kg of feedstock mixture on wet bases. The twin reactor units stand upright with air flowing vertically through the center of the compost mixture. Enclosed units permit online analysis of oxygen, carbon dioxide, ammonia and methane at head space and exit locations. The bottom of each reactor consists of leachate recirculation pumps and out let valves for recirculation and periodic sampling respectively.

An insulated space between the inner vessel and the outer shell reduces heat loss from the reactor during aerobic activity, which will accelerate thermophilic stage of composting. Each composter houses two thermocouples connected to a detector module and a controller, for real-time temperature measurements. Thermocouples reside at two equally spaced vertical locations, one over the head space and another into the compost matrix at the bottom. A standalone thermocouple tracks ambient temperature outside the reaction vessel. During operation, if the temperature exceeds the preset high value, the aeration device is switched-on to ‘continuous mode’, until the temperature drops below the preset value, which will prevent the damage to microbial culture by high temperature. When the temperature drops just below the high preset value, the controller switches the unit back to the normal aeration duty cycle to reduce further heat loss from the reactor.

The invention, in its simplest form, is an integrated or unitized household in-vessel composting system intended to convert cooked and pre-cooked food waste into a nutrient-rich bulk organic end product that are manageable, inoffensive and useful. It utilizes a continuous two-step process which has approximately three to four week throughput cycle. Composting takes place in perforated vessels encased by insulated vertical containers, coupled with a positive and negative aeration system. Additionally, polypropylene moisture capturing unit and a granular activated carbon odor filtering unit is provided at the suction end for added safety. With the twin-chamber system the waste material can be loaded intermittently in the first chamber and vice versa for continuous stabilization and curing activity, after which the matured compost can be harvested. The aeration system is programmed and operated based on the initial characteristics of the feedstock and bulking agent. Leachate is partly re-circulated and rest is collected through the out let at the bottom to be used as compost tea. The overall processing time is approximately 30 to 35 days. As the power consumption is low the entire system can be hooked up to a solar power source for independent operation.

The scope of the study includes design and testing of an in-vessel composting system, and focuses on defining acceptable operating conditions and process characteristics, in order to establish suitable parameters for treatment effectiveness. Parameters of interest include aeration control, moisture dynamics, heat production, physical and chemical properties of the compost mixture etc.

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List of Abbreviations

AD	Anaerobic Digestion
ARTI	Appropriate Rural Technology Institute
BPW	Buffered Peptone Water
C	Carbon
CCQC	California Compost Quality Council
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPCB	Central Pollution Control Board
DISCOMs	Distribution Companies
Dwb	Dry Weight Basis
EMB	Methylene Blue Agar
EPS	Expanded Poylstrene
FDA	Fluorescein Diacetate
FRP	Fiber Re-enforced Plastic
GCAI	German Compost Association Index
GHG	Green House Gas
GNP	Gross National Product
GNP	Gross National Product
GOI	Government of India
HC	Hydro Carbon
HMI	Human Machine Interface
INR	Indian Rupees
IPCC	Inter-governmental Panel on Climate Change
JnNURM	Jawaharlal Nehru National Urban Renewal Mission
Kg	Kilogram
MBT	Mechanical Biological treatment
MIL	Motility Indole Lysine Agar
MOEF	Ministry of Environment and Forest
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MW	Mega Watt
N	Nitrogen
NEERI	National Environmental Engineering Research Institute

NGOs	Non-Governmental Organization
NH_3	Ammonium
NO_x	Nitrogen Oxides
NPE	Nouyl Phenol
O_2	Oxygen
OECD	Organization for Economic Co-operation and Development
ORWARE	ORganic WAste REcycling
OW	Organic Waste
PAH	Poly Aromatic Hydrocarbon
PC	Planning Commission
PLC	Programmable Logic Controller
PM	Particulate Matter
RDF	Refuse Derived Fuel
RTD	Resistance Temperature Detector
RTDM	Resistance Temperature Detector Module
SMPS	Switched Mode Power Supply
SO_2	Sulfur Dioxide
SWM	Solid Waste Management
T	Tonne
TMECC	Test Methods for the Examination of Composting and Compost
TOC	Total Organic Carbon
TPA	Tonnes per Annum
TPD	Tonnes per Day
TPF	Triphenyle Formazan
TPY	Tonnes per Year
TSI	triple Sugar Iron Agar
TTC	Triphenyle Tetrayolium Chloride
UFW	Urban Food Waste
ULBs	Urban Local Bodies
USD	United States Dollars
V	Volt
VS	Volatile Solids
W	Watt
XLT	Xylose Lysine Tergitol

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Chapter 1

INTRODUCTON

Contents

1.1 Introduction

The effective management of solid waste has become a mammoth challenge for India with a population density which is among the highest in the world and a country which is also experiencing the problems of rapid urbanization. Proper waste management helps to protect human health and the environment and preserve natural resources. The planners continue to tackle the problem within the existing infrastructure facilities but only succeed in shifting the solid wastes from densely populated to sparsely populate suburban areas. The problems caused by solid and liquid wastes can be significantly mitigated through the adoption of environment-friendly technologies that will allow for the treatment and processing of wastes before being disposed. These measures would reduce the quantity of wastes; generate a substantial quantity of soil amendment/ energy from them and greatly reduce environmental pollution. Thus, waste management proved to be a significant environmental justice issue. Most of the environmental burdens are more often borne by marginalized groups, such as racial minorities, women and children. However, the need for expansion and setting up of waste treatment and disposal facilities is increasing worldwide.

In India, due to rapid population and commercial growth, cities are facing problems of Municipal Solid Waste (MSW) disposal. The urban population in larger towns and cities in India is increasing at a decadal growth rate of above 40%. As a result of limited funds and poor management practices, a large fraction of municipal solid waste is not collected nor properly disposed and the problem is rapidly aggravating with increased urbanization. Public and private sectors, alike are facing increasing cost and difficulty in disposing of their enormous and increasing tonnage of solid waste and garbage in an environmentally sound and economically acceptable manner. The waste generated from households count for a large percentage of the municipal waste stream and thus contributes to serious environmental impacts and health hazards.

Generally, refuse or garbage has been collected and disposed of by one of several inexpensive means, such as open burning, dumping in water ways and road sides, or in common landfills. As the ecological impacts of such practices became evident, the demand for safer practices grew. Three methods emerged as environmentally suitable means for safe refuse disposal. 1) Sophisticated landfills with costly structures and controls designed to prevent leachate into surrounding ground water. 2) Controlled incineration and 3) Biological processes. There are no sanitary landfill sites in India at present. Municipal Solid Waste is dumped without any treatment into land (depression, ditches, soaked ponds) or on the outskirts of the city in an unscientific manner with no complaisance to legal regulation. Irrespective of urban or rural areas, the un-controlled dumping of wastes at the nearest available low lying lands, results in nuisance and health risks to residents. However in India the engineered landfill is not a viable method for the treatment of municipal solid waste because of economic reasons and resource crunch. Although municipal incinerators are more environment friendly than they were a generation ago, these hi-tech incinerators are not economically feasible for the treatment of municipal solid waste in India, which is characterized with 45 to 80 % of organic fraction, high moisture and low calorific value. The larger portion of organic matter in Indian municipal solid waste indicates the suitability of biological processing.

Aiming at sustainability the two favored options for dealing with organic solid waste is today argued to be composting and biogas production. The benefits from these practices are many; they not only decrease possible contamination of the environment and reduce health hazards, but also save valuable space at landfills and serves as valuable resources. According to Anon, 2005 composting of organics is a more favorable and practical treatment method than anaerobic digestion. Evaluation of these two alternatives by scientists with regard to environmental effects and sustainability criteria, suggests recycling of materials as the preferred method over energy recovery. Many large scale biogas digesters have also failed because of over-size, advanced technology and maintenance problems.

As there are variety of technologies for utilization of waste namely Incineration, Pyrolysis, Anaerobic digestion to produce gas, Thermal gasification, Plasma arc, Sanitary land fill, Pelletization, Micro wave and Laser Waste Destruction are available, “Aerobic composting” of the urban solid waste is opted by many scientists and technocrats in India owing to its simplicity in the process, suitability for the Indian conditions, low cost factors and less pollution effects. Most of the Technologies, except the aerobic composting process, are either costly or pollute the environment by emitting toxic fumes, including dioxins. The concept of “Reduce, Reuse and Recycle” could be fully contemplated by adopting composting technology. It is imperative therefore, that relevant technologies are evolved to treat and recycle waste in order to keep the ecosystem clean. Over the recent past, composting process has been scientifically studied and engineered, thereby allowing it to become a more efficient and manageable waste disposal method.

The benefits of composting have long been known, though not as a bio-fertilizer but as a soil conditioner which improves texture, air circulation and drainage. Compost moderates soil temperature, enhances nutrient and water holding capacity, decreases erosion, inhibits weed growth and suppresses some plant pathogens; Compost can also be used as landfill cover or in-land reclamation projects. However, conventional open windrow composting systems has the potential to pollute environment, cause dis-amenity to the locality or harm to public health if good operating practices are not observed (Slater, 2001). The traditional and current methods of waste disposal like large scale centralized composting units are becoming more and more inadequate and unhealthy in pier-urban villages and rural towns in India, as we know it from our past and present experiences.

In order to minimize the environmental impacts of composting and to enhance/control the composting process, highly sophisticated enclosed composting systems have been developed throughout Europe and other western countries based on forced aeration technology. These often use computer–controlled systems to manage the aeration rate, moisture content and temperature of the composting materials. They have been termed 'in–vessel' and cover a wide range of composting systems. The principle behind an in–vessel system is to provide air and moisture at a level that optimizes microbial activity as rapidly as possible and then maintains it for the desired period. This is obviously easier than in open composting operations where control over ambient temperatures and other elements are more challenging. It is also possible for more difficult feed stocks to be composted using in-vessel systems, since they are protected from the wider environment and enclosure helps prevent pathogen vectors, such as scavenging birds and vermin from gaining access to the feedstock. In addition, the enclosure of decomposing organic materials allows potentially harmful emissions to be contained and possibly treated prior to release into the environment. We know that expensive technologies are being pushed to deal with our waste problem, ignoring their environmental and social implications. Thus, our new approach should be on the use of appropriate technology with significant improvement in output efficiency and also in terms of social costs. The concept of appropriate technology does not mean primitive or low technology but it only emphasizes that it should be labor intensive and economically viable and is based on optimum utilization of local resources.

With this backdrop the present research was initiated for the development of an appropriate in-vessel composting system for the treatment of food wastes on-site at households and community level. The aim of present study is to develop an appropriate low cost in-vessel composting system, so that the above mentioned biodegradable waste reaching the dump sites can be channeled out by source segregation and treating it on-site. At regional settings especially in Kerala the conventional composting systems face severe operational limitations during monsoon seasons but it is envisaged that with appropriate in-vessel composting system and method, such limitations can be overcome, thereby to encourage sustainable growth along with nature which will make ‘The gods own country’ more greener and healthier.

It is envisioned that with proper decentralized treatment of bio-waste at source and with the participation of the informal sectors and stakeholders, who recycles the recyclables, about 95% of the total MSW generated at household levels, can be managed very effectively and only remaining 5% need to be handled by the Municipalities/Corporations. This reduces the burden of the Government agencies in tackling MSW and at the same time, the allocated funds shall be diverted to other developmental/welfare programs, to benefit the public.

1.2 Solid waste management crises in India

With the ever increasing population and urbanization, the waste management has emerged as a huge challenge throughout the world, particularly in the developing countries like India. Not only the waste has increased in quantity, but the characteristics and composition of waste have also changed tremendously over a period, with the introduction of so many new non-biodegradable and toxic gadgets and equipment's. It is estimated that about 62 million tonnes of waste is generated annually in the country, out of which 5.6 million is plastic waste, 0.17 million is biomedical waste. In addition, hazardous waste generation is 7.90 million Tonnes Per Annum (TPA) and 15 lakh tonne is e-waste. The per capita waste generation in Indian cities range from 200 grams to 600 grams per day (2011). 43 million TPA is collected, 11.9 million is treated and 31 million is dumped in landfill sites (Anon, 2016).

Only about 75- 80% of the municipal waste gets collected and out of this only 22-28 % is processed and treated and remaining is disposed of indiscriminately at dump yards. It is projected that by the year 2031 the MSW generation shall increase to 165 million tonnes and to 436 million tons by 2050. If cities continue to dump the waste at present rate without treatment, it will need 1240 hectares of additional land per year and with projected generation of 165 million tons of waste by 2031, the requirement of setting up of land fill for 20 years of 10 meters height will require 66,000 hectares of land (Anon, 2016). As per the Report of the Task Force of erstwhile Planning Commission (PC), the untapped waste has a potential of generating 439 Mega Watt (MW) of power from 32,890

Tonnes Per Day (TPD) of combustible wastes including Refuse Derived Fuel (RDF), 1.3 million cubic meter of biogas per day, or 72 MW of electricity from biogas and 5.4 million metric tonnes of compost annually to support agriculture (Anon, 2016). As per the information available for 2013-14, compiled by Central Pollution Control Board (CPCB), municipal authorities have so far only set up 553 compost & vermi-compost plants, 56 bio-methanation plants, 22 RDF plants and 13 Waste To Energy (WTE) plants in the country (Anon, 2016).

It is estimated that about 2% of the uncollected wastes are burnt openly on the streets. About 10% of the collected MSW is openly burnt or is caught in landfill fires (Anon, 2010). Such open burning of MSW and landfill fires together releases 22,000 tons of pollutants into the lower atmosphere of Mumbai city alone every year. The pollutants include Carbon Monoxide (CO), carcinogenic Hydro Carbons (HC) (includes dioxins and furans), Particulate Matter (PM), Nitrogen Oxides (NO_x) and Sulfur Dioxide (SO_2) (Anon, 2010).

Most of the recyclable waste is collected by the informal recycling sector in India prior to and after formal collection by Urban Local Bodies (ULB). Amount of recyclables collected by informal sector (so-called Rag-pickers) prior to formal collection are generally not accounted. The report by Annepu, (2012) estimates that 21% of recyclables collected formally are separated by the formal sector at transfer stations and dumps. Even though this number does not include amount of recycling prior to formal collection, it compares fairly well with the best recycling percentages achieved around the world (Annepu, 2012). Informal recycling system is lately receiving its due recognition world-wide for its role in waste management in developing nations. In India, the government policies and Non-Governmental Organizations (NGOs) are expected to organize the above sector present in different regions, and to help integrating it into the overall formal system. 'Plastic Waste Management and Handling Rules, 2011' by the Ministry of Environment and Forests (MOEF) is a step ahead in this direction. These rules mandate ULBs to coordinate with all stake holders in solid waste management, which includes waste pickers.

India is the second most populous nation on the planet. The Census of 2011 estimates a population of 1.21 billion which is 17.66% of the world population. Indian population increased by more than 181 million during 2001 – 2011, a 17.64% increase in population, since 2001. India's urban population was 285 million in 2001 and increased by 31.8% to 377 million in 2011, which implies an annual growth rate of 2.8% during this period (Anon 2011). India is facing a sharp contrast between its increasing urban population and available services and resources. Solid Waste Management (SWM) is one such service where India has an enormous gap to fill. Proper MSW management systems to address the burgeoning amount of wastes are absent. The current SWM services incur heavy expenditure and grossly inadequate, posing a potential threat to the public health and environmental quality (Biswas, 2010). Improper solid waste management deteriorates public health, causes environmental pollution, accelerates natural resource degradation, causes climate change and greatly impacts the quality of life of citizens.

The present citizens of India are living in times of unprecedented economic growth, rising aspirations, and rapidly changing lifestyles, which will raise the expectations on public health and quality of life. Remediation and recovery of misused resources will also be expected. These expectations when not met might result in a low quality of life for the citizens. Pollution of whether air, water or land results in long-term reduction of productivity leading to a deterioration of economic condition of a country. Therefore, controlling pollution to reduce risk of poor health, to protect the natural environment and to contribute to quality of life is a key component of sustainable development (Anon, 2010).

1.3 Effects and impacts of deficient waste management

A deficient waste management system affects health, environmental conditions and socio- economic development negatively. If municipal solid waste remains uncollected, it tends to accumulate in the proximity of residents. This proximity increases the immediate risk of exposure to the negative effects of waste either directly or indirectly by the measures that people take to reduce the accumulation (Bradley, 1992). Health and environmental risks from waste may be caused by many factors which relate to occupational health risks and environmental health risks to residents and workers (Cointreau, 2006; Manga, 2007).

- Exposure to disease transmitting vectors which can proliferate or are in close contact to waste (e.g., flies mosquitos, rodents, dogs, birds, etc.).
- Contact with certain waste types and characteristics (e.g. sharps, infectious or toxic substances).

- Physical risk associated with the handling of the waste without protective measures (e.g., physical injuries, accidents, etc.).
- Exposure to the emissions and risks of waste treatment or disposal (e.g. odour, noise, vibration, accidents, physical stability of dump sites, air and water pollution, explosions, fires, smoke, flooding).
- Exposure to the secondary components generated from waste (e.g. odour, gases, leachates or dust).

1.3.1 Environmental health risks

Uncollected waste in settlements often accumulates in open drains, in river gullies, on empty plots, or at the roadsides. During storm events drains are blocked by solid waste. Then, a mix of storm-water, wastewater and waste overflows the drains and floods the neighborhood creating an unhygienic environment and exposing residents to pathogenic and chemical substances.

Solid waste dumped indiscriminately into empty plots, drains or rivers also offers ideal breeding grounds for disease-transmitting vectors. When rainwater accumulates in waste (such as discarded tires) or when waste blocks drains and channels creating stagnant puddles, these are ideal breeding sites are created for the mosquitos *Aedes aegypti* and *Aedes albopictus* both of which are major vectors of dengue which is basically an urban disease (Mahanta, 2006). Furthermore, the malaria transmitting mosquito *Anopheles* was found to breed in similarly polluted, stagnant waters (Awolola, 2007). Awolola et al. (2007) have shown that *Anopheles gambiaes* is able to adapt to a large range of water quality conditions present in urban areas. This has serious consequences on urban malaria. Biodegradable waste also attracts insects, rodents and other animals that feed on waste; the animals then proliferate and when in contact with humans, transmit disease. In Europe between the 14th and 17th century, the historically most devastating pandemics of plague was caused by fleas carried by ground rodents, and is attributed to roads and neighborhoods covered in garbage and excrements which provided ideal breeding grounds for the rodents. A well-documented case in modern times is from the city of Surat in the state of Gujarat India, where the rapid growth of slums, uncollected waste and indiscriminate dumping led to a proliferation of rats and then, as a consequence to the outbreak of pneumonic plague in September 1994 leaving 56 people dead. This event created global panic and severely affected the city of Surat and the National economy of India. About 60% of the Surat population left the city for fear of falling ill. The industry suffered an estimated loss of about 214 million US Dollars (USD), although the disease was controlled within a week. Inadequate waste collection and disposal was mentioned most frequently as main cause of the outbreak. Authorities however, argued that it was the non-cooperation and non-compliance of the public and a lack of awareness about cleanliness that led to the outbreak. This again shows the complexity of providing good solid waste services that are based on an intricate link between stakeholders with different roles and responsibilities (Swamy, 2009; Van Beukering, 1999; Furedy, 1995). Surveys further show that when waste is not collected regularly, the incidence of diarrhea is twice as high as in areas with frequent waste collection. Also, acute respiratory infections are six times higher in areas with deficient waste collection services (Scheinberg, 2010).

Waste in contact with water causes leachate. Chemical substances in waste, usually from household cleaners and industrial solvents, may leach from waste with water in an undiluted or diluted form. If left uncontrolled and untreated, this leachate can pollute groundwater or surface water, creating an environment hazard or threatening health of downstream water users. Similarly, decomposition of organic waste will generate a leachate with high organic loads. If left untreated and then discharged into the environment such leachate may cause severe eutrophication (Cointreau, 2006).

At a global level, Green House Gas (GHG) emissions from municipal solid waste are considered to contribute up to 5% (1,460 tonne CO_2) of annual total global greenhouse gas emissions. Methane released into the atmosphere is a product of anaerobic organic waste decomposition in landfills. It represents approximately 12% of the total global methane emissions (Bnon, 2006). For the municipal waste sector, landfills are the source of about half of the methane emitted in 2008 (Bogner et al., 2008). In developing countries disposal is most often uncontrolled and haphazard in open dumps. Often, at the dump site waste is set on fire to reduce waste volume, thus creating a health risk from smoke in the neighborhood. In the low-income countries of Asia between 80 and 100 % of the waste ends up in open dumps (Anon, 2000). In open dumps, without a concise tipping face, waste is spread out in thinner layers than in an engineered landfill. Thus open dumps tend to emit less methane as compared to sanitary landfills as waste degrades under aerobic conditions (Gyalpo, 2008). The Inter-governmental Panel on Climate Change (IPCC) considers a reduction of methane emissions from shallow (<5m) open dumps by 60% (Gyalpo, 2008). Improvements on landfill management in the near future might therefore even increase the generation of landfill methane emissions (Bogner et al., 2008).

1.3.2 Occupational health risks

Commonly reported health and injury issues linked to occupational aspects in solid waste management are described by Cointreau, (2006). These include: i) injuries as a results of lifting heavy loads, ii) respiratory illness resulting from burning of waste when particulates, bio-aerosols, and volatile organics are generated; iii) injury such as puncture wounds or animal and rodent bites and subsequent infections or, iv) injuries by fires, waste slides or accidents with waste handling equipment. Many occupational health and injury problems can be minimized by better trained staff, simple safety procedures which are systematically followed and protective gear, particularly shoes, gloves and face masks. The dirty nature of solid waste handling also necessitates the provision of water for washing, sanitation, and hygiene facilities to allow workers to maintain personal hygienic conditions (Cointreau, 2006). A study at open dumpsites in Mumbai, India showed that from 95 solid waste workers surveyed 80% had eye problems, 90% had decreased visual perception, 73% had respiratory ailments, 51% had gastrointestinal ailments, 40% had skin infections or allergies, and 22% had orthopedic ailments. Clinical examination further showed that 27% had skin lesions, of which 30% were occupation related (Cointreau, 2006). In Addis Ababa a study shows clear relationships between workplace exposure and health impacts on waste workers specifically related to open wounds and infections as well as musculoskeletal burdens and fatigue from heavy lifting (Bleck 2012).

The same study also indicates that the exposure of workers may have an even higher impact as they belong to the poor population and are thus subject to overall unfavorable hygienic conditions which also contributes to a basic poor state of worker's health.

1.3.3 Economic risks

Uncollected waste has an economic cost for a city and for a nation. A visibly unpleasant and dirty city with severe health risks for the population within will make it difficult to attract businesses and/or tourism. Scheinberg et al. (2010) cites three examples of such economic impacts. The first example is from Tangier, Morocco, where beach pollution by solid wastes led to a tourism decline that cost hotels of the area 23 million USD per year in lost revenues. In the second example in Costa Rica, the utility company responsible for the hydro dams started financing plastics recycling schemes in the water shed to mitigate the high costs of turbine failure from plastic waste damage. A last example is taken from a World Bank report where the environment cost of water contamination from improper waste disposal is estimated at 86 million USD annually with the lives of about 40 million Nigerians at risk (Scheinberg et al., 2010). Just as pollution from waste inflicts serious damage on the environment it endangers ecosystem services. Restoring these services (e.g. providing unpolluted, safe drinking water, ensuring fish habitat, clean air, etc.) will come at a cost, and will impact the national economy. The social perception of pollution has shown to result in the devaluation of capital. The United States of America (USA) landfills although well managed the impact on property values, which decrease as closer the property, is to the disposal site (Thayer, 1992). A similar situation, probably even more pronounced, can be expected in low-income countries with open dump locations. However systematic scientific studies are not yet available to confirm this situation.

1.4 Municipal solid waste treatment in India: a historical view

Composting was a prevalent practise of processing in the past especially initiated as Bangalore and Indore methods in the respective places but, later these techniques were abandoned due some reason or other. The organic fraction of MSW in India makes up to 40-70% (Anon, 2003) and composting was encouraged in the early initiatives of the Government of India (GOI) regarding Municipal solid Waste Management (MSWM) focused primarily on promoting composting of urban waste (Kalamdhad et al., 2009). Today Mechanical Biological Treatment (MBT) is the most widely employed SWM technology in India. It is estimated that up to 6% of MSW collected is composted in various MBT facilities (Anon, 2009). There are more than 80 MBT plants in India treating mixed MSW, most of them located in the states of Maharashtra (19), Himachal Pradesh (11), Chhattisgarh (9) and Orissa (7). More than 26 new MBT plants are proposed in different cities and towns across India. Even though composting of mixed wastes is a better solution compared to landfilling or openly burning those wastes, it is not the best (Kant, 2011). Compost from MBT facilities was found to be of low quality and to contain toxic heavy metals which could enter human food chain if used for agriculture. Anaerobic Digestion (AD) of MSW on a large scale does not work in India due to the absence of source separated organic waste stream. A large scale biomethanation plant built in Lucknow to generate

6 MW of electricity, failed to run because of the above reason. Anaerobic digestion has however been successful at smaller scales, for vegetable and meat markets, restaurants or hotels and at the household level.

MSW rules 2000 made by the Government of India to regulate the management and handling of MSW provide a framework for treatment and disposal of MSW. The rules recommend adoption of different technologies, which included biomethanation, gasification, pyrolysis, plasma gasification, refuse derived fuel, waste-to-energy combustion, sanitary landfills. However, the suitability of technologies to Indian conditions has not been sufficiently studied, especially with regard to the sustainable management of the entire MSW stream and reducing its environmental and health impacts.

Due to lack of data and infrastructural, financial and human resources, the Supreme Court mandate of complete compliance to the rules by 2003 could not be achieved by ULBs and that goal still remains to be a distant dream (Anon, 2009). As a result, even after a decade since the issuance of the MSW Rules 2000, the state of MSW management systems in the country continues to raise serious public health concerns (Guidance Note: Municipal Solid Waste Management on a Regional Basis (Ministry of Urban Development, Government of India. n.d.). Although some cities have achieved some progress in SWM, many cities and towns have not even initiated measures (Anon, 2009). The recent floods in Chennai after a heavy shower can be linked to indiscriminate littering of MSW in streets, channels, small streams and rivers which prevented the rain water from receding. Initiatives in Mumbai were the result of heavy rains and consequent flooding in 2006 due to drains clogged by solid waste. State level legislation pertaining to the collection, transport and disposal of urban solid waste in the state of Maharashtra were enacted (Anon, 2009). Bubonic plague epidemic in Surat in 1994 increased awareness on the need for proper SWM systems all over India and kick started measures to properly manage wastes in Surat.

Scarcity of suitable landfill sites is a major constraint, increasingly being faced by ULBs. Such difficulties are paving the way to building regional landfills, WTE and MBT solutions. The tremendous pressure on the budgetary resources of States/ULBs due to increasing quantities of MSW and lack of infrastructure has helped them involve private sector in urban development (Anon, 2009). GOI has also invested significantly in SWM projects under the 12th Finance Commission and Jawaharlal Nehru National Urban Renewal Mission (JnNURM). The financial assistance provided by GOI to states and ULBs amounted to USD 510 million (Indian Rupees (INR) 2,500 cores) (Anon, 2009).

1.5 Legal framework of solid waste management in India

In India, Solid Waste Management is the primary responsibility and duty of the municipal authorities. State legislation and the local acts that govern municipal authorities include special provisions for collection, transport, and disposal of waste. They assign the responsibility for provision of services to the chief executive of the municipal authority. Most state legislation does not cover the necessary technical or organizational details of SWM. Laws talk about sweeping streets, providing receptacles in various parts of the city for storage of waste, and transporting waste to disposal sites in general terms, but they do not clarify how this cleaning shall or can be done. The municipal acts do not specify in clear terms which responsibilities belong to the citizens (for example, the responsibility not to litter or the accountability for storing waste at its source). Moreover, they do not mention specific collection systems (such as door-to-door collection of waste), do not mandate appropriate types of waste storage depots, do not require covered waste transport issues, and do not mention aspects of waste treatment or sanitary landfills. Thus, most state legislation, with the exception of that of Kerala, does not fulfil the requirements for an efficient SWM service.

Given the absence of appropriate legislation or of any monitoring mechanism on the performance of municipal authorities, the system of waste management has remained severely deficient and out-dated. Inappropriate and unhygienic systems are used. At disposal sites, municipal authorities dump municipal waste, human excreta from slum settlements, industrial waste from small industrial establishments within the city, and biomedical waste without imposing any restrictions, thus provoking serious problems of health and environmental degradation. A public interest litigation was filled in the Supreme Court in 1996 (Special Civil Application No. 888 of 1996) against the government of India, state governments, and municipal authorities for their failure to perform their duty of managing MSW adequately. The Supreme Court then appointed an expert committee to look into all aspects of SWM and to make recommendations to improve the situation. After consulting around 300 municipal authorities, as well as other stakeholders, the committee submitted a final report to the Supreme Court in March 1999. The report included detailed recommendations regarding the actions to be taken by class 1 cities, by the state governments, and by the central government to address all the issues of MSW Management effectively.

On the basis of the report, the Supreme Court directed the government of India, state governments, and municipal authorities to take the necessary actions. The Ministry of Environment and Forests was directed to expeditiously issue rules regarding MSW management and handling. Such rules were already under development and had been under consideration for quite some time. Thus, in September 2000, the ministry issued the Municipal Solid Waste (Management and Handling) Rules 2000 under the Environment Protection Act 1986.

1.5.1 Solid waste management rules, 2016 (Anon, 2016).

The Union Ministry of Environment, Forests and Climate Change (MoEF&CC) recently notified the new SWM rules, 2016. These will replace the Municipal Solid Wastes (Management and Handling) Rules, 2000, which have been in place for the past 16 years. These rules are the sixth category of waste management rules brought out by the ministry, as it has earlier notified plastic, e-waste, biomedical, hazardous and construction and demolition waste management rules.

1.5.2 Salient features of solid waste management rules, 2016

The jurisdiction of the rules have been extended beyond Municipal area to cover, outgrowths in urban agglomerations, census towns, notified industrial townships, areas under the control of Indian Railways, airports, airbase, Port and harbour, defence establishments, special economic zones, State and Central government organizations, places of pilgrims, religious & historical importance .

a) Segregation at source

The new rules have mandated the source segregation of waste in order to channelize the waste to wealth by recovery, reuse and recycle. Waste generators would now have to now segregate waste into three streams- Biodegradables, Dry (Plastic, Paper, metal, Wood, etc.) and Domestic Hazardous waste (diapers, napkins, mosquito repellents, cleaning agents etc.) before handing it over to the collector.

Institutional generators, market associations, event organisers and hotels and restaurants have been directly made responsible for segregation and sorting the waste and manage in partnership with local bodies. In case of an event, or gathering of more than 100 persons at any licensed/ unlicensed place, the organiser will have to ensure segregation of waste at source and handing over of segregated waste to waste collector or agency, as specified by the local authority.

All hotels and restaurants will also be required to segregate biodegradable waste and set up a system of collection to ensure that such food waste is utilised for composting/ bio-methanation. The rules mandate that all resident welfare and market associations and gated communities with an area of above 5,000 sq.m, will have to segregate waste at source into material like plastic, tin, glass, paper and others and hand over recyclable material either to authorised waste-pickers and recyclers or to the urban local body.

b) Collection and disposal of sanitary waste

The manufacturers or brand owners of sanitary napkins are responsible for awareness for proper disposal of such waste by the generator and shall provide a pouch or wrapper for disposal of each napkin or diapers along with the packet of their sanitary products.

c) Collect Back scheme for packaging waste

As per the rules, brand owners who sale or market their products in packaging material which are non-biodegradable, should put in place a system to collect back the packaging waste generated due to their production.

d) User fees for collection

The new rules have given power to the local bodies across India to decide the user fees. Municipal authorities will levy user fees for collection, disposal and processing from bulk generators. As per the rules, the generator will have to pay “User Fee” to the waste collector and a “Spot Fine” for littering and non-segregation, the quantum of which will be decided by the local bodies.

Also, the new rules have mentioned about the integration of rag pickers, waste pickers and kabadiwalas from the informal sector to the formal sector by the state government.

The rules also stipulate zero tolerance for throwing; burning, or burying the solid waste generated on streets, open public spaces outside the generator’s premises, or in the drain, or water bodies.

e) Waste processing and treatment

As per the new rules, it has been advised that the bio-degradable waste should be processed, treated and disposed of through composting or bio-methanation within the premises as far as possible and the residual waste shall be given to the waste collectors or agency as directed by the local authority. The developers of Special Economic Zone, industrial estate, industrial park to earmark at least 5 per cent of the total area of the plot or minimum 5 plots/ sheds for recovery and recycling facility.

Waste processing facilities will have to be set up by all local bodies having a population of 1 million or more within two years. For census towns with a population below 1 million or for all local bodies having a population of 0.5 million or more, common, or stand-alone sanitary landfills will have to be set up in three years' time. Also, common, or regional sanitary landfills to be set up by all local bodies and census towns with a population under 0.5 million will have to be completed in three years. Also, the rules have mandated bio-remediation or capping of old and abandoned dump sites within five years.

f) Promoting use of compost

As per the rules, the Department of Fertilisers, Ministry of Chemicals and Fertilizers should provide market development assistance on city compost and ensure promotion of co-marketing of compost with chemical fertilisers in the ratio of 3-4 bags is to 6-7 bags by the fertiliser companies to the extent compost is made available for marketing to the companies. Also, the Ministry of Agriculture should provide flexibility in Fertiliser Control Order for manufacturing and sale of compost, propagating use of compost on farm land, set up laboratories to test quality of compost produced by local authorities or their authorised agencies.

g) Promotion of waste to energy

In a not-so welcoming move, the SWM Rules, 2016 emphasise promotion of waste to energy plants. The rules mandate all industrial units using fuel and located within 100 km from a solid waste-based RDF plant to make arrangements within six months from the date of notification of these rules to replace at least 5 per cent of their fuel requirement by RDF so produced.

The rules also direct that non-recyclable waste having calorific value of 1500 Kcal/kg or more shall be utilised for generating energy either through RDF not disposed of on landfills and can only be utilised for generating energy either or through refuse derived fuel or by giving away as feed stock for preparing refuse derived fuel. High calorific wastes shall be used for co-processing in cement or thermal power plants.

As per the rules, the Ministry of New and Renewable Energy Sources should facilitate infrastructure creation for Waste to Energy plants and provide appropriate subsidy or incentives for such Waste to Energy plants. The Ministry of Power should fix tariff or charges for the power generated from the Waste to Energy plants based on solid waste and ensure compulsory purchase of power generated from such Waste to Energy plants by Distribution companies (DISCOMs).

h) **Revision of parameters and existing standards**

As per the new rules, the landfill site shall be 100 metres away from a river, 200 metres from a pond, 500, 200 metres away from highways, habitations, public parks and water supply wells and 20 km away from airports/airbase. Emission standards are completely amended and include parameters for dioxins, furans, reduced limits for particulate matters from 150 to 100 and now 50. Also, the compost standards have been amended to align with Fertiliser Control Order.

i) **Management of waste in hilly areas**

As per the new rules, construction of landfills on hills shall be avoided. Land for construction of sanitary landfills in hilly areas will be identified in the plain areas, within 25 km. However, transfer stations and processing facilities shall be operational in the hilly areas.

j) **Constitution of a central monitoring committee**

The government has also constituted a Central Monitoring Committee under the chairmanship of Secretary, MoEF&CC to monitor the overall implementation of the rules. The Committee comprising of various stakeholders from the Central and state governments will meet once a year to monitor the implementation of these rules.

1.6 Impact of food waste on environment

According to Bilitewski et al., 1994, the link between hygiene, wastes and epidemics was first suspected by the Greek scholar Hippocrates around 400 BC and the Arab Avicenna (Ibn Sina, 1000 AD). Early in the 20th century, urban societies began to grow and to have a noticeable impact on the environment because of the increasing amount of urban waste and wastewater produced (Green & Kramer, 1979). At present world, the potentially damaging impacts of farm and FW on the local environment such as water pollution and human health are well recognized (Legg, 1990).

The Urban Food Waste (UFW) that goes to landfill sites not only pollutes the land and water but also contributes to global warming by producing Methane (CH_4). CH_4 is produced in large amounts in landfills as a consequence of the degradation of organic matter (OM) under anaerobic conditions (Borjesson & Svenssen, 1997). At any landfill site, 45% to 58% of the Organic Waste (OW) on a Dry Weight Basis (dwb) is transformed into CH_4 (Anon, 1999). Food waste fraction of MSW has high potential to produce CH_4. According to Wang et al., 1997, FW generates 300 L of CH_4 kg^{-1} of FW. Another laboratory experiment conducted by Hansen et al. (2004) found that solid FW could produce from 200 to 500 L of CH_4 kg^{-1} of FW Volatile Solids (VS).

Although CH_4 and CO_2 are produced in about equal amounts, CH_4 is of greater concern as a greenhouse gas because of its 100 years global warming potential. For example, its infrared absorption potential in the atmosphere is about 23 times greater than that of CO_2 (Anon, 2001).

1.6.1 Reuse of food waste

The environmental ramifications of widely used waste disposal technologies are well-understood (Bilitewski et al., 1994; Barth, 1999). Organic solid waste that goes to landfill sites pollutes air by producing large amounts of CH_4 and CO_2 (Hansen et al., 2004). Also contaminates groundwater by producing important volumes of leachate and occupies vast land surfaces (Pokhrel &Viraraghavan, 2005; Bou-Zeid & El-Fadel, 2004; Shin et al., 2001 and Legg 1990).

FW is a major fraction of MSW, which is a main source of decay, odor and leachate when collected, transported and landfilled together with other wastes (Shin et al., 2001). Multiple waste management alternatives exist for the treatment of Urban FW including burial in a landfill, anaerobic digestion (Ten Brummeler & Koster, 1989; Cecchi et al., 1992) and aerobic composting. The greenhouse gas emission potential and cost effectiveness of all of these techniques must be evaluated to select the most environment friendly treatment system.

Amongst the many available alternatives for reusing of UFW, composting is envisaged as the best way of disposal of FW by using it on the land as organic fertilizer (Pokhrel & Viraraghavan, 2005). Because composting process transforms OM into a stable form (Hamelers 1992). Composting of FW not only reduces the waste mass and volume transported to the landfill also increases its life (Pokhrel & Viraraghavan, 2005). In vessel treatment of MSW waste avoids air and groundwater pollution by landfills (Baeten & Verstraete, 1992). Also recycling of source-separated FW by composting at the urban community centers and in large scale FW composting facilities reduce CH_4 emissions and saves land otherwise needed for landfill sites.

In this context, onsite treatment of FW reduces pressure on MSW management systems about 40% to 85% in developing economies and 23% to 50% in developed economy (Anon, 1995). Composting of source-separated FW at urban centers reduces the mass and volume transported to the landfill and increases its life (Pokhrel & Viraraghavan, 2005). Composting of FW in city itself rather than outside the city reduces the transportation cost of MSW management system because large city corporations already have serious problems transporting the waste outside the city.

However, there are many challenges in building and operating composting facilities in highly urbanized centers. The composing facility must be compact as to use as little space as possible. The FW needs to be mixed to a readily available bulking agent to reduce its moisture content and facilitate composting, and this bulking agent may not be readily available. Cooperation and involvement of communities who produce waste are vital to operate urban composting facilities successfully. Finally, the odors and leachate produced by the composting process require special attention especially in the case of composting facilities installed in a highly populated urban setting.

1.6.2 Composting of food waste

Composting is one of the few natural processes (Barrington et al., 2002) in which, microbial decomposition of OM occurs in aerobic conditions. Composting generates considerable heat, CO_2 and water vapor into the air while minerals and OM are converted into a potentially reusable soil amendment (Renkow et al., 1996, Pace et al., 1995, Biddestone& Gray, 1985, Haug, 1980). Composting also reduces volume and mass of solid waste, thereby increasing its value and transforming it into a safe soil amendment (Cassarino, 1986).

As reported by Renkown et al. (1996), the two basic processes used in large scale composting are windrow-based technologies and in-vessel technologies. The in-vessel technologies are considered appropriate for UFW composting because the process can be fully controlled and at the same time leachate and odor can be collected and treated before discharging in to the atmosphere which is especially important for urban composting centers. In vessel composting of FW were successfully carried out by using wood chip and sawdust (Kwon & Lee, 2004) and peat moss and wood chips (Koivula et al., 2003) as bulking agents.

1.6.3 Potential factors for in-vessel composting of food waste in India

Developing countries like India generate more food waste compared to developed countries. The putrefying nature of food waste makes it less viable for storage and transportation. It also hinders the recovery of recyclable materials. Limited land resource available for dumping of waste which is ever increasing with increase in population, has lead India to think over techniques of reducing waste at the source itself. Composting is one such and the most viable technique to serve the purpose.

The characteristics of the municipal waste in India indicate a high biodegradable fraction of more than 50%. Moreover (Visvanathan et al., 2004), described that the MSW stream in most Asian countries is dominated by organic portion composed of food wastes, yard wastes, and mixed paper. The biodegradable portion of the waste mainly remained in the waste stream. The average moisture content is relatively high, that is greater than or equal to 50%. (Zurbrügg, 2002). The best disposal solution for this type of waste is aerobic composting method. This situation has urged the need to develop and study various alternative composting technologies like in-vessel composting with locally available materials, best suited for Indian conditions. Composting has emerged as an attractive option for treating food wastes due to less environmental pollution and beneficial use of the final product (Filippi et al., 2002; Das et al., 2003; Benito et al., 2006 and Zenjari et al., 2006).

Food waste has unique properties as a raw compost agent, because of high moisture content and low physical structure. However, it is important to mix food waste with a bulking agent like sawdust, yard waste etc., which will absorb some of the excess moisture as well as add structure to the mix. Bulking agents with a high C:N ratios such as sawdust and yard waste are good choices (Chynoweth et al., 2003). An indigenously developed in-vessel composting system has been successfully demonstrated and proved to be efficient, eco-friendly, cost-effective and nuisance-free solution for the management of household wastes (Iyengar et al., 2005). Recently (Joung-Dae Kim et al., 2007) evaluated a pilot-scale in-vessel composting for food waste treatment and found out that the final compost produced along with the bulking agent was satisfactory for agricultural application in terms of electrical conductivity as a salt content index and heavy metal contents.

Today in-vessel composting systems are an established technology in western countries for the treatment food wastes; yard wastes; fish wastes; slaughter house wastes etc., the system ranges from simple to highly sophisticated computer controlled mobile units. However the same technology cannot be applied to the Indian conditions because the selection of the system is dependent on the nature of the waste to be composed, available manpower and economic conditions.

1.7 Selection of appropriate technology

Aiming at sustainability, the two favored options available for dealing with organic solid waste are composting and biogas production (Dübendorf, 2007). The benefits from these practices are several. They do decrease possible contamination of the environment and reduce health hazards, save valuable space at landfills, as well as serve as valuable resources as organic manure. Using compost as soil conditioner, there is the reduction in the requirement of chemical fertilizers, as well as helps reduce soil erosion and improves soil profile for agriculture (Rouse et al., 2008). The use of biogas for household cooking would reduce air pollution (if substituting combustion of firewood) and could hence significantly improve living conditions, especially for women since they are often the ones responsible for cooking and collection of firewood. A reduced usage of firewood would also result in reduced deforestation (Dübendorf, 2007).

Composting and biogas production of organic household waste may evolve at different levels and with various techniques, ranging from small-scale decentralized backyard and community techniques to large-scale centralized techniques. The choice of technique will depend on many factors, including volume of organic waste generated, land availability, cost and availability of water and electricity, cost of labor and possible markets for the end product (Rouse, 2008). Cofie & Bradford, (2010) argue that the best option is decentralized and close to its generation source. This may be explained by the extra cost of transporting organic waste to centralized facilities. Since the organic waste gives the municipal waste stream a high density, it demands specially designed transportation vehicles as well as being more costly to transport. Thus, managing the organic waste close to its source is an important aspect also for saving transportation costs. Rothenberger et al. (2006) summarizes advantages with decentralized composting systems and argues that their main benefits are related to simple technologies, generation of employment, improved relation between authorities and private households, raising of environmental awareness, as well as decreased independence of the already insufficient municipal waste management systems. Drescher & Zurbrügg, (2004) also writes that decentralized management schemes are more flexible and therefore adaptable to external changes. In contrast to decentralized schemes, centralized techniques require technical machinery, which is often costly to invest in, as well as to operate and maintain. Additionally it requires workers with high technical skills (Rothenberger et al., 2006). Many large-scale biogas digesters have also failed because of over-size, advanced technology and maintenance problems. As a result the attention in India today is on low-tech, decentralized, small-scale alternatives (Dübendorf, 2007). Decentralized organic waste management systems may be organized and initiated by a number of different stakeholders, such as neighborhoods, single households, private companies, governmental authorities and institutions, such as NGOs (Drescher & Zurbrügg, 2006).

1.7.1 Environmental impacts from composting and anaerobic digestion

According to Anon (2005) composting of organic waste is a more favorable and practical treatment method than anaerobic digestion. The waste hierarchy, developed by Agenda 21, also suggests recycling of materials as the preferred method over energy recovery. However, Reeh & Møller, (2001) have done an evaluation of the two alternatives in regard to environmental effects and sustainability criteria. The parameters assessed and their conclusions are discussed below.

a) Energy balance

Based on the fact that at this stage the energy generated from composting may not be utilized in other ways than to accelerate the composting process itself, biogas production results in a better energy balance. Furthermore, transportation should arguably be taken into consideration regarding the energy balance. However, research has shown that the transportation of waste and its end products only contributes with a small percentage to the energy balance and thus do not affect the outcome (Reeh & Møller, 2001).

b) Nutrient recycling

Compost is a more stable product than the residues from biogas production, which makes it a more attractive product for soil improvement. Even though the nitrogen content is higher in biogas residues, the nitrogen is water-soluble and much is lost as ammonia when it is spread in soil. Furthermore, compost is because of its chemical stability also more attractive due to less odor and cleaner appearance (Reeh & Møller, 2001).

c) Global warming contribution

Reducing the production of greenhouse gases at landfills is one important incentive for biological treatment of organic waste. In theory, biological treatment, including biogas production and composting, would reduce the greenhouse gas emissions from organic waste at landfills to 100 percent. However, the reality is more complex. Considering the mitigation effect on greenhouse gas emissions from biogas, it was taken into account the reduced emissions by the substitution of fossil fuels. Furthermore, calculations were done with a 3,5 percent loss of gas from the digestion process, resulting in methane emissions to the atmosphere. This percentage might even be higher in developing countries because of low-tech plants and inadequate management and maintenance (Reeh & Møller, 2001). Lohri, (2005) calculated for example that in theory the average loss from the Appropriate Rural Technology Institute (ARTI) of India biogas plant was 22 %. Regarding composting, the composting process was evaluated by its emissions of CH_4 and nitrous oxides. The available data of methane production from composting is scarce and data vary with different calculation approaches. However, in the comparison by Reeh & Møller (2001) the calculations were based on data found from one case of windrow composting. From these calculations biogas has a larger mitigation effect on greenhouse gas emissions than composting. However, if the methane losses are set to 14 %, which might occur in developing countries, the two methods are breakeven (Reeh & Møller, 2001).

d) Xenobiotic compounds

In biogas production complex organic molecules, such as Nonyl Phenol (NPE) may be generated from incomplete degradation. Composting on the other hand increases degradation of organic micro pollutants, such as NPE and Poly Aromatic Hydrocarbon (PAH), and is therefore a preferred alternative in regard to degradation of xenobiotic compounds (Reeh & Møller, 2001). Another comparison of the environmental impacts from composting and biogas production has been done with a model called ORWARE (ORganic WAste REcycle), developed by Swedish University of Agricultural Sciences, 1996. The model is based on lifecycle assessment and evaluates environmental impacts such as global warming, eutrophication, acidification, photochemical oxidants and human health. The ORWARE model also shows a better energy balance for biogas production; however, in regard to nutrient recycling and other impact the results are more uncertain and very sensitive to changes in system boundaries and functional units (Reeh & Møller, 2001).

1.7.2 Sustainable management of household organic waste

Several appropriate technologies exist for proper management of organic waste and there are an increasing number of decentralized projects trying to implement these in developing countries. Unfortunately many of composting projects have failed and there is little research available of why they failed and what should have been done differently. Voegeli & Zurbrügg, (2008) also states that very little research exist about technical feasibility, problems and opportunities for anaerobic digestion.

a) Constraints

An overall reason for why these projects fail may be explained by Al-Khatib et al. (2010) who argues that waste management often is regarded as only a technical issue, however, it is strongly connected to political, legal, socio-cultural, environmental and economic factors. Previous failure also complicate for future incentives, since bad experiences and failures often result in local pessimism. As an example Zurbrügg et al. (2005) explains how institutions today often doubt the possibilities of composting organic waste because of previous failures of oversized, high-tech composting schemes. Clear focus of many composting projects tries to achieve too many goals at the same time resulting in an unclear focus (Ali et al., 2004). An unclear focus might also make it more difficult to set up successful strategies and make important decisions. This aspect might for example be important when choosing which appropriate technology to implement.

Compost produced on a household and community level could be used for private purposes such as gardening and growing of vegetables. However, many composting projects aim at selling the produced compost to raise an income, leaving marketing strategies a critical factor that is often forgotten. When compost is sold as a commercial product quality also becomes an important factor and the fact that compost quality standards are absent in many developing countries may inhibit the commercial status and sale (Ali et al., 2004). Composting projects are usually not prioritized when competing with other waste management projects for funds (Ali et al., 2004). The fact that landfilling still is the cheapest option for disposal of organic waste, in combination with poor municipal funds, also compose an important constraint for implementation of biological treatment methods in developing countries (Hoornweg et al., 1999). The governments are also often neglecting the benefits from reduced cost of externalities associated with inadequate organic waste management (Hoornweg et al., 1999). In regard to stakeholders, they often lack interdisciplinary skills and when co-operation is failing they struggle to attain all necessary details and manage the project successfully (Ali et al., 2004). Constraints in regard to technology and know-how refer to the fact that mechanical technologies often are implemented instead of labor intensive methods. These mechanical technologies need maintenance and spare parts, which require funds and skills (Hoornweg et al., 1999). Furthermore, composting and anaerobic digestion are sensitive processes that require know-how of how to meet the right biological conditions, as well as use feedstock material. Unfortunately, this know-how is often deficient, which results in inadequate compost quality, and development of odors and rodent attraction (Hoornweg et al., 1999). Furthermore, lack of know-how not only results in an inappropriate end product and increased environmental impact.

The response from households regarding composting activities and waste separation at sources are generally low initially. This is commonly associated with land availability, confusion about the separation process and socio-cultural behaviors. It is also a common misconception that the compost always attracts flies and rodents, as well as cause nuisance. However, household participation is a crucial aspect for decentralized schemes to succeed and therefore needs to be addressed (Ali et al., 2004).

1.8 Composting: the environmentally and economically sustainable solution

Composting is well known in the art which is a nature's process of recycling leftover organic materials into rich humus like substance known as compost which can be used as fertilizer and soil conditioner. Composting is a slow process in which mixed bacteria, fungi, insects and worms consume plant and animal waste and convert them slowly into soil like substance very beneficial to plant growth. Compost provides energy, minerals, nutrients and micronutrients, useful microbes and water retaining humus to the soil. This improves the quality and pest resistance of produce, makes crops drought resistance and decreases irrigation water requirements. The use of compost to enrich the soil, along with chemical fertilizer in a balanced ratio, is therefore very necessary. The government bodies as well as the fertilizer association for over a decade have repeatedly expressed this view. Compost can find a good market if properly promoted and made conveniently available to the farming community (Barman, 1999).

Composting is nature's way of recycling. Composting decomposes and transforms organic material into a soil-like product called humus. Food scraps, leaves and yard trimmings, paper, wood, manures and the remains of agricultural crops are excellent organic materials, which can be composted. Composting is an important way to recycle both at home and at work, where organic material is used and waste is created. It is estimated that about 50 percent of the total waste stream could be composted! Composting not only helps to reduce the amount of waste going to landfills, it produces a valuable soil amendment, which can improve the texture and fertility of the soil.

The composting process uses microorganisms such as bacteria and fungi to breakdown the organic materials. For the process to work best, it is important that the microorganisms have a continuous supply of food (i.e. organics), water and oxygen. As well, managing the temperature of the composting material is important to make the process work. It is also important to give the microorganisms a "balanced diet"; they have to grow best with certain levels of Carbon (C) and Nitrogen (N). Papers, leaves and wood are high in C while grass clippings and vegetable scraps are high in N. Combining the correct "mix" of C and N materials in the composting "recipe" helps to get the best results.

The microbes in compost use carbon for energy and nitrogen for protein synthesis. The proportion of these two elements required by the microbe, averages about 30 parts C to 1 part N. Accordingly, the ideal ratio of carbon to nitrogen (C:N) is 30 to 1 (measured on a dwb). This ratio governs the speed at which the microbes decompose organic waste. Most organic materials do not have this ratio and, to accelerate the composting process, it may be necessary to balance the numbers. Composting is not a mysterious or complicated process. Natural recycling occurs on a continuous basis in the natural environment. OM is metabolized by microorganisms and consumed by invertebrates. The resulting nutrients are returned to the soil to support plant growth. Composting is relatively simple to manage and can be carried out on a wide range of scales in almost any indoor or outdoor environment and in almost any geographic location. It has the potential to manage most of the organic materials in the waste stream including restaurant waste, leaves and yard wastes, farm waste, animal manure, animal carcasses, paper products, sewage sludge, wood etc. and can be easily incorporated into any waste management plan.

The essential elements required by the composting microorganisms are C, N, O_2 and moisture. If any of these elements are lacking, or if they are not provided in the proper proportion, the microorganisms will not provide adequate heat. A composting process that operates at optimum performance will convert organic matter into stable compost that is odor and pathogen free, and a poor breeding substrate for flies and other insects. In addition, it will significantly reduce the volume and weight of organic waste as the composting process converts much of the biodegradable component to gaseous carbon dioxide (Haug, 1993).

1.8.1 Chronology of composting method

In early days composting was typically a simple process in which waste materials were piled and allowed to sit until they decomposed. It was most frequently done on a small scale and the ingredients placed into these piles were poorly controlled, and the resulting mixture would decompose unpredictably, frequently anaerobically, with strong odors associated therewith. Unfortunately, often the strength of these odors was in direct correlation to the loss of valuable fertilizer components such as nitrogen.

Vermin were also often attracted to these piles, creating hazardous vectors for transmission of disease. An advance in composting technology came from the realization that adding air to the composting mixture could increase the efficiency of composting. The microbes that produce more desirable fertilizer require air, and will smother inside of a static un-aerated pile. Hence, the initial methods of aeration involved moving or agitating the compost to allow air into the stack. This method only partially satisfies the need for aeration, and consequently only poorly addresses odors and nutrient loss, and does nothing to improve the access by vermin.

A typical example of this aeration is a windrow turner that picks up the compost and dumps it to one side. Most municipal composting sites are currently windrow turner operations, though process control is, unfortunately, quite primitive. Piles are typically turned at the convenience of the operator, rather than to optimize the composting process.

Composting with windrow turners is typically done in an open, unsheltered area. The vagaries of weather and rainfall most often determine the water content of the composting mass. When there is too little rain, the pile is too dry. When there is too much rain, the pile is wet and requires frequent turning. Too much rain can also lead to problems with runoff of leachate. During the loss of leachate there will not only be a loss of fertilizer value but also a potential hazardous contamination of surrounding surface water and soil. In the open, of course, it is also very difficult to control access by vermin. One method used to overcome some of the disadvantages of pile composting is to enclose compost piles in a building. An enclosure that keeps rain off of the compost allows better regulation of water content. However, such a facility is very expensive. Enclosing compost also involves maintaining the quality of large volumes of air within the building. Without high-quantity air handling systems, the atmosphere within an enclosure can be irritating, if not toxic, to an operator. Sadly, with the removal of air in the building is a removal of nutrients from the compost. Consequently, the resulting compost is little better in fertilizer value than the compost of the open windrows and piles. These enclosed buildings do, however, help to control or prevent access to the compost by most vermin.

Some of the disadvantages of pile composting are overcome by more modern reactor vessel processes. By design, the reactor vessel is typically only slightly larger than the compost which it contains. This reduces the land area required to store the compost during the composting process. In-vessel reactors also provide the opportunity for collection of potentially odorous emissions. The compost is enclosed, and exhaust air may be routed through a filtration system. This separation of operator from compost air benefits the health and safety of all operators. Unfortunately, vessel systems to date are complicated systems which require precision construction techniques and permanent, stable foundations. This necessarily drives the cost of present reactor vessels systems to levels even higher than required for building-type enclosures. In exemplary prior art systems, organic waste is fed into an opening at one end of the reactor and compost is removed from the other end. The material is moved through the reactor by, for example, a complex moving floor apparatus or hydraulic ram. Aeration is sometimes provided by pressurized air forced through the organic waste from air vents located throughout the moving apparatus. Some in-vessel systems also include mixing systems, typically rotating paddles or prongs, within the compost mass. Other in-vessel systems are static. The agitation systems used with in-vessel systems are expensive, prone to wear and failure, and provide agitation at intervals that are not readily controlled with respect to the progress of the composting process.

Even in the advanced in-vessel systems, there is still a limitation of the composting systems that must be addressed for wider acceptance in the marketplace. During the composting process, even in highly controlled in-vessel systems, there will always be a potential for generation of significant quantities of undesirable and odorous gases such as ammonia. Some artisans have reduced the levels of emissions of these gases through very careful measuring and control of the source materials which are undergoing biological transformation, but this control adds expense and undesirably limits the application of the composting system to only a very few applications.

There is a large body of art relating to in-vessel composting, some providing useful descriptions of the basic biological process. Existing in-vessel composters typically have one or more of the following general short-comings. There remains a need for an affordable, simple to operate, energy efficient, in-vessel composting system that substantially reduces the volume and weight of the input materials, and processes a useful end product of commercial value.

Moreover, presently available composting technologies in the western countries are not suitable to handle a wide variety of source material especially for the type of food waste found in the regional settings in India, which is high in organic content and moisture with less physical structure. Secondly, these highly automated systems are not economically viable for a country like India and the maintenance costs for these units are very high due to import of spare parts.

1.9 Microbiology of composting

Composting is a microbial aerobic transformation and stabilization of heterogeneous organic matters in aerobic conditions and in solid state. The process is exothermic and energy is released. A part of this energy (about 50-60 %) is utilized by microorganism to synthesize ATP; the other is lost as heat. This heat can generate a temperature increase in the mass. The first phase of the composting process is mesophilic and starts the aerobic decomposition of easily degradable organic matter; this rapid decay of material releases a great quantity of energy in the form of heat, which enhances the mass temperature and the degradation rates of the organic waste. Within a few days this gives rise to the thermophilic phase. Without control, the temperature can easily reach and exceed 70°C. The main positive effect of operating at such high temperature is the reduction of pathogenic agents present in the waste. In controlled composting process this phase is limited in terms of temperature and exposure time (degree and days) to obtain a balance between high stabilization rates and good sanitization, often to satisfy local legislation regarding sanitization condition. The third phase, maturation includes not only the mineralization of slowly degradable molecules, but also the humification of lignocellulosic compounds. This phase can last some weeks, according to the composition of the starting material. During the microbial transformation intermediate metabolites are produced which can make the composting material phytotoxic. This phytotoxic is completely overtaken at the end of the process; thereafter the final product becomes beneficial to plant growth. From a microbial point of view, composting is discontinuous process (batch) resulting from a sequential development of different microbial communities. The microorganisms involved in the composting process are normally present in the starting material. Inoculum is needed only when the starting material is deficient in microorganisms.

1.9.1 Microbial biomass and succession

Bacteria, actinomycetes and fungi are the main microbial biomass responsible for the degradation of organic waste. Higher organisms, for example compost worms (e.g. Eiseniafoetida) may be numerous in very mature compost or in dedicated vermiculture. Mesophilic bacteria, actinomycetes and fungi start their activity in the first stage of composting until high temperature inhibits their metabolism. Most of them die drastically reduce their activity in the thermophilic phase. Only a few sporigenous bacteria and non sporigenous thermophilic bacteria (such as Bacillus, Clostridium, Thermus) show metabolic activity above 70°C (Finstein & Morris, 1975; de Bertoldi et al., 1983). During the thermophilic phase only organisms adapted to high temperature can survive and metabolize organic matter. Previously flourishing mesophiles die off and are eventually degraded by the succeeding thermophiles. The high temperature is the direct consequence of heat produced during composting. Owing to the lower activity of fewer thermophilic microorganisms and to the decreasing degradability of the organic waste remaining, the rate of release of heat reduces and the process slowly enters in a new mesophilic phase.

Mesophilic microorganisms start to recolonize the substrate, either starting from surviving spores and microorganisms or from microorganisms colonizing from the outside. This phase is characterized by an increasing number of organisms able to degrade the long polymers: lignin, cellulose, pectins and hemicellulose. The prevalent micro flora consists of fungi and actinomycetes. Bacteria also are present but in reduced number. In the later phases of composting the number of cellulotic fungi (eumycetes) increases. The fungi benefit from the decrease in temperature, pH and moisture content and from the higher oxygen concentrations caused by lower water content and lower degradability of the organic waste. The same environmental factors positively affect the presence and diffusion of actinomycetes. With the degradation of lignin, an enzymatic aerobic transformation restricted to a limited microbial group namely the higher fungi (basidiomycetes), humification of organic matter begins together with the production of aromatic compounds (e.g. geosmin). This process gradually lead to the final biological stabilization of the product (Christnson, 2011).

a) Bacteria

Bacteria are the smallest living organisms and the most numerous in compost; they make up 80 to 90% of the billions of microorganisms typically found in a Gram of compost. Bacteria are responsible for most of the decomposition and heat generation in compost. They are the most nutritionally diverse group of compost organisms, using a broad range of enzymes to chemically break down a variety of organic materials. Bacteria are single-celled and structured as either, rod-shaped bacilli, sphere-shaped cocci or spiral-shaped spirilla. Many are motile, meaning that they have the ability to move under their own power. At the beginning of the composting process (0-40°C), mesophilic bacteria predominate. Most of these are forms that can also be found in topsoil.

As the compost heats up above 40°C, thermophilic bacteria take over. The microbial populations during this phase are dominated by members of the genus Bacillus. The diversity of bacilli species is fairly high at temperatures from 50-55°C but decreases dramatically at 60°C or above. When conditions become unfavorable, bacilli survive by forming endospores, thick-walled spores that are highly resistant to heat, cold, dryness, or lack of food. They are ubiquitous in nature and become active whenever environmental conditions are favorable. At the highest compost temperatures, bacteria of the genus Thermus have been isolated. Composters sometimes wonder how microorganisms evolved in nature that can withstand the high temperatures found in active compost. Bacteria belonging to the genus Thermus were first found in hot springs in Yellowstone National Park and may have evolved there. Other places where thermophilic conditions exist in nature include deep sea thermal vents, manure droppings, and accumulations of decomposing vegetation that have the right conditions to heat up just as they would in a compost pile. Once the compost cools down, mesophilic bacteria again predominate. The numbers and types of mesophilic microbes that recolonize compost as it matures depend on what spores and organisms are present in the compost as well as in the immediate environment. In general, the longer the curing or maturation phase, the more diverse the microbial community it supports.

Actual bacteria populations are dependent upon the feedstock, local conditions, and amendments used. During the high-temperature stage of composting the mesophilic bacteria are at their lowest level while the thermophilic bacteria are prevalent. However, as temperatures decrease to below 40°C there is a striking repopulation by the mesophilic bacteria, which have been inactive during the thermophilic stage (Webley, 1947).

b) Actinomycetes

The characteristic earthy smell of soil is caused by actinomycetes, organisms that resemble fungi but actually are filamentous bacteria. Like other bacteria, they lack nuclei, but they grow multicellular filaments like fungi. In composting they play an important role in degrading complex organics such as cellulose, lignin, chitin, and proteins. Their enzymes enable them to chemically break down tough debris such as woody stems, bark, or newspaper. Some species appear during the thermophilic phase, and others become important during the cooler curing phase, when only the most resistant compounds remain in the last stages of the formation of humus. Actinomycetes form long, thread-like branched filaments that look like gray spider webs stretching through compost. These filaments are most commonly seen toward the end of the composting process, in the outer 10 to 15 centimeters of the pile. Sometimes they appear as circular colonies that gradually expand in diameter.

Actinomycetes belong to the order actinomycetales. Although they look similar to fungi, forming branched mycelium (colonies), they are more closely related to bacteria. Usually they are not present in appreciable numbers until the composting process is well established. Visual growth of actinomycetes may be observed under stabilized conditions, usually between 5 to 7 days into the composting process (Finstein and Morris, 1974; Golueke, 1977). When present in a composting process they can be readily detected due to their greyish appearance spreading throughout the composting pile. Golueke,

(1977) suggests that actinomycetes are responsible for the faint "earthy" smell that the compost emits under favorable conditions and which generally increases as the process proceeds. Species of the actinomycetes genera Micromonospora, Streptomyces, and Actinomyces can regularly be found in composting material. These species can be spore formers and are able to withstand adverse conditions, such as inadequate moisture. Because the actinomycetes can utilize a relatively wide array of compounds as substrates, they play an important role in the degradation of the cellulosic component. To some extent they can also decompose the lignin component of wood (Golueke, 1977).

c) Fungi

Fungi include molds and yeasts, and collectively they are responsible for the decomposition of many complex plant polymers in soil and compost. In compost, fungi are important because they break down tough debris, enabling bacteria to continue the decomposition once most of the cellulose has been exhausted. They spread and grow vigorously by producing many cells and filaments, and they can attack organic residues that are too dry, acidic, or low in nitrogen for bacterial decomposition. Most fungi are classified as saprophytes because they live on dead or dying material and obtain energy by breaking down organic matter in dead plants and animals. Fungal species are numerous during both mesophilic and thermophilic phases of composting. Most fungi live in the outer layer of compost when temperatures are high.

Fungi appear within the composting process about the same time as the actinomycetes. More types of fungi have been identified in composting than either the bacteria or the actinomycetes. Kane & Mullins, (1973a) identified 304 uni-fungal isolates in one batch of compost in a solid waste reactor composting system in Florida. Two general growth forms in fungi exist, molds and yeasts. The most commonly observed species of cellulolytic fungi (Bhardwaj, 1995) in composting materials are Aspergillus, Penicillin, Fusarium, Trichoderma, and Chaetomonium. Although some fungi are very small, most are visible in the form of fruiting bodies - mushrooms - throughout the compost pile. While cellulose and hemicellulose (as in paper products) are slower to degrade than either sugars or starches, lignin is the most resistant organic waste and as such is usually the last in the food chain to be degraded (Epstein, 1997). However, the Basidiomycetes, or white rot fungi, play a very important role in the degradation of lignin.

The upper limit for fungal activity seems to be around 60°C. This inactivity of the mesophilic and thermophilic fungi above 60°C has been reported by (Chang & Hudson, 1967; Finstein & Morris, 1974; Gray, 1970). However, at temperatures below 60°C, the thermophilic fungi can recolonize the compost pile. At temperatures below 45°C, the mesophilic fungi reappear. One of the few thermophilic fungi that survive above 60°C is the thermo tolerant species Aspergillus fumigatus (Haines, 1995). The spores of this species readily withstand temperatures above 60°C and this species becomes the dominant fungus in the compost pile at those temperatures. Aspergilllus fumigatus is a mold and has a special significance as a cellulose and hemicellulose degrader (Fischer et al., 1998).

d) Protozoa

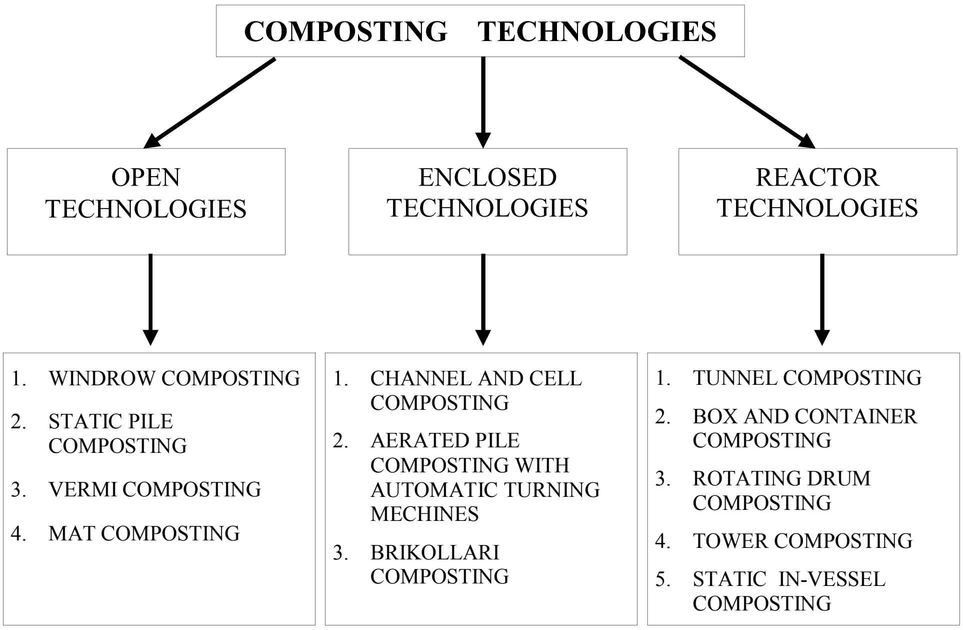
Protozoa are one-celled microscopic animals. They are found in water droplets in compost but play a relatively minor role in decomposition. Protozoa obtain their food from organic matter in the same way as bacteria do but also act as secondary consumers ingesting bacteria and fungi.

e) Rotifers

Rotifers are microscopic multicellular organisms also found in films of water in the compost. They feed on organic matter and also ingest bacteria and fungi (Haug, 1993).

For both composting and biogas production the management process as a whole includes various steps from initial sorting, to transportation, mixing and final usage or sale. Organic waste from households should be separated at source to decrease the risk of contamination, as well as increase the quality of the end product and ensure safe working conditions for the people handling the waste (Hoornweg et al., 1999).

1.10 Composting technologies



1.10.1 Open technologies

a) Windrow composting

The turned windrow method is commonly used in yard waste composting facilities as a versatile, lower-tech method which can be adapted to changing conditions. In this method, organics are mixed according to C: N ratio and moisture content and placed into long rows. The height of the rows depends not only on the machinery used to stack materials, but also on the materials' likelihood to aid or hinder air circulation (piles with greater percentage of moist materials, such as dairy manure or food residuals, should be made smaller than piles containing bulkier yard debris which permits greater air flow). Aeration occurs two ways: Primarily by convection, when heat vapours rise through and exit the piles drawing fresh air in behind; and secondarily by direct exposure when piles are mechanically turned inside out, clumps are broken apart and materials are fluffed thereby improving circulation. Because the piles are repeatedly agitated, the recipe can be adjusted if needed in response to changing conditions or odours. Turning windrows also ensures materials are evenly mixed and exposed to high temperatures in the pile's core. If odours emerge after turning, windrows can be covered with a 3-6″ layer of finished compost. Because of the versatility and facility of operations, turned windrows are as useful for composting food residuals as for composting strictly yard waste.

There are several factors to consider when using turned windrows to process food residuals. Being aware of these will help the composter avoid odours, pests and pathogenic contamination. Because these materials may contain more moisture and/or nitrogen-rich ingredients than yard waste, decomposition may occur more rapidly in the first several weeks. Excessive moisture and rapid decomposition can lead to odours. Odours attract pests, and may also cause problems with local residents. Piles with food residuals may need more frequent turning initially than those with yard waste alone, and will likely decrease in size more rapidly. While smaller windrows enable greater air circulation, they also lose heat faster. Maintaining temperatures in excess of 131ºF is necessary to kill pathogens in food residuals. Therefore, it may prove useful to combine adjacent windrows after the initial rapid decomposition phase is complete. Though these factors can present challenges not previously encountered with composting yard waste, they are minor and infrequent if piles are managed in accordance to processing basics delineated earlier in this Section. Using turned windrows to manage food residuals is a versatile system that can be easily adjusted to accommodate changing conditions.

b) Static pile composting

The main difference between the windrow and the static pile technology is that static piles are not agitated or turned. The lack of agitation in static pile composting requires the maintenance of adequate porosity over an extended period of time even more than in windrows. Either the feed stocks itself need to have sufficient porosity (e.g., certain yard waste feed stocks) or a bulking agent needs to be added to feed stocks without any structure (e.g., food waste). In most cases, the static pile has the shape of a truncated pyramid. Typical dimensions are between 12 and 15 meter at the base with a height of 3 meter. In piles without active aeration, a few facilities try to enhance the natural ventilation by placing aeration pipes (loops or open-ended pipes) in the piles. The pipes enhance the natural ventilation inside the pile. In another modification, the feed stock can be stacked in open composting cells. To compensate for vertical moisture and temperature gradients in the piles, the compost is moved from one cell to another.

More recently, in some cases aerated or un-aerated static piles are covered by fleeces containing air-permeable membranes. The fleece overcomes some of the disadvantages of this relatively inexpensive composting method (odors, run-off, and leachate). The fleece allows gas exchange but prevents rain from entering. Water vapor condenses on the inside of the fleece. Another more recent inexpensive modification of the aerated static pile is an aerated pile in a patented plastic bag system which is primarily used in the United States. These plastics bags were originally used as silage bags and are modified for composting application. The company recommends composting in the bags for 8 weeks followed by 1-3 months of curing.

c) Vermicomposting

Vermicomposting is a simple, very unique technology. Biodegradable organic wastes are inoculated with compost worms (i.e., *Eiseniafoetida*) which breakdown and fragment the waste. Low, medium and high technology vermicomposting systems, all without agitation–are available. Vermicomposting is relatively labor-intensive and for large-scale production, requires large land areas to cool the waste to avoid temperatures which are detrimental to earthworms. The temperature suitable for growing compost worms ranges between 22 and 27°C. As a result, in traditional open vermin composting systems, the waste is placed in beds or windrows only up to a height of about 0.5-1.2 meter. At elevated temperatures, worms are only found in a fairly localized zone towards the outside of the compost pile. Sometimes vermicomposting is only implemented for curing where temperatures are low. Another reason for combining high-rate degradation (3-15 days) without worms with vermicomposting for stabilization and curing is the need for pathogen reduction. At the end of the process, the worms are separated from the castings by screening. The end product is a fine, peat-like material. Retention times of 6-12 months are reported for techniques relying solely on vermicomposting.

d) Mat composting

Other less often used, special applications of the previously discussed composting systems include mat composting and vermicomposting. Mat composting is almost more a storage and preprocessing measure than a composting technology. It is a simple process to mix different yard waste feed stocks like grass clippings, branches, leaves and hedges cuttings which are delivered to the facility over a period of 3-12 months. The first 0.5 meter mat layer consists of mostly bulky yard wastes. Additional yard waste layers are spread in this initial layer up to a final height of about 1.5-3.0 meter. A front-end loader drives regularly over the previous layer, fluffs and mixes the yard wastes with a fork-like device. Due to the lack of effective turning of the entire mat, the bulky particle size of the feed stock and the permanent addition of only a thin layer of fresh yard waste, temperatures in the mat reach only 40-50°C. To continue stabilization and curing the yard waste, the mat is reformed to windrows.

1.10.2 Enclosed technologies

The major difference between open technologies and enclosed technologies is that in the latter case composting takes place in an enclosed building. The main advantage of an enclosed building composting technology is that the off gases of the composting process can be collected and treated there by reducing odor emissions from the composting facility. However, the warm, humid off gases of the composting process condense on the cooler building roof, walls and pipes and can lead to corrosion.

a) Channel and cell composting

In an enclosed building, the feed stock is placed in triangular or trapezoidal windrows, however, in most cases the feed stock is divided by walls which are used as tracks for a turning machine. In these uncovered channels, the feed stock is stacked up to a height of about 2-2.5 meter (Haug, 1993). The length (i.e., 50, 65, or 220 meter) and the number of channels depend on the capacity of the facility and the proposed retention time. A facility can start with only two channels and additional channels can be added as the capacity of the facility increase. Short channels (about twice the width) are called cells.

Both active aeration (forced or vacuum-induced) and turning are used to control the composting process. Air is supplied from manifolds below each channel and aeration rate and water addition are controlled separately for each channel. In many cases, each channel is divided in to several aeration areas each aerated by its own fan. Due to frequent turning, the compost moves from the beginning to the end of the channel. Turning frequencies of every day or every other day are reported. Some technologies compensate for the volume loss during turning to keep the height of the compost constant while other systems compensate for the volume loss when restacking the compost in another channel. Typical retention times in these channels are 6-8 weeks for all composting phases (Schmitz & Meier-Stolle, 1995). However, some facilities compost for 21 days in channels followed by 6 months curing outside in static piles (Haug, 1993).

b) Aerated pile composting with automatic turning machines

The difference between channel composting and aerated pile composting with automatic turning machines is that the feedstock is not placed in channels which can be individually controlled but in one large pile with heights up to 1.8 and 3.3m (Kugler et al., 1995). A forced and /or vacuum-induced aeration system is placed under the compost bed similar to the aerated static pile bed. The composting hall is subdivided into several aeration areas that can be separately aerated and moistened depending on the progress of the composting process. In most cases, the feedstock is conveyed from the preprocessing area to one end of the composting hall, moves through the composting hall via a turning machine and exits the composting hall at the opposite site. The volume loss in compensated for in most systems via the turning machine. The aeration rate can be reduced from 18000 m^3/t bio-wastes for forced aeration to 7000 m^3/t bio-waste for a combination of vacuum-induced and forced aeration with a heat exchanger (kugler et al., 1995).

In some technologies the feedstock is stacked in one area in the composting hall, where it remains for the whole retention time. In these systems, the height of the pile decreases during composting. In most cases, water is added during turning. Turning machines vary with the manufacturer, but they are typically floor–independent and movable over the entire composting hall (e.g., bucket wheel, diagonally working screws, double spindle agitators, or vertically working screws).The turning frequencies range from once a day to once a week which, of course, affects the moisture gradient in the pile. A few systems do not turn for the first four weeks (Zachaus, 1995). Retention time range between 4 and 12 weeks, followed by windrow composting for the shorter retention times.

c) Brikollari composting

The Brikollari process is a unique type of static composting used in some facilities in Germany (Linder, 1995). Bio waste, well mixed and amended with a bulking agent, is compressed into blocks (30-60 kg) that are stacked crosswise on pallets. Channels pressed into the surface of the blocks provide aeration via natural diffusion. The coarse structure of the blocks ensures aeration even within the block. The compaction requires more electrical energy than other preprocessing steps which in turn is compensated for by the low space requirements. An automatic transport system moves the stacks with a mass of 1.2-1.4 t each to a multi-floor high-rack warehouse for high-rate and stabilization degradation. Dividers separate the warehouse in several areas which can all be ventilated separately depending on the progress of the composting process. Retention times in the warehouse range between 5 and 6 weeks. At this time the moisture content in the blocks is about 20%. The blocks can be marketed as ‘stabilized compost’ after grinding, can be stored before being processed further due to the low moisture content or can be immediately cured after the addition of water. Retention time for curing in windrows is about 8-10 weeks.

1.10.3 Reactor technology

In comparison to enclosed technologies, reactor or in-vessel technologies have minimal free air space above the compost and this reduces the volume of exhaust gases that requires treatment. Additionally, the aeration system can be better controlled (i.e., exhaust air recirculation, conditioning of the aeration air).

a) Tunnel composting

Tunnel reactors include static and agitated composting technologies with different levels of process control. They have been used for composting of MSW, sewage sludge and manure for many years. During the past ten years, there has been special interest in tunnel reactors used for composting manure in the mushroom industry because these reactors are better controlled than previous MSW tunnel composting reactors and their design and operation are based on many years of experience. Several manufactures adapted this concept for composting bio waste. A characteristic of this system is that it maintains a relatively homogeneous temperature and moisture profile over the height of the compost due to large amounts of recycled exhaust gases. As a result, less turning is needed to homogeneous the compost. (Zachaus, 1995)

b) Box and container composting

In box and container composting, the reactor units are very similar to tunnels, however shorter. Composting boxes with volumes of about 50-60 m3 (7×3×3m) up to volumes of 250 m^3 are found. The entire front area of a box reactor consists of a door. In comparison to composting boxes, the smaller composting containers with volumes of about 20-25 m^3 (5×2×2 or 6×2×2) are movable. Next to the preprocessing area, the containers that can be opened at the top are filled.

The boxes and containers are filled by a front-end loader or automatically by specialized conveyor belts. In the composting area, the aeration and air conditioning system are individually controlled for each reactor. Forced aeration, vacuum- induced aeration or a combination of both are possible. A homogeneous moisture and temperature profile is accomplished due to air recirculation and the addition of fresh air. Some reactors have segmented aeration floors which enable control of the different aeration areas individually. Some composting boxes pull air from a box filled with fresh feedstock and force it through a composting box with more mature feedstock. The retention times in container box reactors are usually between 7 and 14 days followed by curing for about 12 weeks in windrows, resulting in total retention times of 13-14 weeks (zachaus, 1995). The retention time is shorter if the compost after the first run in backfilled twice to a box for a second and a third run with a total retention time of 6-7 weeks.

c) Rotating drum composting

Composting in a rotating drum is a dynamic process; this technology has been used for composting MSW all over the world. Rotating drums are inclined to move the material and volumes vary between 30 and 500 m^3 (Haug, 1993; Kasberger, 1995). The reactors are not completely filled to ensure sufficient mixing. Feedstock inlets and compost outlets are located on opposite ends of the rotating drum and the compost tumbles slowly through the reactor. To prevent possible short circuiting of compost stages resulting in some material undergoing less processing, the rotating drum can be divided into sections. The rotational speed (i.e., 0.1-1.0 rpm) and whether the rotation is continuous or intermittent (i.e., 45 minute in 24 hour on the average for bio-wastes (Kasberger, 1995) can be controlled. Especially for wet feed stocks like bio waste, high rotational speeds can result in compaction. In most cases, aeration is provided by a fan, less often the rotating drum is perforated allowing aeration via natural diffusion. In the last case, the rotating drum is vented to minimize odor emissions. The retention time in the rotating drum system ranges between 1 and 10 days. (Kern, 1991; Kasberger, 1995). At lower retention times only a portion of the high-rate degradation is performed while at higher retention time, high-rate degradation and stabilization are conducted in the rotating drum. In any case, additional windrow composting between two and three months will be required (Haug, 1993; Kasberger, 1995; Chiumenti et al., 2005).

d) Tower composting

Vertical flow reactors, mostly cylindrical towers and less often rectangular reactors are agitated or dynamic composting technologies. They are often used to compost sewage sludge and less often MSW and bio-waste. Some towers are divided into separate vertical compartments by interior floors. Tower volumes of 400-1800 m^3 with total material depths of 6-9 meter can be found (Haug, 1993).Vertical reactors are commonly fed at the top on a continuous or intermittent basis as the feed stock in the tower moves slowly from the top to the bottom during composting. If interior floors are used, the material is transported vertically to the next floor by flaps or movable grates. The floors enhance agitation during the movement down through the reactor. Without the floors, the movement through the reactor is more like a plug flow.

In most cases, the reactors are aerated by forced aeration counter-current to the compost flow. Large compost depths result in a high pressure drop in the compost which affects the efficiency of the aeration system. In addition due to the lack of effective agitation, the compost can become compacted. This can potentially result in anaerobic niches. In particular, odor problems have led to the closure of a significant number of tower facilities. After movement through the vertical composting reactor, the material is either cured in open windrows or filled into another composting tower for a second run. Typical retention times in vertical reactors range between 14 and 20 days. Stabilization and curing in windrows follow (Christensen, 2011).

e) In-vessel composting

A number of studies have investigated the process engineering and technical aspects of commercial composting with particular regard to more advanced methods such as static pile and in–vessel systems. Examples are De Bertoldi, (1992); Canet & Pomares, (1995) and Lopez–Real & Baptista, (1996). More advanced systems of in-vessel composting are seen as having many advantages over open air windrow systems. As for all waste processing systems, Slater et al., (2001) contend that open windrow composting has the potential to pollute the environment, cause dis-amenity to the locality or harm to public health if good operating practices are not observed. In order to minimize the environmental impact of composting and to enhance and control the composting process, highly sophisticated enclosed composting systems have been developed throughout Europe, based on forced aeration technology. These often use computer–controlled systems to manage the aeration rate, moisture content and temperature of the composting materials. They have been termed ‘in–vessel' and cover a wide range of composting systems. The principle behind an in–vessel system is to provide air and moisture at a level that optimizes microbial activity as rapidly as possible and then maintains it for the desired period. This is obviously easier than in open composting operations where control over ambient temperatures and the elements are more challenging. It is also possible for more difficult feed stocks to be composted using in-vessel systems since they are protected from the wider environment and enclosure helps prevent pathogen vectors such as scavenging birds and vermin from gaining access to the feedstock. In addition, the enclosure of decomposing organic materials allows potentially harmful emissions to be contained and possibly treated prior to release into the environment.

In-vessel systems share the common feature that the material being composted is contained and, usually, enclosed. In most cases, enclosure means that the composting materials are not affected by the external environment (temperature, rainfall, etc.) and the processing conditions can be controlled accurately to make composting more efficient. In addition, emissions from enclosed composting processes, such as bio aerosols, odors and leachate, can be monitored and treated. In-vessel composting systems have been developed from a wide range of industries. Tunnels have come from the mushroom industry, air handling equipment and computer controls from the development of greenhouses and mixing techniques from sewage processing. This has led to the diversity of in-vessel systems that are now employed for the 'active' thermophilic phase of composting. With the development of the in-vessel composting sector there is potential to transform increasing amounts of biodegradable waste into higher value compost products. The composting industry is likely to introduce in-vessel technology in combination with other traditional composting methods.

1.11 The Kerala scenario

The rapid urbanization, constant change in consumption pattern and social behaviour have increased the generation of MSW in Kerala beyond the carrying capacity of our environment and management capability of the existing waste management systems. Therefore, there is an urgent necessity of improved planning and implementation of comprehensive MSW management systems for upgrading the environmental scenario of the State.

Generally, data on the quantity of MSW generation is maintained by the ULBs. This is generated based on the quantity of waste collected and transported on a day to day basis, based on the number of trips made or on approximation based on guesstimates. Normally, there is no practice of weighing the MSW or measurement of its volume while transportation. Therefore, the data has very little authenticity (Anon 2006). Based on the studies carried out by the Centre for Earth Science Studies and data compiled by the Clean Kerala Mission for all the Municipalities and Corporations of the State, the average daily per capita generation comes to 0.178 kg with a very high variation from 0.034 kg for Koothuparamba to 0.707 kg for Thalasseri (Padmalal & Maya, 2002; Varma & Dileepkumar, 2004). This is due to the fact that the quantification of generation from different types of sources has not been done in any of the ULBs by direct method of source wise sample surveys or by indirect method of assessing collected waste, uncollected quantities and that separated for recycling and reuse.

The studies carried out by the National Environmental Engineering Research Institute (NEERI) in Indian cities have revealed that quantum of MSW generation varies between 0.21-0.35 kg/capita/day in the urban centres and it goes up to 0.5 kg/capita/day in large cities (NEERI, 1996).

Considering this, the waste generation in the Municipalities of Kerala can be taken as a minimum of 0.21 kg/capita/day with an increment due to the increasing trend of waste generation and that the estimate was that of 1996. The studies conducted by the Urban Development Section (East Asia and Pacific Region) of the World Bank, considering the relation between Gross National Product (GNP) and per capita waste generation, indicated that the rate of waste generation is estimated to grow at an exponential rate of 1.41 per cent per annum. Therefore, the present minimum generation of MSW can be considered as around 0.242 kg/head/day (Varma, 2011).

The physical and chemical characteristics of municipal solid waste in Kerala indicates that 60 – 70 % are biodegradable matter with high moisture content, low calorific value and substantially high contents of nitrogen, phosphorus and potassium *(CPCB, 2000)*. Such wastes are not suitable for incineration because it requires high-energy input to bring the waste to its ignition level. Nevertheless, land filling and open dumping of such wastes creates nuisance owing to the generation of high concentrated leachate, methane emission and quick settlement of waste due to decomposition that eventually affects the stability of landfill. Therefore the best disposal solution is biological processes, which promote waste stabilization with significant mass and volume reduction that conserve landfill space. Composting and anaerobic digestion were the recognized biological treatment systems. The vegetative fraction of MSW in Kerala is more suitable for composting to organic manure after separating recyclable fractions. The inert non-biodegradable residue left after composting could be disposed of using sanitary landfills. Aerobic systems are in widespread use, like windrows, open-pit, static pile, vermi-compost etc. but were found to have some feedback limitations in Kerala during monsoon season. However with the in-vessel composting systems such limitations can be successfully overcome. A decentralized treatment of food wastes at household level using a simple, efficient and widely acceptable technology is inevitable in the present day scenario.

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Chapter 2

REACTOR DESIGN AND DEVELOPMENT

Contents

2.1 Rationale for this Research

Decision-makers in solid waste at the local government level in urban areas are struggling to solve the problems of solid waste management. Existing solid waste services and infrastructure are often dysfunctional or lacking, severe environmental pollution is the consequence, and the low-income population suffers most. Sophisticated technologies as used in high-income countries are often considered by decision makers in developing countries as state-of-the-art to strive for. Ultimate objective is to implement these solutions without considering costs, required skills, education, and technical expertise. In their desperate situation, decision makers often believe forceful ''sales representatives'' from the private sector, promoting one technical solution as the best to solve "all" problems. Information provided by such interest groups however, is most often biased to only show the special merit of a particular system or technology and disregards the risks and disadvantages and very seldom considers the specific local conditions. As decision-makers often lack technical and engineering expertise and a good overview of the current state-of-the-art in waste management, they are often uncertain about what to believe and may follow these private sector recommendations. Subsequent failures set back the municipality in terms of finances, image and trust by the residents in their municipalities and also delay the achievement of an appropriate solution. The focus of this study is to find out a sustainable solution through technological innovation, for the recycling of bio-wastes, on-site at household level in urban areas.

2.2 Objectives

The broad objective of the present study is to find a sustainable solution for the decentralized treatment and recycling of biodegradable portion of municipal solid waste, through technological innovations.

Specific objectives are

a) To develop an in-vessel composting apparatus for the treatment of food waste on-site at household and community level.

b) To develop a highly efficient integrated aeration system for the treatment of food waste characteristic of high nitrogen and moisture content and to make a composting apparatus more tolerant of variations in source material.

2.3 Study Hypothesis

The study hypothesis is based on the existing physical and socio-economic situation of solid waste management in India.

In-vessel composting technology is seen as a feasible approach towards sustainable treatment and disposal of food wastes at household and community level.

It is envisaged that an integrated twin chambered in-vessel composting system will synchronize the stabilization and curing phases of composting, which will make the reactor to be operated continuously with daily input of food waste and periodic harvest of finished compost.

It is assumed that an integrated positive and negative aeration system, controlled by a temperature feedback mechanism, will improve the in-vessel composting efficiency of food waste, characteristics of high moisture content and less physical structure.

2.4 Limitations

The focus of this thesis is on one specific element in the service chain of solid waste management; that is specific technological approach. Here the focus is set on food waste management at household and community level in urban settings where the main responsible authority is the local government, most often represented by the municipal waste management services. The solution for mixed wastes arising at specific urban and commercial Centre’s like railway stations, bus stand and shopping malls are not taken into account. The limitation was given due to the scope of this thesis. Nevertheless, this hypothesis still needs to be verified and validated at household and community level, through more in-depth assessment and evaluation, which will be the object of future research.

2.5 Reactor design

Prototype composter evaluation at School of Environmental Studies, Cochin University of Science and Technology, Kochi -22, proceeded through several different designs. The performance of each design was evaluated by conducting a treatability experiment using food waste obtained from the University canteen and then redesigned or upgraded into a more efficient system. The final prototype (Design V) offered considerable versatility. This design was standardized and used for trial runs under ground conditions to prove its field worthiness.

The guiding principle of this research is that “responsible management of wastes must be based on science and best available technology and not on ideology and economics that exclude environmental costs and seem to be inexpensive now, but can be very costly in the future”. In search for appropriate technology for the treatment of organic wastes especially food waste, several years were spent in search of literature, attended many National and International seminars and workshops in the area of solid waste management, had discussion with experts, visited most of the dump sites and municipal solid waste treatment plants in south India. Keeping in mind the nature of MSW and the failure of the prevailing treatment and disposal technologies in India, in-vessel composting methodology was opted as the most suitable and sustainable technology. This technology is well developed in western countries but the same technique cannot be applied to Indian condition as the nature and composition of MSW, climatic conditions, socio-economic situations etc., are different, which will make the system unsustainable. Therefore, the challenge was to develop a simple, scientifically proven, sustainable in-vessel composting technology suitable for the India condition especially in Kerala, were it is very difficult to do a composting process due to high moisture content in the atmosphere and long rainy days.

The principle behind an in-vessel composting system is to provide air and moisture at a level that optimizes microbial activity as rapidly as possible and then maintains it for the desired period. In the present study the reactor was designed and constructed based on the above principle, in order to provide optimum levels of oxygen, moisture and temperature inside the vessel, so as to encourage the growth of aerobic microorganisms for the bio-conversion of organic matter in an effective way. With this idea in mind a pioneer in-vessel composter was developed made up of conventional plastic bucket and a computer exhaust fan to the latest twin chambered in-vessel composter with integrated aeration system. The design I was a double walled single chamber system with simple aeration. This system did not meet the required operational parameters of an in-vessel composting method and it became anaerobic. Design II was a twin chambered apparatus coupled with negative pressure system. There were problem in maintaining a uniform aeration inside compost matrix and required temperature was not attained. Design III is same as design II, except the aeration method which was replaced with a highly integrated positive and negative aeration system. This design showed good operational indices but the temperature rise was not satisfactory. This was followed by design IV which was provided with a thermal insulation on the inner side of the reactor vessel to rectify the above said problem. Finally, the Design V was equipped with a Programmable Logic Controller (PLC) for precise control of aeration system based on temperature feedback mechanism in order to enhance and speed up the microbial degradation process. The lid was modified from the previous design by providing a small conical shaped elevated opening with an air tight lid. This was helpful in reducing the exposer of compost matrix while loading the food waste on daily bases, thus the temperature fall at the time of loading was kept at minimum. There is still scope for improvement of the newly developed in-vessel composting system as there is lot of gap areas which has to be explored. The sequence of designing and development of the novel in-vessel composter is shown in figure 2.1.

2.5.1 Reactor construction

Design I was fabricated using commercially available plastic buckets, PVC pipes and fittings. The outer basket is of size 65 cm height and 40 cm diameter and the inner basket which is perforated with size 45 cm height and 35 cm diameter. 1 inch PVC pipe with perforations was fixed at the bottom center of the inner vessel vertically. Secondly a 2.5 inch PVC pipe was fixed at the bottom side of the outer vessel horizontally and then using a bend the pipe is positioned vertically up above the reactor to a height of 7 feet. A 12V, 1W cooling fan was fixed at the top end of the elevated pipe so that air will be drawn out of the reactor which will in turn create a negative pressure inside the reactor. In the initial run, 20 Kg of raw food waste (both cooked and un-cooked) obtained from university Canteen was mixed with 1 kg of saw dust, to adjust the C/N ratio and moisture content of the feedstock. The completely mixed feed stock was loaded into the reactor and closed using an air tight lid. The fan was connected to a 12 V power source for continues operation. The basic operational parameters observed were oxygen consumption, evolution of CO_2, CH_4, NH_3 and temperature profile. The main inference observed in trial run of design I was, 1) There existed deficiency of aeration, 2) Synchronization of stabilization and curing phases of composting was not able to be carried out with single vessel design. 3) Deficient temperature rise and 4) Generation of higher amount of methane and ammonia. After one week of operation the reactor became anaerobic and collapsed. Critical appraisal of design I lead to the development of a new design. It consists of two chambers with lid and an integrated negative aeration system. The chambers are made up of Fiber Re-enforced Plastic (FRP) with 4 feet height and 2.5 feet diameter. The chambers are inter-connected with 1 inch PVC pipe and coupled with a 600 W, 250 V suction motor. Inside each chambers a perforated baskets of size 3 feet height and 2 feet diameter are placed with 1 inch perforated pipe at the center. An outlet valve was provided at the bottom of each chamber for the removal of compost tea. During the trial run the reactor was loaded with 50 Kg food waste mixed with 2.5 kg saw dust. Intermittent aeration was planned and the on/off duty cycle was determined after several trial runs. After evaluation of the operational parameters the following short falls were observed in design II 1) Maximum temperature of 40 degree centigrade was observed on 13th day of composting, not sufficient for the thermophilic micro-organisms, the fast degraders. More than 55°C has to be maintained for at least three days for complete elimination of pathogenic micro-organisms. Methane, to the tune of 3.5% was observed on an average during composting which indicated the presence of anaerobic pockets due to insufficient distribution of air inside the compost matrix. The deficiencies in design II was rectified in design III by replacing the aeration system with an integrated and interconnected highly efficient positive and negative aeration. The positive pressure is provided at the air inlet end with help of a blower of 500W rating. Here it is assumed that the addition of blower will increase the efficiency of air distribution through the compost matrix, and at the same time the suction motor will create a negative pressure and removes spent gases from the reactor. The sequence of developments of novel in-vessel composter is represented as Figure 2.1. A trial run with 50 kg food waste mixed with 2.5 kg saw dust was loaded into the reactor. The operational parameters were observed and evaluated. No methane emission was detected which clearly indicated the efficiency of the aeration system. Maximum temperature reached was 50 ^{o} C on 8th day of composting which was encouraging but a temperature increase of 60 to 65 ^{o} C was expected. A longer lag and mesophilic phase of 10 to 13 days indicates a delayed thermophilic phase of composting. This design showed good operational indices but the temperature rise was not satisfactory. This was followed by design IV which was provided with a thermal insulation on the inner side of the reactor vessel to rectify the above said problem. Design V was developed based on the feedback from design IV. Here the aeration control system was replaced with Programmable Logic Controller, which activated the blower and suction motor based on temperature feedback mechanism. Several trial runs were carried out in order to optimize and programme the control unit so as to synchronize the aeration duty cycle to that of microbial degradation process.

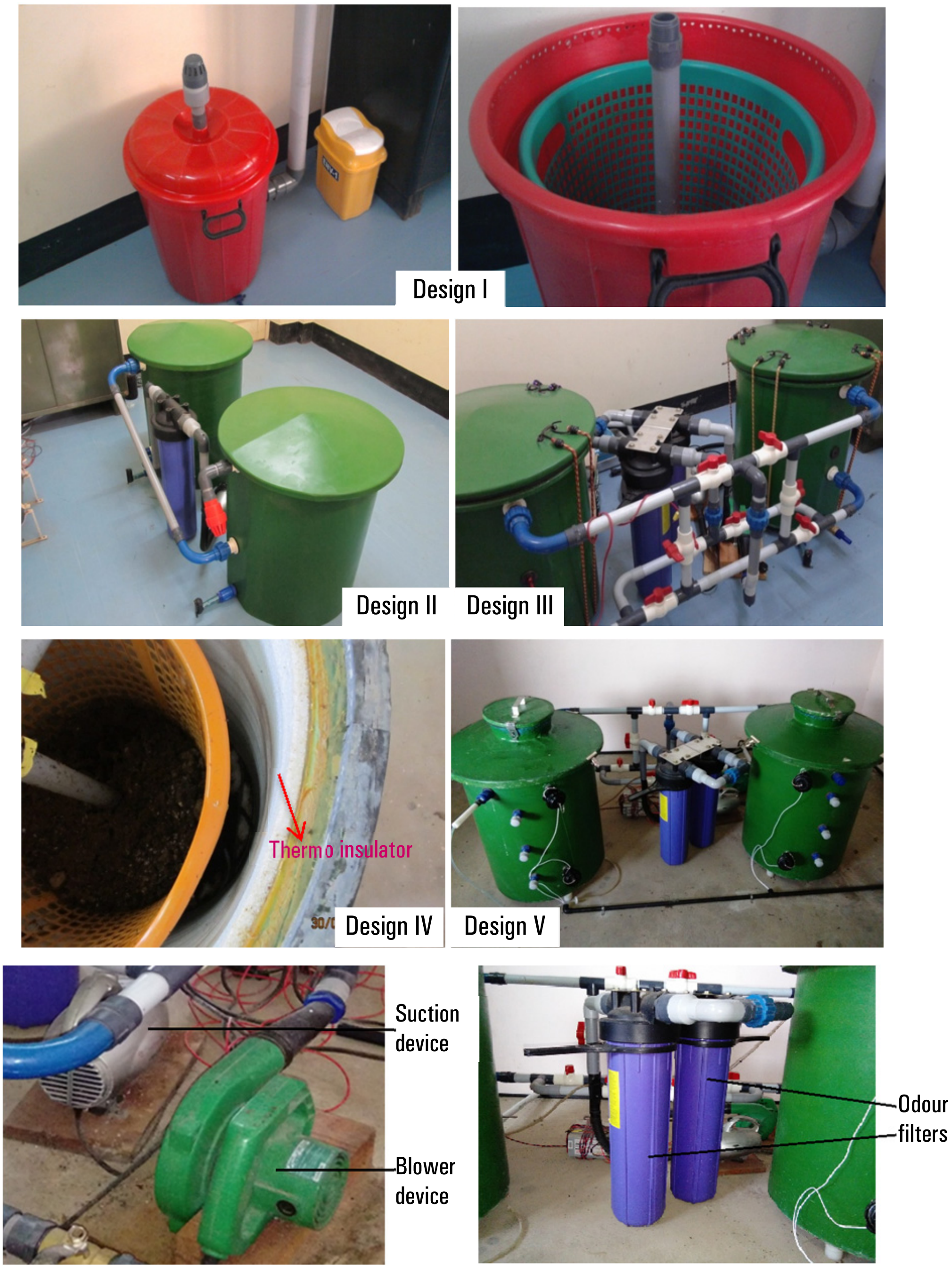

Figure 2.1: **Photograph of sequence of developments of novel in-vessel composter**

2.5.2 Reactor configuration

Composting is done in perforated vessels encased by insulated and air tight vertical container made up of FRP. The unique double walled arrangement of the unit with positive and negative aeration system enhanced composting. Air inlet is provided at the center of each perforated vessels, and the chambers are interconnected in such a way that the exhaust air from the first chamber is diverted through the second chamber which contains mature compost, so as to facilitate capturing noxious gases. Additionally, two external filters; one filled with activated carbon and other with 5 micron polypropylene fiber are provided at the suction end of the aeration system for added safety. With the twin-chamber system the waste material could be loaded intermittently in the first chamber and vice versa for continuous stabilization and curing, after which the matured compost could be harvested. Schematic diagram of the newly developed in-vessel composter is shown in Figure 2.2.

The aeration system consists of interconnected piping with manual and solenoid valves and controlled by a programmable logic control system, working on temperature feedback method. The aeration system is programmed and operated based on the initial characteristics of the feedstock and bulking agent, into three stage aeration duty cycles, to enhance and speed up the pre/post mesophilic and thermophilic stages of composting. Moisture is maintained mainly by aeration and recirculation of leachate and the excess leachate is removed through the outlet valve provided at the bottom of each chamber.

2.5.3 Operational procedure

The apparatus is self-contained to facilitate continuous input of raw waste material, generating a bulk compost material of significantly less total volume and weight than the input material. A quantity of 2 – 3 Kg of raw compost mixer was transferred to the first chamber on daily bases till it got filled, after which it was transferred to the second chamber and vice-versa. During the degradation process the temperature build-up inside the chambers was monitored individually by the control unit and the blower and suction devices are switched on and off, as per the programmed duty cycle for respective temperature range. This method helps to synchronize the stabilization and curing phases of composting in the system and the finished compost can be withdrawn from the respective chambers on monthly basis.

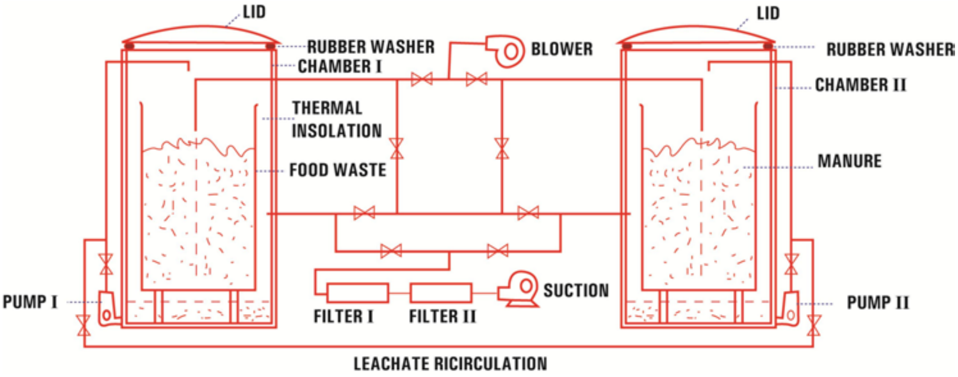

Figure 2.2: Schematic diagram of in-vessel composter

2.6 Development of aeration system

Aeration is a crucial and inherent component of composting. It provides the O_2 needed for aerobic biochemical processes, and also removes heat, moisture, CO_2, and other products of decomposition. In fact, during most of the composting period, the amount of aeration required for cooling greatly exceeded the amount required for removing moisture or supplying O_2 (Finstein, 1986; Haug, 1993; Kuter, 1995). Thus, the need for aeration was more often determined based on the temperature profile than based on O_2 concentration.

Although there are many variations in aeration generally takes place either passively or by forced air movement, passive aeration, often called natural aeration, takes place by diffusion and natural air movement. Forced aeration relies on fans to move air through the mass of composting materials. A possible third mode of aeration being developed is a system that injects nearly pure O_2 into a closed composting reactor (Rynk, 2000c).

2.6.1 Passive Aeration

Passive or natural aeration is driven by at least three mechanisms: molecular diffusion, wind, and thermal convection. O_2 diffuses into material because there is more O_2 outside than within. Similarly, CO_2 diffuses outward. Although molecular diffusion is constantly at work to correct concentration imbalances, the process is slow and probably does not have a major effect on aerating piles (Haug, 1993; Miller, 1991). In exposed outdoor locations, wind can be a significant factor in O_2 transfer. Many composting site operators have observed gusts of wind causing puffs of steam to spout from piles. The influence of wind on aeration of open piles has not been widely documented.

Thermal convection is probably the greatest driving force for passive aeration in most composting systems (Haug, 1993; Lynch 1996a; Randle, 1978). The heat generated during composting increases the temperature of gases with the materials, which in turn decreases their density. The warm gases rise out of the composting mass, create a vacuum, and cool fresh air enters. The aeration rate is determined by the temperature difference between the interior gases and the ambient air plus the air flow resistance of the composting media. Therefore, the keys to obtaining reliable passive air movement are generating heat to drive thermal convection and establishing a porous physical structure within the composting materials (Rynk et al., 1992). Porosity is particularly important. A dense, wet mixture such as sludge reduces or eliminates the potential for convective O_2 transfer (Finstein et al., 1980).

Most composting systems that rely on passive aeration commonly include periodic agitation or “turning” of the materials. The traditional method to aerate a pile of compost depends on mechanical equipment to turn over the material twice daily to once every other day. After turning, the compost has the highest oxygen content but the oxygen gradually depletes so that anaerobic conditions may develop in the compost until the next turning. While the turning provides oxygen, it also disperses the odor to cause serious environmental pollution. The odorous emission is difficult to control with mechanical aeration. It causes the general public to complain about the odor and even appeal to regulatory agencies for the problem. Additionally, traditional mechanical composting may take as long as 2–6 months to mature (Solano, 2001; Li, 1999; Wei, 2000;

Trois, 2001). How to shorten the composting time and alleviate the odor problem is an emerging topic for research on composting technology.

2.6.2 Forced aeration

With forced aeration, air is supplied mechanically, via fans and associated ducts, plenums and control devices-the aeration delivery and control system. There are innumerable possible combinations of aeration and control strategies and equipment configurations. Materials can be aerated by individual fans each turning on and off independently, or by a group of fans feeding a common manifold with valves controlling air flow to individual piles, pile sections, bins, or vessels. Air can be provided by positive pressure, forcing air into the distribution network and up through the materials (Stentiford, 1996), or by negative pressure, sucking air through the materials from the exterior and into the distribution network.

Using the forced-air (positive pressure) aeration that blows air into the composting container will maintain a favorable composting environment to reduce the composting time to about 28–35 days. A major disadvantage of this method is the emission of odorous gas to the environment causing serious pollution. The odor problem can be controlled if extra equipment is attached to collect and treat the odor containing gaseous emission at extra costs (Li, 2008). Additionally, improper design and/or operation of the forced-air system will cause the moisture content in the composting material near the bottom of the reactor too low to support adequate microbial growth. On the other hand negative-pressure aeration uses perforated pipes placed near to the bottom of the composting reactor and connected to a blower. When the blower is turned on to withdraw air from the reactor, negative pressure is created in the reactor. Air is gently forced by atmospheric pressure into the reactor downward through the open top to aerate the compost mixture and maintain an oxic fermentation environment (Chang, 2006). The foul volatile gaseous produced during the fermentation process, e.g. volatile organic acids, ammonia, methylamine, mercaptan, etc., can be collected and treated in a biological filter bed or elution tower for controlling the odor problem. Additionally, if watering properly at the reactor top, the air flow will bring the moisture downward evenly to maintain adequate moisture in the entire reactor to support adequate microbial growth (Lin, 2008). The aforementioned review clearly indicates that both mechanical compost turning and forced-air (positive pressure) aeration will make the composting an open process such that the escaped odor will cause environmental problems. Secondly the problem with the negative pressure systems is that the efficiency of the aeration decreases with high moisture content and particle size, therefore proper pretreatment of the food waste has to be done in order to increase the distribution of air inside the compost matrix. Keeping in mind the advantages of positive and negative aeration methods, an integrated highly efficient aeration system with positive and negative aeration coupled together was developed in order to minimize the feedstock preparation and human interference. Kerala is densely populated with limited land space; the odor problem must be carefully evaluated and controlled to avoid the resistance from the general public against building a composting plant in their backyard. Using the positive and negative pressure aeration with adequate oxic conditions and moisture content during composting odor problems can be avoided. In this research, the integrated positive and negative pressure aeration system was attached with the newly developed twin-bin composter and tested for composting of food wastes. Physical and chemical parameters that affect the fermentation process and the product quality were evaluated.

The Present invention is a better method for providing effective aeration capability and at the same time to capture and treat the biologically evolved gas. Positive aeration is effected by connecting the blower outlet to the inlet of the composting process air distribution system. Negative aeration is effected by connecting the outlet of the composting process air distribution system to the suction device inlet. the novelty of the present invention is that 1) two separate devices for positive and negative aeration respectively are provided at the inlet and outlet of the composting process air distribution system, for efficient passage of air through the composting matrix and at the same time the evolved gases are sucked out through a series of filters for effective removal of odorous gases at the outlet end of the composting process aeration system; 2) The blower and suction devices are switched on at a predetermined time interval to enhance the aeration strategy. Here the suction device is switched on first which creates a negative pressure inside the vessel and after a short time interval the blower is switched on which creates a sudden burst of air through the inlet side of the reactor were the active composting is done. By this method it has been found that the air penetrates through the compost matrices even with high water content; 3) the present integrated aeration system consists of interconnected 1 inch pipe with 8 ball valves. The valves are positioned in such a way that the air flow can be changed between reactor vessels, having simultaneous flow in both the vessels and sequential air flow between the reactors etc. The aeration system is connected to the reactor vessels using union connectors and the valves are operated electrically as well as manually as and when required.

The aeration system consists of interconnected piping with manual and solenoid valves and controlled by a PLC, which consists of 1) Resistance Temperature Detectors (RTD) 2), Resistance Temperature Detector Module (RTDM), 3) Human Machine Interface (HMI), 4) Switched Mode Power Supply (SMPS), working on temperature feedback method. The aeration system is programmed and operated based on the initial characteristics of the feedstock and bulking agent, into three stage aeration duty cycles, to enhance and speed up the pre/post mesophilic and thermophilic stages of composting. Moisture is maintained mainly by aeration and recirculation of leachate and the excess leachate is removed through the outlet valve provided at the bottom of each chamber. The schematic diagram of aeration control system is represented in Figure 2.3.

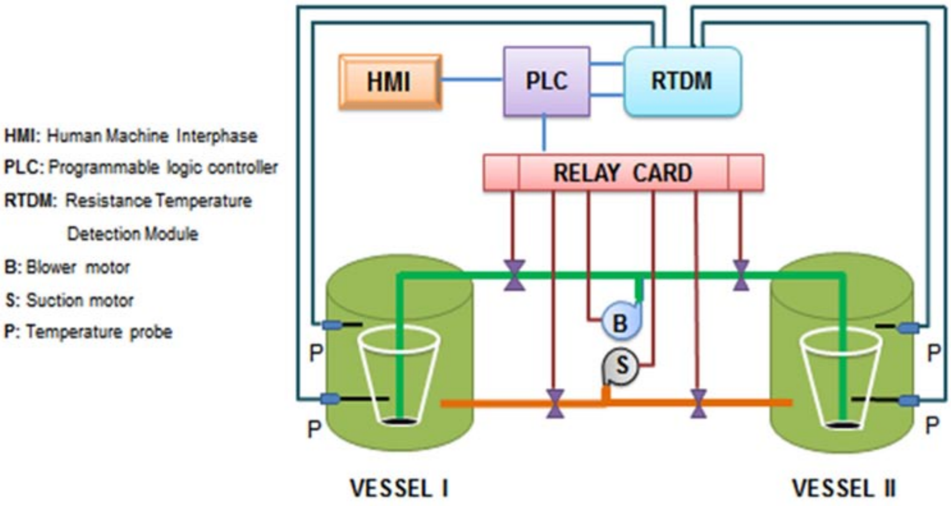

Figure 2.3: Schematic diagram of aeration control system

2.7 Aeration duty cycle

Composting is essentially an oxidation process where O_2 is consumed and CO_2 is produced. Consequently monitoring these two gases during the composting process can provide a reliable indication of composting activity. Studies generally show a 1:1 ratio between O_2 consumption and CO_2 generation (Harper et al., 1992; MacGregor et al., 1981; Wiley et al., 1955), but because CO_2 can be produced by anaerobic respiration and fermentation in addition to aerobic composting (Citterio et al., 1987) its measurement alone is not a good indication of compost activity. On the other hand the measurement of O_2 consumption is a more suitable parameter for monitoring the composting (Haug, 1993). In fact several studies have been conducted where O_2 levels have been used to control the composting process (Citterio et al., 1987; De Bertoldi et al., 1988). Although O_2 and CO_2 levels are usually measured in the gases exiting the compost pile, the in situ O_2 consumption and CO_2 accumulation are more important indicators of whether aerobic or anaerobic condition prevail (Jackson & Line, 1988).

Numerous studies have reported values of O_2 depletion and CO_2 evolution and related them to the composting process. Although most of the data have been obtained using laboratory scale reactors, several studies have been made using actual commercial compost piles. Because O_2 is required for composting, it is essential to ensure that adequate aeration is available. Several studies have actually calculated aeration requirements based on temperature (Wiley et al., 1955) and free air space (Snell, 1957). Regan & Jeris, (1970) and Jeris & Regan, (1973b) demonstrated the correlation between O_2 uptake was highest at low moisture levels where more free air space was available.

Typically, during a composting run, the O_2 concentration in the exit gas from a compost reactor mirrors the changes in the CO_2 evolution and temperature curves (Day et al., 1998; Palmisano et al., 1993). The O_2 will decrease from its initial value of 21% to a value approaching 10% over the first few days of composting as the compost temperature increases and the CO_2 evolution increases. Subsequently, as the rate of composting decreases, the O_2 level should gradually increase, slowly returning to the 21% level as the temperature start to approach ambient. Based upon several controlled tests it would appear that typical O_2 utilization rates for composting at 50 to 70°c are within the range of 1 to 10 mg O_2 g^{-1} h^{-1} (Strom, 1985b).

Aeration is a key element in composting, especially in aerobic composting, as a large amount of oxygen is consumed during initial stages. Aeration provides oxygen to the aerobic organisms necessary for composting. Proper aeration is needed to control the environment required for biological processes to thrive with optimum efficiency. O_2 is not only necessary for aerobic metabolism of microorganisms, but also for oxidizing various organic molecules present in the composting mass. It also has the important function of controlling temperature as well as of removing excess moisture and gases. If the oxygen supply is limited, the composting process might turn anaerobic, which is a much slower and odorous process. A minimum oxygen concentration of 5% is necessary to avoid an anaerobic situation. Turning the pile regularly or by mechanical agitation will ensure sufficient oxygen supply.

Required aeration rate for supply of oxygen was determined by estimating in-situ oxygen refresh rate in percentage and heat output of the compost. Here intermittent aeration was planned while maintaining oxygen level between 12 to 15 %. Commercially available blower with 600 W motor and a mini suction unit with 450 W motor was used in the aeration system.

When reviewing the aeration rates used for each run during the preliminary trial runs, differences are often visible from one run to the next. This was mainly due to the unpredictability of the actual airflow rate achievable by the blower under varying compost porosity, moisture content etc. For partial air recirculation the suction motor out is kept face to face with the inlet of the blower at a distance of 2 cm. so that the spent air from the suction out is drawn in by the blower along with fresh air as the blower motor is of higher rating. The temperature range and aeration duty cycle is shown in Table 5.

2.8 Conclusion

Composting is well known in the art which is a nature's process of recycling decomposed organic materials into a rich soil known as compost which can be used as fertilizer. Composting is typically conducted outdoors due to odours and messy liquid by products. Composting tends to attract insects and other vermin. Composting can produce large quantities of toxic bacteria. As of now variety of compost devices exist. One type of composting relies on micro-organisms to consume organic waste materials, thereby reducing the volume of the waste material and rendering it safe for handling.

The simplest compost devices of this type are stationary or rotating bins that constrain the compost material and aid in manual mixing and airflow. These are intended for use in the backyard or a well-ventilated utility room, for example. More advanced devices may include automatic equipment for mixing and handling compost material while providing air flow. Such devices require special training for operation and maintenance. They generally produce odours and noise. These are intended for industrial use by municipal waste sites, hospitals, schools, prisons, and others. Devices such as compost toilets for composting specific materials also exist. A related group of compost devices relies on a process known as worm composting, or vermin-composting. These devices use worms rather than micro-organisms to consume the waste. Worms can quickly consume large quantities of organic waste, although certain wastes such as dairy and meat are not suitable.

As such, composting has been practiced for hundreds of years. However, several operational problems related to existing technology have limited the use of composting. Primarily, most composting apparatuses utilize poorly designed aeration systems that compost inefficiently and require expensive agitation equipment and buildings to prepare and compost the organic waste. Expensive specialized equipment is usually required to handle and treat the organic waste as it goes through the preparatory stages, such as dewatering and batch mixing, and composting stages. During the preparatory treatment and composting, liquid and gaseous by-products are exposed to the environment causing nuisance odour and water pollution.

Further, most composting apparatuses use pressurized air to induce the flow of air through the compost. The pressurized air is generally introduced at the base of the compost pile through an air distribution system, such as an aeration floor. Air may be forced into the base of the pile causing an upward flow, or drawn out of the base of the pile causing a downward flow of air in the compost pile. The pressurized air may be activated or deactivated by several means including operator or automatic observation of time, temperature or oxygen levels. And sometimes, if less resistance is encountered adjacent to the side walls, then the air will "short circuit" up the side walls through the path of least resistance. The organic waste near the side walls will receive more air than the organic waste in the centre of the container. This result is inefficient composting.

Moreover, presently available composting technologies in the western countries are not suitable to handle a wide variety of source material especially for the type of food waste found in the regional settings in India, which is high in organic content and moisture with less physical structure. Secondly, these highly automated systems are not economically viable for a country like India and the maintenance costs for these units are very high due to import of spare parts.

Therefore there is a need in the art with the composting apparatus and system which is optimized and customized for the source material in the regional settings, economically viable, simple to operate, highly efficient with less maintenance/operational costs and made using locally available material.

Present invention provides a twin chambered in-vessel composting apparatus for passive and active compositing, the apparatus comprising: composting chambers are with body portion having a bottom, at least one sidewall from the bottom, and an top with a lid, wherein the first and second composting chambers are to receive and harvest compost material and vis versa. An air distribution system is positioned in-between the composting chambers consists of several interconnected ducts with valves, blower and suction device, wherein the air distribution system is to blow air in to the composting chambers (positive aeration) and to draw out the air from the composting chambers (negative aeration) for higher aeration efficiency and filtration for odor control and hygiene, a blower device outlet coupled to inlet line of the air distribution system for the positive aeration by blowing air to the composting chambers, a suction device inlet coupled to the outlet line of the air distribution system for the negative aeration by sucking out air from the composting chambers, wherein the outlet line further includes carbon filter and polyethylene filter before suction device to absorbs odor’s before returning air to external environment and a leachate recirculation pump and wastage line with a valve is provided at the bottom of each chamber to remove excess leachate. Composting within a home provides convenience. Food scraps are simply placed in the appliance (versus discarded in the trash). The benefits of composting include the reduction of waste in landfills and an economical source of plant food. The present invention pertains generally to an in-vessel composting system for biologically converting food waste into safe and agriculturally beneficial soil amendments and fertilizers. More particularly, the invention comprises two enclosed containers which perform the various steps of composting, curing and bio filtration. In an even more specific embodiment, the source materials are first stabilized, then cured, and finally serve as bio filtration media in an open-loop system. Gases from the fresh compost matrix are passed through curing compost matrix and then through activated carbon and polypropylene filters before letting it to the environment. While the temperature and gas content within the open loop are carefully regulated.

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Chapter 3

METHODOLOGY

3.1 Introduction

Composting, being a microbial process, can be proceeded with a desired efficiency when the environmental requirements for decomposition are met at their optimal levels. To attain this, it is necessary to control the treatment process and thereby it becomes necessary to monitor these parameters and maintain them within the optimum range.

The methodology adopted in the present research is to evaluate and optimize the working condition of the in-vessel composting system, thereby to make it a highly efficient and sustainable technology for the treatment of different food wastes in the hands of common man. A proper methodology plan was sorted out for the evaluation and optimization of the reactor system and the finished compost. The methodology flow chart is given in Appendix I.

3.1.1 Process control strategy

The most critical conditions for achieving maximum microbial activity by maintaining conditions favorable for micro-organisms are temperature, oxygen, and moisture (Finstein et al., 1992; Miller et al., 1993). The most common method of controlling the process temperature is through aeration. Aeration controls temperature primarily through evaporative heat loss (Finstein & Hogan, 1993).

A number of studies, summarized by Haug, (1993), have investigated oxygen consumption. These studies have found that oxygen consumption increases with increasing temperature. Some data showed temperature optima of 40 to 60 ^{o}C after which oxygen consumption decreased. Other data showed increasing consumption rates up to about 70 ^{o}C. It was suggested by Jeris, (1973) that the differences in temperature optima might be in part due to differences in the cellulosic content of the substrate. The data suggested that temperature could be a useful indicator on which to model oxygen consumption and therefore control oxygen level in the compost. Minimum desirable interstitial oxygen concentration has been reported as 12 to 14 % (Miller, 1993) to prevent a decrease in microbial activity.

Process control has been successfully used to reduce odours from composting operations (Murray, 1991). Traditionally, the main mechanism used to achieve this is maintenance of aerobic conditions through aeration; however maintenance of aerobic conditions does not yield odour-free compost, due in part to odorous intermediate products of the composting process (Haug, 1993).

The central issue in composting process design is temperature control, according to Finstein et al. (1992) and the most commonly utilized process control strategies focus on aeration as the process variables, as described in **Beltsville Process** and **Rutgers Process**.

- In the **Beltsville Process**, aeration of a static pile is provided by a timer which turns a blower on and off on a predetermined schedule (Finstein et al., 1983). The process control objective is to maintain oxygen in between 5 and 15 %. This strategy, while being relatively simple, proved to have some limitations.
- In the **Rutgers process**, the control objective is to maximize microbial activity by regulating temperature via controlled ventilation of the compost (Finstein et al., 1983). In the initial stage, rapid temperature ascent is encouraged by timer-controlled aeration; once temperature reaches the desired range, it was limited to a maximum value through temperature feedback controlled ventilation.

a) **Temperature and Oxygen Feedback:** A modified Rutgers strategy was tested that combined temperature feedback control with oxygen feedback control (Vallini et al., 1989). In this control strategy, when the temperature exceeded the set points, the blower worked continuously. At temperatures lower than the set point the blower was controlled by the oxygen level. When the oxygen level dropped below the oxygen set point, the blower worked continuously. When the oxygen level was above the oxygen set point, the blower operated on a low duty cycle timer. In this experiment, the thermophilic (greater than 45 ° C) stage was completed within 21 days, and the C: N ratio, pH, and phytotoxicity tests all indicated that the final compost was of satisfactory quality md maturity.

Finstein & Hogan, (1993) stated, however, that oxygen feedback was not necessary. During temperature feedback control, a high level of oxygen was a result of temperature-induced aeration. During come-up (increasing temperature) and come-down (decreasing temperature) stages when the temperature did not demand aeration, maintenance of oxygen level could be achieved using an adequate fixed baseline schedule. Study using only baseline ventilation during come-up in conjunction with feedback temperature control demonstrated this (Vallini & Pera, 1989). Also, equipment currently available for measuring oxygen concentration tended to be more expensive and less reliable than equipment for measuring temperature, due to the higher complexity. In spite of these arguments against combined temperature and oxygen feedback control, no literature could be found directly comparing this method with others such as Rutgers.

b) **Oxygen Feedback**: Use of oxygen feedback aeration control was tested in the composting of MSW in a “closed” reactor (de Bertoldi et al., 1988). Forced aeration was provided with the aeration rate controlled by oxygen level feedback. Using a set point of 15%. During the experiment, temperatures peaked at close to 70 °C, although temperatures above 60°C only occurred in the upper 10 cm of the compost. Compost quality was judged to be good and pathogen reduction was judged to be adequate. However, organic matter (dry) reduction was only 14%. Processing time using this scheme was 'medium' longer than Rutgers, shorter than Beltsville. There may be energy and cost savings, since aeration was done only when oxygen demand was high, and there was no agitation. However, oxygen monitoring equipment was required, and since there was no temperature feedback, the potential for excessively high temperatures remained.

c) **"Leeds" System:** Leeds University (Leton & Stentiford, 1990) developed a temperature feedback aeration control system that used temperature measurement to implement a simple model of the process. When the temperature is above the set-point, a fan is turned on for a fixed period. However, when the temperature is below the set-point, the current temperature reading is compared with the previous temperature reading. Depending on whether the temperature is increasing or decreasing, the fan is turned on for a longer or shorter period of time. This allows the aeration rate to be adjusted to three different rates for different portions of the process: the initial come-up portion, the high temperature portion, and the final come-down portion. It is not clear what benefit, if any, is derived from this system compared to other systems.

d) **Air Recirculation:** An alternative aeration strategy using air recirculation was tested in a composting tunnel, using temperature feedback aeration control (Miller et al., 1990). Dry matter loss, physical consistency, pathogen content, odour production, nutrients and composting time were all judged to be satisfactory. Air recirculation design allowed separate control of temperature and oxygen, by using a heat exchanger and variable fresh air intake respectively. A potential benefit offered by this system is improvement of the manageability of odour emissions by reducing the volume of exhaust air that must be handled and treated. Using recirculation, emission rates of some odorous gases (reduced sulphur gases and ammonia) may be lower, based on the longer residence time of exhaust gases in the compost (Mathur et al., 1994).

In the present study the effects of different aeration schemes on odor production, maintenance of minimum oxygen level, temperature rise etc., were investigated.

Based on the analysis a modified and novel process control strategy was developed taking into account economic viability, efficiency, sustainability and suitability for the type of food waste, characteristic of high moisture at the regional setting. Moving parts like agitators and anguars intended for mixing and aerating the compost matrix were not opted during the design strategy because these mechanical parts may wear and tear during operation and require periodic maintenance, which will increase the operation cost and chances of failures are high.

3.2 Feedstock characterization and preparation

The food waste was obtained from cafeteria inside the university campus. The collection timing was fixed at 11.00 a.m. in order to get a uniform composition of food waste, which mainly consists of breakfast stuffs like idle, dosa, sambar, chatney, poori etc., along with vegetable peelings. The composition of food waste is presented in Table no. 3.1.

The cooked food wastes and vegetable peelings were collected separately and later blended into 1:1 proportions before subjecting it to composting process. Sawdust was used as a bulking agent to adjust the moisture content, carbon -to-nitrogen ratio and to maintain air spaces. Actual food waste was used during the experimental trial runs carried out on the final design (design V), on a daily loading bases. During experimental trial runs important physical and chemical parameters of the feed stock were analyzed. The range of physical and chemical properties of blended food waste, the bulking agent and actual kitchen waste are presented in Table 3.2. The moisture percentage of the FW and bulking agent varied between 70 – 85 and 36 – 40 respectively. The purpose of adding bulking agent was to adjust the moisture content of the feedstock apart from providing carbon and porosity. The moisture content of the blended FW was between 70 and 78 percentage. The pH and conductivity values of the FW and bulking agent was in the range of 6.5 – 8.7; 6.8 – 8.4 and 57 – 72 mV; 62 – 68 mV respectively. Carbon and nitrogen was also found to be highly variable in feed stock and bulking agent collected at different times. This may be due to the change in characteristics of the feed stock. FW contained carbon and nitrogen percentage in the range of 25 – 38 and 2.5 – 3.26 respectively. Sawdust contained carbon and nitrogen percentage in the range of 57 – 68 and 0.22 – 0.38 respectively. The final C/N ratio obtained after mixing FW and sawdust in appropriate proportion was in the range of 32:1 to 38:1.

Table 3.1: Composition of food waste (breakfast) along with vegetable peelings

SL. No	Items	Percentage %
1	Idle	16
2	Dosa	18
3	Poori	12
4	Appam	4
5	Vegetable peelings	48
6	Chappathy	1.8
7	Puttu	0.2
8	oil	Trace

Table 3.2: Physical and chemical properties of feedstock

Sl. No	Composition	Blended food waste	Sawdust	Kitchen waste
1	Moisture %	70 – 78	36 – 40	70 – 85
2	pH	6.8 – 8.4	5.2 – 6.0	6.5 – 8.7
3	Conductivity (mV)	62 – 68	-	57 – 72
4	Carbon %	40 – 52	57 – 68	25 – 38
5	Nitrogen %	1.43 – 2.60	0.22 – 0.38	2.50 – 3.26
6	C/N ratio	34:1 – 38:1	170:1 – 300:1	11.1– 17.1

3.3 Experimental design

One of the first tasks in developing a successful composting activity is getting the right combination of ingredients. Two parameters are particularly important in this regard: moisture content and the carbon to nitrogen (C/N) ratio. Moisture is essential to all living organisms, and most microorganisms, lacking mechanisms for moisture retention, are particularly sensitive in this regard. Below a moisture content of 35 to 40%, decomposition rates are greatly reduced, below 30% they virtually stop. Too much moisture, however, is one of the most common factors leading to anaerobic conditions and resulting odor complaints. The upper limit of moisture varies with different materials, and is a function of their particle sizes and structural characteristics, both of which affect their porosity. For most compost mixtures, 55 to 60% is the recommended upper limit for moisture content. Because composting is usually a drying process through evaporation due to biologically generated heat, starting moisture contents are usually in this upper range. Carbon and nitrogen are both the most important and the most commonly limiting (occasionally phosphorous can also be limiting). Carbon is both an energy source and the basic building block making up about 50 percent of the mass of microbial cells.

Nitrogen is a crucial component of proteins, and bacteria, whose biomass is over 50% protein, need plenty of nitrogen for rapid growth. When there is too little nitrogen, the microbial population will not grow to its optimum size, and composting will slow down. In contrast, too much nitrogen allows rapid microbial growth and accelerates decomposition, but this can create serious odor problems as oxygen is used up and anaerobic conditions occur. In addition, some of this excess nitrogen will be given off as ammonia gas that generates odors while allowing valuable nitrogen to escape. Therefore, materials with high nitrogen content, such as food wastes, require more careful management to insure adequate oxygen transport, as well as thorough blending with a high carbon waste. The usual recommended range for C/N ratios at the start of the composting process is about 30/1, but this ideal may vary depending on the bioavailability of the carbon and nitrogen. As carbon gets converted to CO_2 (and assuming minimal nitrogen losses) the C/N ratio decreases during the composting process, with the ratio of finished compost typically close to 20/1.

Actual food waste was obtained from the University canteen, and for each experimental run fresh batch of blended food waste was used. There was slight variation in the physical and chemical composition of the food waste obtained for each experimental run but it did not have significant impact on the efficiency of the reactor. Here, sawdust obtained from the nearby carpenter shop was used as the bulking agent and carbon source throughout the study.

The values of mass, moisture content, carbon and nitrogen percentage of food waste and sawdust was substituted in the following Equation no: 3.1, in order to obtain the desired values of moisture percentage and C/N ratio for starting the composting operation.

$$R = \frac{Q_1\{\mathrm{C}_1 \times (100 - M_1)\} + Q_2\{C_2 \times (100 - M_2)\} + \ldots}{Q_1\{N_1 \times (100 - M_2)\} + Q_2\{N_2 \times (100 - M_2)\} + \ldots} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

In which:

R = C/N ratio of compost mixture

Q_n = mass of material n ("as is", or "wet weight")

C_n = carbon (%) of material n

N_n = nitrogen (%) of material n

M_n = moisture content (%) of material n

This equation can also be solved exactly for a mixture of two materials, knowing their carbon, nitrogen, and moisture contents, the C/N ratio goal, and specifying the mass of one ingredient. By simplifying and rearranging the above equation, the mass of the second material required can be calculated as per Equation no: 3.2, below.

$$:Q_2 = \frac{\mathrm{Q1} \times N_1 \times \left(\mathrm{R\ u}\frac{C_1}{N_1}\right) \times (100 - M_1)}{\left(N_2 \times \frac{C_2}{N_2} - R\right) \times (1000 M_2)} \ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Here the moisture percentage goal was set at 60 % and the C/N ratio obtained after mixing 50 Kg of food waste with 2.5 Kg of sawdust was in the range of 32:1 to 36:1

3.3.1 Process monitoring and physico-chemical analysis

The process to convert organic waste into compost is affected by many parameters to influence the composting rate, compost quality, and the generation of odorous gasses. Parameters used to monitor the progress of a composting process and the product quality include temperature, moisture content, pH, Electrical conductivity, C/N ratio, O M, in-situ O_2 consumption and CO_2 evolution rate, microbial activity, NH_4 and CH_4 gas emission, germination tests, pathogen and nutrient analysis.

Samples were collected from three vertical sampling ports provided on the reactor chambers, one on the upper, middle and lower portion of the compost matrix. Samples were collected on every alternate day from the start of the experiment till 30 to 35 days of composting period. Samples were collected, stored and analyzed according to the handbook of Test Methods for the Examination of Composting and Compost by US Composting Council, 2002. All analyses were triplicated in order to ensure reproducibility and representativeness of the sample.

About 50g of the wet sample was weighed and subjected for physico-chemical and microbiological analysis. A quantity of 25g of the above sample was dried in a hot air oven at 105°C for 24hours for the determination of moisture, C/N ratio, Organic Matter etc. Remaining 25g of the sample was diluted in the ratio of 1: 10 using distilled water and stirred for 2 hours, filtered and subjected for the analysis of pH, conductivity, microbiological analysis.

Changes in temperature were measured at intervals of 30 min through thermocouples, one fixed above the compost matrix inside the chamber and another one fixed at the lower middle portion which passes through the compost matrix, on both the chambers. Gas sampling was performed with a portable gas analyzer equipped with infrared absorption sensors to measure CH_4 and CO_2 and with a galvanic cell type sensor to measure O_2. The measurements of the in-situ O_2 and CO_2 contents at the head space of the compost matrix inside the chambers were performed using a sampler. Acquisition time per measurement was approximately 30 – 60 seconds so that to achieve a constant reading by the gas analyzer. The O_2 and CO_2 concentration in the ambient air within the incubation room were always measured prior to the initiation of a series of measurements. The ammonia gas was detected using real-time ammonia monitor which has 1 ppm low detection level.

3.3.2 Control Algorithms

The process control system is based on PLC. A Human Machine Interface (HMI) monitoring system with touch operation and data logging facility was coupled with PLC and RTD module, while controlling the aeration solenoid valves, blower and suction motors. Interfaces to external measuring and control devices are provided through a series of relay cards. Intermittent aeration with a positive and negative pressure aeration system controlled by a programmable logic control unit with temperature feedback mechanism was the strategy adopted in this study. The upper temperature set point is 70°C, above which the blower and suction device would work continuously to bring down the temperature below to the set point.

For linear temperature feedback functions, programmes were written in LADDER LOGIC and integrated into PLC-HMI control unit. The source code for this software was not included in this report as the embodiment is patent pending. The linear temperature feedback algorithm was designed in such a manner that the oxygen level inside the reactor could be maintained within a desirable range 12 to 15 % on an average. Schematic of linear temperature feedback method is represented in Appendix III.

3.4 Materials and Method

Appendix II lists the items and methods of the analysis for monitoring the composting process. All proximate analysis was done in automated instruments at STIC (Sophisticated Test and Instrumentation Centre), Cochin University P. O., Kochi -22, Kerala State.

a) Moisture measurement: TMECC03.09-A

An aliquot of 1.5 cm^3 prepared feedstock/in-process compost/finished compost material was transferred to a 150-ml open beaker and after determining the weight it was subjected to air drying at 70 ± 5 °C in hot air oven (LG, MS-2049UW, India) for 18 -24 h or until constant weight was obtained.

The oven-dried sample was placed in desiccator and cooled to ambient laboratory temperature, and net weight of dry sample was determined. Moisture content was determined using the formula below:-

$$M = 1 - [dw / A] \times 100$$

Where

M = percentage moisture in sample, wet basis, % g g^{-1}.
dw = net dry weight, oven at 70 ± 5 °C, g, and
A = net sample weight at as-received moisture, g.

b) Electrical conductivity: TMECC 04.10-A,

A compost sample (40g) was blended with deionized water, free from ammonia and carbonate, having resistivity of 17 $M\Omega\cdot cm^{-1}$ at a ratio of 1:5, dw/v equivalent basis. The sample was shaken on a reciprocating shaker at 180 rpm for 20 min at room temperature to allow the salts to solubilize in the water. Electrical conductivity was measured in the 1:5 sample slurry using Conductivity /Resistivity Meter (EUTECH, Con 510, Singapore) and recorded as dS m^{-1} = mMhos cm^{-1}.

c) pH determinations (Slurry pH). TMECC 04.11-A

A quantity of 40.0 g. dry compost sample was blended with 200 ml deionized water in 500 ml screw capped flask. The sample was shaken on a reciprocating shaker for 20 min at 180 rpm or excursions per minute at ambient temperature. The pH was measured using pH meter (EUTECH, pH Tutor, Singapore) while the slurry was under gentle agitation.

d) **Organic Carbon:** Carbon Combustion with CO_2 detection: TMECC 04.01- A

Organic carbon was analyzed using CHN analyzer (Elementar, Vario MAX cube - Germany) following manufacturers protocol and expressed as % C

e) **Nitrogen:** Total Nitrogen - Oxidation by dry combustion: TMECC 04.02- D

Dumas method was followed for the determination of total nitrogen using automated CHN analyzer (Elementar, Vario MAX cube- Germany) and expressed as % N.

f) **Carbon to Nitrogen Ratio:** TMECC 05.02-A

Carbon – Nitrogen ratio was calculated following the equation given below:-

$$C{:}\ N = C/TN$$

Where

C: N = OC to N ratio, unitless,
C = percent organic carbon, % and
TN = percent total nitrogen, %

g) **Gaseous analysis:** Oxygen; Carbon dioxide and Methane:

Gas sampling and analysis were done by a portable multi-gas analyzer, model-BIOGAS 5000 (Geotechnical Instruments Ltd., U.K.). A sampling port with connector was provided at the head space and at three locations vertically in each chamber of the composting system, for collection and analyses of gaseous samples. A second sampling port was provided at the inlet and exit point of the aeration system in the composting apparatus. The gas sampler consists of 1.5 feet 5 mm non-corrosive metal pipe with provision for connecting a polyvinyl flexible tube, through which the gas analyzer was connected via a moisture trap.

The instrument automatically carries out a self-calibration test on every operation. After calibration the sampler is connected to the respective sampling port in the device via flexible hose. Upon activation the instrument detects the chamber partial pressure and fixes it. Then on third initiation, the instrument draws the gaseous sample into the system with the help of a built-in pump for about 30 to 60 seconds, which is the acquisition time. The instrument starts showing the gas values of all the gases instantly and once when the values become stable, it can be fixed and stored.

Ammonia gas was sampled and analyzed by a real-time Gas Analyzer (UNIPHOS – 282 (PM), India). The instrument was connected to the sampling ports by flexible hose with moisture trap. The acquisition time for detection is 1 min. The photograph of portable multi-gas (BIOGAS 5000) and single-gas analyzers (UNIPHOS 282-PM) used in the study is shown in Fig. 3.1.

Figure 3.1: Photograph of 1) UNIPHOS 282-PM ammonia detector and 2) BIOGAS 5000

h) Respirometry:

i) In-situ oxygen refresh rate: TMECC 05.08 - C

- In situ oxygen refresh rate was measured using oxygen sensor analyzer through a galvanized steel pipe of 1.5 feet long through an on line filter device for water vapor. Oxygen analyzer was calibrated as per the manual to ambient O_2. Aeration procedure was performed, and the probe inserted to a specific depth and kept in position until the end of the experiment.
- Percent O_2 was recorded at ten minute interval for two hours or until readings leveled off. The O_2 readings were rounded off to the nearest reading. The results were plotted with Y-axis as O_2 percent and X-axis as time in minutes.

ii) Dewar Self – Heating Test: TMECC 05.08-D *(Bnon, 2009)*

- Self-heating test was conducted in Dewar vessel, custom made with a capacity of 1L having a digital thermometer with ± 1 ^{o}C increments over a range of 10 ^{o}C through 80 ^{o}C. It has a thermocouple probe of 30cm.
- A quantity of 600 gm. representative compost sample was taken based on the density of the compost material. The sample moisture was determined, corrected to the required level, and equilibrated to ambient temperature.

  The Dewar flask was filled with sample material and gently shaken to stimulate natural settling. The high point reading thermocouple probe was inserted into the flask to a point about 5 cm from the bottom of the flask. The thermocouple recorded both maximum ambient and sample temperatures. The ambient temperature and that of the vessel were maintained at 18Δ ^{o}C to 22Δ ^{o}C. The ambient and sample temperatures were recorded on daily basis. The compost temperature was achieved its highest temperature within three to five days. The temperature recording was continued for at least two days after maximum temperature was reached.

Net temperature rise Δ ^{o}C was calculated as per the equation given below:

Net Temperature Rise: $R = H – A$

Where:

R = net temperature rise. $\Delta\ ^{o}C$,

H = highest temperature recorded over test period,°C and

A = ambient temperature recorded ^{o}C.

The net temperature rise reading was interpreted and classified based on the chart given below (table no: 3.3).

Table 3.3: Interpretation of Dewar self-heating test:

Temperature rise above ambient	Official class of stability	Description of maturity class or group	Major group of compost
$<10\Delta\ ^{o}C$	V	Finished compost, stable to very stable compost	Finished
$10 – 20\Delta\ ^{o}C$	IV	Maturing, moderately unstable, curing compost	Curing
$20 – 30\Delta\ ^{o}C$	III	Active compost, material decomposing and unstable	Active
$30 – 40\Delta\ ^{o}C$	II	Immature compost, young or very active compost	Active
$>40\ \Delta\ ^{o}C$	I	Raw Feedstock; fresh compost, mixed ingredients.	Raw or Fresh

i) **Biological Assays:** 208: Seedling Emergence and Seedling Growth Test (As per OECD guidelines for the testing of phytotoxic chemicals).

The test assesses effects on seedling emergence and early growth of higher plants following exposure to the test substance in the soil (or other suitable matrix). Seeds are placed in contact with soil treated with the test substance and evaluated for effects following 14 to 21 days after 50% emergence of the seedlings in the control group. Endpoints measured are visual assessment of seedling emergence, biomass (fresh or dry shoot weight, or shoot height) and visual detrimental effects (chlorosis, mortality, plant development abnormalities, etc.). Measurements are made at least weekly or more often when recording the emergence of the seeds and compared to those of untreated control plants.

- *Leachate Bioassay:* Compost leachate was prepared in 1:10 (weight/volume) compost to water ratio. This compost-water mixture was kept on a rotary shaker for 24 hours, and later extracted by filtering through whatman No.1 filter paper. A concentration series (0, 6.25, 25, 50, 100% leachate) was prepared by diluting the leachate using distilled water. Mustard (Sinapsis alba) was used as the test species. The seeds were purchased from local market and stored at 4 ^{o}C until use. The seeds were washed thoroughly in tap water followed by distilled water before it was used in bioassay. The bioassay was performed in plastic petri dishes (90 mm dia.) filled with 10 ml of leachate concentration series prepared earlier. Ten seeds of *S. alba* were put in each petri dish. The test was performed in triplicates. The petri dishes were kept under 16/8 hour light/dark regime with a light intensity of 160 µol m^{-2} s^{-1} for 4 days. After 4 days, the root length and shoot length was recorded.
- *Soil bioassay:* A concentration series of 10, 5, 2.5 and 0% compost was prepared in plastic cups (10 cm diameter and

4 cm height) by mixing the compost with soil. The compost soil mixture along with the control soil was kept for one day to equilibrate. Here Ragi (*Eleusine corocana*) was used as the test species. Ten seeds of Ragi was added into each cup. The exposure conditions were the same as described earlier. After 4 days of exposure, the plants were washed to remove the compost and the shoot and root lengths were measured.

j) Enzyme Activity and Analysis

Dehydrogenases: TMECC 05.04-B

Reagents

1) Methanol
2) 2, 3, 5-triphenyl-tetrazolium chloride (TTC, 3%)

   3 g of TTC was dissolved in 80 ml of water into a 100 ml volumetric flask. The flask was made up to 100 ml with water and store in the dark.

3) Triphenyl formazan standard solution (25 mg ml^{-1})

   2.5 g of triphenyl formazan was dissolved in 50 ml of methanol into a 100 ml volumetric flask. The content in the flask was made up to 100 ml with methanol.

   Standard triphenyl formazan solutions containing 20, 10, 5, 1 and 0.5 mg of triphenyl formazan ml^{-1} solution was placed in a 25 ml volumetric flask respectively. Each flask was made up to 25 ml with methanol.

Method

A quantity of 3 g sample was added into each of two 25 ml Erlenmeyer flasks and labeled as control and sample. A third flask was labeled as the blank which contained the sample without compost. Aliquots of 3 ml water and 3 ml 3% TTC were added to the sample and blank flasks and 6 ml water were added to the control flasks. The contents in the flask were swirled for 30 s to mix the content and stoppered the flasks. The flasks were then placed in an incubator at 37^{o}C for 24 h in the dark. Stoppers were removed and 10 ml of methanol was added to the three flasks and swirled the flasks for 5 min. The sample suspension was filtered through a glass fiber filter into a 100 ml volumetric flask. The glass fiber filter was washed with methanol to remove the reddish color caused by the reduced TTC and the filtrate was collected in to the same 100 ml volumetric flask. This flask was made up to 100 ml with methanol. The filtrates were measured at 485 nm on a spectrophotometer. The triphenyl formazan content of the filtrate was calculated using the calibration curve plotted with Triphenyl Formazan standards (TPF) these steps were repeated using control and blank samples.

The dehydrogenase (mg of TPF released g^{-1} of air dried compost 24 h^{-1}) activity was measured using the following equation:-

$$AC = E \div 3 \times M$$

Where

E = mg of triphenyl formazan mL^{-1} in Compost filtrate as a result of catalysis of TTC by dehydrogenase and M = Mass of compost (g).

i) **Fluorescein diacetate (FDA) hydrolysis** (For non-specific esterases, proteases and lipases) *(Schnurer et al., 1982)*

A quantity of 2 g sample was placed in a 50 ml conical flask and 15 ml of 60 mM potassium phosphate buffer (pH 7.6) added. Stock solution (0.2 ml 1000 μg FDA ml^{-1}) was added to start the reaction. Blanks were prepared without the addition of the FDA substrate along with a suitable number of sample replicates. The flasks were stoppered and the contents shaken manually.

The flasks were then placed in an incubator at 30°C for 20 min. The following steps involving chloroform/methanol were carried out in a fume cupboard. Once removed from the incubator, 15 ml of chloroform/methanol (2:1 v/v) was added immediately to terminate the reaction. Stoppers were replaced on the flasks and the contents shaken thoroughly by hand. The contents of the conical flasks were then transferred to 50 ml centrifuge tubes and centrifuged at 2000 rev min^{-1} for approximately 3 min. The supernatant from each sample was then filtered (Whatman, No 2) into 50 ml conical flasks and the filtrates measured at 490 nm on a spectrophotometer. The concentration of fluorescein released during the assay was calculated using the calibration graph produced from 0 to 5 μg fluorescein ml^{-1} standards which were prepared from a 20 μg fluorescein ml^{-1} standard solution. The 0 μg ml^{-1} fluorescein standard was used to adjust zero reading in the spectrophotometer before each set of blanks and samples were read. The enzyme activity (μg of fluorescein released g^{-1} of air dried compost h^{-1}) was calculated using equation 4:

k) Detection of Pathogens

1) Total Coliforms: TMCC 07.01-A

Total coliforms were detected following most probable number method.

Procedure:

A quantity of 20 g of compost was placed in a sterile stomacher bag. The weight was made up to 200 g with the addition of Buffered Peptone Water (BPW) for attaining 1:10 dilution (10^{-1}). The content was homogenized for 2 min at 260 rpm. The sample as diluted to $10^{-3.}$ The samples were inoculated to Lauryl Triptose (LT) broth each containing an inverted Durham's tube first three tubes in double strength and the rest six tubes single strength. The first three double strength tubes received the same quantity of inoculum and three tubes having single strength medium received 1ml inoculum and the rest 0.1 ml inoculum. The tubes are incubated for 24 h to 48 h in a 36 ^{o}C ± 1 ^{o}C incubator. The inverted gas tubes were observed for the presence of small air bubbles. Gas formation indicated positive result for lactose fermentation, and therefore positive result for Coliforms. The numbers of tubes in each dilution set that were positive for gas formation were recorded. Dilutions were converted to dry weight by multiplying tube concentration by the total solids ratio as determined on parallel aliquots. This number was used to calculate the MPN g $^{-1}$ for total coliforms.

2) **Fecal Coliforms:** TMECC 7.01-B

Fecal coliforms were determined following Most Probable number method using EC-MUG – E. Coli Medium plus 4-methylumbelliferone-β-D-Glucuronide. Dilution of the samples and inoculations were done as described above under total coliforms. The tubes were incubated at 44.5°C± .2°C.

The EC-MUG gas tubes were observed for the presence of small air bubbles. Gas formation indicated ‘positive’ result for lactose fermentation; ALL EC-MUG tubes that contained gas were considered POSITIVE for growth of fecal coliforms. Dilutions are converted to dry weight bases by multiplying tube concentration by the total solids ratio as determined on a parallel aliquot as per method 03:09-A (Total solids and Moisture determination) in TMCC. This number is used to calculate the MPN g^{-1} for fecal coliforms.

3) ***Escherichia coli:*** TMECC 7.02- B

To enumerate E. coli the positive EC-MUG tubes were streaked on MacConkey’s Agar (MAC) and Eosin-Methylene Blue Agar (EMB) and incubated at 44.5 °C ± .2 °C.

Escherichia coli produced a deep pink coloration on MAC plates, and the medium surrounding this culture showed a ‘fuzzy’ pink appearance due to the precipitation of bile salts and low pH (due to lactose fermentation). Growth on EMB should be metallic green within 18 h-24 h, but could also appear dark purple. Prepared Triple Sugar Iron Agar (TSI) slant and Motility Indole Lysine Agar (MIL) deep for each isolate to be tested. Picked three colonies from the

MAC plate that were pink, had precipitated bile salts and that had a corresponding sector of EMB that had metallic green sheen (or appears dark purple). The colonies were inoculated to the TSI tube (stabbed and streaked) and then stabbed the MIL tube twice. Incubated the TSI and MIL tubes for 18 -24 h at 36° C ± 1°C. Placed two drops of Indole reagent onto the surface of each MIL tubes Escherichia coli exhibited the following biochemical characteristics: a) TSI- Acid slant 9A/yellow), Acid Butt (A/Yellow), Gas production (bubbles) throughout the medium;

b) MIL- Basic Slant (K/Purple), basic Butt (K/Purple), Motility (medium is cloudy), and indole production (Red band at the top of the tube, after the addition of Kovac's Reagent).

4) ***Salmonella:*** TMECC 7.02-B/C

Enrichment Procedure:

A quantity of 25 g sample (as-received) was weighed into a sterile stomacher bag and 225 mL of Buffered Peptone Water (BPW) was added and blended at 260 rpm for 60 sec. The bag was placed at 37°C incubator for 18 to 24 h., and homogenized by gently shaking and massaging. An aliquot of 2.5 mL homogenate was aseptically transferred into a 50-mL conical tube. An aliquot of 22.5 mL Tetrathionate Broth was added and vortexed for 10 sec. The tubes were placed at 35°C incubator for 18 to 24 h. The tube was vortexed for 5 to 10 sec and two loops of broth mix was aseptically transferred onto

Xylose-Lysine Tergitol 4 agar (XLT4) and streaked for isolation. XLT4 plates were incubated for 24 h at 35°C. If no black colonies were seen, the plates were incubated for additional 24 h (Total 48 h). The Presumptive Positive was red colonies with black centers, and black colonies were considered presumptive positive colonies of salmonellae.

The three presumptive positive colonies from the XLT4 plates were picked and biochemical and serological confirmation tests were performed.

3.5 Results and Discussion

For years, the researchers have studied the complex interaction among physical, chemical and biological aspects of composting. The controlled parameters are bulk density, porosity, particle size, nutrient content, C/N ratio, temperature, pH, moisture and the oxygen supply, has demonstrated the key for composting optimization since they determine the optimal condition for microbial development and organic matter degradation. The optimization of compost means to maintain enough amount of substrate initially in the compost and during the whole process of composting. Optimization cannot be generalized for all kind of substrate and management condition. The basic aspect of the composting has been summarized in the section. The factors affecting the composting process can be divided into two groups: those depending on the formulation of composting mix such as nutrient balance, pH, particle size, porosity and moisture and those dependent on the process management such as O_2 concentration, water content and temperature.

Firstly the operational indices like moisture content, pH, temperature, oxygen consumption, carbon dioxide evolution and other off-gases were evaluated during initial experimental runs in order to optimize the reactor design. Based on the observation of the results of the pioneer reactor, design modifications were carried out to optimize the operational parameters and enhance the efficiency of the reactor system. The observations of the operational indices with detailed review of each parameter are discussed below. Secondly the effectiveness of compost with regard to beneficial effects on soil physical, chemical and biological properties, as well as constituting a nutrient source, depends on the quality of the compost. The quality criteria for compost are established in terms of nutrient content, humified and stabilised OM, the maturity degree, the hygiene and the presence of certain toxic compounds, such as heavy metals, soluble salts and xenobiotics.

3.5.1 Aeration control

Prior to conducting optimization studies, several preliminary experiments were carried out to identify proper ranges of operating parameters. When the system was provided with only a negative air pressure, intermittent aeration, the oxygen concentration in the head space, dropped below 5% during the peak temperature range, which gave rise to obnoxious odors. A continuous aeration supplied more oxygen to the system and produced more CO_2, but it also cooled the matrix. When the aeration duty cycle was increased the cooling effect became so important that the temperature was lower than 45℃ in the initial days. It took longer for the temperature to reach 55°C or above. The proper range of aeration duty cycle was selected after repeated trial runs with uniform feed stocks. We know that agitation of composting content facilitates solid mixing and air–solid contact, but the draw backs are frequent wear and tear, increase in maintenance costs and break down of the system etc. The method of agitation with mechanical devices were excluded in present design in order to make it trouble free and sustainable system. Here in the final design, positive pressure aeration was provided with the help of a blower device to increase the movement of air through the composting matrix and negative pressure aeration was provided with a suction device, which creates a drop in pressure inside the chambers, to enhance the movement of air and at the same time removes the spent air out of the system. The integrated operation of a positive and negative aeration method drastically increased the air distribution through the compost matrix, characterized with high moisture content and less physical structure. To mention, no anaerobic pockets were observed and the spent air was able to be passed through a filtering system, for the purification of the exhaust gases. Morning 11.00 a.m. was chosen as the timing for food waste collection in order to make the breakfast composition of food waste as the standard feedstock material for repeated experiments. As observed in the literature, pre-characterized synthetic food wastes are widely used for the optimization studies, but in the present study, actual food waste with more or less uniform characteristics (cooked and non-cooked food wastes blended in equal proportions by weight) was used. The trial runs were carried out in batch modes, with 50 Kg of food waste as one time loading and the parameters evaluated are oxygen consumption, carbon dioxide evolution; temperature changes; and methane and ammonia gas emissions. The final design (Design V) was subjected to a detailed evaluation with real time food wastes loaded on daily bases.

Based on the temperature data obtained during the trial runs, the aeration duty cycle was divided into two main regions: the increasing temperature region and the decreasing temperature regions. The increasing temperature region is again divided into two zones based on the mesophilic and thermophilic stages of composting. Altogether the aeration process control system works on three duty cycles: Duty cycle I –Room temperature to 45 °C; Duty cycle II – 45 °C to 70 °C and Duty cycle III – 70 °C to room temperature. The final temperature range and duty cycle adopted in the present is given in Table no: 3.4. Linear regression was used on each of these data sets to determine an equation relating to aeration duty cycle to temperature. The novelty here is that the two chambers are controlled separately using temperature feedback method in order to synchronize the various stages of composting process during continuous feeding operation. Secondly, the system was maintained in an air tight condition and the suction device was switched on for 1 second prior to the blower device, which created a vacuum inside the chamber and found that the air distribution inside the compost matrix was efficient and uniform. There were no anaerobic pockets inside the compost matrix as observed from the oxygen consumption and carbon dioxide evolution studies.

Table 3.4: Temperature range and Duty cycle

	Temperature range	**Duty cycle**				**Process control and Set point**
		Blower on in seconds	**Blower off in seconds**	**Suction on in seconds**	**Suction off in seconds**	
I	Ambient – 45°C	4	600	3	600	**Temperature feedback 70°C**
II	45 – 70°C	3	900	2	900	
III	70°C – Ambient	2	1800	1	1800	

3.5.2 Moisture

Moisture in compost comes from either the initial feedstock or the metabolic water produced by microbial action (0.6-0.8 g/g), but, during aerobic composting, 1 g of organic matter releases about 25 kJ of heat energy, which is enough to vaporize 10.2 g of water (Finstein et al.,1986). This will be further coupled with losses due to aeration (Naylor, 1996), resulting in water loss during composting. Hence, moisture is an important factor to be controlled during composting as it influences the structural and thermal properties of the material, as well as the rate of biodegradation and metabolic process of the microbes.

The moisture content of compost should be 60% after organic wastes have been mixed. Depending on the components of the mixture, initial moisture content can range from 55%-70%.However, if this exceeds 60%, the structural strength of the compost deteriorates, oxygen movement is inhibited, and the process tends to be anaerobic. Low C:N ratio materials (e.g., meat wastes) putrefy when anaerobic, while high ratio materials ferment. Both these processes produce odor, leach nutrients, increase pathogens, and block air passages in the pile, hence they must be avoided. As the moisture content decreases below 50%, the rate of decomposition decreases rapidly. Excessive moisture in the compost will prevent O_2 diffusion to the organisms. Reduction in the moisture content below 30%-35% must be avoided since it causes a marked reduction in the microbiological activity. At moisture content under 20%, no biological processes are possible (Biliteueski et al., 1994). According to McGaughey et al. (1953) and Haug, (1980), were able to compost mixtures of vegetable trimmings at initial maximum moisture contents as high as 85% when using straw as bulking agent, and 76% when using paper. Fibrous or bulky material such as straw or wood chips can absorb relatively large quantities of water and still maintain their structural integrity and porosity (Haug, 1980).

Moisture can be controlled either directly by adding water or indirectly by changing the operating temperature or the aeration regime. Feedstock with different moisture holding capacities can be blended to achieve ideal moisture content.

In the final trial run 1 and 2 the initial moisture content was 73 and 75 percentage respectively (Fig.3.2). This was the minimum level attainable after adding the required amount of bulking agent, because, along with the moisture correction, carbon to nitrogen ratio was also a variable and optimization parameter in the calculation. In both the trial runs moisture decreased 62 % on the 7th day and with slight increase again dropped to 54 and 52 % on the 19th day respectively. This reduction in moisture content is due to the evaporation loss associated with increase in temperature as a result of metabolic activity. It was observed that the moisture level fluctuated between 50 and 60 % throughout the later stages of composting period. At the end of the composting process final moisture value were 58 and 53 % for trial run 1 and 2 respectively. Here in the study the moisture level was maintained above 50% in both the trial runs irrespective of their initial values by programmed intermittent recirculation of leachate back into the reactors which are interlinked. The excess leachate was wasted and utilized as fertilizer after dilution. It is understood that the periodic recirculation of leachate not only helped to maintain the optimum moisture level but also it activated the composting process by seeding the compost matrix with mature microbial flora.

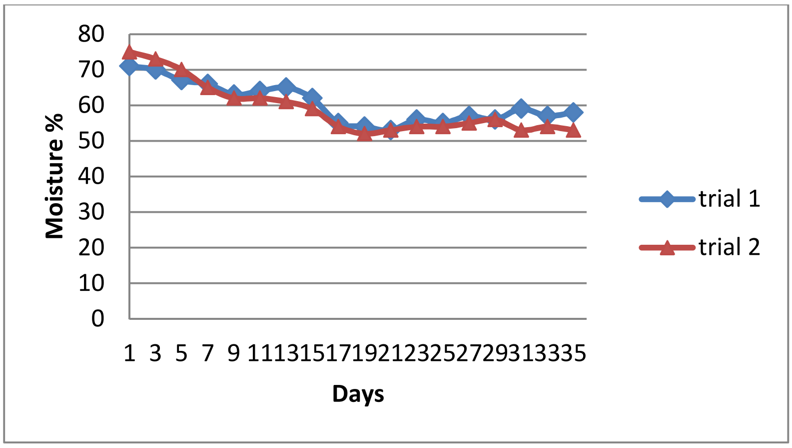


Figure 3.2: Moisture

3.5.3 pH

It is necessary to monitor the pH and maintain it between 6 and 7.5, which is an optimum range. It is well understood that during the process, this parameter undergoes considerable change from an initial pH of 5-6 due to the formation of carbon dioxide and organic acids. As the process progresses, the value will rise to 8-8.5, which is due to the decomposition of proteins and elimination of carbon dioxide. In a practical operation, very little evidence exists that pH should be artificially adjusted. The microorganisms that produce the acids can also utilize them as food after higher oxygen concentrations are established. This typically occurs within a few days after the most readily biodegradable substances have been destroyed. The net effect is that the pH begins to rise after a few days. The rise continues until a level of 7.5-9.0 is reached, and the mass becomes alkaline. Attempts to control pH with sulphur compounds are often difficult to justify because of the cost involved.

For optimum microbial activity during composting, a neutral to slightly alkaline pH range is ideal. Organic substrates offer a wide range of pH levels ranging from 3 to11 and this pH must be neutralized (Zucconi et al., 1986). Generally, the pH level drops at the beginning of the composting process as a result of the acids formed by the acid-forming bacteria which initialize the process by breaking down complex carbonaceous materials. The later break down of proteins and liberation of ammonia account for the subsequent rise in pH *(*Zucconi et al., 1986; Biliteueski et al. (1994). According to pace et al. (1995), the preferred range of pH is 6.5 to 8.0.

During the trial runs the average pH values of the food waste loaded on daily bases was between 6 and 7.2. This did not have any influence on the overall composting activity. With the increase in feedstock the pH started to gradually drop to 5.01 and 5.36 on the 11th day of composting respectively due to the formation of organic acids. After this the pH tends to move towards neutral again when these acids have been converted to carbon dioxide by the microbial action. This drop in pH value was observed for the days of loading due to daily addition of biodegradable organic waste, and then during the maturation phase, the pH subsequently rose and ended up with 6.8 and 6.7 respectively. The graphical representation is shown in figure 3.3 below.

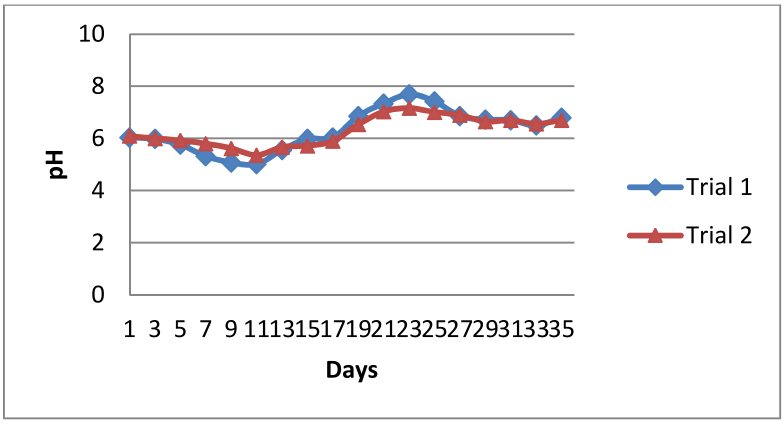


Figure 3.3: pH

3.5.4 Temperature

Temperature is one of the most important parameters of compost quality and reflects the microbial activity in composting process. Reaching the peak temperature is very important because the peak temperature of 50 °C- 60 °C causes further degradation of organic matter and destruction of all pathogens (Ko et al., 2008). Temperature is produced during the composting process, resulting from the breakdown of organic materials by microbes. The organisms in composting systems can be divided into three classes: Cryophiles or psychrophiles (0°C - 25 °C); mesophiles (25°C -45 °C); and thermophiles (>45°C). Cryophiles are found only during winter composting. The organisms that predominate in composting systems are mainly mesophiles and thermophiles each contributing at different times during the composting cycle. Temperature is also a good indicator of the various stages of the composting process. Based on microbial activity, the composting process can be divided into four different stages. The first stage is the mesophilic stage, where the predominant microbes are the mesophilic bacteria. The abundance of substrate at this time ensures that the microorganisms are very active, leading to the generation of large quantities of metabolic heat energy, which causes the temperature of the compost pile to increase. According to Burford, (1994); Finstein (1992) and McKinley et al. (1985), the microbial activity in the 35 to 45°C range is prodigious. As the temperature rises past 45°C, conditions are less favourable for the mesophilic bacteria and instead begin to favour the thermophilic bacteria. The resulting increased microbial activity of the thermophiles causes the temperature in the compost pile to rise to above 60°C. Eventually, with the depletion of the food sources, overall microbial activity decreases and the temperature falls resulting in a second mesophilic phase during the cooling stage. As the readily available microbial food supply is consumed, the temperature falls to ambient and the material enters the maturation stage. Microbial activity is low during this stage, which can last a few months. Thermophilic temperatures above 50 ^{o}C should be reached within a few days. Temperature above 60 ^{o}C- 65 ^{o}C should be prevented because the more sensitive microorganisms may be killed and the decomposition process may be slowed. Nevertheless, a continuing high temperature of 55 ^{o}C - 60 ^{o}C, lasting beyond 5 to 6 weeks, indicates an abnormally prolonged decomposition and a delayed transition to the stabilization stage (Zucconi et al., 1986).

A comparative temperature profile obtained during the experimental and trial runs are provided in Fig.3.4. This shows that the increase in temperature and its change in trend was evident, which can be directly correlated to the enhancement of the microbial degradation process as a result of design modification and change in process control strategy. The design I was a simple double walled composting system which was fitted with a cooling fan to facilitate air movement through the compost matrix. But this system did not work as expected and turned anaerobic within a short period of time, which was loaded with 20 Kg of food waste. There was no significant rise in temperature and this design was not included in the comparative study. The design II was a twin chambered double walled composting system which was integrated with a simple negative pressure aeration system. A quantity of 50 Kg of food waste was blended with 2.5 Kg of saw dust for adjusting the C/N ratio and moisture content and loaded into the reactor. The temperature profile of design II for 35 days composting period indicates that during the initial period a gradual temperature rise was observed from 28 ^{o}C to 48 ^{o}C on 15th day. This was the maximum temperature reached and was retained barely for one day. From 16th day onwards the temperature started to decrease indicating the decrease in microbial degradation. The initial delay in temperature rise was attributed to deficiency in aeration and air distribution throughout the compost matrix. There exited anaerobic pockets which was indicated by the detection of ammonia and methane gases, which are by products of aerobic microorganisms. The aim and goal set in the present research was to reach a maximum temperature of 65 ^{o}C and retain it to more than 5 days. The quick temperature rise will encourage thermophilic organisms there by the degradation rate will be increased which will in turn shorten the composting time. Temperature above 55°C for more than 5 days will deactivate all human pathogens if ever present. With this in mind the aeration system was redesigned and a highly integrated positive and negative aeration system was coupled with the reactor system. In the experimental run with design III the temperature rose from 27.5 °C to 49.5 °C within 8 days, which was the maximum achievable temperature. Temperature above 49 °C was maintained for three days. On 28th the temperature touched 31 °C and remained constant at 30 °C thereafter indicating the complete stabilization of the compost material. So the deficiency in design III was that the maximum temperature reached was only 49.5 °C and for one day. It was observed that there was temperature loss through convection and conduction. This was taken into account and a polyethene thermo insulator of 10 mm thickness was fixed on to the inner side of the reactor outer vessel including the lid. This thermo sealed design IV was subjected to experimental run with same characteristic blended food waste along with bulking agent as stated in the previous experimental runs. A drastic change was observed in the temperature profile, this time 65 °C was within in a short period of 6 days and the maximum temperature of 66.4 °C was reached on the 8th day of composting. Temperature above 60 °C was maintained for more than 6 days which was sufficient for the deactivation of all human pathogens, as per table. The overall processing time was 29 days. When design IV was subjected to daily loading of waste as a result of continuous operation study, the expected temperature rise and overall stabilization time was not achieved. This was due to less organic matter inside the vessel in the initial days as the food waste of 2-3 Kg was loaded on daily bases. Secondly the already fixed aeration duty cycle has to be fine-tuned in order to further optimize the microbial degradation as well as to see that the ambient air which is entering into the vessel has less cooling effect. So there was a need to perfect or regulate the running time of blower and suction device. This was achieved by replacing the analog control unit with a PLC unit, were the aeration was controlled with a temperature feedback mechanism. This final prototype (design V) with a PLC temperature feedback system was subjected to real-time field condition studies.

Two consecutive trial runs were carried out in which the compost temperature increased from 28°C to 34.6°C and 33.6 °C on the 4th day, respectively. The temperature profile showed more or less same trend. In both the trial runs and gradually increased above 60°C on 16th day in both the runs. To mention in batch mode studies a temperature of 60 °C was reached within 8 days as against 16 days in continuous mode operation, this was due to less amount of feedstock present inside the vessel during the early loading stages as the food waste loaded was around 2 – 3 Kg's per day. The highest temperature remained for more than five days, which is sufficient to sterilize all the pathogenic microorganisms as stated in the international standards. Additionally, the high temperature will facilitates the metabolism of organic matter to shorten the composting time with enhanced maturity of the final compost. The temperature started to decrease from 21st day on wards in both the trial runs and reached 33.3°C and 30.2 °C on 35th day, respectively. The temperature remained constant thereafter but slightly elevated than the ambient temperature, for the rest of the days which indicates that the feedstock has been stabilized.

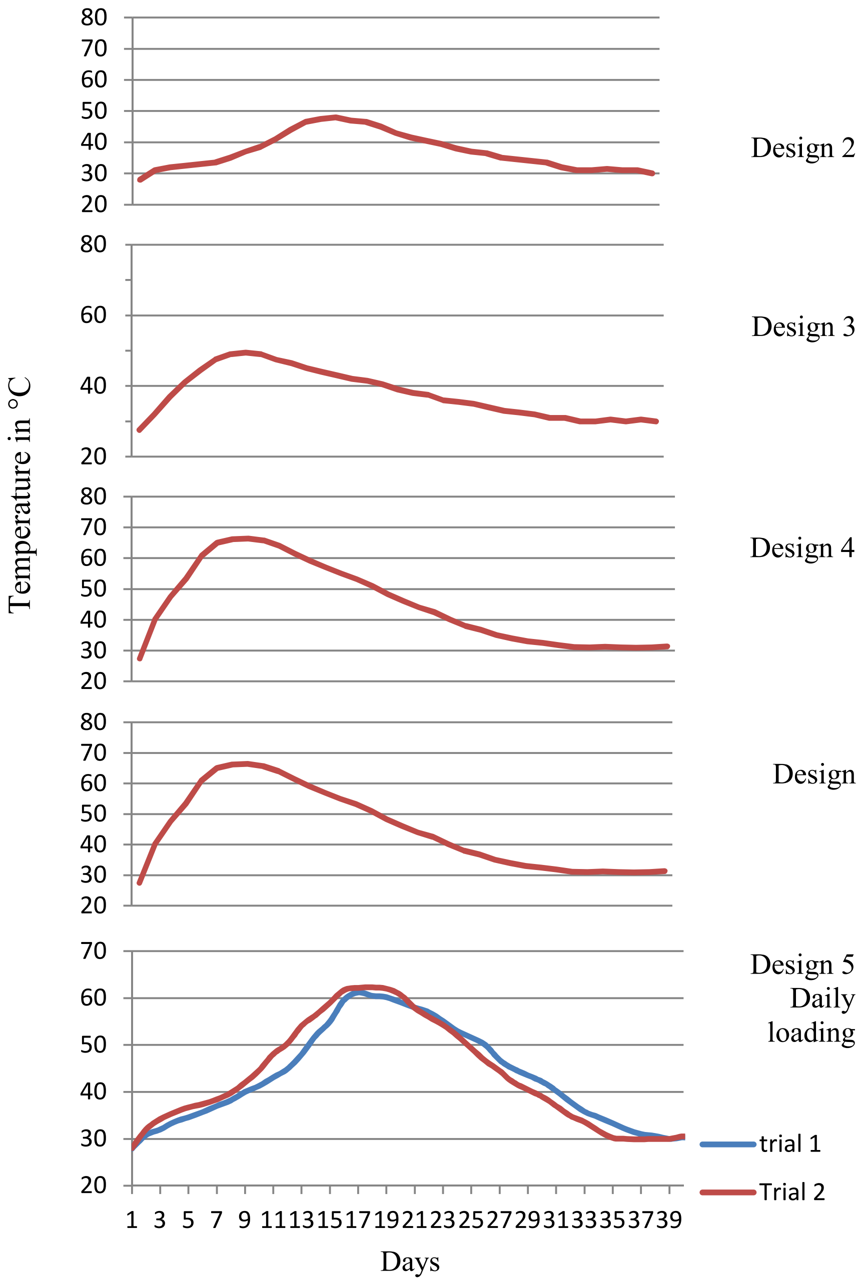


Figure 3.4: Temperature Profile

3.5.5 Maturity assessment

The organic portion of MSW has been always considered as a very rich source of organic compost having rich nutrient required for agriculture use but, the quality of compost is important from maturity and stability viewpoint. (Tiquia, 2005) which unfortunately in most of compost factories, proper attention is not paid (Heydarzadeh & Abdoli, (2009). The application of unstable and immature compost would fix nitrogen in the soil and restrict plant growth by competing for oxygen in the rhizosphere and releasing toxic substances (Bernal et al., 2009). There are few reports on compost maturity analyses using solid waste composts in developing countries and there are no standard procedures for determining compost maturity. Stability is not only an important compost quality characteristic but it can also be used for process performance monitoring and comparative evaluation of different composting systems (Gomez et al., 2006). The most common waste management strategy today is landfilling (Hogg et al., 2008), and it is expected to increase due to developing countries moving away from open dumping to engineered land filling. More importantly, there has been a movement to divert waste from landfills in order to reduce the negative environmental impact of landfills, such as leachate contamination, GHG emissions and space limitation (Norbu et al., 2005).

Compost maturity and stability are often used interchangeably. However, they each refer to specific properties of these materials. Stability refers to a specific stage or decomposition or state of organic matter during composting, which is related to the types of organic compounds remaining and the resultant biological activity in the material (CCQC, 2001). Maturity is the degree or level of completeness of composting and implies improved qualities resulting from 'ageing' or 'curing' of a product. Immature and poorly stabilized composts may pose a number of problems during storage, marketing and use. During storage these materials may develop anaerobic ''pockets" which can lead to odours and the development of toxic compounds. Continued active decomposition when these materials are added to soil or growth media may have negative impacts on plant growth due to a decreased supply of oxygen and/or available nitrogen or the presence of phytotoxic compounds. Maturity is not described by a single property and, therefore, maturity is best assessed by measuring two or more parameters of compost. A number of criteria and parameters have been proposed for testing compost maturity, although most of them refer to composts made from city refuse. Maturity parameters are based on different properties: physical, chemical and biological, including microbial activity.

Physical characteristics, such as colour, odour and temperature give a general idea of the decomposition stage reached, but give little information as regards the degree of maturation. Compost maturity can also be defined in terms of nitrification. When the Ammonia nitrogen (NH_4-N) concentration decreases and nitrate nitrogen (NO_3-N) appears in the composting material it is considered ready to be used as a Compost.A high level of NH4-N indicates unsterilized material, leading to establish a limit of 0.04% for mature city refuse compost.

An NH_4-N/NO_3-N ratio lower than 0.16 is denoted as a maturity index for composts of all origins (Finstein & Miller, 1985). The maturity of compost can be assessed by its microbial as the microbial biomass count and its metabolic activity, and by the concentration of easily biodegradable constituents. In aerobic conditions, one carbon atom derived from catabolism is attached to two oxygen atoms to form carbon dioxide, releasing energy, including heat, in the process. Therefore, respiration can be measured in several ways: carbon dioxide evolution, oxygen consumption and self-heating, which are indicative of the amount of degradable OM still present and which are related inversely to stabilization. Insufficiently mature compost has a strong demand for O_2 and high CO_2 production rates, due to intense development of microorganisms as a consequence of the abundance of easily biodegradable compounds in the raw material.

Compost maturity index is a very important parameter for compost production and application. Numerous maturity indices have been proposed, but no single method can be universally applied to all composts due to variation in feed stock and composting technology (He, et al., 1995). Respirometry, microbial activity, organic matter reduction and carbon to nitrogen ratio were investigated as compost maturity indices in this study.

3.5.5.1 **Respirometry:** In-Situ Oxygen Refresh Rate

Respirometry is the measurement of CO_2 evolved or O_2 consumed by heterotrophic microorganisms within the compost and provides an estimate of biological activity of a composted material. Oxygen consumption during composting is influenced primarily by the rate of aerobic biological activity. Since aerobic activity is a function of compost stability, respiration rates are also related to compost stability.

Microorganisms utilize O_2 and generate CO_2 and water vapor during aerobic decomposition of organic matter. Microorganisms respire at high rates in biologically unstable compost and consume more oxygen and generate more carbon dioxide and water vapor than in more stable compost. During anaerobic decomposition of feedstock materials, CO_2 and CH_4 are generated. This test covers the indirect determination of microbial activity in compost by measuring respiration rates in a compost sample. It is used as an indicator of compost stability. Refresh rate is considered excellent if pile O_2 does not fall below 5 % within two hours. If pile O_2 falls under 2 % in thirty min, then odor events are likely. A higher minimum O_2 reading may be appropriate for feedstocks that are predisposed to produce odor like food waste. Here, the aeration duty cycle was programmed based on the in-situ oxygen refresh rate of fresh feed stock; mesophilic; thermophilic; post mesophiic and stabilized stages of composting respectively. The aim was to maintain an oxygen concentration of 12 %, which was achieved. As a requirement for compost maturity test, in-situ oxygen refresh rate was carried out on the stabilized compost material obtained from the finished compost of trial run 1 & 2. The results are represented in Fig. 3.5. It was observed that the oxygen concentration in trial 1 & 2 decreased from 19.8 % and 19.7 % to 15.2 and 12.8 respectively during the two hour, ten min interval observation. This clearly indicate that there is little microbial activity as there is less demand for oxygen as compared against the oxygen demand of fresh feedstock which decreased from 19.55 to 4.6 % within 50 min. There was slight variation in the oxygen demand between the trial runs which may be due to variation in feedstock characteristics as the experiments were conducted as on field condition. The variation in moisture content, C/N ratio, organic content etc., of the initial feedstock has an impact on the rate of microbial degradability and the time taken for stabilization. But the values are below the standard value recommended for finished compost.

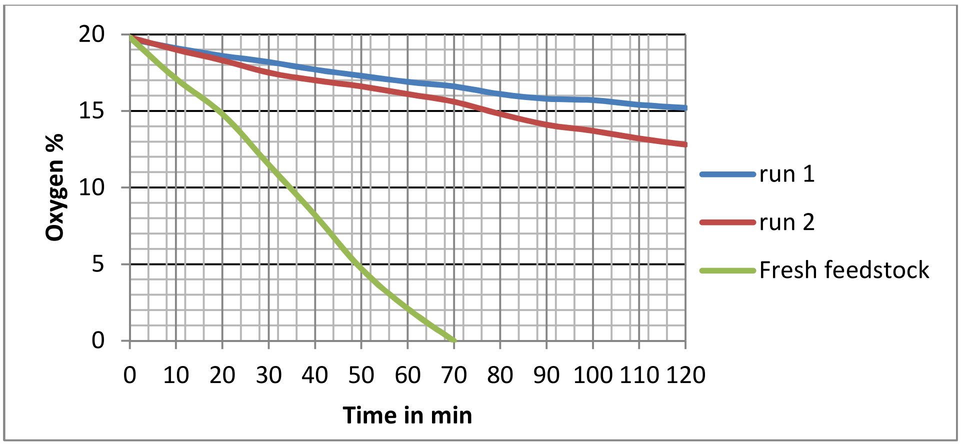


Figure 3.5: In-situ oxygen refresh rate

3.5.5.2 Dewar self-heating test

The test was first introduced in Europe in 1982 by Jourdan and recently re-evaluated. Numerous workers have reported investigations on compost maturity and the heating traits of composts. The Dewar self-heating method was adopted as an official standard for stability by the German Department of the Environment in 1984 as a follow up to the 1982 Sewage Sludge Order (TMCC, 2002).

The self-heating test based on Dewar flask measurement has merit as a general technique to evaluate compost stability and maturity, provided general conditions of the test and the specific equipment are applied. The method may be utilized by producers under field conditions where a relatively stable room temperature of 20-25 °C (but not more than 25 °C) can be maintained around the vessel. The Dewar test integrates a number of factors present in normal composts and can reflect well with field observations about the stability status of compost. It does not provide the same type of data as the more precise laboratory respirometrty procedures, but, like all respiration methods, (Dewar self-heating, CO_2-evolution, O_2 consumption), it gives a relative indication of the biological activity status of the compost as it pertains to biological stability.

In the present study a Dewar flask was custom made by modifying a wide mouth stainless steel vacuum flask. A 30 cm thermometer probe was used and inserted from the top through the lid by boring a 1mm hole. As per the standard method for a bulk density of 356 Kg/m^3 approximately 600 grams of finished compost was taken with moisture level adjusted to 25 – 30 % and loaded into the reactor as per the procedure mentioned in the methodology chapter. Daily rise in temperature of the sample was noted along with the ambient temperature. The results are tabulated in the following table 3.5.

Table 3.5: Self heating test – trial run 1

TERM	FLASK Temp °C	AMBIENT Temp °C	NET RISE in °C (Flask – Ambient)
Day 0	24	24	0
Day 1	26	23	3
Day 2	29	24	5
Day 3	30	24	6
Day 4	28	25	3
Day 5	27	24	3

The lab was air-conditioned and the temperature was maintained between 20 and 25 °C, throughout the experiment. At the start of the experiment the flask temperature and ambient temperature was equilibrated to 24 °C, Gradual increase in temperature was noted on daily bases and the maximum temperature of 30 °C was reached on the third day. The temperature started to decrease from the fourth day onwards and ended with 27 °C on fifth day when the experiment was stopped**.** The net – rise in temperature calculated on the maximum temperature was 6 °C. This value was compared with the reference table of original 1988 German Compost Association Index (GCAI) from Dewar is given in table. 3.3. Here the net rise in temperature was 6 °C, which was in the range of 0 – 10 °C and falls in the category no: V which is interpreted as mature compost.

Table 3.6: Self heating test – trial run 2

TERM	**FLASK Temp** °C	**AMBIENT Temp** °C	**NET RISE In** °C **(Flask – Ambient)**
Day 0	23	23	0
Day 1	24	24	0
Day 2	26	24	2
Day 3	29	24	5
Day 4	28	25	3
Day 5	27	24	3

In trial run 2 (Table. 3.6) the maximum temperature of 29 °C was reached on the third day and with an ambient temperature of 24 °C on the same day, the net rise in temperature was 5 ^{o}C. As the net rise in temperature was below the 10 ^{o}C, which is interpreted as mature compost. There was no much difference between the two consecutive trial runs experimented with actual field condition food wastes. This proves the consistency in operation of the novel reactor system.

3.5.5.3 Microbial activity

The importance of microbial communities (bacteria, actinomycetes and fungi) take part in the composting process is well established. However, the microbial diversity during the composting process may vary with the variety of composting materials and nutrient supplements hence it is necessary to study the diversity of microorganisms involved in the composting process (Chandna et al., 2013).

In a satisfactory composting process, microbial diversity is a prerequisite. A wide variety of mesophilic, thermo tolerant and thermophilic aerobic microorganisms are involved in the composting process. Distinct microbiological features provide information on the stability and maturity of composted materials, because decomposition and microbial activity are linked (Boulter et al., 2000). Total microbial activity is a good general measure of organic matter turnover in natural habitats, because more than 90% of the energy flows through the microbial decomposers. There are many criteria for determining overall microbial activity in compost; for example, respiration, enzyme activity and heat evolution determined by microcalorimetry (Johan Schnurer et al., 1982). An understanding of the dynamics of the microbial community would therefore be useful as part of an attempt to improve the efficiency of composting. Studying the nature of microbial succession via in vitro cultivation of species present can lead to misinterpretation of diversity (Yumei et al. 2013).

The species which dominate the composting process releases a range of hydrolytic enzymes (in particular, cellulases, hemicellulases, proteases, lipases, phosphatasesand arlylsulphatases) which act to de-polymerase various organic waste constituents. Thus activities of the key microbial enzymes involved in composting were characterized to gain information that relevant to control of the process (Yumei et al., 2013). The biochemical reactions involved in the compost are catalyzed by enzymes, which are specific to the type of reaction and they are specific for a given substrate. These enzymes may be studied indirectly through their activity. The study of enzymes revealed their role in evolution and in the degradation of organic matter. Measurements of enzyme activities are considered as potential measurements and they can be useful for the monitoring of soil characteristics (after damage or use). A technique suitable for measuring total microbial activity must be nonspecific and sensitive (Moran et al., 2004). Tests based on microbial activity such as enzyme assays are valuable methods for determining activity and maturity in compost. The biases involved in culturing of microbes are eliminated by these tests. Enzyme assays has been used to determine microbial composition changes during composting by describing functional and physiological diversity and structure in communities (Boulter et al., 2002). The measurement of dehydrogenase activity gives information on the overall metabolic activity of micro-organisms. Dehydrogenase activity is considered to be associated with the respiratory processes of microorganisms, and therefore more directly related to microbial activity.

As the enzyme activities are substrate-specific, a group of enzymes has to be measured in order to determine indices of microbial activity (Moran et al*.,* 2004).

Quantifying the enzymatic activity during composting can reflect the dynamics of the composting process in terms of the decomposition of organic matter and nitrogen transformations, and may provide information about the maturity of the composted product (Tiquia et al., 2002).

3.5.5.3.1 Dehydrogenase activity

The samples were taken and analyzed on weekly bases for a duration of $1\frac{1}{2}$ month which was beyond the composting peroid. This was done in order to ensure the maturity of the finished compost at the curing and storage stages.

A calibration curve was plotted based on the absorbance values obtained against a series of standard TPF. Concentration of compost as a result of catalysis of dehydrogenase was calculated in terms of TPF mg/ml, from which the Activity of dehydrogenase (mg of TPF released g^{-1} of air dried compost 24 h^{-1}) was calculated. The absorbance vs concentration for TPF standard is provided in Table no.3.7 and the corresponding calibration curve is represented in Fig. 3.6 (a)

Table 3.7: Dehydrogenase calibration Table

Concentration (in TPF mg ml^{-1})	Absorbance (at 485 nm)
0	0
0.5	0.201
1	0.462
5	0.755
10	1.067
20	1.294
25	1.505

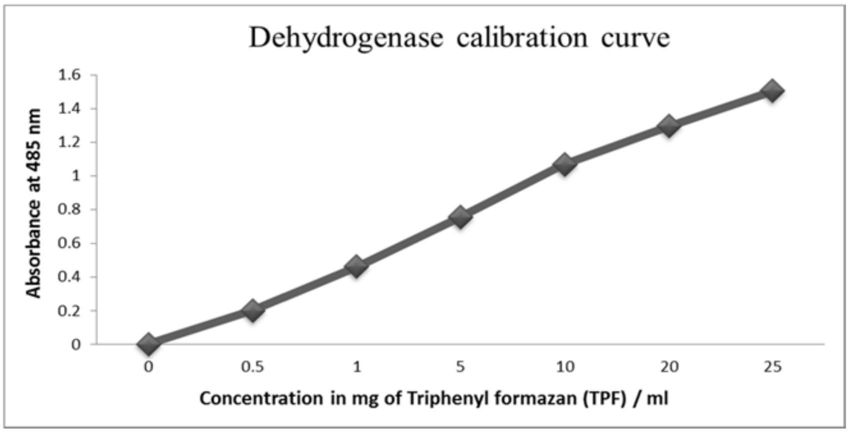


Figure 3.6 (a): TPF calibration curve

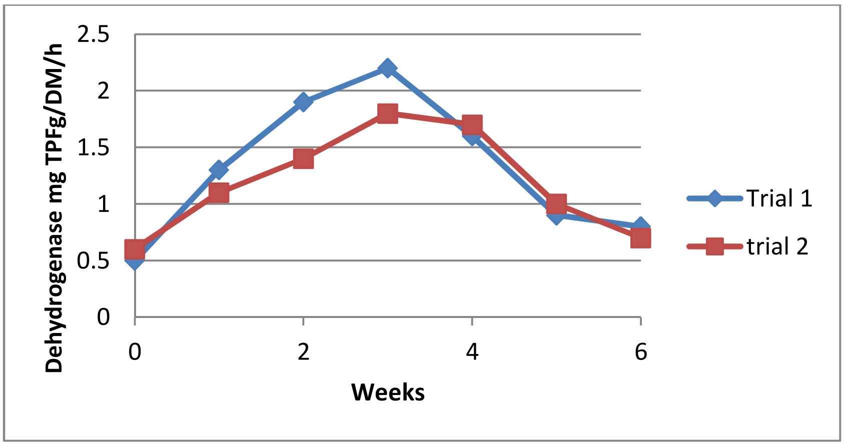


Figure 3.6 (b): Dehydrogenases activity

Dehydrogenase activity has been confirmed as a measure of total microbial activity in composts and has been suggested as an indicator of OM stabilization because it is involved in the respiratory chain (Garcia et al., 2010; Saviozzi et al., 2004). Significant fluctuations were observed in the dehydrogenase activities between the trial runs. At the early stages of the process, both trial run 1 & 2 showed high dehydrogenase activities. However, high variation was observed in this activity in the following period. It appears that the variation in feedstock and bulking agent which was added on daily bases caused variation in dehydrogenase activity profiles among the mixtures. Dehydrogenase activity was at the highest level in the thermophilic phase of the experiments. The highest dehydrogenase activity of 2.2 mg TPF g^{-1} DM d^{-1} was recorded in trial run 1 at the 20th day when compared with 1.8 mg TPF g^{-1} DM d^{-1} recorded in trial 2 at the 19th day of composting. The rapid increase in dehydrogenase activity in the initial stages of composting was caused by oxidation of available organic compounds catalyzed by this enzyme (Garcia et al., 2010). The dynamics of dehydrogenase activity showed no significant variations after six weeks of composting (Fig.3.6 (b)), which illustrated exhaustion of readily degradable sources of carbon and energy for microorganisms, consequently indicating compost maturity (Benitez et al., 1999). Similar findings were reported in a study by Tiquia et al. (2002), who stated that at the initial stages of the composting process, the activity of dehydrogenase reached the maximum level, decreasing as the process progressed. Similar observations were made by Barrena et al. (2008) during composting of organic fractions of municipal solid waste. Castaldi et al. (2008) reported that dehydrogenase activity increased significantly during the initial stages of composting of municipal solid wastes with plant waste, and proposed the evolution of enzymatic activities during composting as indicators of the OM stabilization.

The final value of 0.28–0.5.2 mg TPF g^{-1} DM d^{-1} in this study strongly indicates that the in-vessel composting system achieved a good degree of stability. The results of this study indicated that the food waste composts were close to, or even at, maturity, as no significant changes in dehydrogenase activity was observed at the end of one and a half month.

3.5.5.3.2 Fluorescein diacetate (FDA) hydrolysis

Recent studies on compost science have used the FDA assay to study compost microbial properties. Hydrolysis of fluorescein diacetate is performed by a variety of enzymes including esterase, proteases, and lipases. Recent studies on composting have successfully correlated enzymatic activity with respiration activity (Komilis et al., 2011; Ntougias et al., 2006). According to Diaz-Burgos et al. (1993), the maturation phase and the dynamics of substrate decomposition were better indicated by hydrolytic enzyme activities. In addition, this parameter has recently been proposed as an indicator of the progress of the composting process (Benitez et al., 1999). The absorbance vs concentration for Fluorescein standard is provided in table.3.8 and the calibration curve is represented in Fig.3.7 (a).

Both trial runs showed a parallel FDA evolution throughout the process, as observed in Fig.3.7 (b), at the initial stages of the composting process, FDA hydrolytic activity showed very low values, ranging between 80 and 100 μg FDA g DM^{-1} h^{-1}. These values increased significantly with composting time at the end of the thermophilic phase, with fluorescein production rates ranging between 420 and 580 µg FDA g DM^{-1} h^{-1}. According to Diaz-Burgos et al. (1993), hydrolysis is mostly involved in the early phases of the composting process because of the large amount of available organic matter. The slight increase in FDA activity was observed between 2 and 3 weeks in trial run 1 and 2 respectively. Zambrano et al. (2010) reported that a progressive decrease in FDA hydrolytic activity toward the end of the composting process, probably due to insufficient nutrients, indicates stability. The results of our study are in agreement with those reported by Ntougias et al. (2006), who observed an increase in FDA activity during composting of agricultural residues. However, these results are contrary to the results by Saviozzi et al. (2004), who reported that FDA showed uniform values during composting of urban wastes and could not be considered a good indicator of compost stability. Here the FDA activity progressively decreased to 56 and 48 µg FDA g DM^{-1} h^{-1} in trial 1 and 2, respectively.

Table 3.8: Absorbance vs. concentration (Fluorescein)

Concentration (in fluorescein µg ml^{-1})	**Absorbance (at 490 nm)**
0	0
1	0.131
2	0.274
3	0.403
4	0.541
5	0.672

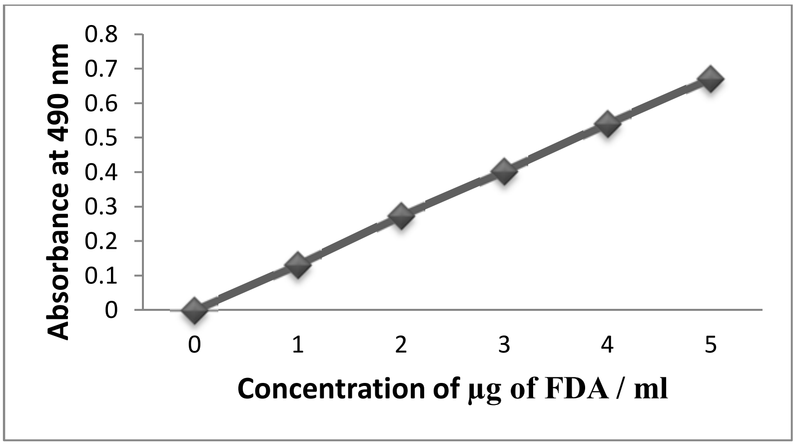


Figure 3.7 (a): FDA calibration curve

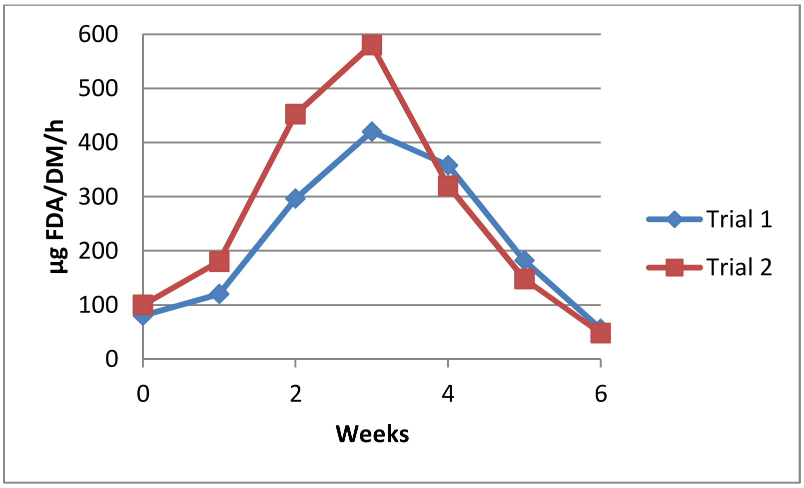


Figure 3.7 (b): FDA Activity

3.5.5.4 Organic matter (OM)

Organic matter is composed of organic compounds that have come from the remains of once living organisms such as plants and animals and their waste products in the environment. Basic structures are created from cellulose, tannin, cetin and lignin along with other various proteins, lipids, and sugars. It is very important in the movement of nutrients in the environment and plays a role in water retention on the surface of the planet. Organic matter is an important reservoir of carbon and a dynamic component of soil and the carbon cycle. It impacts the physical, chemical and biological properties of soil. Addition of organic matter to soil alters its physical characteristics by plant available soil retention, infiltration, drainage and aeration. Structural parameters are optimized for plant growth by lowering soil bulk density, increasing water holding capacity is enhanced by organic matter. Biologically, an enhanced soil organic matter fraction serves as a rich nutrient reservoir and energy source for beneficial microbes.

Organic matter test determinations will correspond to compost's stability status and aid in defining the commercial value of compost's stability status and aid in defining the commercial value of a compost relative to its organic matter content. Compost stability is related to the rate of OM mineralization (Lu et al., 2008). It is useful for purposes of composting to report the initial and final OM contents; as such reporting gives an idea of the extent of decomposition (Chazirakis et al., 2011). The OM content variation is shown in Fig.3.8. A significant reduction in OM content was observed during the composting because of the mineralization process. At the initial stage of composting process, the OM decreased from 2.36 % in trial run 1and 3.21% intial run 2 to 1 % and 1.24%, at the end of the process, respectively (Fig.15). The relative losses of OM were 57.63% and 61.37% for trial run1 and 2 after 5 weeks of composting. It appears that the change in moisture content of the piles during composting has a considerable effect on OM degradation, which indicates that microbial activity decreased by decreasing moisture content. Moreover, the highest temperatures were recorded during the thermophilic phase due to the higher microbial activity and OM decomposition. The variation between two trial runs was due to the variation in the feedstock composition as the trial runs were conducted on actual field conditions.

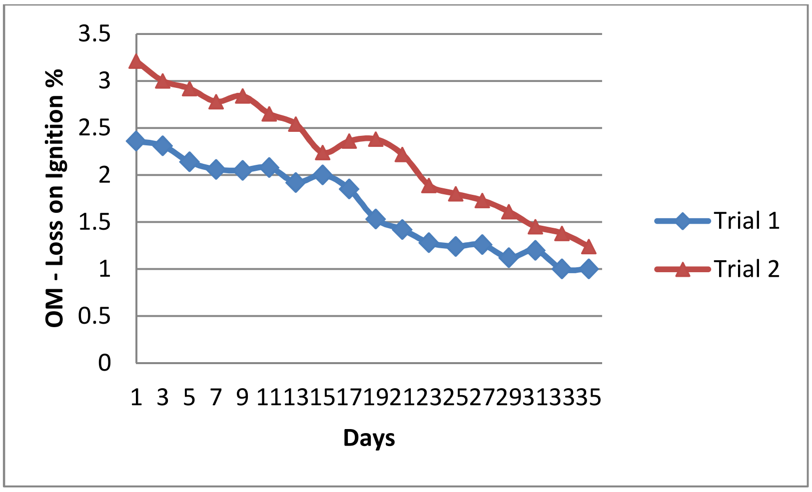


Figure 3.8: Organic Matter loss on ignition %

3.5.5.5 C/N ratio

The course of decomposition of organic matter is affected by the presence of carbon and nitrogen. The C/N ratio represents the relative proportion of the two elements. A material, for example, has 25 times as much carbon as nitrogen is said to have a C/N ratio of 25:1, or more simple, a C/N ratio of 25. Actually, the ratio of available carbon to available nitrogen is the important relationship because there may be some carbon present so resistant to biological attack that its presence is not significant.

Organisms that decompose organic matter use carbon as a source of energy and nitrogen for building cell structure. They need more carbon than nitrogen. If there is too much carbon, decomposition slows when the nitrogen is used up and some organisms die. Other organisms form new cell material using their stored nitrogen. In the process more carbon is burned. Thus the amount of carbon is reduced while nitrogen is recycled. Decomposition takes longer, however, when the initial C/N ratio is much above 30.

In the soil, using organic matter with excess carbon can create problems. To complete the nitrogen cycle and continue decomposition, the microbial cells will draw any available soil nitrogen in the proper proportion to make use of available carbon. This is known as "robbing" the soil of nitrogen, and delays availability of nitrogen as a fertilizer for growing plants until some later season when it is no longer being used in the life-cycles of soil bacteria.

When the energy source, carbon, is less than that required for converting available nitrogen into protein, organisms make full use of the available carbon and get rid of the excess nitrogen as ammonia. This release of ammonia to the atmosphere produces a loss of nitrogen_from the compost pile and should be kept to a minimum.

A C/N ratio of 20, where C and N are the available quantities, is the upper limit at which there is no danger of robbing the soil of nitrogen. If a considerable amount of carbon is in the form of lignin or other resistant materials, the actual C/N ratio could be larger than 20. The C/N ratio is a critical factor in composting to prevent both nitrogen robbing from the soil and conserving maximum nitrogen in the compost.

Since organisms use about 30 parts carbon for each part of nitrogen, an initial C/N (available quantity) ratio of 30 promotes rapid composting and would provide some nitrogen in an immediately available form in the finished compost. Researchers report optimum values from 20 to 31. A majority of investigators believe that for C/N ratios above 30 there will be little loss of nitrogen. University of California studies on materials with an initial C/N ratio varying from 20 to 78 and nitrogen contents varying from 0.52% to 1.74% indicate that initial C/N ratio of 30 to 35 was optimum. These reported optimum C/N ratios may include some carbon which was not available. Composting time increases with the C/N ratio above 30 to 40. If unavailable carbon is small, the C/N ratio can be reduced by bacteria to as low a value as 10. 14 to 20 are common values depending upon the original material from which the humus was formed. These studies showed that composting a material with a higher C/N ratio would not be harmful to the soil, however, because the remaining carbon is so slowly available that nitrogen robbery would not be significant.

Rate of decay and release of nutrients to the soil vary greatly. Likewise, demands of living soil microorganisms vary as they "break down" plant residue. Sawdust (made primarily of lignin and cellulose) uses vast amounts of energy to maintain the lives of microorganisms digesting it. A major product of plant decay is N while the undigested portion is primarily carbon (C). The optimum ratio in soil organic matter is about 10 C to 1 N, or a C/N ratio of 10:1.

The C/N ratio defines the nutritional balance and it is an important index for evaluating whether the compost has been thoroughly stabilized. It also acts as the energy source (degradable carbon) and N for their development activity. The C/N ratio range required for composting initially is 25-35 (Kumar et al., 2010) and since it is considered that the microorganism require 30 parts of C per unit N (Bishop et al., 1983). High C/N ratio makes the composting process slow as there is an excess of degradable substrate for the microorganisms to break down. But with low C/N ratio, there is an excess of N per degradable C and inorganic N is produced in excess and can be lost by ammonia volatilization or by leaching from the composting mass. Hence, initial C/N ratio is considered to be one of the most important factors influencing the compost quality. For completely decomposed compost the range should be from 16-20 (Elango et al., 2009). Successful studies have been carried out on the low initial C/N ratio by Kim et al. (2008); Ogunwande et al. (2008); Zhu et al. (2006); Huang et al. (2004); as it not only helps to increase the compost amount but also can increase the loss of nitrogen as ammonia gas. C/N correlates well with the degree to which composting is completed (Kim et al., 2008). A study was carried out by Li et al. (2012) by fixing C/N ratio at 15, 18 and 21 and the aim was to estimate the composting at low C/N ratio which would reduce the need of cornstalk used as bulking agent. Where at the end of the experiment, the germination index (GI) of all treatments with low C/N ratio of 15 was lower than 80%, consequently the mixture was not matured. The final content of NH_4^+ in the compost is still high and may be toxic for the root growing. Haung et al. (2004) had found the similar result after composting for 63 days at low C/N ratio. The condition also leads to the salinity of the compost. On the other hand, the treatment of C/N ratio of 18 and 21 were all matured, but then low C/N ratio can be corrected by adding bulking agent to provide degradable organic-C. The matured compost should ideally have a value of about 15 in order to avoid nitrogen immobilization when it is applied to soil (Erhart & Burian, 1997).

In the comparative evaluation of experimental results of 5 design modifications presented in Appendix IV shows that the initial C/N ratio values obtained after mixing food waste with sawdust was in the range 32.1–37.2:1, even though the ideal C/N ratio for composting is 15 – 30:1 as suggested by Haug, (1993), a higher C/N value was preferred in this study because of the presence lignin content in sawdust which will reduce the available carbon for microbial degradation.

Organic matter rich in nitrogen like food wastes are readily degradable by microorganisms than ones rich in carbon. The consumption of organic carbon by microorganisms liberates large amounts of CO2. The gradual decrease in carbon content in the feedstock results in a significant decrease of C/N ratio. Indeed, nitrogen fixed in microbial protein remains in the compost mass (except for any losses of ammonia release). The final C/N ratios obtained in the experimental runs of five design modification ranged between 29:1 and 21:1 respectively (Appendix IV). This difference was observed due to slight change in composition of the feedstock and related change in the initial C/N value.

In the final trial runs 1 and 2 the matured compost showed a C/N ratio of 21:1 and 24:1 respectively and therefore they are in the standard of maturity of compost cited by Hirai et al., 1983.

3.5.5.6 Conductivity

To evaluate the quality of final compost, electrical conductivity (Fig. 3.9) as a salt content index and heavy metal content of the final compost produce were analyzed. The electrical conductivity indicates the total salt content in compost that indicates whether the salt content may affect the quality of compost to be used as a fertilizer. Electrical conductivity measures the total soluble salts in the compost; higher electrical conductivity may indicate more nutrients. The conductivity at the start of the trial runs was 65 and 68 mV respectively. The electrical conductivity slightly increased in the initial stages of composting in both the trial runs which may be due to the release of decomposable compounds. It reached 120 mV on 19th day in trial run 1 and 119 mV in trial run 2. The hike was there for almost 4 days in both the trial runs with slight variation and then started to decrease due to the decrease in microbial activity and ended up at 82 and 80 mV respectively. Overall electrical conductivity was in the normal range.

After 35 days of composting, the stabilized organic manure was spread over a plastic sheet for curing. Later on, the manure was subjected for nutrient and heavy metal analysis. The analyses are compared with the quality standards prescribed by Department of Agriculture, Government of India and all the parameters were within the limits. The comparisons are represented in Appendix V.

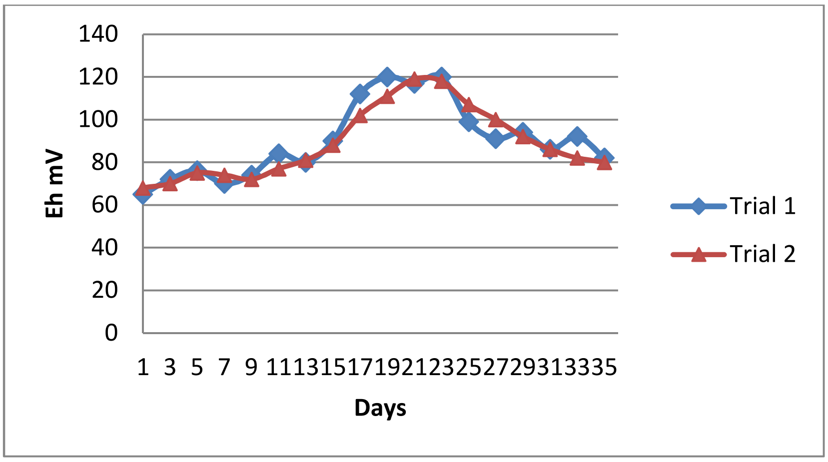


Figure 3.9: Conductivity

3.5.5.7 Pathogens

Pathogenic organisms, present in various organic materials, are a potential public health threat to site operators and compost users. Pathogens belong to four main groups: bacteria, viruses, parasites, and fungi. In composting, heat is the primary factor in pathogen inactivation. Thermophilic temperatures must be reached and maintained for adequate time to inactivate pathogens effectively. At the present study, microbial parameters including *Salmonella* and total and fecal coliforms were monitored during the composting process. The presence of coliform is often used as an indicator of the overall sanitary quality of soil and water environments. Use of an indicator such as coliforms, as opposed to the actual disease-causing organisms, is advantageous as the indicators generally occur at higher frequencies than the pathogens and are similar and safer to detect.

Total coliformsis a parameter to indicate the microbiological quality of water and food. Table 3.10 lists variations of total coliforms, fecal coliforms and salmonella in the compost subject to fermentation and the final compost are monitored using the multiple-tube fermentation method. Since food waste comes from a variety of sources with no sanitary facilities to store the material, the initial total coliforms were high. In this study with decrease in pH and increasing temperature during the initial stage of composting process the number of indicator organisms decreased. Stentiford, (1996) pointed that the compost temperature maintained between 55 and 65 ^{o}C would be sufficient for their total inactivation of pathogens. Lopez-Real and Foster (1985) also reported that only 3-4 days at 55 ^{o}C were enough for their total elimination. The compost temperature in this study reaches as high as 60 – 65 ^{o}C and maintained for 5 days which is sufficient to disinfect the compost.

One of the requirements of a commercial operation is to maximize the destruction of pathogens that may be present in the composting feedstock. Theoretically, if the feedstock does not contain manures or biosolids there should be few enteric pathogens. However, where composting operations allow disposable diapers and pet feces to be a part of their waste collection, this may not be the case. Other nonenteric pathogens can be found in meat scraps (*Trichinella spiralis*) and viruses of human origin (poliovirus) have also been found in refuse (Golueke, 1977). As the temperature rises in the composting process the pathogens are usually destroyed as they reach their thermal death points (Table 3.9). Viruses are killed in about 25 min at 70°C (Roediger, 1964). There is a relationship between temperature and time for pathogen kill. A high temperature for a short period of time may be just as effective as a lower temperature for longer duration (Haug, 1993).

The U.S. EPA in "Process to Further Reduce Pathogens" (Composting Council, 1993) established criteria for composts made with biosolids. According to the Federal Biosolids Technical Regulations, a windrow operation must reach a minimum temperature of 55°C for 15 days, with a minimum of five turnings. For an in-vessel or static pile system a minimum temperature of 55°C for 3 days is required. However, Hay, (1996) suggested that bacterial regrowth may be possible under certain conditions following composting. Haug, (1993) also indicated that a properly operated compost process should maintain an active population of non-pathogenic bacteria so as to prevent explosive regrowth of the pathogenic bacteria.

Table 3.9: Thermal Death points for some common pathogens and parasites

Organism	**50°c**	**55°c**	**60°c**
Salmonella thyphosa	_	30 min	20 min
Salmonella sp.	_	60 min	15-20 min
Shigella sp.	_	60 min	_
Escherichia coli	_	60 min	15-20 min
Streptococcus pyogenes	_	10 min	_
Mycobacterium diptheriae	_	45 min	_
Brucellus abortus or suis	_	60 min	3 min
Entamoeba histolytica (cysts)	_	1 sec	_
Trichinella spiralis	_	_	1 sec
Necator americanus	50 min	_	_
Ascaris lumbrigoides (ova)	_	60 min	_

Data based on Burford (1994); Finstein & Morris (1974); Glotass, (1956), Haug (1993); and Polprasert (1989)

The presence of E. coli and *Salmonella* spp. and the enumeration of indicator microorganisms (coliforms and fecal coliforms) were determined using standard bacteriological methods (TMECC, 2002). All the results reported in the text were the means of determinations made on three replicates and reported on a dry-weight basis.

The presence of *Salmonella* is considered as the major and specific problem of the hygienic quality of compost Yanko et al. (1995). This was probably because these bacteria are ubiquitous and have a capacity for very fast growth. The United States Environmental Protection Agency (US-EPA) imposes for Salmonella a rate of < 3 MPN/4 g total solids on a dry weight basis for safe application of compost in agriculture. Salmonellae come from food wastes, especially from meats, poultry, milk and its derivatives.

The analysis of indicator organisms during the experimental runs with design V indicates that the initial total coliform activity at room temperature was 740 MPN/g with no detection of fecal coliforms and E.coli. Presence of Salmonella species was observed. This low activity of indicator organisms in the feedstock was because the food waste contains equal amount of cooked and non-cooked items. The only chance of contamination is the non-cooked items like vegetable peelings. Secondly as the food wastes were directly collected from the source for experimentation, the chance of cross contamination is also less. It has been found that as the composting process is started and when the temperature started to increase, the total coliform number increased from 740 to more than 1100 MPN/g. and the existence of faecal coliform to the tune of 12 MPN/g and salmonella increased from less than 3 to 10 MPN/g. This may be due to ideal condition prevailing in the reactor as the temperature was in the range of 28 to 60 °C in the first week of composting. As the composting process progressed the temperature started to increase and entered into thermophilic stage of composting. During the second and third week the temperature was between 60 and 62 °C, which shows non-existence of any indicator organisms. The temperature above 55 °C was maintained for more than a 2 weeks and the maximum temperature reached was 65 °C on 21st day of composting. At the end of the composting process all the indicator organisms were inactivated and their reappearance did not take place even after 1 week of curing phase. This indicates that the finished compost obtained after the experimental run is stable. Microbiological examination were also performed on the finished compost obtained after two consecutive trial runs carried out on daily loading bases, showed absence of indicator organism.

Table 3.10: Variation of indicator organisms during the composting process

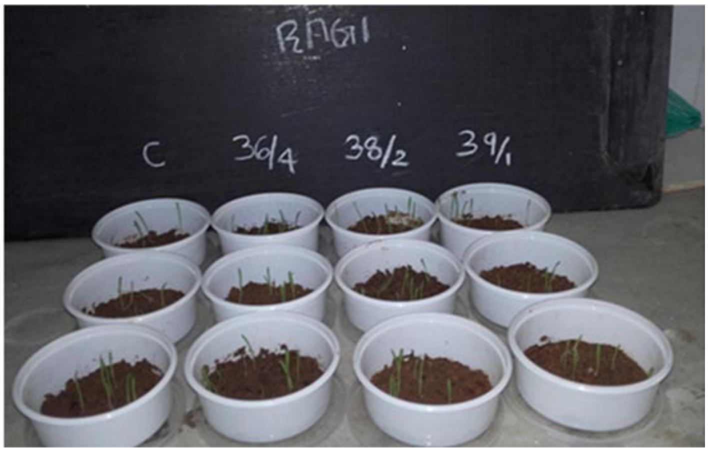
Weeks	**Temp °C**	**Total coliforms MPN/g**	**Fecal coliforms MPN/g**	**E. coli MPN/g**	**Salmonella MPN $(4g)^{-1}$ dw basis**
0	28	740	NIL	NIL	<3
1	60	1100	12	NIL	10
2	62	<3	NIL	NIL	NIL
3	50	NIL	NIL	NIL	NIL
4	38	NIL	NIL	NIL	NIL
5	32	NIL	NIL	NIL	NIL

3.5.5.8 Phytotoxicity tests

Although there are several parameters used in monitoring compost maturity such as temperature, oxygen uptake rate, NH_4/NO_3 ratio and C/N ratio among others, germination index is one of the most reliable methods used in quantifying compost maturity. Seed elongation test, which is a measure of phytotoxicity, has been considered as a reliable indirect quantification of compost maturity.

Phytotoxicity tests were conducted on Ragi (*Eleusinecorocana*) by growing the seeds on control soil substituted with 10%, 5% and 2.5% of finished compost respectively and for leachate bioassay test, 1:10 (w/v) compost extract was prepared, filtered and a concentration series of 6.25%, 12.5%, 25%, 50% and 100% was prepared using distilled water. The experiments are conducted and analyzed as per (208: Seedling Emergence and Seedling Growth Test as per OECD guidelines for the testing of chemicals) standard methods. Enhanced growth was observed in the shoot and root lengths at 5 % compost substitution and 25 % of leachate dilutions respectively. The photographs of phytotoxicity experimental setups are given in Fig. 3.9. (a) and (b). The graphical representations of the mean values are given in Fig. 3.10. (a),(b), (c) and (d).

a) Compost test - Ragi



b) Leachate test - Mustard

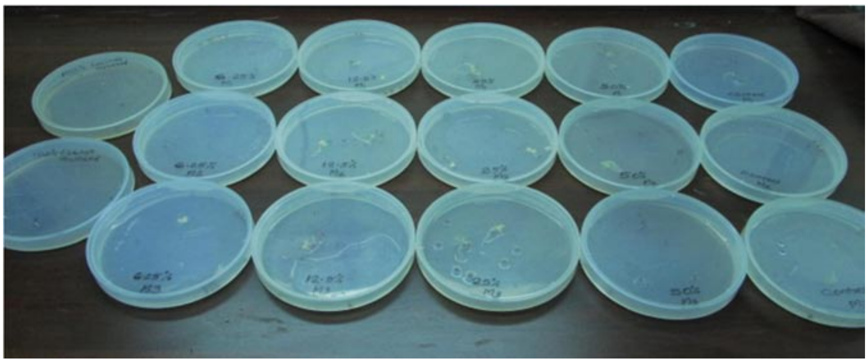
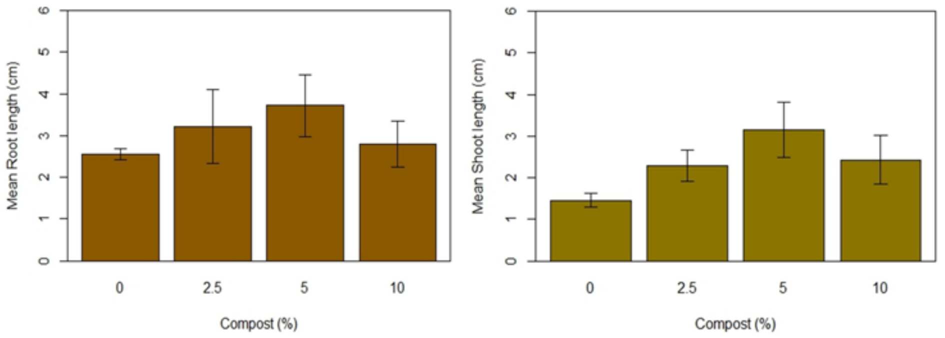
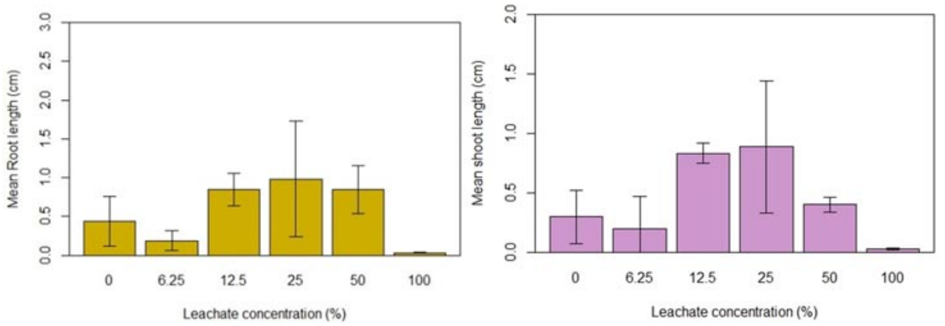


Figure 3.9: Photographs of phytotoxicity tests carried on (a) Ragi and (b) mustard



a) Ragi – root length

b) Ragi – shoot length



c) Mustard – root length (leachate)

d) Mustard – shoot length (leachate)

Figure 3.10: a, b, c, d, : Mean root and mean shoot length

Three way ANOVA OUTPUT

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
compost	3	6.385	2.128	4.598	0.00872
organ	1	0.067	0.067	0.145	0.70601
plant	1	24.724	24.724	53.415	2.62E-08
compost:organ	3	0.155	0.052	0.112	0.95265
compost:plant	3	4.806	1.602	3.461	0.02763
organ:plant	1	5.303	5.303	11.456	0.0019
compost:organ:plant	3	1.401	0.467	1.009	0.4016
Residuals	32	14.812	0.463		

Ragi Output

ANOVA TEST (Root)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
compost	3	2.378	0.7926	1.907	0.207
Residuals	8	3.325	0.4157		

No significant difference between the treatments. However, there was significant growth stimulation at 5 % compost as compared to control (student t- test)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
compost	3	2.378	0.7926	1.907	0.207
Residuals	8	3.325	0.4157		

t = 33.3873, df = 2, p-value = 0.0008959

ANOVA TEST (Shoot)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
factor (compost)	3	4.36	1.4534	5.991	0.0192
Residuals	8	1.941	0.2426		

Significant difference between the treatments were found with significant increase in shoot growth at 5 % compost mixture

TUKEY HSD

	diff	lwr	upr	p adj
2.5-0	0.833667	-0.45417	2.121499	0.240079
5-0	1.697222	0.40939	2.985054	0.012427
10-0	0.975	-0.31283	2.262832	0.149268
5-2.5	0.863556	-0.42428	2.151387	0.217591
10-2.5	0.141333	-1.1465	1.429165	0.984034
10-5	-0.72222	-2.01005	0.56561	0.341395

Mustard			
Leachate Data (Fitted using nonlinear regression method)			
		Estimate	**Std. Error**
Root	EC 50	63.055	43.646
Shoot	EC50	84.275	42.431

The estimate values are above EC 50 but the standard error was very high. Therefore further experiments have to conducted with more sample frequency and with accurate measurements and forms part of the future study.

3.5.5.9 Nutrient analysis

Chemical elements present in compost feed stocks can also influence the composting process, the quality of compost produced, and the general acceptance of the composting process. Although compost feed stocks must have Carbon and Nitrogen to provide the fundamental nutrients to the living organisms for the composting process, Phosphorus is also an essential element especially in composting MSW. Brown et al. (1998). Although feed stocks such as biosolids, yard debris, and agriculture wastes may have sufficient Phosphorus for effective composting. The quantities of Phosphorus (P) along with N and Potassium (K) present in the final material also are important in determining the quality of the compost product because they are the essential nutrients for plant growth. Although not as critical as the C/N ratio, a C: P ratio of 100-200 seems to be desirable (Howe & Coker, 1992; Mathur, 1991). Phosphorus composition and the C: P ratio can vary widely depending up on the source of the feed stocks.

Based up on the assumption that loss of C occurs during composting while P is not loss by volatilization or lixiviation, the percentage P in the compost would be expected to increase as composting proceeds. These effect have indeed seen noted (Chandler et al., 1980; Cooper band & Middleton, 1996; Grebus et al.,, 1994; Mato et al., 1994) resulting in compost containing 0.2-0.7% P (Canet & Pomares, 1995; Fricke & Vogtmann, 1994; He et al.,1995; Warman & Termeer, 1996).

Nutrient evaluation of the final stabilized compost was analyzed and compared with Indian standard values and reported in Table 3.11.

After 30 day of composting process, the stabilized organic manure was spread over a plastic sheet for curing. Later on, the manure was subjected for nutrient analysis. The nutrients analyzed were Phosphorus, Total nitrogen, and Potassium. Phosphorus was not deductible in the analysis and the literature says that food waste contain very little phosphorus or untraceable. Therefore the compost produced from food waste has to be enriched with necessary nutrients before application into soil. The values obtained were comparable with that of the ideal compost standard values proposed by Department of Agriculture government of India. In trial run 1 and 2 the total organic carbon (TOC) percentage was found to be in the higher side of 35 and 32 respectively. This validates the minimum requirement of 12 % TOC mandated in standards for urban compost in India. The reason for the presence of high amount of TOC in finished compost was due to addition of sawdust as bulking agent along with food and vegetable waste.

It has been known that metals cause a marked delay in germination, and that they can inhibit plant growth severely (Geckil, 2002). Normally, some organic contaminants such as ammonia and phenol disappear during the composting process, but most of heavy metals tend to remain in the end-product; this constitutes a very important problem from an environmental and agricultural standpoint. Consequently, it is necessary to evaluate the concentration and phytotoxic effects of heavy metals in compost. Heavy metals like Arsenic (as As2O3), Cadmium (as Cd), Chromium (as Cr), Copper (as Cu), Mercury (as Hg), Nickel (as Ni), Lead (as Pb), Zinc (as Zn) were analyzed and was found to be below detectable limit as the food waste was collected from the source.

Table 3.11: Compost quality evaluation

Parameters	City/Urban compost *	Matured compost Trial run 1	Mature compost Trial run 2
Moisture, per cent by weight, maximum	15.0- 25.0	30	32
Colour	Dark brown to black	Brown to black	Brown to black
Odour	Absence of foul odour	No foul smell	No foul smell
Particle Minimum 90% material should pass through 4.0 mm	Minimum 90% material should pass through 4.0 mm, IS sieve	-	-
Bulk density (g/cc)	<1.0	0.36	0.34
Total organic carbon per cent by weight, minimum	12.0	35	32
Total nitrogen (as N) per cent by weight, minimum	0.8	1.6	1.8
Total phosphates (as P2O5) per cent by weight, minimum	0.4	0.1	0.12
Total potash (as K2O) per cent by weight, minimum	0.4	0.5	0.3
C:N ratio	<20	21	24
pH (compost : water :: 1:2)	6.5-7.5	6.8	6.7
Conductivity (as dS m-1) not more than	4.0	3.2	3.8
Pathogens	Nil	Nil	Nil

*Quality Standards for City/Urban Compost as per FCO (2013) **Dept. of Agriculture Cooperation, Govt. of India**

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Chapter 4

CONCLUSIONS

4.1 Benefits of food waste composting

Food waste comprises the single largest component of the waste stream by weight in India. Food waste includes preparation waste and scraps, as well as uneaten food from households, commercial, institutions (i.e. school, cafeterias), and industrial sources such as food processors. Nationally, we spend cores of rupees each year to dispose of food waste. Restaurants, grocery stores, schools, pilgrimage centers, prisons, and other facilities can benefit in many ways from composting food scraps and leftover food, whether it is done on-site or at a compost facility. Food items such as spoiled fruits and vegetables, stale bakery items, kitchen prep trimmings, and leftover plate scrapings can be diverted from landfills and composted into a beneficial soil amendment.

Redistributing excess food be used as animal feed, followed by composting the inedible remainders, reduces garbage collection and disposal costs. By separating food waste, businesses can also make inventory of the excess food prepared and implement a variety of source reduction practices to ultimately lower expenses. Separating food waste from other types of waste also reduces issues associated with insects and vermin in or near dumpsters.

Controlled composting allows the safe storage and transport of the final product, adds value to the product because compost is a more concentrated and uniform product than the manure, permits easy spreading and thus uniform distribution in the soil and results in an absence of pathogens and weed seeds. The compost also can be used as fertilizer for pots and as a basis for soil-less substrates.

Composting of food waste should be seen as a technology which adds value, producing a high quality product for multiple agricultural uses. Certain chemical characteristics of the food waste are not adequate for composting and could limit the efficiency of the process: excess of moisture, low porosity, high N concentration for the organic-C, which gives a low C/N ratio, and in some cases high pH values. Thus, adequate composting management of the manure is required in order to obtain quality compost. Therefore, different aeration strategies, substrate conditioning-feedstock formulation, bulking agents and process control options have been used in manure composting in order to reduce composting time and costs and enhance the quality of the end-products. The addition of a bulking agent for waste composting optimizes substrate properties such as air space, moisture content, C/N ratio, particle density, pH and mechanical structure, affecting positively the decomposition rate. In this sense, lignocellulosic agricultural and forestry by products are commonly used as bulking agents in composting of nitrogen-rich wastes, such as food waste. The most generally used materials are cereal straw, hay and wood byproducts such as pine shavings, chestnut burr and leaves and sawdust, Barrington et al. (2002). Parades et al. (1996) used cotton waste as bulking agent. All have low moisture and high organic-C contents and high C/N ratios, which can compensate for the low values of the food waste.

Leftover food waste is mostly considered 'waste' and very less steps are taken to divert the resource in to renewable energy and good quality compost. Considering all the criteria, in-vessel composting is a very good solution to the current requirement as an environment friendly method. As in-vessel composting is a system that comprises a number of integrally related components including material amendment, recycling, handling, storage, mixing, reactor system, odour-control system, aeration system, exterior curing with storage facilities and marketing of produced compost. This technology offers a highly controlled, enclosed environment for effecting the biological decomposition needed to produce a high quality product and tend to be considerably less capital intensive than windrow technologies. In-vessel composting has advantages over the window system: it would require less space and provide better control than windrows. It has high processing efficiency. The process is aerobic, and hence the by-products are primarily CO_2 and water.

Management of MSW, especially FW, is a challenging operation in urban areas as its half-life is less than 6 hours. This implies that there is an urgent need to treat the highly putrifiable waste on-site employing an efficient and user friendly technology. In the present study, an appropriate in-vessel composting system could be developed to address the problem of management of food waste in urban areas. The results indicated that the system was efficient to compost food waste, and the composter developed could be designated as the prototype for commercialization. .

The composting of FW has been demonstrated to be an effective method for producing end products which are stabilized and sanitized, ensuring their maximum benefit for agriculture. The compost should be of high quality in order to guarantee its marketability. The following controllable factors influence food waste composting to a great extent:

1) The selection of appropriate bulking agents plays a vital role in controlling the decomposition rate and favoring nutrient retention within the compost.
2) In food waste with a low initial C/N ratio the degradable carbon exceeds inorganic nitrogen which leads to nitrogen loss by ammonia volatilization or by leaching. These can be corrected by adding suitable bulking agent with adequate degradable carbon.
3) The process control features of the composting system of in-vessel (moisture, temperature, aeration) have been shown to reduce ammonia volatilization and hence nitrogen losses, these being a major concern in MSW composting from an environmental point of view.

4) The agricultural value of a compost increases when the OM reaches a high level of stability and maturity, which cannot be established by a single parameter. Several indices based on chemical and stability parameters have to be used for manure compost.

5) The standardizations of the criteria for a matured state of compost of food waste should be adopted for better understanding of the compost of a particular region with particular type of climate.

6) The leachate produced in the compost of food waste can be re-circulated, collected safely and disposed properly through in-vessel composter .Thus probing it to be a better method to treat in and check the level of pollution it is causing to the environment.

4.2 Reactor performance

A comparison of the operational indices of the five stages of reactor development is shown in appendix IV. Each design modification was subjected to a uniform feedstock loading of 50 Kg of Blended FW with 2.5 Kg of saw dust. To maintain uniformity in the feedstock, the collection timing was streamlined to 11 a.m. every day and the food waste was physically blended with cooked and non-cooked items like vegetable peelings. It could be observed that there was an enhancement in the operational parameters after each developmental stage. The average room temperature was between 27°C to 29°C during the period of experimental runs which extended to more than 3 years. The starting C/N ratio was obtained within a range of 32:1 to 36:1, after mixing with proportionate sawdust which was a higher value for normal composting activity. It was interpreted from the literature that the presence of lignin content in saw dust and other plant parts will hinder the utilization of carbon by the microorganism to a great extent. Therefore, in the present study of bioavailable carbon in sawdust was understood to be less due to the presence of high amount of lignin and decided to maintain a higher initial C/N value, so that the actual available carbon for microbial degradation would be in proportion to that of nitrogen content. At the start, Design I and II was employed with a simple fan and negative pressure system respectively. The evolutions of off-gases were analyzed during each experimental runs in order to evaluate the aeration efficiency. In design I and II CH_4 and NH_3 were detected and was in the range between 3.2 to 3.6 and 1.8 to 10 ppm respectively, which indicated the presence of anaerobic pockets. In order to increase the efficiency of air distribution through the compost matrix an integrated positive and negative pressure aeration method was developed, which was coupled to the reactor system and named as design III. After enhancing the aeration method in design III no noxious gases were observed thereafter, which indicates the efficiency of the aeration system.

Another main constraint observed in the design and operation of the present reactor system was with reference to attaining a higher internal temperature retained for maximum number of days. This was aimed to encourage thermophilic organisms which were good degraders and to inactivate all pathogenic organisms if ever present. During the experimental runs, design III was able to attain a maximum temperature of 63 °C which could be retained only for 2 days. Therefor to enhance the reactor temperature and its retention a 10 mm Expanded Polystyrene (EPS) thermal insulation was provided on the inner walls and lids of the reactors. This design modification (Design IV) enhanced the reactor temperature to a maximum of 67 °C during the experimental runs and was able to maintain the peak range above 65°C for more than five days, which was sufficient enough for the destruction of all pathogenic microorganisms. Lastly, focus was given on the development of a better aeration control method which was observed to be necessary for increasing the efficiency of an in-vessel composting system with respect to the treatment of FW. To achieve this, conventional analog timer based aeration control method was replaced by a more reliable, flexible and efficient PLC controlled method in design IV. This improved the operation of the reactor system by automatic selection of preprogramed temperature range, based on temperature feedback mechanism. In the process of development of appropriate in-vessel composting system in the present study, design V was taken as the final model and was subjected to two trial runs with actual real-time food wastes loaded on daily bases in contrast to one time loading done during the experimental runs. Trial runs were carried out with real time food wastes in order to analyze the efficiency and field worthiness of the technology. During the trial runs 2.5 to 3.5 Kg of actual FW as on received condition was mixed with 100 to 150 grams of saw dust and loaded in to the reactor. Loading is done sequentially in the vessels and it takes 12 to 15 days for filling up of single vessel. In the prototype reactor system FW could be stabilised within 30 days on daily loading bases, then the compost is withdrawn and dried for 1 to 2 days. The final compost weighted approximately 11 kg which indicated a mass reduction of more than 80 %.

During the experimental trial runs, the process cycle completion time was found to be between 29 to 35 days on daily loading bases of 2.5 to 4 kg of FW. The reactor was intended to be used on daily loading bases, with the provision of two vessels, one for loading fresh FW and another for stabilization and vice versa. On an average 3 kg of FW was loaded per day and it took 14 to 18 days to fill up and then the loading was continued into the second vessel. Again after 14 to 18 days the second reactor was filled up, by that time the content in the first reactor was completely stabilized and was emptied for drying. Therefore to complete the process cycle it takes 29 to 37 days but the actual stabilization time is only 14 to 18 days. This result was substantiated during the experimental trial runs carried out during batch mode studies. 50 kg of FW was loaded into the vessel and the process parameters were monitored in real time mode on-site. The results indicate that the raw material got matured within 12 to 15 days. The final matured compost weighed around 11 kg, which showed a volume reduction of 80 % approximately. During continuous loading mode the minimum stabilization time was around 15 days and the matured compost withdrawal time depends on the amount and frequency of FW loading.

The results presented in this thesis are that of single reactor at a time because both the reactors are identical and undergo same process control strategy. A sequential photograph of composting activity carried out with the novel in-vessel composter is represented in Appendix VI.

The maintenance of optimal condition of three important parameters like oxygen, temperature and moisture are very crucial in any in-vessel composting system. Secondly a higher moisture level in the feed stock also effects the penetration of air into the compost matrix, there by affect the availability of oxygen in the interstitial space for microbial degradation. The experimental results indicated that temperature and in-situ oxygen concentration were successfully controlled via automatic programmed aeration and the periodic leachate recirculation and withdrawal helped to maintain optimum the moisture level.

While many different criteria can be used to measure compost maturity and quality, but those most widely accepted and easy to apply were adopted in the present study, namely organic matter reduction, decrease in carbon to nitrogen ratio, pathogen reduction, pH and phytotoxicity tests. All the quality parameters were within the limits, except phosphorus which was in very low concentration as the feedstock had limited quantity of phosphorus. There were small variations between the results of two trial runs as it was due to the variation in the composition of feedstock which is inevitable. The results of two consecutive trial run are compared with the standard prescribed by the department of agriculture, Government of India. The table is represented as appendix V.

The capital cost for the construction of the in-vessel composting system on commercial bases will be around ₹ 15,000/- to 20,000/- because the system was made using locally available material with local innovative technology. Regarding the operating cost it was kept at minimum as main objective was to construct an economically viable, technologically feasible and sustainable system. The power consumption of the composting system with 600 W blower and 450 W suction unit operated at 2 to 3 seconds on hourly bases, comes to around less than 1 unit per month. The only recurring cost involved is with regard to the usage of sawdust as bulking agent but this cost can be redeemed by the sale of finished compost and compost tea (leachate), which has high demand in the market.

The maturity of the final compost was again substantiated with dewar self-heating test. The temperature interpretation of the finished compost obtained after trial run 1 and 2 was well below 6 °C which falls under category No: V, which indicates that the compost is highly mature.

4.3 Salient features of the reactor system:

1) In-vessel composting technology proved to be an ideal method for composting food wastes with high moisture content at the regional/local setting.
2) Converts food wastes into manure within 15 to 30 days
3) Produces highly consistent end product.
4) 80 – 85% volume reduction is achieved
5) Less than 1 unit of power consumption per month
6) Microbial growth is enhanced by fuzzy logic temperature feedback aeration control method.

7) Maximum temperature of 67 °C is achieved and maintained for 4 to 5 days, which disinfects, especially reducing Gram negative bacteria in the compost.
8) Can be operated on all weather conditions in Kerala.
9) All types of kitchen wastes can be loaded.
10) Automatic process control with less human intervention.
11) No internal moving parts so less wear and tear.
12) No odor or leachate problem
13) Less area required for installation and operation.
14) Problems of fly breeding and rodents have been eliminated.
15) Simple operation and less maintenance required.
16) Encourages decentralized waste management at household level.
17) Constructed using locally available materials and indigenous technology.
18) Economically viable and sustainable technology.
19) Good quality compost produced.
20) Highly energy efficient.
21) Fully aerobic process.
22) Environment friendly technology.
23) Fully complies with three R’s concept.
24) Clean spent air with integrated air filtration.
25) Reduces synthetic fertilizer use and increases food security.
26) Good soil amendment and increases soil fertility.

4.4 Novel Features of the invention

1) Integrated twin chamber twin vessel system for passive and active composting.

2) Positive and Negative aeration system with unique temperature feedback control method for higher aeration efficiency.

3) Unique integrated air circulation method with two stage filtration for odour control and hygiene.

4) This in-vessel composting technology offers low operating costs due to low energy consumption, maintenance and labour costs; it has a small footprint and offers great flexibility as its modular design allows it to be easily modified. Optional solar power source can be hooked up to this system for independent operation.

5) During power failures for long duration, there is provision in the reactor system, for coupling air pumps which can be operated manually. This makes the system more sustainable in any adverse conditions.

4.5 Limitations

1) There are limitations in scaling up of the reactor system due to structural, technical and process limitations. But it can be scaled up to a maximum of 10 Kg of food waste on daily loading bases as far as the design configuration and operational parameters are maintained to the scale.

2) Continuous requirement of a particular bulking agent is a constrain for common man. Studies have been initiated in testing various readily available bulking agents for possible application in the composting process.

4.6 Future research:

1) Even though there was no emission of methane and ammonia gases during the final stages of composting experiments, the need for monitoring and evaluation volatile organic gaseslike sulphides, acids and alcohols are required for more understanding of the biochemical changes taking place during composting process and environmental impacts

2) The use of bulking agent is a continuous requirement for the operation of the present in-vessel composting system. Here in the present study, saw dust was used as the sole bulking agent. Further studies are required to test other materials, such as dried leaves, tea leaf waste, organic industrial wastes etc, as a source of carbon. Also detailed studies are required to know the available carbon in these bulking agents while considering the lignin and cellulosic contents.

3) Leachate management has to be studied in detail and new methods have to be evolved when the reactor system is scaled-up and operated on a commercial scale.

4) Another area of focus will be on the treatment and recycling of large quantity of food waste arising during festival seasons,

wedding ceremonies, meetings and gatherings etc., which municipalities find difficult to tackle. A laboratory rotating drum composter has developed and tested for the above said purpose.

5) Quantification of bio waste from different sources in a city needs to identify, in order to have a holistic approach towards the treatment and recycle of bio wastes from the city. A GIS based study for site selection and collection of bio waste from different sources like, apartments, cafeteria's, offices etc., has to be done.

The reactor system is ready for commercialization.

* * *

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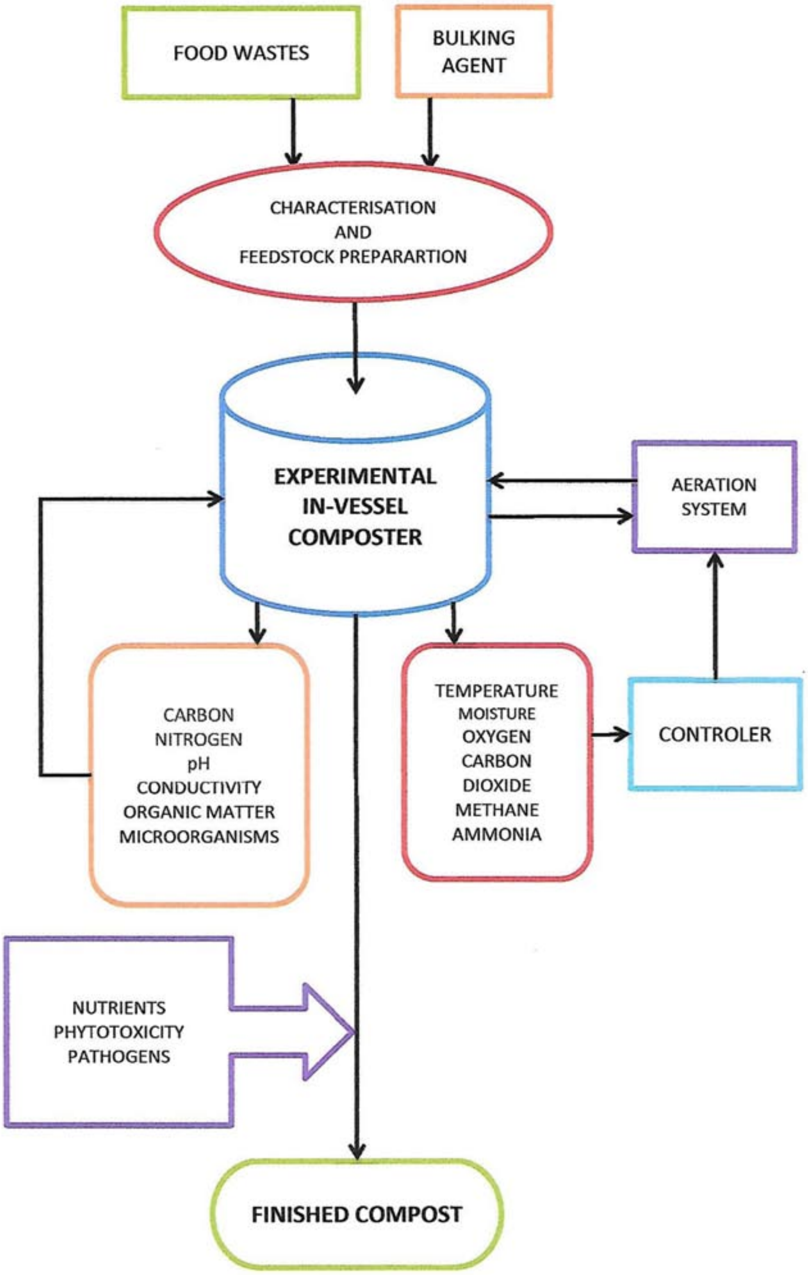
Appendices

Appendix I

Methodology Flow chart



Appendix II

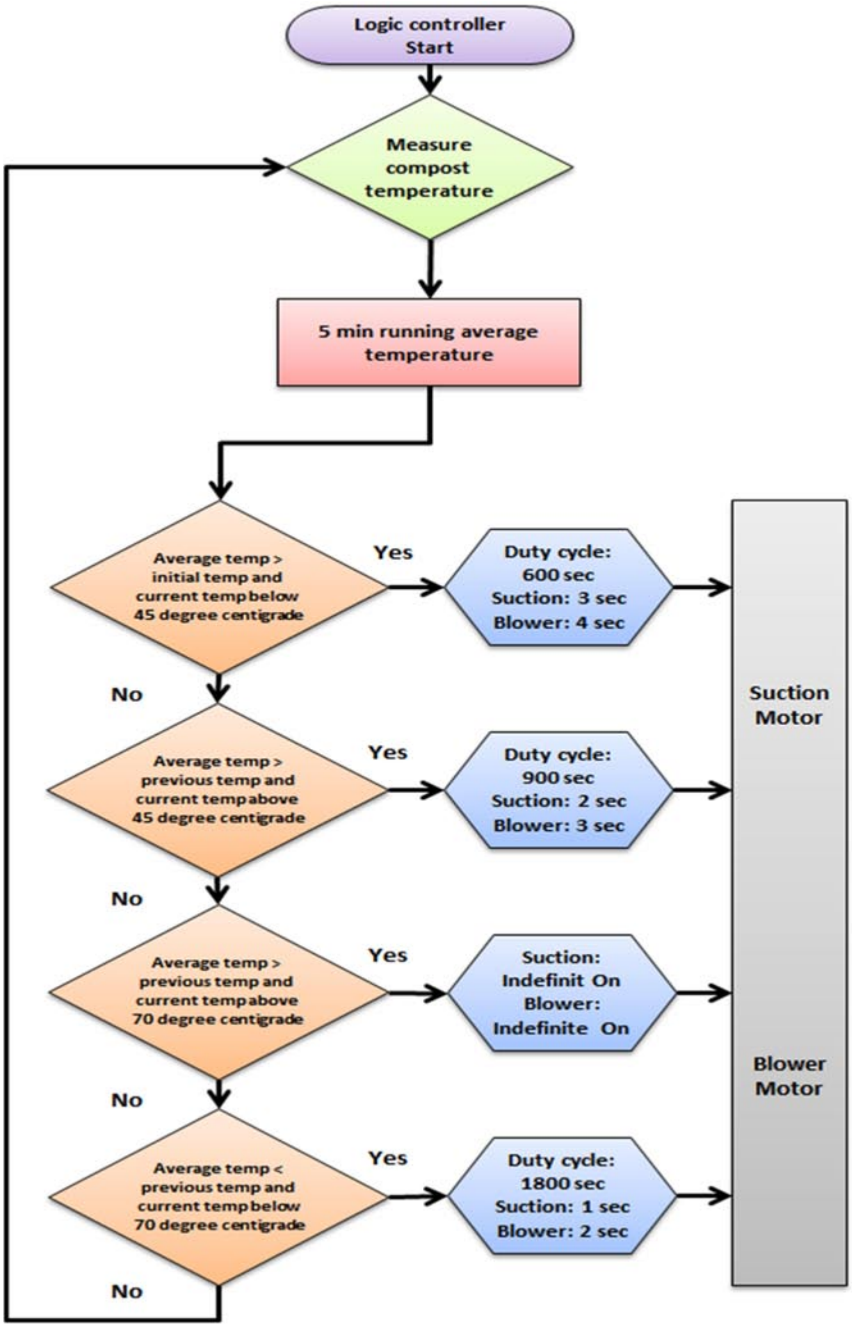
Items and Method of analyses for monitoring the composting process

Items	Method of analyses	Unit
Temperature	Direct measurement with an industrial digital thermometer/ gas analyzer/ RTD module	°C
Moisture	*TMECC 03.09-A	%
Electrical conductivity	*TMECC 04.10-A	dS/m
pH	*TMECC 04.11-A	
Organic carbon	*TMECC 04.01- A (CHN analyzer)	% g g^{-1}dw
Total nitrogen	*TMECC 04.02- D	% dw
C/N ratio	*TMECC 05.02-A	unit less
Oxygen	Gas analyzer (BIOGAS 5000)	Percentage
Carbon dioxide		Percentage
Methane		Percentage
Ammonia	Gas analyzer (UNIPHOS – 282 (PM))	ppm
Total phosphorus	*TMECC 04.03- A	% dw
Total Potassium	*TMECC 04.04- A	% dw
Organic matter	*TMECC 05.05- A	% g g^{-1}dw
Respirometry 1. In-Situ Oxygen Refresh Rate 2. Dewar Self-Heating Test	*TMECC 05.08 –C *TMECC 05.08-D	% O_2 hr^{-1}chart Δ°C
Enzyme activity 1. Dehydrogenases 2. FDA Hydrolysis	*TMECC 05.04-B (Schnurer et al., 1982)	mg g^{-1}dw 24 h^{-1}
Biological assays 1. Seedling Emergence and Seedling Growth Test.	*OECD - 208	% of control
Pathogens 1. Total Coliforms 2. Fecal Coliforms 3. E. Coli 4. Salmonella	*TMECC 7.01-A *TMECC 7.01-B *TMECC 7.02- B *TMECC 7.02-B/C	MPN g^{-1} MPN g^{-1} MPN g^{-1} MPN (4g)$^{-1}$dw basis

- TMECC - Test Methods for the Examination of Composting and Compost by US Composting council, 2002.
- OECD – Organization for Economic Co-operation and Development, Guideline for testing of chemicals, 2003.

Appendix III

Schematics of Linear temperature feedback method



Appendix IV

Tabulation of experimental results of Design I to V

Trial condition	**Design I**	**Design II**	**Design III**	**Design IV**	**Design V**
Feedstock in Kg	20	50	50	50	50
Bulking Agent in Kg	1	2.5	2.5	2.5	2.5
Room Temp in ^{o}C	29	28	27	27	28
pH	7.2	6.8	7.8	7.5	7.3
Initial C/N ratio	35:1	36:1	32:1	34:1	37.2
Initial Moisture %	70	65	64	66	68
Max Temp reached in ^{o}C	34	48	50	63	67
Max Temp retained in days	-	1	1	2	4
Time for stabilization in Days	-	35	33	29	30
Final C/N ratio	-	29:1	24:1	21:8	21:1
Final Moisture in %	-	62	58	54	58
Methane %	3.6	3.2	ND	ND	ND
Ammonia in ppm	10	1.8	ND	ND	ND
Aeration	Fan	Suction Motor	Blower and Suction	Blower and Suction	Blower and suction
Control	-	analog	analog	analog	Logic

Appendix V

Compost quality evaluation:

Parameters	City/Urban compost *	Matured compost Trial run 1	Mature compost Trial run 2
Moisture, per cent by weight, maximum	15.0- 25.0	30	32
Colour	Dark brown to black	Brown to black	Brown to black
Odour	Absence of foul odour	No foul smell	No foul smell
Particle Minimum 90% material should pass through 4.0 mm	Minimum 90% material should pass through 4.0 mm, IS sieve	-	-
Bulk density (g/cc)	<1.0	0.36	0.34
Total organic carbon per cent by weight, minimum	12.0	35	32
Total nitrogen (as N) per cent by weight, minimum	0.8	1.6	1.8
Total phosphates (as P2O5) per cent by weight, minimum	0.4	0.1	0.12
Total potash (as K2O) per cent by weight, minimum	0.4	0.5	0.3
C:N ratio	<20	21	24
pH (compost : water :: 1:2)	6.5-7.5	6.8	6.7
Conductivity (as dS m-1) not more than	4.0	3.2	3.8
Pathogens	Nil	Nil	Nil
Heavy metal content (as mg/kg), maximum	Arsenic (as As2O3) 10.0, Cadmium (as Cd) 5.0, Chromium (as Cr) 50.0, Copper (as Cu) 300.0, Mercury (as Hg) 0.15, Nickel (as Ni) 50.0, Lead (as Pb) 100.0, Zinc (as Zn) 1000.0	Nil	Nil

Appendix VI

Photograph of sequence of composting activity carried out with the novel in-vessel composter. The pictures are represented chronologically starting from number 1 to 12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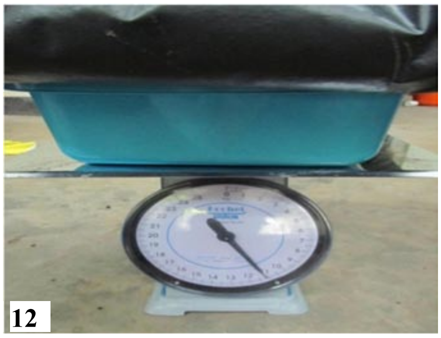

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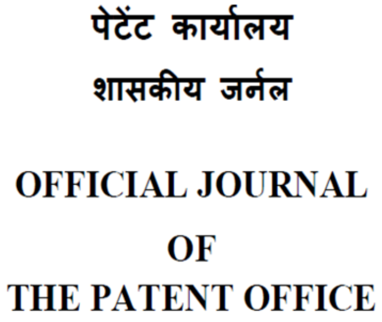
Citations



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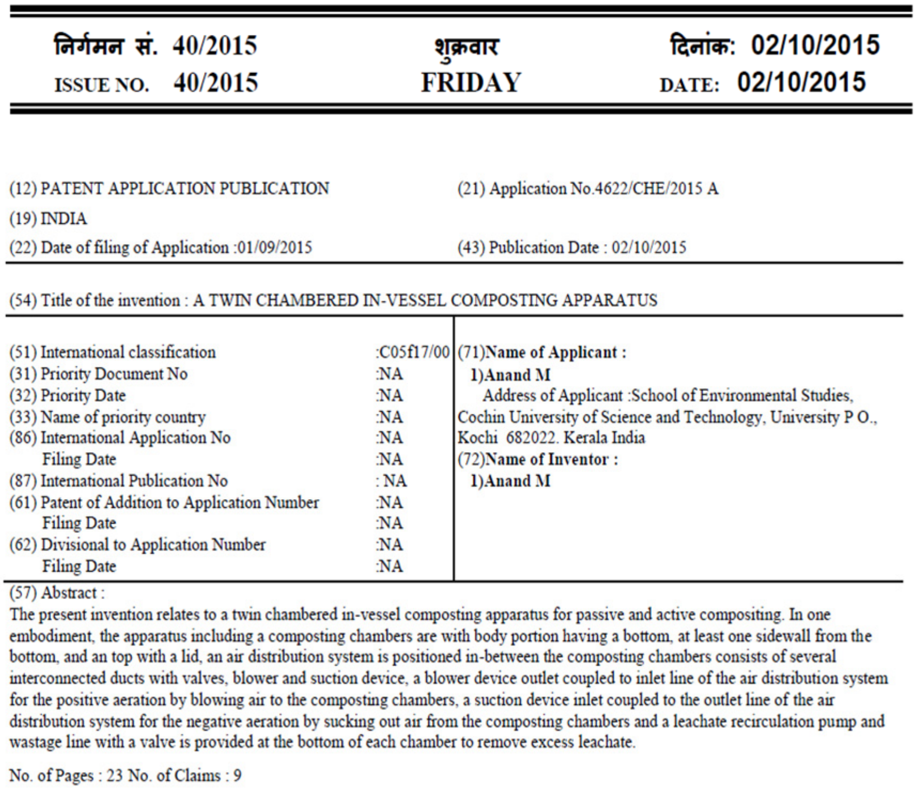

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(57) Abstract :
The present invention relates to a twin chambered in-vessel composting apparatus for passive and active compositing. In one embodiment, the apparatus including a composting chambers are with body portion having a bottom, at least one sidewall from the bottom, and an top with a lid, an air distribution system is positioned in-between the composting chambers consists of several interconnected ducts with valves, blower and suction device, a blower device outlet coupled to inlet line of the air distribution system for the positive aeration by blowing air to the composting chambers, a suction device inlet coupled to the outlet line of the air distribution system for the negative aeration by sucking out air from the composting chambers and a leachate recirculation pump and wastage line with a valve is provided at the bottom of each chamber to remove excess leachate.

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Photograph of the Prototype Reactor

Patent pending

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