In-Vessel Composter Technique For Municipal Solid Waste Composting

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Abstract**—** the presence of mixed organic substrates is a privilege of composting. Composting means a controlled process involving microbial decomposition of organic matter. This paper pertains to the study of in-vessel composting process. The objectives of this paper were to collect and analyze information about in-vessel composting process and anaerobic digestion, and compiling an overview of this process. This paper also present the versatility and multivariable profile of these processes, showing the biological, chemical and physical factors which is effected by composting process having with its different ranges.

Keywords*- Composting, anaerobic digestion, composting parameters, in-vessel composting process.*

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I. INTRODUCTION

Composting is the aerobic decomposition of organic materials in the thermophilic temperature range (50-80^{0}C) (Stelmachowski M. et.al. 2003; Palmisano and Barlaz, 1996). Compost production is the process whereby thermophilic, aerobic microorganisms convert organic materials into a biostable product (Agnew J. M., et. al. 2003; Thomas J. A. et.al. 2015; Wichul and McCartney, 2010; and Iyengar S. R., 2006). Composting process the micro-organisms decomposes the substrate through breaking down from complex to simpler compounds under aerobic conditions (Bernal M. P., 2009; Sarra S. M., 2010).Composting is the natural breakdown of organic materials under aerobic conditions to carbon dioxide, methane, alcohol (Haug, 1993), humus(Chynoweth and Pullammanappallil, 1996; Iyengar S. R., et .al., 2006), water and generates heat. Compound is a gradual complex process, one in which both chemical and biological processes must occur in order to organic matter to change into compost. The product is odourless, with fine texture and low moisture content and can be used for application in agriculture, gardens and green-lands (Kim D. J. et. al., 2008; Kalamdhad et. al., 2009). The maturity and stability of compost is important because it interferes in the retardardation of plant growth due to nitrogen starvation, anaerobic conditions, phytotoxicity of NH_3 and some organics (Huang et al., 2004). It also affects the potential for odor generation, biomass re-heating, residual biogas production, re-growth of pathogens, plant disease suppression ability, and effects on other process parameters (Adani et al., 2006). Many factors can affect composting process like, biological chemical, and physical. These factors should be appropriately collected for achieving compost maturity efficiently (Ekinci, 2001).

II. LITERATURE REVIEW

In anaerobic digestion, four different types of microorganisms are responsible for the degradation of MSW: hydrolytic, fermentative, acetogenic, and methanogenic (Braber, 1995). In the first step of anaerobic digestion (depolymerization), the hydrolytic bacteria are responsible for depolymerization of polymeric solid substrates into smaller molecules such as organic acids, alcohols, and the methanogenic substrates. Some bacteria involved in this step are: Bacteroides succinogenes, Clostridium lochhadii, Clostridium cellobioporus, Ruminococcus flavefaciens, Rumminococcus albus, Butyrivibriofibrisolvens, Clostridium thermocellum, Clostridium stercorarium, and Micromonospora bispora. In anaerobic digesters with MSW, the predominant bacteria are Clostridia. In this stage, typically only 50% of the organic matter is degraded. Also, some intermediate reactions occur: for example, products of depolymerization reactions are converted to fermentation products (Chynoweth and Pullammanappallil, 1996).

Even through the microbial population may be vast; the main microorganisms that affect the composting system are fungi, actinomycetes, and bacteria. Also present are protozoa and algae (Stofella and Kahn, 2001). Bacteria and fungi are most important microorganisms for composting (Haug, 1993).

A composting system may contain three classes of microorganisms: cryophiles or psychrofiles, mesophilic bacteria predominate. Above this temperature, thermophilic bacteria work faster. When the temperature of the compost comes down, mesophilic bacteria again predominate (Wassenaar, 2003).

Considering a windrow system, mesophilic and thermophilic are the most common microorganisms in composing, contributing to composting at different times of the process. This has four different stages. In the first stage, there are abundance of substrate and mesophiles that are predominant and very active. During this stage, large quantities of heat energy are generated, which increase the temperature of the compost pile. The favorable temperatures to kind of microorganism are between 35^0C and 45^0C (Miller, 1996; Stofella and Kahn, 2001).In the 1950s, work was also carried out on determining the utility of adding enzymes to promote digestion (Heukelekian and Berger, 1953).

As the temperature rises, it becomes more favorable to thermopiles, for which the best temperature is higher than 45^0C (Mohee and Mudhoo, 2005). The compost pile reaches about 65^0C to 70^0. At this stage, the food sources decreases for microorganism and the temperature falls, resulting in one more mesophilic stage. In the last stage, the temperature falls to ambient temperature again (Miller, 1996; Stofella and Kahn, 2001).

Fungi are important because they can break down tough debris and organic residues that are too dry (fungi have a lower moisture requirement), acidic (fungi can live in a broad range of pH), or low in nitrogen, enabling bacteria to continue the decomposition process. Fungi are most common in mesophilic and thermophilic stages of composting. Species more are Mucor, Aspergillus, and Humicola (Epstein, 1997; Miller, 1996; Wassenaar, 2003).

Now days the municipal solid waste management is a big problem in most of the urban cities in India due to generation of its huge quantity and non availability of suitable cost effective technologies for treatment and disposal (Kumar et.al. 2009; Bunela et.al. 2010). The composting is acceptable solution because it reduces the volume of municipal, organic and bulky solid waste and results with organic material becoming a stable end product (Haug, 1993; Insam and Bertoldi, 2007; Kalamdhad S. A. et. al., 2009; Iyengar R. S. et. al., 2006).

There are many methods of composting organic materials and wastes including sewage sludge: active windrow (with turning), passive composting-piles, passive or active aerated windrow, composting bins or containers, in-vessel composting contain rotating drums and bioreactors (Elorriota M. A., et.al. 2003; Huang et al., 2004).

The several in-vessel composting method have been explored (Haug, 1993; Iyengar R. S. et. al., 2006; Kalamdhad S. A. et. al., 2009; and Smith R. D. et. al., 2006). One of these is a rotating drum method (Haug, 1993; Iyengar R. S. et. al., 2006), which provides agitation, aeration and mixing of the compost, to produce a consistent and uniform end product. Units used for this technology are small enough that they can be fitted to handle continuous flow of wastes, and have been used to compost such diverse organic wastes, as cattle manure, swine manure, municipal biosolids waste, brewery sludge, chicken litter, animal mortalities, food waste, vegetable and leaves waste (Smith R. D. et al., 2006; Kalamdhad S. A. et. al., 2009; Iyengar R. S., et. al., 2006; and Cawthon, et. al., 1997). Some studies have focused on procedures to formulate optimum organic blends for composting. These studies have demonstrated that appropriate mixing of compost components ensure the best results (Smith R. D. et al., 2006). Bulking agents contain product like, dry cornstalks, wood shaving, saw dust, cow dung are often added to compost feedstock to absorb water, add porosity, or adjust the C/N ratio (Smith R. D. et al., 2006; Iyengar R. S., et. al., 2006; and Yuan J. et. al., 2015).

However, after comparing with conventional composting system, the use of in-vessel composting systems operate with more system control, enabling them to select suitable operating parameters (e.g. temperature, moisture content, pH, C/N and, particle size, etc) to promote both microbial activity and contaminant degradation (Ladislao B. A., 2004; Rihani M. et. al.,2010; Cekmccelioglu D. et. al., 2005).

The purpose of this study was to determine the effect and changes in physicochemical characteristics of biomass using in-vessel composting techniques. The aim at the selection of appropriate maturation method for primary stabilized compost and rapidly volume reduction of the bio-waste using in-vessel composter.

III. TYPES OF COMPOSTING PROCESS

Composting may be performed in various ways. Currently, the leading concepts are: non-reactor systems (windrows and static pile) and reactor systems (in-vessel system -vertical flow, horizontal and inclined flow processes, and non flow processes). With in-vessel systems, all or part of the composting takes place in a reactor. It should be noted that many of the current in-vessel systems involve the use of windrows for curing and maturation (Dziejowski and Kazanowska, 2002). Below flow chart shows the different type of composting process.

Amongst these technologies windrow composting is more popular than two others. After referring the various literatures which are related to in-vessel composting .It is seen that the research as on in-vessel composting is limited. The below figure 1 shows the different type of in-vessel composting process

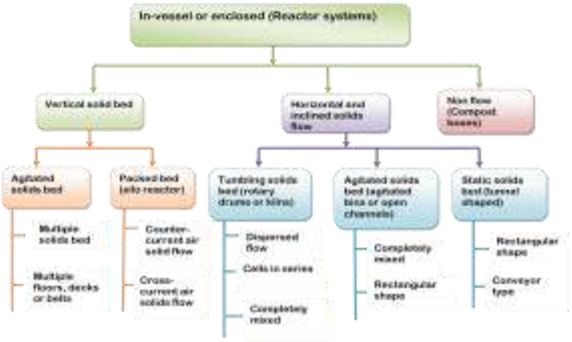

Figure 1: The different type of in-vessel composting process.

IV. NONE REACTOR COMPOSTING SYSTEMS

A. WINDROW COMPOSTING TECHNOLOGY

Windrow is the most common composting method practiced (Diaz et. al., 1993; Haug, 1993; Stofella and Kahn, 2001) and is a potential treatment technique for MSW (Komilis, 2006). Mixed feedstocks are placed into long narrow piles and turned periodically, usually by mechanical equipment.

Height, width, and shape of the windrow vary depending on the nature of the feed material and the type of equipment used for turning (Haug, 1993). Windrow process can be naturally aerated. In this case, the oxygen is supplied primarily by natural ventilation resulting from the buoyancy of hot gases in the windrow system and, to a lesser extent, by gas exchange during turning. Another variation of the windrow process is the one with forced aeration. In this case, oxygen transfer into the windrow process is the one with forced aeration. In this case, oxygen transfer into the windrow is aided by forced or induced aeration from blowers (Haug, 1993; Manser and Keeling, 1996).

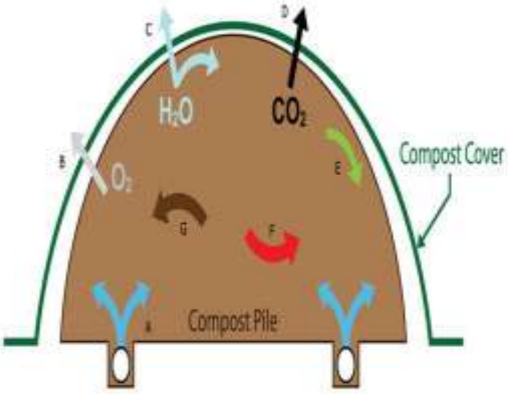

Figure 2: Windrow composting

B. STATIC PILE COMPOSTING TECHNOLOGY

This process may be passively aerated, assisted passive aerated, and aerated. The passively aerated process is based on passive aeration, natural decomposition, to produce compost. It is normally used to slowly decompose cellulostic feedstocks, such as leaves, brush, bark, wood chips, and some agriculture residues. Feedstocks may be combined and mixed to adjust moisture, porosity, density, and C/N ratio. After the pile is formed, this is turned with a bucket loader every one to three month, resulting in one or two turning during the composting cycle (Stoffela and Kahn, 2001).

V. REACTOR COMPOSTING SYSTEMS

A. IN-VESSEL COMPOSTING TECHNOLOGY

The technologies described either in buildings and / or specific designed vessels (e.g. tunnels, drums, or towers) and are typically known as in-vessel composting. The techniques used to control the supply of oxygen required by the process are the mechanical agitation through the waste and forced aeration offering differing levels of process control automation. (Department of Environmental Food and Rural Affairs, 2007).

In-vessel composting techniques differ from conventional composting systems in that they are closed systems, like large incubators, providing the opportunity to ensure the use of high temperatures ($>70^{0}$C) in order to meet regulatory requirement for pathogen control (European commission, 2003,).The physical and biological changes in composting process mainly depends on temperature, aeration, moisture, etc. are directly related to the surface/volume ratio. However, it is generally accepted that composting is essentially four-phase process that may be summarized as follows.

1. *Mesophilic Phase (25–40◦C)*

   In this first phase (also called starting phase), energy-rich, easily degradable compounds like sugars and proteins are abundant and are degraded by fungi, actinobacteria, and bacteria, generally referred to as *primary decomposers.*
2. *Thermophilic Phase (35–65◦C)*

   Organisms adapted to higher temperatures get a competitive advantage and gradually, and at the end, almost entirely replace the mesophilic flora. The decomposition continues to be fast, and accelerates until a temperature of about 62◦C is reached. Thermophilic fungi do have growth maxima between 35 and 55◦C, while higher temperature usually inhibits fungal growth.
3. *Cooling Phase (Second Mesophilic Phase)*

   When the activity of the thermophilic organisms ceases due to exhaustion of substrates, the temperature starts to decrease. The second mesophilic phase is characterized by an increasing number of organisms that degrade starch or cellulose. Among them are both bacteria and fungi.
4. *Maturation Phase*

   During the maturation phase, the quality of the substrate declines, and in several successive steps the composition of the microbial community is entirely altered. Usually, the proportion of fungi increases, while bacterial numbers decline.

   The following microorganisms involved in composting process:

a. Cultivation and Molecular Techniques

b. Bacteria

c. Fungi

The technology called "in-vessel composting" is systems that comprise a number of integrally related components including: materials amendment, recycle, handling, storage mixing, reactor system, odour-control system, aeration system, exterior curing/storage facilities as well as marketing (of produced compost). (Marek Stelmachowski, 2003).Two stages are obtained in in-vessel composting system which one is the high rate phase and another one is curing phase. The first stages is performed in the bioreactors and send one is often in an exterior composting pile, although it may be performed also in the reactor or both in the reactor and the pile. No precise distinction exists between these two stages, but high (bio) reaction rates (i.e. rapid biodegradation), high oxygen - uptake rates, high temperatures and high potential for odour production are essential for the first step. In the second step, these processes are slower and the temperatures are lower. There are three general classes of reactors in the first stage periodic bioreactors (active aerated vessels without agitation or stirring), plug flow reactors (horizontal and vertical) and agitated-bed reactors (Bernacka J. et. al. 1996, US EPA 1994).

Advantages of in-vessel composting:

1. It required least amount of land.
2. It reduces volume of organic waste going to landfills.
3. Reduces odor and vermin attraction.
4. Compost is slow-release and will not leach out.
5. Reduces greenhouse emission (production of landfill methane also produces CO_2 which is more harmful than methane)
6. Compost has valuable nutritional value and has a ready market.
7. Control release of leachate.
8. Provide additional recycling credits.

Disadvantages of in-vessel composting:

1. Requires extensive training of personnel.
2. Higher maintenance and operational costs.
3. In-vessel composting may not be the ideal disposal solution for all producers, but it does represent a bio-secure and environmentally viable alternative to rendering.

VI. REASEARCH DONE IN IN-VESSEL COMPOSTING

The table 1 shows the research work on in-vessel composting system, and it also shows the different parameter and factor of composting process with its different ranges and it also contain different type of waste composting study and it also shows what type of work done in particular paper. The below figure 3 shows the reactor rotary drum composter with waste. The figure 4 and 5 shows the internal view with baffle of reactor and flow diagram of waste composting process.

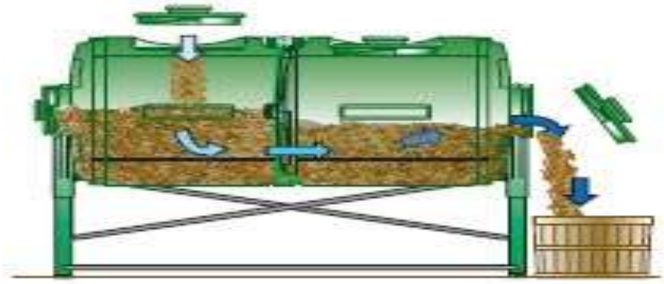

Figure 3: Rotary drum composting

Figure 4: Internal view of rotary composter with baffle

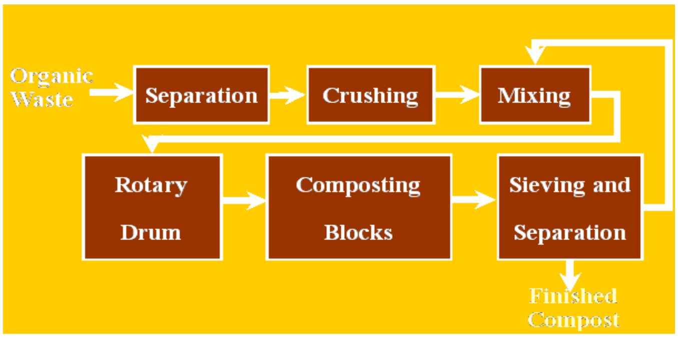

Figure 5: Flow chart waste material transfer in one process to next process in composting

Table 1: The research work on in-vessel composting system

Sr. No.	Author name	Type of waste	Types of reactor/ in-vessel composter used	PH	Temperature	Moisture content %	C/N Ratio	Electrical conductivity	Nitrogen content	Potassium	Remark
1.	Jing Y., et. al., (2015)	KW, BAP with Fecl$_3$	20L Reactor (SS)	7.83	>50^0C	-	14.36	2.78	-	-	The study shows the effect of adding a bulking agent and chemically pre-treatment municipal kitchen waste before aerobic composting were studied using a laboratory –scale system. The objective of this to decrease NH_3 and H_2S emission during composting. This composting process less leachate was produced by the compost kitchen waste after mixing bulking agent then material has reached required maturity.
2.	Ali M. et. Al. (2014)	VW	$3.5m^3$ Reactor (Metal sheet)	7.5± 0.3	60-65 ^{0}C	72	-	-	-	-	All observation of this study suggested that removal and degradation kinetic of organochlorine pesticides residues in vegetable waste through high rate composting proved the full-scale continuous rotary drum is one of the best suited technique for removal of organic pollutants like pesticide in full scale composting plant used for various kind of waste.
3.	Jiwan. S. et. al. (2013)	HW, CM, SW	550L Reactor (Metal sheet)	7.4	52-60^0C	27.4	-	3.4-2.1	-	-	The study indicated that the optimum proportion of cattle manure can enhance organic matter degradation and humidification process. After adding manure in compost then toxicity of metals reduces during rotary drum composting.
4.	Chun J. et. al., (2012)	FW	30L Reactor (Acrylic column)	5.79	62.4^0C	62.35	32.46	-	1.39	-	This study investigated the influence of coal ash and uric acid on the composting of food waste in the in-vessel system. The result shows that the temperature level has increased in the presence of CA and UA

											during the first 8 days. The significant drop in PH was observed in the treatment without any amendment. But the presence of CA could alleviate the drop in PH. Both thermophilic and mesophilic microorganisms were present throughout the composting period.
5.	Maliki D. A.et. al., 2011	SW,CW , GW	9.8L Reactor (Wooden crate and insulated with kingspan siteline)	-	> 70^{0}C	-	8.6	-	-	-	The study shows the design a test step to guide the best mixing ratio of food waste to green waste to meet the regulation. The result obtained best mixing ratio for sausage waste to green waste is 1:4 wet weight volume, while for cheese waste, a lower mixing ratio is needed. In industrial practice, time and cost are a major operational concern. This study demonstrates a simple way to improve the composting operation.
6.	Rahani M. et. al.,(2010)	PS, SBL, SSM	3.979 m^3 Bioreactor	7.3-7.2	>50^{0}C	50-60%	10.2-12	-	-	-	He Studied that the recycling urban primary sludge by in vessel aerobic composition way. Two series of composting trails were carried out in an automated accelerated bioreactor in mixture with agricultural waste.
7.	Kalamdhad A. S., et. al (2009)	VW, TL	Rotary drum composter (Iron sheet) 3.5m^3	8.39	60-70^0 C	73.5	8.51	4.42	-	-	In present study windrow and vermicomposting method employed for maturation of primary stabilized compost from rotary drum. It shows the higher loss of moisture content during vermicomposting after comparing to windrow in all season.
8.	Williams A. P., et. al., 2009	DAW	6.5 m^3 Reactor (High density polyester and thermostable glass fibre)	8.68 ± 0.12	40.9± 1^{0}C	-	2.9	-	903	100± 9	The study shows the in-vessel composting process two experimental scenarios were tested for the efficiency of bio-reduction vessels as a mechanism of sorting and reducing the volume of fallen livestock prior to ultimate disposal. This study concluded that bio reduction could potentially offer livestock farmers a

											practical, cost-effective, and bio-secure method of containing fallen livestock prior to disposal by an approved collector.
9.	Kalmdhad S. A. et. al., 2008	GC MWW, CM, FW, SD	250L Rotary drum composter (Metal sheet)	7.2	-	72.32	16	-	-	-	The study show that the stability of compost using respiration technique is evaluated for four C/N ration waste combinations with different type of wastes in rotary drum composter. The result after 20 days of composting in rotary drum was found out that the initial C/N ratio of 22 can produce more stable compost within 20 days.
10.	Kim J. D. et. al., 2008	FW	324 m^3 Composting plant	4.4	60 ^{0}C	80	25	-	-	-	The study shows to evaluate the performance of pilot-scale in-vessel composting for food waste treatment. In composting process high CO_2 concentration was generated, high temperature and high consumption rate there found, revealing vigorous microbial activity. Bulk density and moisture content then decreased. In that study also studied the linear correction analysis for the compost without bulking agent, it shows that negative correlations existed between heavy mental content and organic matters.
11.	Iyengar S. R., et .al., (2006)	Raw as well as cooked VW	Five different types of Aerobic and anaerobic 0.5-1kg loading	7.32	-	22.53	15.3	-	0.12	0.147	The study shows Complete mix type of reactor is more ideal than other reactor because it is more efficient than other; it reduces 60-70% volume of organic fraction household waste. In case of CM reactor observed that the variation of temperature with respect to ambient/ room temperature was less because of lower levels of available organic matter. The enclosed design of complete mix type reactor minimized the heat loss from the mulch formation in composting process. The

											result shows anaerobic reactor failed to qualify as a household reactor because of the poor quality of the mulch produced, and low level of volume reduction obtained in that reactor.
12.	Smith D. R., et. al (2005)	FW	Mechanical in-vessel rotating drum 0.4 m^3	6-8	>45^{0}c	>50	-	-	1.11	0.192	This study suggested that in-vessel mechanical rotating drum composting. It is an alternative composting process for food residuals. The study shows the oxygen levels generally inversely proportional to the temperature and result indicated that the in-vessel composter effectively aerated the biomass under most circumstances.
13.	Cekmcceloglu D. et.al. (2005)	FW, MW, BA	55L, Reactor (Polypropylene sheet)	8.2	>65^{0}C	61.3	13.2	-	-	-	This present study related to an optimised composting mixture from previous in-vessel composting studies was evaluated using windrow composting. Conclusion – The optimum compost mixture determined from in-vessel data was composted better in under higher temperature and longer retention time, which both contributed to higher reduction of C/N and volatile solids.
14.	Mohee R. et. al., 2005	BOW, CM, MGV	200-L (Plastic drum)	7.48	66.3 ^{0}C	62.4	20.6	-	-	-	The study determine the corrections between a selected set of physical properties of batch composting matrix and the correlation developed among free airspace, wet bulk density, dry bulk density and wet moisture content were in agreement with previously determined equation from literature.

*MSW- Municipal solid waste, FW- Food waste and VW-Vegetable waste, TL-Tree leaves, KW- Kitchen waste, BAP- bulking agent pretreated with Fecl$_{3,}$ CM- Cattle manure, SD- Sawdust, GW- Green waste, PS- Primary sludge, SBL - Sugar beet leaves, SSM- Straw sheep manure, BOW –Blend of woodchips, CM –Chicken manure , MGV- Mixed green vegetable, GC- Grass cutting waste, DAW – Dead animal wastes, SW- Sugar waste , CW – Cheese waste. SS- Stainless steel, MS- Mild steel, YW- Yard waste

VII. CONCLUSIONS

A review of literature indicated that the greater research has being made in the preparation of MSW before any other composting application of appropriate technologies. Also a wide range of studies are going through all over the world for making the In-Vessel technology more durable, feasible, eco-friendly and more convenient for the wide range of applications. In-vessel composting offers poultry producers a variety of benefits: low operational costs, fast processing time, ability to process large breeder birds and an end product which can be sold or used. The various studies that are going on the In-Vessel technology includes separation of inert material, metals, degradable organic matter and various waste materials that are usually found in solid waste.

In developing countries, along with the application relevance on wide scale more attentions are being paid on environmental impacts of In-vessel composting approaches and various measures for its application are followed. There is a need for minimizing the health and environmental impacts. Hence, research is being directed towards process acceleration, enhanced stabilization of organic fraction, improved quality of compost and increased productivity of the technology. The quality of product should be such that it achieves a high level of nutrients and of plant growth regulators with a minimum inert fraction and environmental and human health impact. Research is also needed to resolve the relevant and important but neglected aspect is the minimization of the production cost of compost and its technology so that it could be used for wide range of solid waste treatment.

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