ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization *Volume 3, Special Issue 4, March 2014*

National Conference on Recent Advances in Civil Engineering (NCRACE-2013)

During 15-16 November, 2013

Organized by

Department of Civil Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar, Arunachal Pradesh, India.

Changes in Characteristic of Municipal Solid Waste by Bulking Agent In-vessel Composting: Critical Review

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Abstract—The trend of treating the Municipal solid waste (MSW) is less compared to the dumping of the potential nutrient rich compost into land filling in India. Composting is increasingly considered a good way for recycling the surplus MSW to a stabilised and sanitized end product for agriculture. However, high quality compost should be produced to overcome the cost of composting which can be achieved through controlled composting in in-vessel system of composting but the initial cost is huge The first part of this paper explains the basic concepts of the composting process and how MSW characteristics (like temperature, aeration rate, moisture content, porosity, C/N ratio, microoraganism) can influence its performance. The nitrogen losses (which directly reduce the nutrient content), organic matter humification and compost maturity which affect the quality of composts produced by MSW composting are also discussed in this paper. The use of an adequate bulking agent of different types and size for reducing N-losses and the necessity of standardizing the maturity indices due to their great importance amongst compost quality criteria are also discussed.

Keywords—Aeration rate, C/N ratio, moisture content, MSW, nitrogen losses

I. INTRODUCTION

The waste sector is a significant contributor to greenhouse gas (GHG) emission accountable for approximately 5% of the global greenhouse budget [1] which includes both methane and CO_2, as we know the heating effect of methane is less compared to CO_2. Methane is produced in the anaerobic form of decomposing on the other hand CO_2 and H_2O are given out by aerobic method of decomposing and so the current wave for adopting solid waste management is aerobic method (ref??) Municipal solid waste is a good and easily available raw material for the compost production at low cost. In a developing country like India, MSW has been always considered as a very rich source of organic compost having rich nutrient required for agriculture based country (ref????). But,the quality of compost is important from maturity and stability viewpoint [2] which unfortunately in most of compost factories, proper attention is not paid[3]. 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 [4]. 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 [5]. The most common waste management strategy today is landfilling [6] 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

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contamination, GHG emissions and space limitation [7]. In this review, the physical and chemical changes in the characteristics of MSW and different types of other organic waste when mixed with different type of bulking agents (BAs) have been presented. Following the transformation process of the mixture to attain maturity and stability, different parameters have been compared. The in-vessel composter has been suggested as the suitable reactor for composting of MSW with different ratio of bulking agents according to the study which study, reference???. The summary of information allows for the start and/or a further understanding and even encourages using the locally available BAs to prepare a recipe for cost and time effective composting mixture with MSW ref????

II. The Basic Concepts Of Composting Process

The present trend is going organic and being cost effective in every field. Composting cannot be considered a new technology, but amongst the waste management strategies which has gained huge popularity in the recent decade. When Biodegradation of any solid waste is termed successful, the volume of waste and hence the frequency of collection and associated disposal cost should be considerably reduced [8]. For years, the researchers have studied the complex interaction among physical, chemical and biological ?????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 O_2 concentration, water content and temperature.

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 [9] and since it is considered that the microorganism require 30 parts of C per unit N [10]. 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 ref??/. Hence, initial C/N ratio is considered to be one of the most important factors influencing the compost quality. For a completely decomposed compost should range from 16-20 [11] Successful studies have been carried out on the low initial C/N ration by the researcher (Table 1) ,as it not only help to increase the compost amount but also can increase the loss of nitrogen as ammonia gas.

TABLE 1: SUCCESSFUL COMPOSTIG SYSTEMS IN LOW INITIAL C/N RATIOS

C/N ratio	Raw material	Reference
19.6	Green waste and food waste	[9]
20	Chicken manure with sawdust	[12]
20	Swine manure with rice straw	[13]
15	Pig manure with sawdust	[14]
17	Food waste	[15]

C/N correlates well with the degree to which composting is completed [15]. In the study carried out by Hamidi Abdul Aziz et al [16] who considered two type of composting process i.e., (i) the normal composting process (NCP), and (ii) the chemical–biological integrated thermophilic composting process (CBITPCP) [Table II]. In the normal NCP, C/N ratio was reduced to 20.57 from an initial value of 25.02 after 45 days ref??. In Rice Straw Biodegradation process (CBITPCP), C/N was greatly reduced compared to that of the NCP process in the matured compost; in particular, the C/N value was decreased to 16.57 -14.29 from an initial value of 25.99 at the end of the composting period, respectively. C/N reduction in CBITPCP is 146% higher than that in NCP

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[16]. All data should be supported by proper reference Fixing the initial C/N ratio, a study was carried out by Guoxue Li [17] 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 had found the similar result after composting for 63 days at low C/N ratio [14]. 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 [18].

Temperature is one of the most frequently used indexes to determine the progress of the composting process. The increase in temperature in the composting pile results in an increase in the rate at which chemical bonds in substrate compounds are broken. The microbial activity in the compost can be enhanced by rising the temperature to 28–55 $^{\circ}$C. However, Xiao et al. [19] indicated that the duration of the MSW composting process decreases from 28 to 14 days by using a continuous thermophilic composting method at 50°C. 50°C is considered as the demarcation of mesophilic and thermophilic phase. Other studies (WHICH STUDIES, PL PROVIDE have also indicated that maximum thermophilic composting activity occurs at temperatures in the range of 50–60 $^{\circ}$C [20]. The composting period of the MSW organic fraction is also decreased to 40 days under thermophilic aerobic composting conditions [21]. These results are consistent with those in another study, in which the effect of temperature on composting of cattle manure and rice straw for 21 days was investigated [22]. The development of the temperature profile indicates the different phases of the process. In general, the composting process can be divided into two main phases: The bio-oxidative phase and the maturing phase also called the curing phase [23]. The bio-oxidative phase is developed in three steps : (i) an initial mesophilic phase lasting 1–3 days, where mesophilic bacteria and fungi degrade simple compounds such as sugars, amino acids, proteins, etc., increasing quickly the temperature; (ii) thermophilic phase, where thermophilic microorganisms degrade fats, cellulose, hemicelluloses and some lignin, during this phase the maximum degradation of the OM occurs together with the destruction of pathogens; (iii) cooling phase, characterized by a decrease of the temperature due to the reduction of the microbial activity associated with the depletion of degradable organic substrates, the composting mass is recolonised by mesophilic microorganisms which are able to degrade the remaining sugars, cellulose and hemicellulose. During the different steps of the biodegradation phase, the organic compounds are degraded to CO_2 and NH_3, with the consumption of O_2. However, during the maturation phase stabilisation and humification of the OM occur, producing mature compost with humic characteristics in its OM. Thus, compost can be defined as the stabilized and sanitised product of composting, which has undergone an initial, rapid stage of decomposition, is beneficial to plant growth and has certain humic characteristics, making the composting of waste a key issue for sustainable agriculture and resource management [24].

The regulation of temperature is required for controlled composting. Excess heat removal can be achieved by several strategies [25]: control the size and shape of the composting mass; improve cooling by forced aeration [26] and favourable temperature redistribution by turning operations, which means heat removal through evaporation cooling; and achieve superior temperature control in systems that actively remove heat through temperature feedback-controlled ventilation.

pH: A pH of 6.7–9.0 supports good microbial activity during composting ,in the earliest stage of composting pH value decreases due to the production of organic acids derived from the intense carbohydrates fermentation ref ?/?. Optimum values are between 5.5 and 8.0 [25]. Usually pH is not a key factor for composting since most materials are within this pH range. However, this factor is very relevant for controlling N-losses by ammonia volatilisation, which can be particularly high at pH > 7.5. Elemental sulphur (S) has been used as an amendment for avoiding excessively high pH values during composting [27]. Chefetz et al. Year???reported that the pH exhibited a typical pattern during the composting process [28]. It drop temporarily during the thermophilic stage due to

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accumulation of the organic acids reflect the high rate of OM degradation and these acids are later used as substrate by other microorganism ref??/. During the cooling down and maturation stages the pH drop to neutral value.

The aeration rate (AR) (Table III) is considered to be the most important factor influencing successful composting [29]. Proper aeration controls the temperature, removes excess moisture and CO_2 and provides O_2 for the biological processes, so aeration should be managed at appropriate level for effective composting. The optimum O_2 concentration is between 15% and 20% [25]. Controlled aeration should maintain temperatures below 60–65^o C, which ensures enough O_2 is supplied. Insufficient aeration can lead to anaerobic conditions due to the lack of oxygen, while excessive aeration can increase costs and slow down the composting process via heat, water and ammonia losses. Higher aeration during the initial stages of decomposition intensifies the activities of microorganisms, shortens the period of active stabilization [30]. It has been suggested that aeration rates of 0.2 and 1.33 l/min kg volatile matter are suitable for composting of municipal sewage sludge and garbage ref???/. Although significant amounts of laboratory, pilot and field scale practices have taken place regarding aerobic bioreactors during the last decade the subject of the aeration rate is still not very clear. The turning of the compost material is the most common method of aeration when composting is conducted in enclosed reactors. Turning exposes fresh material for microbial colonization and leads to release of ammonia that has accumulated in the internal void space of compost [31]. Thus it is important to optimize the turning frequencies or to develop an appropriate regime that results in higher pathogen kill and retain nutrients in the rotary drum. As shown in the Table IV 4, Ventilation method also plays a vital role in the time and cost reduction of the composting process. There are two ways i.e continuous and intermittent mode. Guoxue Li et al adopted Intermittent aeration of 30 min on/ 30 min off for the first 7 days and then continuous aeration for the rest of the composting time at the rate of 0.01, 0.1 & 0.2 m^{-3} min^{-1} m^{-3} and he found that 0.2 m^{-3} min^{-1} m^{-3} was most suitable [32]. The change in the rate of aeration based on the temperature also helps the compost to attain the most suited condition to attain maturity of compost at greater phase [33A].

Moisture content affects microbial activity, as well as the physical structure, in the composting process, and thus has a central influence on the biodegradation of organic materials The optimum water content for composting varies with the waste to be composted, but generally the mixture should be at 50–60% [24]. Previously reported optimum moisture contents for composting ranges from 25% to 80% on a wet basis (w.b.), with generally recommended values in the 50% to 70% range. When the moisture content exceeds 60% O_2 movement is inhibited and the process tends to become anaerobic [34]. Because it is relatively easy to measure, moisture content often serves as a proxy for other critical factors such as water availability, which limits microbial activity in the low moisture range. Very low moisture content values would cause early dehydration during composting, which will arrest the biological process, thus giving physically stable but biologically unstable composts [35]. On the other hand, high moisture may produce anaerobic conditions from water logging, which will prevent and halt the ongoing composting activities. Also, high moisture content affects particle aggregation, matrix porosity, air-filled porosity, and matrix gas permeability, all of which can limit transport of essential oxygen into the composting zone where carcass decomposition occurs. Because of its importance to the composting process, the effect of moisture content on the decomposition rate has been investigated by many researchers. As is evident from this relatively wide range of reported values, there is no universally applicable optimum moisture content for composting materials. This is because each material has unique physical, chemical and biological characteristics, and these affect the relationship between moisture content and its corollary factors water availability, particle size, porosity, and permeability. During composting a large quantity of water can evaporate, to control temperature, and as water content diminishes the rate of decomposition decreases, then rewetting should be required in order to maintain the optimum moisture content for the microbial activity.ref???/

Porosity: Substrate porosity exerts a great influence on composting performance since appropriate conditions of the physical for air distribution must be maintained

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during the process. Porosity greater than 50% causes the pile to remain at a low temperature because energy lost exceeds heat produced. Too little porosity leads to anaerobic conditions and odour generation. The percentage air-filled pore space of composting piles should be in the range of 35–50%.

III. Implications of Key Ingredients (Bulking Agents) on MSW Composting Performance

A bulking agent is the material that provides the optimum free air space (FAS).FAS is an important factor in determining the quantity and movement of air through the composting matrix. Bulking agents (BAs) are composting amendments that are usually used to create inter-particle voids, providing air space in composting materials and regulating the water content of waste [36]. Numerous BAs, including wood chips, straws, sawdust (SD), rice husks, and peanut shells, have been mixed with waste materials to adjust moisture content, C/N ratio, and void spaces between particles [36]. The results of these studies showed that different BAs can modify the physical properties of the composting feedstock, and also change the biodegradation kinetics and shorten the composting period [37]. Iqbal et al. reported that the addition of 40% full form SD was the best BA in terms of adjusting the moisture content to 60% in MSW composting [36]. Chang and Chen found that increasing the amount of SD during food waste composting resulted in an increased water absorption capacity and composting rate also reduced composting time and acidification times, and a lower final pH value[38]. Jolanun et al. concluded that the ratio of BA sawdust to waste material has greatly influenced the percentage of FAS in fed batch composting [39]. Most of the bulking agents act as a buffer against the organic acids produced during the early stages of composting and thus help to maintain the mixture, pH within a range from 6 to 8 [40]. Selection of bulking agents for composting should be typically inexpensive and made from the waste materials that are readily available, with little consideration of what type and shape of bulking agent are used. Naturally using more bulking agent may provide more FAS. For the successful composting, different types of bulking agents available in the region were used, because they have different properties due to their carbon source, physical shape, particle size and BD. The BA absorbs part of the leachate produced during the decomposition process; to keep the mixture moist and sustain an active microbial activity. When a wet Substrate is mixed with a bulking agent it provides the structural support to create inter particle voids with the wet substrate occupying a portion of those voids. When a wood chips porous bulking agent is used air will also be contained in the intra-particles voids. A long list of waste materials have been used as the bulking agents but sawdust is one of the most widely used materials [41]. Besides in few studies sugarcane bagasses, rice hull and woody residues have also been used as BA in composting. Leaves can be used as carbon source and have relatively low porosity than wood chips. Recently Adhikari et al. investigated the effectiveness of three bulking agents namely Chopped wheat straw, chopped mature hay and wood shaving in different ratios in composting [42]. Eftoda and McCartney found that a volumetric ratio of biosolids to woodchips of 1:2.5 provided the best aeration level for the least BA [43]. Furthermore woodchips with a small particle size of 5.2 mm resulted in a lower moisture loss as compared to a large particle size of 40 mm because of greater resistant to ventilation. Particle size distribution determines the availability of surface area to microbes for degradation and by decreasing the particle size, a great surface area is exposed to microbial attack. Raichura and McCartney year also found that a low particle size of bulking agent is preferred to give the material an adequate porosity instead of using large quantity of bulking agent. [44] Bulking agent of small particles create a real porous structure and the homogenous porous size distribution inside the material that act as efficient oxygen consumer.

TABLE V
BULKING AGENTS OF DIFFERENT SIZE

Reference	Different Bulking Agent used in Composting	Size
[45]	Cornstalk and Sawdust	5cm and <1.5 mm
[46]	Sawdust and peanut shell	< 1.5 mm
	News paper	2.5 mm width,16 mm length
	Rice husk	10 to 50 mm

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[17]	Cornstalk	1-5 cm
[16]	Rice straw	5-10 cm
[47]	Wood chip	diameter:1-1.5 cm, length : 1.5 - 2 cm

IV. Characteristics and Modelling of Compost

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 a fertiliser for pots and as a basis for soil-less substrates. The advantages of composting organic wastes compared with direct application can be summarised below:

- – Elimination of pathogens and weeds.
- – Microbial stabilisation.
- – Reduction of volume and moisture.
- – Removal and control of odours.
- – Ease of storage, transport and use.
- – Production of good quality fertiliser or substrate.

However the disadvantages are derived from:

- – Cost of installation and management.
- – Requirement for a bulking agent.
- – Requirement for large areas for storage and operation.

Composting of MSW should be seen as a technology which adds value, producing a high quality product for multiple agricultural uses. Certain chemical characteristics of the MSW 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 optimises 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 co-composting of nitrogen-rich wastes, such as animal manures ref. The most generally used materials are cereal straw [48], cotton waste [49], hay [48] and wood by products such as pine shavings, chestnut burr and leaves and sawdust [48]. All have low moisture and high organic-C contents and high C/N ratios (an average of 50 for cereal straw and > 80 for wood by-products), which can compensate for the low values of the MSW.

Municipal solid waste is mostly considered a waste and very less steps are taken to divert the resource into renewable energy and good quality compost. Considering all the criteria, in-vessel composting is a very good solution to the current requirement as an environmental friendly method. As in-vessel composting is a system that comprises a number of integrally related components including: material amendment, recycle, handling, storage, mixing, reactor system, odour-control system, aeration system, exterior curing with storage facilities and marketing of produced compost. This technology offer 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. Among different types of in-vessel composter rotary drum are considered to be efficient and promising technology as this type of composter provides agitation, aeration and compost mixing in order to produce a consistent and uniform end product without any odours or leachate related problems [50]. Different types of waste (cattle manure, swine manure, municipal bio-solids, chicken manure, animal mortalities and food residues) can be effectively composted in rotary drums [47]. The compost turning system produces less CH_4 and N_2O emissions than the passive aeration of a static pile/ windrow system that have an assured aerobic environment. Composting by forced aeration gives even lower CH_4 and N_2O emissions than that by turning due to the more plentiful oxygen supply. In the Table IV, in-vessel composter with different waste material products

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show different change in characteristics with time. The rate of composting varies depending on the method of aeration [45].

IV. Strategies For Producing High Quality Compost Content and OM Humification

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 hygienisation and the presence of certain toxic compounds, such as heavy metals, soluble salts and xenobiotics. The first three factors are reviewed in the present paper. The production of compost with a high nutrient content requires the control and reduction of nutrient losses during the process, whilst to ensure a high degree of OM at one place, pl wite full form, humification enough time should be allowed for the maturation phase. Finally, a high degree of compost maturity requires the establishment of adequate maturity indices. During the active phase of the composting process, the organic-C decreases in the material due to decomposition of the OM by the microorganisms. This loss of OM reduces the weight of the pile and decreases the C/N ratio. The degradation rate of the OM decreases gradually as composting progresses because of the reduction in available carbon sources, and synthesis reactions of new complex and polymerised organic compounds (humification) prevail over mineralisation during the maturation phase. This process leads to stabilised end-products which act as slow-release fertilisers for agricultural purposes. However, the major concern MSW composting is to control C and N-losses since they reduce the agronomic value of compost and contribute to greenhouse gas emissions [51].

The degradation of the OM during composting can be estimated as a dry matter loss, as an OM loss, or as an organic-C loss. The composting system and conditions, characteristics of both the bedding material and the bulking agent added for composting and even the environmental conditions of the season (winter or summer) have a great influence on the mineralisation of the OM during composting. For instance, the use of woodchips instead of cereal straw as bedding material in beef manure reduced the organic-C loss during composting [51] due to the combination of larger particle size, higher C/N ratio and the recalcitrant nature of the woodchips.

Generally, the total N concentration increases during composting due to the concentration effect [23]. The evolution of N forms shows the mineralisation of the organic compounds during the active phase of composting with the formation of NH_4-N (Ammonium-Nitrogen). Thus, the highest NH_4-N concentration occurs during the thermophilic phase, but the concentration quickly declines as the process progresses. In the thermophilic phase, OM degradation (NH_4-N production) and aeration demand are at their maxima, pH is usually > 7.5 and nitrification hardly occurs because the high temperatures inhibit the action of the microorganisms responsible for the process [52]. All these conditions favour NH_3-volatilisation [52]. Nitrification, detected by the formation of NO_3-N, occurs when the temperature falls below thermophilic values (40 °C), the intensity of the process depending on the amount of NH_4-N available to the nitrifying bacteria [52]. Most of the nitrification occurs during maturation, leading to a low NH_4-N/NO_3-N ratio in mature compost. Nitrogen losses impact negatively on the MSW composting process, by decreasing nutrient concentration and hence compost quality, and generate health and environmental problems. Nitrogen losses through composting can occur by NH_3-volatilisation, leaching and denitrification. Denitrification can occur as a result of the development of anaerobic micro sites within the material. Thus, the aerobic conditions of the compost should be ensured throughout the process. Losses by leaching can be reduced easily by controlling the moisture content of the pile and by an adequate composting system, designing the installation with an adequate cover from the rain and a system for leachate collection and recirculation within the same compost. The losses as NH_4-N can be particularly relevant at the beginning of the process and as NO_3-N in the last phase of composting, when the nitrification occurs [31], since nitrate is a very mobile anion, highly soluble. The lack of leachate collection can imply a risk of nitrate contamination of the groundwater.

Therefore, most N-losses during composting of animal manures have been found to be due to ammonia volatilisation [31]. The main factors conditioning NH_3-volatilisation are those implicated in the reactions involved in the following processes: formation of NH^+_4 in the compost, its deprotonation for NH_3 formation, conversion of ammonia in solution in the compost into ammonia gas and transfer of ammonia in the gas phase of the compost to the atmosphere.

$$NH_4^+ \text{ (Compost)} \leftrightarrow NH_3 \text{ (Compost)} + H^+ \leftrightarrow NH_3 \text{ (Gas)} \leftrightarrow NH_3 \text{ (Atmosphere)}$$

Therefore, the main factors controlling NH_3-losses are the composition of the initial mixture, such as total-N, C/N ratio, degradable organic-C and particle size, and the composting conditions, such as temperature and turning frequency (composting system). Martin et al. found that bulking agents with a high content in ligno-cellulose have a lower microbial degradability and lead to higher nitrogen losses [53]. Barrington et al. noted the importance of particle size as a factor affecting carbon availability and hence N immobilisation by microorganisms during composting [48]. As the oxygen supply into the composting mass controls important processes, such as biodegradation, ammonification and nitrification, then the aeration rate exerts an important influence on nitrogen dynamics. Nitrogen immobilisation by the microbial biomass depends on carbon biodegradability and hence factors, such as oxygen (free air space), moisture and C and N biodegradability affect gaseous emissions. It is concluded that reduced NH_3 emission implies active immobilisation of the NH_4-N by the microbial biomass and that the presence of the less biodegradable organic-C in sawdust increased NH_3 emission, which was decreased by increasing the ratio of wheat straw in manure composting. During composting of dairy manure and wheat straw, the addition of a readily available carbon source, such as molasses greatly reduced ammonia losses, while no significant reduction occurred when carbon was hardly degradable, for example when supplied as office paper [54]. Therefore, amending materials rich in available carbon can reduce nitrogen losses during the composting of organic wastes with a high nitrogen concentration. So, for effective composting to obtain high quality compost, the selection of the bulking agent is essential. Paredes et al. found that changing the bulking agent from cotton waste to maize straw decreased OM degradation, organic-N mineralisation and, therefore, causing NH_3-losses in sewage sludge composting [49]. Parkinson et al. found that increasing the number of turns from 1 to 3 increased the ammonia-N losses during composting of cattle manure, these being 11% and 18% of initial total-N, respectively [31]. The system used for turning operations also had a high influence on ammonia losses. Composting leads to higher C and N-losses compared to stockpiling or a direct application to soil. Therefore, for C-conservation, the losses occurring during composting and those occurring after soil application should be considered. In addition, nutrients in composted materials are less susceptible to losses by leaching and volatilisation, and composting also avoids the spreading of pathogens.

Humification process: The agricultural value of a compost increases when the OM reaches a high level of humification. The humification of the OM during composting is revealed by the formation of humic acids with increasing molecular weight, aromatic characteristics, oxygen and nitrogen concentrations and functional groups, in agreement with the generally accepted humification theories of soil OM [55]. The most appropriate and reliable approach to the evaluation of the humic character and behaviour of the compost is based on the identification of the chemical and structural composition and functional properties, also in comparison with those of humic substances from native soil.

VI. MATURITY ASSESSMENT FOR COMPOST QUALITY

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 OM during composting, which is related to the types of organic compounds remaining and the resultant biological activity in the material [56]. 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 stabilised composts may pose a number of problems during storage, marketing and use.

ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization   Volume 3, Special Issue 4, March 2014

National Conference on Recent Advances in Civil Engineering (NCRACE-2013)

During 15-16 November, 2013

Organized by

Department of Civil Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar, Arunachal Pradesh, India.

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.

TABLE VI
MATURITY INDICES ESTABLISHED FOR COMPOST OF DIFFERENT SOUREC

Parameters	Value
NH_4-N /NO_3-N Ratio	0.5 - 3
water soluble (C/N)	5 to 6
Germination index	> 50%
Total NH_3-N	100 - 500
NH_4-N	<0.4 G/kg
C/N ration	<20, perferable<10
Mineralisable -C in 70 days	<30%

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 NH_4-N concentration decreases and NO_3-N appears in the composting material it is considered ready to be used as a compost [57]. A high level of NH_4-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 (Table VI). The maturity of compost can be assessed by its microbial stability, by determining microbial activity factors, such as the microbial biomass count and its metabolic activity, and by the concentration of easily biodegradable constituents. The aerobic respiration rate was previously selected as the most suitable parameter to assess aerobic biological activity and hence stability. 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 stabilisation. 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.

VII. CONCLUSION

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

1) The selection of appropriate bulking agents plays an essential role in controlling the decomposition rate and favouring N retention within the compost.
2) 2) In MSW with a low initial C/N ratio the degradable carbon exceeds inorganic N which leads N loss by ammonia volitilisation or by leaching. These can be corrected by adding bulking agent with adequate degradable C.
3) The process control features of the composting system of in-vessel (moisture, temperature, aeration/turning and particle size) have been shown to reduce ammonia volatilisation and hence nitrogen losses, these being a major concern in MSW composting from an environmental point of view.
4) From the review we have found that the pH of 6.7-9 supports the microbial activity in composting. However, this factor is very relevant for controlling N-losses by ammonia volatilisation, which can be particularly high at pH >7.5.

ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization *Volume 3, Special Issue 4, March 2014*

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Elemental sulphur (S) has been used as an amendment for avoiding excessively high pH values during composting.

5) 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 been used for manure compost by different authors.
6) The standardizations of the criteria for a matured state of compost of MSW should be adopted for better understanding of the compost of a particular region with particular type of climate.
7) The leachate produced in the compost of MSW can be 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.

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IJIRSET

ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization Volume 3, Special Issue 4, March 2014

National Conference on Recent Advances in Civil Engineering (NCRACE-2013)

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Department of Civil Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar, Arunachal Pradesh, India.

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ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization Volume 3, Special Issue 4, March 2014

National Conference on Recent Advances in Civil Engineering (NCRACE-2013)

During 15-16 November, 2013

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Department of Civil Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar, Arunachal Pradesh, India.

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ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization Volume 3, Special Issue 4, March 2014

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TABLE II: THE CHEMICAL CHARACTERISTICS OF MSW DURING COMPOSTING

Reference	Components	C/N ratio		pH		TKN (%)		OM (%)	
		Initial	Final	Initial	Final	Initial	Final	Initial	Final
[58]	Mixture A, composed of TrH 80% þ olive tree pruning 20% (w/w); Mixture B, composed of ExH 70% þ olive tree pruning 22% þ cereal straw 8% (w/w/w)	57 and 25.9	26.2 and 16.6	4.6 and5.5	7.4 and 8.1	0.2 and 0.3	0.4 and0 .5		
[16]	a) Chemical–biological integrated thermophilic composting process (CBITPCP), b). Normal composting process(NCP)	25.99 and 25.2	16.5 -14.29 (CBITPCP) and 17.73 (NCP)	6.3(CBITPCP) and 6.51 (NCP)	8.1 (CBITPCP) and 7.18 (NCP)	1.6 and 1.6	2.3 and 1.83	86.91 and 87.95	68.71 and 68.71
[59]	Swine manure with pine sawdust	40.2		6.5	5.86	1.12	1	77.99	81.05
[17]	Pig faeces with cornstalks with different initial C/N ratio	18.3	12.5	8.5	8.5	20.8(g/kg dm)	25.5 g/kg dm		
[60]	Municipal solid waste	29±1.2		5.95	8.2	11.8±0.39		344±3.8	
[61]	Municipal solid waste	26	12.2,14.6,18	6.38	6.18≤pH≤7.18	1.82		92.4	14.66
[62]	Municipal solid waste			6.83 ± 0.28				743.8 ± 26.3	
[32]	Chicken manure, dry grasses and straw	20		6.9-7	6.5-8				
[45]	MSW with bulking agents (cornstalks, sawdust, and spent mushroom substrate)	31	18	6–7	7–8.5				
[33, B]	Chicken manure and sawdust in different ratio	28.1	16.2	7.68	7.58			59.7	44.3
[64]	Foodwaste and bulking agent (wood chip)	25	16	4.4 -7.3	8.6				

ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

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[65]	Organic waste (cattle manure ,green vegetables)bulking agents (sawdust)	22	11 to 19						
[33, B]	Chicken manure and sawdust in different ratio	28		7.3	7.9				

TABLE III: OPTIMAL AERATION RATES FOR AEROBIC COMPOSTING SYSTEMS

Optimal aeration rate	Raw material	Ventilation method	Reference
0.4 L min^{-1} $kg^{-1}OM^{a}$	Grass, tomato, pepper and eggplant wastes	Intermittent aeration of 15 min on/45 min off	[66]
0.25 L min^{-1} $kg^{-1}VS^{b}$	Dairy manure with rice straw	Continuous aeration	[22]
0.6L min^{-1} kg^{-1} in active phase, 0.4 L min^{-1} kg^{-1} in curing phase	Active municipal solid waste	Continuous aeration	[67]
0.5L min^{-1} $kg^{-1}OM^{a}$	Chicken manure with sawdust	Continuous and intermittent aeration	[68]
0.1 m^{-3} min^{-1} m^{-3}	Grass, tomato, pepper and eggplant wastes	Intermittent aeration of 30 min on/ 30 min off	[69]
0.29-0.33$m^{3}min^{-1}$	Swine manure with pine sawdust	Intermittent aeration of 10 min/h interval	[26]
0.48 L kg^{-1} $DM^{c}min^{-1}$	Pig faeces with cornstalks with different initial C/N ratio	Intermittent aeration with 25 min of aeration following 5 min interval	(17)
0.01,0.1,0.2 m^{-3} min^{-1} m^{-3}	Chicken manure, dry grasses and straw	Intermittent aeration of 30 min on/ 30 min off fo the first 7 days and then continuous aeration for the rest of the composting time.	[32]
0.25 L min^{-1} kg^{-1}(wet wt)	Municipal solid waste	Continuous aeration	[62]
0.2 L min^{-1} kg^{-1}(wet wt)	Municipal solid waste	Continuous aeration	[60]
180 L min^{-1}	Chicken manure and sawdust in different ratio	Change in the rate of aeration to continuous or intermittent mode based on the temperature of compost.	[33, B]
0.1 $Lmin^{-1}$ kg^{-1} OM^{a}	Municipal solid waste	Continuous aeration	[70]

OM^{a}: oraganic matter , DM^{c}: dry matter , VS^{b}: volatile solid

TABLE IV: THE MAIN GOVERNING CHARACTERISTICS OF ORGANIC SOLID WASTE

Reference	Composting Material	Aeration Strategy	Composting Pile type	Moisture (%)	Max Temp (^{0}C)	Thermophilic phase duration	Composting duration (days)

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During 15-16 November, 2013

Organized by

Department of Civil Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar, Arunachal Pradesh, India.

						(days)	
[58]	Olive tree pruning and cereal straw	Forced aeration	Laboratory-closed vessel	50-60	55-58	45	126
[16]	Pre- treated Rice straw and cattle manure	Forced aeration and manual rotation after every 24 hours	in-vessel	59.76	50	43	44
[59]	Swine manure with pine sawdust	Forced aeration and turned once on the 12th day	in- vessel	59.9	65.7	16	29
[17]	Pig faeces with cornstalks with different initial C/N ratio	Forced aeration	in-vessel	65,70,75 (constant)	75	21	37
[60]	Municipal solid waste	forced aeration and manual rotation	in-vessel	64	56	10	37
[61]	Municipal solid waste	forced aeration	in-vessel	70	52		
[62]	Municipal solid waste	Forced aeration and also turned manually at an interval of one day	in-vessel	60	73	29	60
[63]	Food wastes (Sausage) with green waste (of ratio 1:4)	Manual turning	in-vessel		67	6	17
[32]	Chicken manure, dry grasses and straw	Aeration and also manual turning	in-vessel	65	73	10	25
[45]	MSW with bulking agents (cornstalks, sawdust, and spent mushroom substrate)	Forced aeration	in-vessel	79	79	7	28
[17. a]	Chicken manure and sawdust in different ratio	Forced aeration	in-vessel		68	8 to 9	62
[64]	Food wastes and bulk agent (wood chip)	Forced aeration	in-vessel	58	60	15	30
[65]	Organic waste (cattle manure ,green vegetables)bulking agents (sawdust)	Manual turning	in-vessel	65(averag e)	58	5	15
[33. A]	Chicken manure and sawdust in different ratio	forced aeration	in-vessel	78.2 (chicken), 8.5 (sawdust)	68.9 (for initial C/N ratio of 28)	10	120