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Composting of Municipal Organic Solid Waste and Biological Way For Odor Removal -A Review

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ABSTRACT
Composting is the process of microbial degradation of organic solid waste material to form a humus like substance. Compost formed after this process is rich in nutrients, thus can be used as an amendment in soil fertility and fertilizer for plants. Municipal solid waste generated from urban cities is in large amount. This waste can be processed to form compost by the microbial composting method. Odor generated by waste is an important concern because it releases many volatile organic compounds (VOCs) and harmful gases like Hydrogen sulphide and Ammonia. These gasses and VOCsare harmful for environment and human health. Hence, odor removal is also of great importance along with composting of waste. Odor generation and composting of waste are related to each other. As slow rate of composting can cause high odor generation, composting should take place at efficient rate for reduced odor generation. The current review focused on the process, types of composting, factors affecting the composting. This review also provides an overview of generation of odor and existing biological ways to remove the odor of Municipal solid waste.
Keywords: *Municipal Organic Solid Waste, Composting, Odor Removal, Microbial Inoculants.*

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INTRODUCTION

Generation of municipal solid waste is rising continuously. Rapidly increasing population is responsible for urbanization which leads to production of waste and waste processing problems. About 43% of municipal solid waste is generated annually by the Asian countries [1].Rapid industrialization in India has led to the migration of people from villages to cities, which generate thousands of tons of municipal solid waste (MSW) daily [12].Most of the waste is subjected to dumping yard or managed by incineration and landfill. Dumped waste produces undesired products and leachate which is responsible for unpleasant odor [2]. The greatest challenge is to manage such waste with eco-friendly way. Application of microorganism for decomposition of municipal solid waste is a better way to manage waste [3]. Municipal solid waste contains about 70-85% of biodegradable waste [24]. The biodegradable waste mainly consists of carbohydrates, proteins, fatty acids, amino acids, volatile acids etc. composting of such waste appears to cost effective and eco- friendly [6].Composting is an aerobic, microorganism mediated solid state fermentation process by which complex material is transformed into simple and stable form [4]. Variety of microorganisms are involved in composting process such as thermophilic and mesophilic bacteria, fungi and actinomycetese.g.,*Bacillus sp., Thurmus sp.,Hydrogenobacter spp.,Pseudomonas sp., Clostridium sp.,Trichoderma sp., Aspergillus sp., Thermoactinomycetacea* family etc. [5,7,8]. Composting is widely used method because of its resource utilizing potential. Odor and volatile organic compounds are produced during loading, unloading, sorting and processing. These compounds are produced in high concentration, they are corrosive, irritant and it has unpleasant odor.The bad odor causing compounds are hydrogen sulfide, ammonia, mercaptan, low molecular weight fatty acids, chlorides, linear alkanes and aromatic hydrocarbons etc. They are responsible for health hazardous and risks in human [9]. The odorous gas emission generally consists of carbon dioxide, methane and non- methane compounds such as nitrates, alcohol, ester, ketone, sulphides etc. In addition, if the waste is too wet, bulk density is too high or air supply is limited, in such cases the generation of odor causing compounds is more and it increases emission of volatile organic compounds. The odor generation and its impact are very clear during the composting phases. Less aeration condition or oxygen deficit condition can be observed during composing due to utilization by microbes. Thermophilic condition and waste composition also contributes in production and emission of volatile compounds which produces odor. Biological process as well as waste characteristics play important role in generation and emission of volatile organic compounds [10]. Hence, before starting the composting process there must have odor management system or treatment because, odorous waste is more health hazardous and difficult to handle and process.Municipal solid waste and their generation problems are the continuous but the effective management and process is challenging part. Decomposition is the best way to treat the organic part of MSW. Compost formed through the process is a need of agriculture in present and in future also. Making a valuable resource from the organic waste by the composting process is an efficient way of managing MSW. It is possible to have an effective treatment process for odor removal and enhanced decomposition of municipal organic solid waste. In municipal solid waste management, there is no single approach can apply due to community diversity and waste composition. In this case composting is the only technique can be utilized in environment friendly and sustainable manner.

COMPOSTING

Composting is a natural degradation process. In different composting methods, decomposition of organic matter using microorganisms under controlled condition is carried out. Different types of organic residues such as crop residues, food waste as well as municipal wastes are decomposed and nutrient rich compost has been prepared. The addition of microbial enrichment in soil is necessary to restore the soil health because organic matter in soil plays very important role in sustainable agriculture and soil fertility.Composting is an integrated waste management process and used to recycle organic wastes into a useful product. There are several composting methods and their duration, potency, stability and maturity parameters are also varied and depends upon the decomposing material [11]. The only most effective option to manage waste is composting because it has some advantages such as low operational cost, less environmental pollution i.ewater and air pollution and beneficial use ofit's end product. It can remediate soil and degrade hydrocarbons. Contaminated soil, toxic compounds, metal organic residues can be remediated by composting process and it can accelerate destruction of contaminants. Composting can degrade various organic compounds present in the waste with proper aeration, mixing, water content and time [41].Odor emission is the basic problem in composting and waste treatment site. Odor generation and emission is associated with the decomposition process. There is a relation between odor generation and slow composting at prolonged low pH in food waste. Hence, a strategy for reducing odor from waste is to overcome the initial low-pH phase is essential. This can be obtained by providing oxygen, mixing and additives such as recycled compost [13]. To control odor in waste the Bio-filtration technique is available [15]. The waste can be treated without generating hazardous residue and has an ability to remove odorous compounds. The volatile organic compounds are the major cause of odor generation such compounds are generated during slow composting. The volatile organic compounds and other odor causing compounds are removed with the help of microorganism present in the biofilter [9,14]. Effective, mature and enhanced composting process may reduce foul odor production during decomposition.

TYPES OF COMPOSTING

Composting is an aerobic process. There are several known composting methods: 1) Windrow Composting 2) Pit Composting 3) Heap Composting 4) In-Vessel Composting 5) Vermicomposting. Among these known methods Pit and Vermicomposting commonly practiced by farmers. Along with these methods there are some mechanical machines available for composting by which composting is done aerobically and anaerobically also. Hot water jacketed rotating drum is used in aerobic composting machine and in anaerobic composter machine is closed at all and mixing and mechanical part is same as aerobic composter machine. The composting process requires minimum 90 to 120 days to complete the process and maturity of the compost[11,16,17].

1) **Windrow Composting:** In this composting method, 1 m^3 volume of homogenized waste (~275 kg dry weight) is heaped into conical piles in about 1 m^2 area and moisture is maintained to 50 60%. by spraying or adding water. The waste is decomposed for 100 days. The piled heap is turned after every week and moisture is balanced as per need [11].
2) **Pit Composting:** Waste is decomposed in a pit (4feet dept.) or with dimension of 1 × 1 × 1 m (length width and depth). Moisture level is maintained by adding water and turning of waste is done every week [11,17].
3) **Heap Composting**: A mixed waste is arranged in a heap.A heap can be prepared in a size of 3m × 1.5m×1m (length×width×depth). The waste is allowed to wilt for few days to remove excess moisture. The heap is built in a layer form. Water and cattle dung is spread in layers and layering sequence is continued till the heap is raised to a height of 50 100 cm above the ground level. Top layer of heap is then covered with a thin layer of soil, and the heap is kept moist. Water balanced is maintained by spraying water and turning can be performed three times in 60 days composting period [18].

4) **In- Vessel Composting:** The mixed waste decomposed into an earthen pot or vessel. Waste is arranged in a layer with cow dung. Turning and mixing is done after every week [17]
5) **Vermicomposting:** The earthworms are used in vermicomposting to decompose the waste. It is performed in vermicomposting bed made by polyethylene sheet measuring 1 × 1 × 0.3 m (length, width and height respectively). The excess water is drained from tiny holes on bottom of the sheet. Mature earthworms (*E.foetida*) are introduced at the recommended stocking rate of 250 adult worms per 20 kg of bio-waste. The moisture is maintained between 70 and 80% [19].

GENERATION OF ODOR AND FACTORS AFFECTING COMPOSTING PROCESS

When treating municipal organic solid waste using the composting process, odor generation is a major challenge. In high quantities, waste primarily consists of molecules comprising sulphur, nitrogen, oxygen, and different hydrocarbons; these compounds are quite similar to those found in landfill gases. Studies that examined the ambient air quality of garbage disposal and landfill sites frequently employed substances including ammonia, hydrogen sulphide (H2S), fatty acids, and aromatic acids. Hydrogen sulphide concentrations and odor concentrations have been found to be correlated [2].Composting is a technique for both recycling and garbage decomposition. Agricultural residues are broken down by microbes with lignocellulolytic activity, including bacteria, fungi, and actinomycetes. When compost is put to soil, the fertility and health of the soil are improved. The C/N ratio affects nutritional balance during composting, which is equally significant. For a quick and effective composting process, a C/N ratio of between 25 and 30 is ideal during active aerobic decomposition. The depletion of available nitrogen is caused by excess carbon conditions (a higher C/N ratio). While low C:N ratios (less than 20:1) suggest that the compost is unstable. It is in charge of momentarily stifling microbial development and activity [20]. When composting, ideal circumstances include moisture, pH, temperature, and aeration. For quick, aerobic degradation, microorganisms are necessary. The optimal conditions for degradation are moisture content between 45% and 60% by weight, pH between 5.5 and 8.5, accessible oxygen concentration greater than 5%, and waste particle size no greater than 1 inch. These elements and factors have an impact on the composting process, and the affected process is in charge of the delayed decomposition and odor creation on the property. Due to their synergistic activity and use of intermediate degradation products, mixed microbial consortia made up of fungi, bacteria, and actinomycetes can accelerate the rate of lignocellulose degradation [21].

ODOR REMOVAL TECHNOLOGIES AND PROCESS METHODS

As the odor is generated from different types of volatile organic compounds, gasses during conversation, low pH condition and affected process. Hence the odor reduction strategy for municipal solid waste is to overcome low pH condition as well as give oxygen to the process. Different type of amendments such as ready mature compost, ash, lime, wood waste etc. are used to overcome odor problem and enhance composting process. In large scale composting, high aeration and oxygen supply through mixing is important to increase pH and reduce odor. Mixing or aeration always speed up the process [13]. This is the natural way to treat the odorous waste.

BIOFILTRATION TECHNOLOGY

Biofiltration is a simple process to treat odor and volatile organic compounds in municipal solid waste. Biological mechanical treatments such as biostabilization and mechanical separation are widely used as a pretreatment for municipal solid waste. During these biomechanical processes odor is generated due to decomposition of organic compounds. In an aerobic treatment, carbonyl compounds, alcohol, ether and sulphur compounds are present. Biofiltration technology has an ability to remove odorous compounds without generating hazardous residue. It can effectively eliminate of VOCs, such as ethylbenzene, benzene, styrene and toluene using biofilters. Biofilter contains layers of filter material such as soil, wood chips, compost or mixed materials. The odorous gas stream is passed through the biofilters and it is treated or get degraded through biofilter media with the help of different types of microorganisms [14].*Pseudomonas* sp., *Bacillus* sp., *Arthrobacter*sp.,*Actinobacteria* sp., *Brevibacillus* sp., *Aspergillus*sp., *Paenibacillus* sp., are used in the packing media. Firmicutes and Proteobacteria are the dominant bacteria in the inoculums [22, 23].

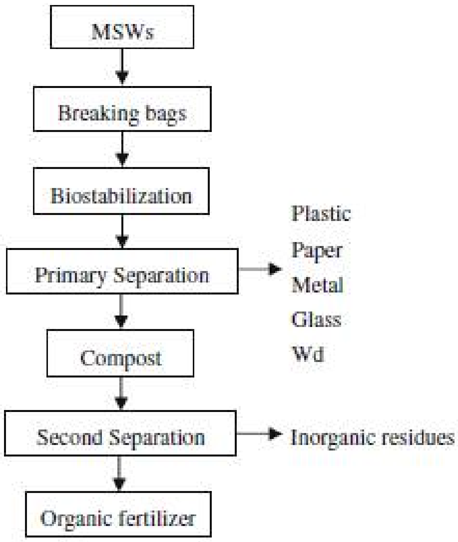

Fig. 1. Technological process of Meishang Company.

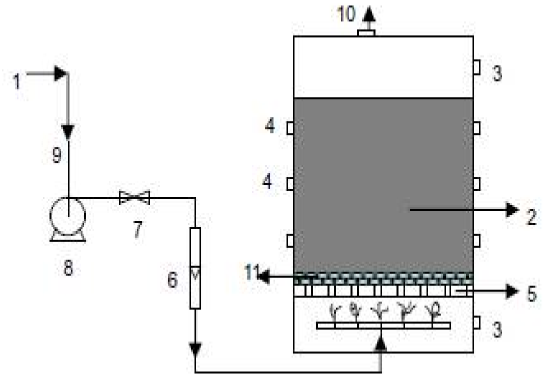

Fig. 2. Schematic diagram of the compost biofilter. (1) Odor from MSW composting, (2) compost material, (3) gas sampling ports, (4) solid sampling ports, (5) perforated support, (6) rotator flow meter, (7) valve, (8) blower, (9) 40 m PVC tubes, (10) treated air and (11) ceramic particles.

[14]

Three-stage integrated biofilter:

Three-stage integrated biofilter (TSIBF) composed of acidophilic bacteria reaction segment (ABRS), fungal reaction segment (FRS) and heterotrophic bacteria reaction segment (HBRS). It is used for the treatment of odors and volatile organic compounds (VOCs)from municipal solid waste (MSW). This is stable and efficient system for removal of hydrogen sulfide, ammonia and VOCs. Due to the differences in reaction conditions and mass transfer in each segment the removal efficiencies of odors and VOCs are different.

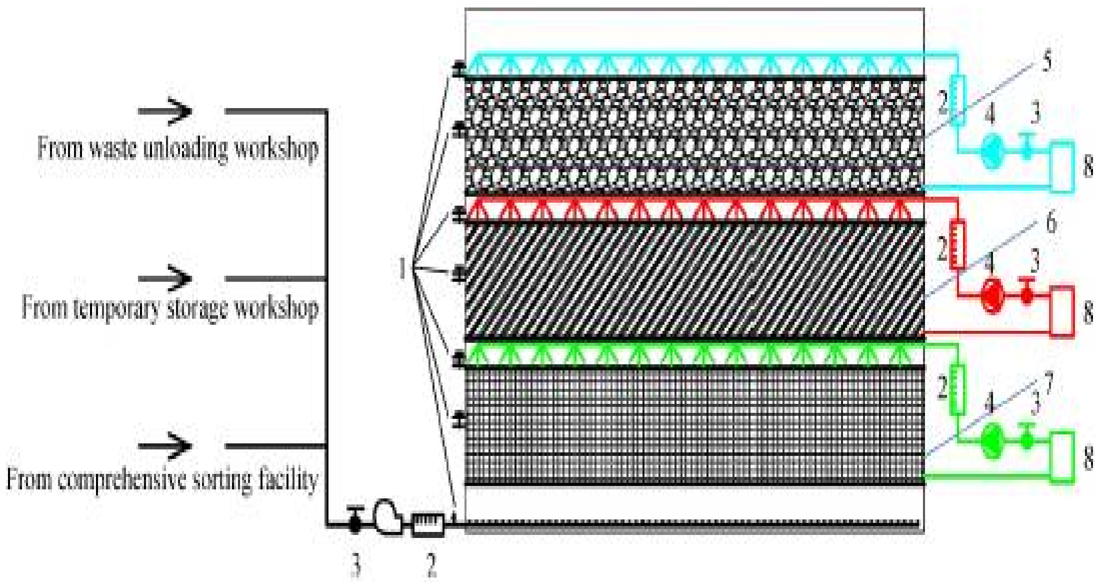

Fig.3. The TSIBF diagram. 1. Sampling port, 2. Flowmeter, 3. Valve, 4. Pump of liquid circulation, 5. Heterotrophic bacteria reaction segment, 6. Fungal reaction segment, 7. Acidophilic bacteria reaction segment, 8. Nutrient solution tank.

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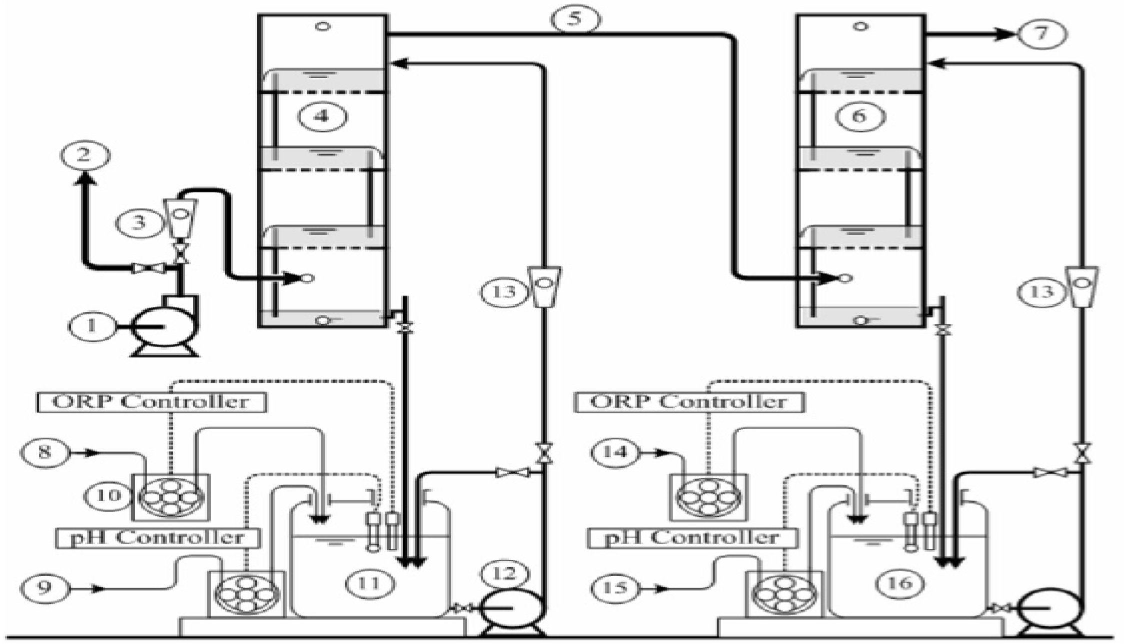
Pollutants	Total removal efficiency (%)	Removal efficiency of ABRS (%)	Removal efficiency of FRS (%)	Removal efficiency of HBRS (%)	Average removal efficiency (%)
Ammonia	99.57±5.82	65.31±3.63	23.06±1.64	11.63±0.85	99.57
Hydrogen sulfide	98.96±6.17	74.87±3.92	9.76±0.81	14.39±1.03	98.96
Methylmercaptan	99.32±6.34	70.25±3.43	13.45±1.15	15.62±1.27	99.32
Dimethyl sulfide	99.05±6.51	71.08±3.78	11.22±0.96	16.75±1.33	99.05
Ethanethiol	98.75±6.22	76.22±3.73	13.15±1.04	9.38±0.93	98.75
Dimethyl disulfide	96.47±6.48	73.59±3.66	12.06±0.98	10.82±0.95	96.47
Methanol	99.92±6.78	6.75±0.52	14.99±1.05	78.18±4.26	99.92
Ethanol	99.84±6.61	7.87±0.63	17.74±1.33	74.23±5.05	99.84
Acetic acid	99.67±7.35	8.05±0.77	16.28±1.29	75.34±5.84	99.67
Acetone	99.21±7.14	10.14±0.95	13.05±1.41	76.02±5.59	99.21
Ethyl acetate	99.48±6.82	9.76±0.85	18.37±1.33	71.35±4.86	99.48
Butyl acetate	98.93±6.90	11.38±1.05	17.15±1.56	70.4±4.75	98.93
Benzene	99.12±5.87	4.81±0.25	78.26±5.05	16.05±1.21	99.12
Toluene	98.76±6.22	5.26±0.34	76.33±4.78	17.17±0.81	98.76
Ethyl benzene	98.05±5.17	5.84±0.31	81.58±5.44	10.63±0.69	96.25
Styrene	98.38±5.92	6.67±0.38	78.81±4.97	12.9±1.14	97.88
P-xylene	97.17±6.15	4.22±0.19	79.32±5.16	13.63±1.23	96.17
α-pinene	95.86±4.94	4.55±0.30	81.44±4.93	9.87±0.73	95.86
Cyclohexane	94.39±6.61	5.54±0.42	79.04±5.07	9.81±0.72	94.39

Fig. 4. Odor and VOC substances removal characteristics of TIBS. [9]

The volatilization of the packing and the collection of microorganisms from the intake are both necessary for the emission of bioaerosols in the TSIBF. The TSIBF was logically segmented, high-density packings were filled, and the majority of functional microorganisms accumulated in each segment improved bioaerosol collection and decreased microorganism emission in the outlet. TSIBF can successfully eliminate a variety of smells and VOCs. pollutants that contain sulphur, pollutants that are both hydrophobic and hydrophilic[9].

SCRUBBING TECHNOLOGY

Municipal solid waste gases are treated using a two-stage oxidative-reductive scrubber tower system. It has four metering pumps, two sieve-plate scrubbers, sodium hypochlorite (an acidic cleaning liquid), sodium bisulfite (an alkaline cleaning liquid), sodium hydroxide, and sulfuric acid for pH adjustment.



[2]

Fig.5. A schematic figure of two-stage oxidative-reductive scrubbing tower system. (1) kitchen waste composting gas stream (2) vent gas (3) gas flow meter (4) sieve-plate scrubber (5) effluent gas from the acidic scrubber (6) sieveplate scrubber (alkaline scrubber) (7) effluent gas from the alkaline scrubber (8) NaOCl solution (9) H_2SO_4 solution (10) metering pump (11) acidic chlorine solution (12) scrubbing liquid pump (13) liquid flow meter (14) $Na_2S_2O_3$ solution (15) NaOH solution (16) alkaline $Na_2S_2O_3$ solution.

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The odour of the composting gases is eliminated by oxidising the odor-causing molecules, which is followed by reduction in the second scrubbing step to eliminate those that cannot be oxidised. Ammonia and hydrogen sulphide, which contain both nitrogen and sulphur, can be oxidised to produce nitrogen gas and sulphate [2].

PHASES OF COMPOSTING PROCESS AND ODOR EMISSION

Composting is a degradation process which is carried out by various microbes. According to the microbial growth, proliferation and degradation conditions there are three different phases occurs during composing process. 1) Lag phase 2) Active phase 3) Maturation phase. The microbial community found in lag phase i.e., Mesophilic condition, Log phase i.e., Thermophilic and Maturation i.e., stabilization phase, are different and adapted to particular type ofenvironment and organic material. During these intense phase of microbial activity, organic waste undergoes an aerobic, anaerobic and anoxic transformations which leads to release of potential odorants. The composition of gases and odorants are different with their substrate composition and also depends upon operational conditions. Emission of odor compound such as alcohols, esters, and ketones are generally found in vegetable, feedstock and municipal solid waste. Emission from agricultural waste, sewage sludge mainly composed of ammonia and it generates strong odor emission [27].

1) **Lag Phase:** It is an early stage of composting process also called mesophilic phase. During this phase microbe begins to proliferate using compounds present in the waste such as starch, sugar, amino acids. Breakdown of waste releases different nutrients and it accelerate microbial proliferation. Due to this microbial action and breakdown of waste temperature begins to rise in waste [24]. Volatile fatty acids and reduced sulphur compounds are the main causes of odor in municipal solid waste. Anaerobic decomposition results in the formation of sulphur gases, and it has been discovered that odorous gases, such as methyl mercaptan and dimethyl sulphide, are also created under aerobic composting conditions. Due to the anaerobic microenvironment the anaerobes are responsible for significant metabolic activity. Low oxygen concentration in early stage of composting produces more odorous gases.It is also reported that increased aeration and oxygen can cause reduction in concentration of odorous compounds but it also increases emission. Maintaining aerobic conditions in compost through process management did not stop the production of potent aromas in terms of odor emissions. As a result, larger odor treatment facilities are needed. If aeration is fixed or constant during the composting process, it would lead to higher gas concentrations but lower emission rates. It may also potentiallyreduce size of odor treatment facilities [25].Application of bulking agent like wood ash is useful to accelerate the process by increasing pH, heat and microbial activity. In composting process increase in pH and temperature may leads to ammonia emission. Hence, a careful control of aeration and amendment of bulking agent such as wood ash can be useful to avoid the potential odor annoyance [26].Odor emission greatly affected by initial moisture conditions of waste. The generation of odor causing compound, its concentration and emission are also high with initial high moisture condition. Odor and ammonia emission is significantly high at 65% moisture level. It is also observed that if the organicvolatile solid is increased up to 55% which contributes in odor emission rate and concentration [28].
2) **Active Phase:** It is second and thermophilic phase of composting process. Thermophilic phase of composting indicates rapid increase of microbial number in waste. This phase remains constant until the easily decomposable material remains in enough quantity to support their growth and intense activity. During this phase the temperature may peak at 70^{0}C or more if countermeasures are not taken [24].While performing mixing or turning of the waste material the odorants such and volatile organic compounds are at its high peak due to the temperature.Hence, in active phase of composting odor emission may found more diverse.Hydrogen sulfide, methanethiol, dimethyl sulfide, and dimethyl disulfide are highlighted as the major odor contributors during composting of organic substrates [29].
3) **Maturation phase:** It is a stabilization phase in which compost is matured with their nutritional values. This phase begins because the decomposable material and nutrients gets depleted by the microbes. The microbial number and temperature also decrease. The temperature remains constant to the ambient stage. It requires time for stabilization of final compost and it depends on environmental factors, operational conditions and function of substrate [24].

ENHANCED COMPOSING PROCESS USING MICROBIAL INOCULANTS

Composting of municipal organic solid waste is a need of waste management. Organic compost is a very essential part of fertilizers and agriculture sector. Hence, the proper and effective composting process is required to produce a good quality of compost. As the composting process is microbial decomposition process and it can be enhanced or modified with the help of process change and microbial inoculum.

Lignocellulose is a major component of municipal and agriculture waste. It can be decomposed by bacteria, fungi and actinomycetes. Degradation is possible due to synergistic activity of these microbes. In order to enhance decomposition processes and humification, microorganisms such as *Bacillus casei, Lactobacillus buchneri* and *Candida rugopelliculosa* and ligno-cellulolytic *Trichoderma* and *White-rot fungi* are respectively inoculated in the composting process [30].

Inoculation of microbes enhances the degradation of proteins, and polysaccharides and increases the molecular weight, humicand fulvic-like compound content. To improve composting process an optimized inoculation should be followed according to the organic matter composition and temperature. The stage of microbial inoculation also plays important role in processenhancement. Cellulose degrading bacteria can be inoculated in active stage and lignin decomposing microbes can be inoculated in curing stage of the process for better results. Microbial deodorization can be possible when inoculated in initial stage of the process and it consists of ammonia-oxidizing bacterium, *Nitrobacter sp.* and *Thiobacillussp*. respectively and cellulose decomposition composite microorganisms [31]. The microbial population slightly different according to the stage of composting process. It is possible that microbial groups, counts are more at the mesophilic phases in comparison to those at the thermophilic stage. Fungi are less in numbers than bacteria and actinobacteria [32]. The microorganisms having metabolic capability to hydrolyze starch, pectin, lipid, and protein; lignocellulose fractions degradation, ammonification, and phosphate solubilization are considered best for inoculum development. [33]. Organic acids produced during decomposition process are used by fungi to enhance their growth. However, the fungi are responsible for modification of the environmental conditions allowing for the activity of thermophilic bacteria. Degradation of organic acids, pH modificationand enhanced growth of thermophilic bacteria can accelerate composing process.Hence, Lactic acid bacteria can be used for enhanced degradation of municipal organic solid waste. Following table describes the microbial diversity according to the phases of composting [34].

Strain	Origin description[a]	Inoculation time (d)[b]	Accession no.[c]	Metabolic activities[d]
Bacillus licheniformis AM-2	Raw materials	0	JN013202.1	1,4,5,8
Bacillus subtilis AM-25	Raw materials	0	JQ403532.1	1,4,5,8
Microbacterium gubbeenense AM-28	Raw materials	0	EU863414.1	1,4,5
Bacillus licheniformis AT-1081	Raw materials	0	EU650317.1	4,8
Bacillus licheniformis BM-1988	Raw materials	0	EF472268.1	1,3,4,8
Brevibacterium halotolerans BM-2015	Raw materials	0	KC967073.1	1,3,4,5,8
Bacillus licheniformis BT-2928	Raw materials	0	HM753625.1	1,2,4,5,8
Bacillus subtilis BT-2938	Raw materials	0	FJ969738.1	4
Scopulariopsis brevicaulis HM-4299	Raw materials	0	EU436681.1	1,3,4,5,8
Gibellulopsis nigrescens HM-4232	Raw materials	0	HE972037.1	1,2,3,4,5,8
Scopulariopsis brevicaulis HM-4276	Raw materials	0	EU821476.1	2,4,5,8
Plectosphaerella cucumerina HM-4244	Raw materials	0	EU594566.1	1,8
Gibellulopsis nigrescens HM-4234	Raw materials	0	HE972037.1	1,2,3,4,5,8
Candida mycentagii HM-4205	Raw materials	0	FJ381698.1	2,3,8
Corynebacterium casei AM-52	Mesophilic phase (↑)[e]	1	JX966460.1	8
Microbacterium indicum AM-54	Mesophilic phase (↑)	1	NR_042459.1	1,4,8
Brachybacterium paraconglomeratum AM-62	Mesophilic phase (↑)	1	JN6495995.1	1,4,8
Bacillus thermoamylovorans AT-1163	Mesophilic phase (↑)	1	AB360815.1	1,4
Bacillus licheniformis BT-3008	Mesophilic phase (↑)	1	KC441778.1	3,4
Ureibacillus thermosphaericus BT-3010	Mesophilic phase (↑)	1	AB300774.1	8
Aspergillus fumigatus HT-5360	Mesophilic phase (↑)	1	HQ026746.1	3,5,8
Scopulariopsis brevicaulis HM-4378	Mesophilic phase (↑)	1	EU436681.1	3,4,5,6,8
Cladosporium lignicola HM-4334	Mesophilic phase (↑)	1	AF393709.2	7,8
Microbacterium gubbeenense AM-81	Thermophilic phase	2	EU863414.1	4
Pseudoxanthomonas taiwanensis BT-3042	Thermophilic phase	2	AB681369.1	8
Chelatococcus daeguensis BT-3147	Thermophilic phase	5	HM000004.1	8
Arthrobacter russicus BT-3271	Mesophilic phase (↑)	9	NR_024783.1	8
Ochrocladosporium frigidarii HM-4685	Mesophilic phase (↑)	9	FJ755255.1	8,9
Scopulariopsis brevicaulis HM-4784	Thermophilic phase	12	KC311514.1	1,2,3,4,5,8
Unidentified strain AM-321	Mesophilic phase (↓)	14	–	1,4,8

[a] Stage at which the strains were isolated in a previous composting trial.
[b] Days after the beginning of composting in E2 pile at which the strains were inoculated.
[c] National Center of Biotechnology Information (NCBI, http://blast.ncbi.nlm.nih.gov/Blast.cgi).
[d] Metabolic activities: amylolysis (1), pectin hydrolysis (2), lipolysis (3), proteolysis (4), hemicellulolysis (5), cellulolysis (6), lignolysis (7), ammonification (8), phosphate solubilization (9).
[e] Temperature was increasing from mesophilic to thermophilic stage (↑) or decreasing from thermophilic to mesophilic stage (↓).

Development of the inoculum, the number of cells, and the effectiveness of the microbes are crucial aspects. It was important to utilize cultures in a liquid medium to get the ideal amount of microbial cells in the inoculum. Microbes need time to adjust to semisolid and solid media, which are hostile to them. The conditions in an experiment are also distinct from those in nature [35]. The temperature changes during the composting of different organic matter, along with chemical changes such as changes in organic C, total N, C:N ratio, activities of cellulase, xylanase, and protease, and biological changes such as microbial cell count, indicate a succession of active microbe populations and the process. The microbial count reaches its optimum level during the active phase of composting, leading to maximum microbial activity and a higher rate of breakdown. On the other hand, a declining C:N ratio denotes the completion of the process and the maturity of the compost [36]. A more economical method for open windrow composting is fungus consortia. It needs to be turned every week, is efficient at changing the temperature, and degrades more quickly. Enzymatic activity (cellulases, proteases, amylase, and lipases) at a variety of temperatures and pH levels, as well as substrate-specific organic waste degradation, can be used to make it. Species are chosen for inoculum preparation based on the performance of synergistic enzymatic activity. On potato dextrose agar, *Trichodermaviride*, *Aspergillus niger*, and *Aspergillus flavus* are employed and grown. For the generation of the inoculum, the spore suspensions of *T. viride*(6.8 106 spore/ml), *A. niger* (4.5 104 spore/ml), and *A. flavus* (4.5 104 spore/ml) are each necessary [37]. In comparison to a fungal consortium, a bacterial and fungal consortium may degrade more quickly. It is made of dried fermentation byproducts of Saccharomyces cerevisiae, *Trichodermareesei*, *Aspergillus niger*, *Bacillus megaterium*, *Bacillus licheniformis, Bacillus subtilis*, dried whey, and silicon dioxide. Bacillus bacteria must have a minimum of 4 109 Colony Forming Units (CFU) g1 [38]. A human-induced technique called inoculum generation and inoculation can greatly improve the composting process by boosting the original microbial population, creating viable microbial communities, and producing the required enzymes. If inoculation is carried out in accordance with process parameters and requirements, it can greatly improve biodegradations and reduce odor emissions [39]. Inoculation is a practical method for hastening the breakdown of lignocellulosic waste. When administered throughout various composting phases, the inoculations had various results. Since it increased temperature and sped up the composting process, the inoculation during the active period was more successful than that during the lag phase [40].

UTILIZATION OF MSW COMPOST IN AGRICULTURE AND AMENDMENT OF SOIL MICROBES

Compost is a significant source of organic fertilizer for plants and is rich in organic matter. The microbiological activity of the soil is stimulated by MSW compost, which is directly related to soil fertility. As a result, compost influences soil biological characteristics either directly or indirectly [47]. Compost made from municipal solid waste can be improved by adding consortiums of *Trichoderma* species, Nitrogen Fixing Bacteria, Phosphate Solubilizing Bacteria, Zinc Solubilizing Bacteria, and Potassium Mobilizing Bacteria. Chemical fertilizer usage can be successfully decreased thanks to it [42]. Compost made from municipal solid waste is excellent for seedling growth. It can lessen the detrimental effects of high pH and EC on the growth of seedlings [43]. It can replace sphagnum peat in container media and enhance the physical qualities of the soil. Compost can provide important NPK plant nutrients that release slowly [44]. Application of MSW composts to the soil is a useful waste management technique and may significantly reduce the need for mineral fertilizers [45]. By enhancing the soil's ability to hold nutrients and water, municipal solid waste composts enhance soil fertility and physical characteristics. It can boost soil nutrients, pH, cation exchange capacity, total pore space, and apparent soil density [46].

CONCLUSION

Composing can be a good option for management of municipal organic solid waste. Compost produced from this waste has nutritive values and used as organic fertilizer in agriculture. Soil microbes and fertility can be restored using municipal solid waste compost. Composting is microbial process but appropriate process and balanced reaction is equally important. Unbalanced process, affected segregation may leads to process failure.

High moisture, low aeration, C:N ratio, pH, inoculum addition, temperature and environmental factors such as different seasons has great influence on the process.Odor emission during different phases and its control is an important part of composting process. This occurs due to slow and inappropriate process but it can be controlled by adding beneficial microbes.Controlled process, inoculum addition to enhance the reaction, odor control practices with application of microbes are interlinked processes. Hence, if it is carried out with in controlled manner then it can be served as good process practice for municipal solid waste management. Application of microbial inoculumdoes not correct the process faults. It cannot enhance the process and unable to control odor if the proper process is not followed.Composting of organic waste is always a better approach for waste management but it should be done in a proper and controlled way then only it will serve a quality byproduct “Compost”.

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