OPEN ACCESS INTERNATIONAL JOURNAL OF SCIENCE & ENGINEERING

# IN-VESSEL COMPOSTING: A RAPID TECHNOLOGY FOR CONVERSION OF BIOWASTE INTO COMPOST

**Vivek Manyapu[1], Sudeep Shukla[2], Sunil Kumar[3] ,Kushagra Rajendra[4]**
*Amity School of Earth and Environmental Sciences, Amity University Haryana, Gurgaon 122413, India*
*CSIR-National Environmental Engineering Research Institute (NEERI), Nehru Marg, Nagpur 440020, India*
***krajendra@ggn.amity.edu***

---

*Abstract:* **Composting always proved to be the Nature-friendly and sustainable method for getting rid of the huge burden of biowaste. As we witness, there is an intractable growth of human population and their unlimited consumption of different goods produce a tremendous amount of waste. In New Delhi itself, more than 9500 tons of waste is generated every day, out of which 8000 tons per day goes to the landfilling, which is the most commonly practiced method. This malignant process instead of solving the problem of waste, in turn, causes more problems like methane emission, heavy metal leaching into groundwater, soil pollution, etc. Composting mimics natural mineralization process which is the alternative solution of resource recovery with no side-effects. To curb such a huge amount of waste, the composting process must be rapidified and achieved by in-vessel composting, where the partial anaerobic condition is reduced by enforced aeration and critical parameters like moisture and temperature can be controlled. Aerobic bacteria are the main agents which speed up the composting process. Moreover, easily available natural additives like buttermilk, jaggery, sugar, etc. also speed up the microbial process and increase the efficiency. So, the in-vessel composting provides efficient compost in a very short time period. This paper will provide a critical assessment of In-vessel composting in terms of process parameters and efficiency in comparison with conventional methods. This process can be critically utilized for community-based composting at small scale compost production, which will be a key to link daily household waste with resource generation with the aim to achieve Swach Bharat Mission.**

***Keywords:*** *Composting, biowaste, landfilling, methane, heavy metals, in-vessel composting, additives.*

---

## I INTRODUCTION

The population of this Earth is increasing at a tremendous rate and becoming uncontrollable. The population count reached to 7.5 billion and is still increasing [1]. The exaggerating population is supposed to be fed with a huge amount of food. It's been estimated that by the year 2050 the population will touch 9.1 billion and the food demand will increase by 70% [2]. Every year, globally, 1300 million tons of food is being wasted [3] which results in substantial loss of precious resources which otherwise can be utilized as source for value added products including fertilizers, energy materials. In general, the food waste finds its way to dump yards or landfills along with MSW finally. According to UNDP, in India, about 40% of produced food is wasted. Apart from wastage of food and money, the most important resource being wasted is fresh water. About 25% of fresh water which is used to produce food is wasted [4]. In MSW, more than 54% contribution is from the uneaten food waste which is the cause for emission of methane and other green house gases, and responsible for water contamination [5], [6]. Not only harmful gases but also the food waste is a source of many pathogens which cause jeopardous diseases. Therefore, it is a matter of concern for improving sustainability through utilizing the food waste and producing beneficial products. There are several methods like composting, incineration, landfilling, anaerobic digestion amongst composting [7], [8] and anaerobic digestion [9], [10] are considered for recycling of organic waste and produce beneficial products viz. soil amendment and biogas respectively. Food waste, because of its very high organic content, low C:N ratio, and high nitrogen levels [11]–[13]. Food waste proves to be a convenient substrate for composting because of its easily degradable organic substances [13].

## II A BRIEF HISTORY ON COMPOSTING

Composting was, is and will be a great technology gifted by Mother Nature. From our backyards to the municipal waste piles it is practiced on every scale. History reveals that the Romans and the Bible have references to this novel process. Composting was even practiced by the Greeks, the Egyptians, and the Romans. They used to take the straw from animal stalls and bury it in croplands [14], [15]. It is assumed that 10,000 years back, the people who were living in between the Tigris and Euphrates rivers transformed from hunters to food growers and domesticated animals. In all of a sudden there may be a clue that animal manure is aiding the plant growth, so say started putting the manure in the soil for the cultivation of crops [15].

During 2320 BC-2120 BC i.e. the Akkadian Dynasty under the reign of King Sargon, the first written proof of composting, carved on clay tablets. A retired general of 234-149 BC, Marcus Porcius Cato, elaborated the composting process in his book entitled *"De Agri Cultura".* He was the pioneer to use Earthworms for composting and from there vermicomposting idea emerged [15]. Egyptians were considered as the early composters. In 50 BC, Cleopatra declared worms as sacred after she observed their composting potential [15].

There are many mentions in the Bible, about the dung and the manure being spread over the fields. Liquid manure was also prepared by soaking straw contaminated with manure. During 200 AD, the Hebrew Talmud have records of using burnt ashes, agricultural waste and sacrificed animal blood were used as fertilizers to augment the soils. In medivial era, Arab scholar worked substantial on composting and manure which is compiled by Ibn-al-Awwam in his tretise Kitāb al-Filāḥa (Book on Agriculture). In 1943, the great George Washington Carver was a very dedicated and renowned composter. When he recognized the degrading soils due to farming, he prepared a Dung Repository, to make compost from animal manure so that the organic matter of a soil can be replenished [15]. The significance of compost was not felt until World War II. Before that, it was a process by Nature only [14], [16].

## III SCIENCE OF COMPOSTING

### *A. Definition*

Composting is the decomposition process occurring naturally to break down the organic residues from raw organic waste materials into biologically stable compounds rich in humic substances that ameliorate the soil [14]. Compost refers to the organic matter that has been decomposed and recycled as a fertilizer and other soil additive. The decomposition process is aided by shredding the plant matter with water and continuous churning to ensure aeration. Worms, fungi and microbes further break up the material to maximize biochemical reaction [17]. Composting is conversion of complex organic matter into simplest mineralized form, which can be explained in terms of Rabee, 1981, that it is a process in volume reduction of rapidly decomposable materials. In this process, the ratio of carbon to other elements is brought into balance, that generally reduce the possibilities of temporary immobilization of nutrients. One of the many benefits of adding compost to the soil is that the nutrients in it are slowly released to the soil and are then available for use by plant [18]. The rate of decomposition of the compost organic matter rely on the relative moisture content, proper aeration of compost material and subsequent action of soil microflora i.e. fungi and worms [17]

### *B. The Importance of Compost*

As we all witness, there is a huge aggravation of concrete forests which drastically gobbling the natural tree forests and ruining the productive soils. The concrete forests are digging their way for the future but they are also reducing the availability of soil for the agricultural production. Thus, farmers are bound to grow crops on the same piece of land which results in overexploitation of nutrients present in the soil. This, in turn, poses the farmers to use fertilizers and pesticides in a slapdash manner. Thus, it strangles the soil more tightly to death. So there is an immediate need for rejuvenating the dying soils. Compost is the most efficient and proven technology that potentially can bring the dying soils from the mouth of death. Moreover, composting also reduces the burden of solid waste generated naturally and due to the huge mass of the population.

### *C. Role of Compost in Soil Fertility*

Compost acts as an additional source of organic matter that alters the physical, chemical and biological properties of soil, make them more suitable for plant nutrient requirements, viz. soil texture, soil structure, water holding capacity, porosity, particle density, microbial activity, etc. It acts as soil conditioner exceptionally. Being a rich source of nutrients, it thus eliminates the use of harmful chemical fertilizers which bring apocalypse to the soil. Application of compost also reduces soil erosion.

Compost has high stage capacity and thus can be applied to soil at the time of requirement. One of the peculiar qualities of compost that can't be left unseen is that it diminishes the bio-availability of heavy metals that cause soil and groundwater pollution. So, it also acts as bioremediation for contaminated soils [14], [19].

### *D. Life processes behind the Composting process*

Composting is carried out by microorganisms (bacteria, fungi, and actinomycetes) initially and it may be aided by the soil macro organisms (Earthworms, millipedes, centipedes, snails, slugs, ants, sowbugs, springtails, mites, fly maggots, nematodes, beetles, spiders etc.) which break down the complex organic matter into simpler inorganic forms by their idiosyncratic activities. The macro-organisms by their action of digging, sucking, chewing, digesting and excreting they break down the complex matter into smaller parts amassed with their enzymes and hormones. The most crucial factors are temperature, Carbin Nitrogen ratio, pH, aeration and moisture content, which are responsible for guiding organisms that carry out composting. The microbes release acids to degrade the organic matter [16], [20], [21].

*E. Different Phases in Composting*

There are two predominant phases in the composting process

- Active phase: Active phase is the initial stage when thermophilic microorganisms act upon the organic matter and lead to increase in the temperature of the compost pile. So there is a shift from mesophilic to thermophilic phase. The high temperature (55-65oC) generated ensures pasteurization and stabilization which kills the pathogenic microbes and unwanted seeds and also causes the break down of phytotoxic organic compounds present in the pile. There is a rapid utilization of O¬2 and thus it must be reclaimed by the means of enforced aeration or turning over of the pile [14], [16].
- Curing phase: Curing phase is recognized when the temperature declines to less than 40oC. So there is a shift from thermophilic to mesophilic phase. In this phase, oxygen consumption rate declines and biologically stable humic substances are formed which is the sign of maturity of compost [14]. Thus, maturity phase is achieved.

Naturally, in the soils, the composting process is initiated by the soil-dwelling macro organisms which convert the complex matter into simpler forms mechanically. Then the microorganisms act upon and finish the work by producing final compost. The composition of ideal compost consists of various physico-chemical components in its appropriate amount (Table 1).

***Table 1: The Composition Of Ideal Compost***

| Sl. No. | Parameters | Best range | References |
|---|---|---|---|
| 1 | Colour | Dark brown to black | [22] |
| 2 | Texture | Crumby | [22] |
| 3 | Odour | Odorless | [22] |
| 4 | C:N ratio | 10-15:1 | [23] |
| 5 | pH | 6.5-7.5 | [23], [24] |
| 6 | Moisture | 15-25% | [24] |
| 7 | Organic matter | 40-60% | [23] |
| 8 | Electrical conductivity | 0-4 dS $m^{-1}$ | |
| 9 | Nitrogen | 1-3% | [24] |
| 10 | Phosphorus | 0.5-1% | [24] |
| 11 | Potassium | 1-1.5% | [24] |
| 12 | Heavy metals (mg $kg^{-1}$) | | [25] |
| a | Arsenic | ≤10 | |
| b | Cadmium | ≤1 | |
| c | Chromium | ≤100 | |
| d | Copper | ≤300 | |
| e | Mercury | ≤1 | |
| f | Nickel | ≤50 | |
| g | Lead | ≤100 | |
| h | Selenium | ≤1.5 | |
| i | Zinc | ≤600 | |
| 13 | Pathogens | | |
| a | *Salmonella sp.* | ≤75 MPN/100g | [25] |
| b | *E. coli* | ≤1000 MPN/g | [25] |

*F. Conventional Composting Methods*

In general, there are six methods of composting followed [14]:

*F.1) Static Piles*

It is the simplest of all methods of composting which require very low management and fewer equipments. Aeration can only be ensured if there is a high percentage of porosity (more than 60%) and high bulking materials present in the pile. The disadvantages of this method are

- Controlling moisture and aeration is too difficult after it is once established.
- Takes the longest time for the finished product to form.
- Heterogeneous materials found.

*F.2) Windrow Composting*

This term is generally used for a pile of stacked raw materials. Piles should be small (not more than 6 feet height) and porous for easy air exchange. The pile is turned mechanically using windrow turner, manure spreader or bucket loader. Turning enhances the aeration and allows all the raw materials exposed to the microorganisms to colonize. Heat, water vapor and other gases expelled from the pile. The disadvantages are

- Highly labor intensive
- Controlling moisture and temperature difficult.

*F.3) Passively aerated windrow system (PAWS)*

In this method of composting, perforated pipes are placed at the bottom of windrow to ensure convective aeration throughout the pile. Prior to placing the substrates over the perforated pipes, the substrates are mixed well. The thermophilic condition is ensured by covering the outer surface of the windrow by the finished compost.

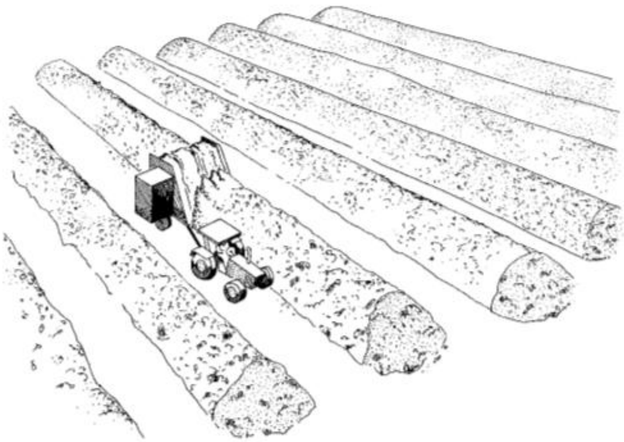

***Figure 1: Windrow method of composting***

***Figure 2: Passively Aerated Windrow System***

*F.4) Forced Aerated Static Piles*

It is similar to PAWS piles. Air blowers are fitted at the ends of perforated pipes to enforce aeration. The air flow rate can be moderated by adjusting the frequency and duration of the blowers. Usually, when the temperature reaches 65$^{o}$C, blowers are turned on.

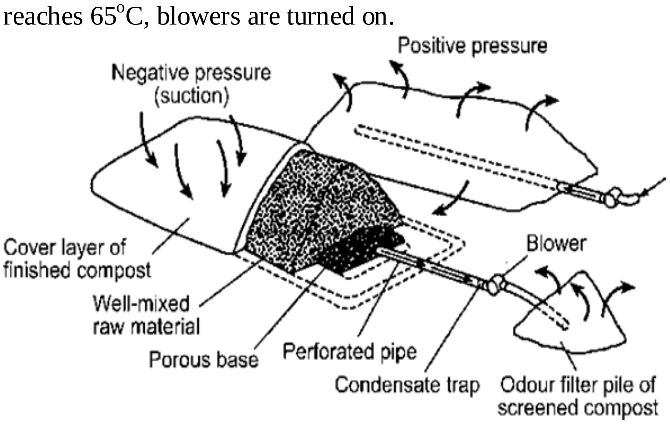


***Figure 3: Forced Aerated Static Piles***

*F.5) Vermicomposting*

In this method, Earthworms are used to decompose the decaying organic matter into compost which is in for of worm castings. The worms engulf the organic matter and mix up with essential enzymes and hormones in their gut. They excrete the residue in form of worm castings which contains crucial plant nutrients which plants can easily uptake. The thermophilic condition is not suitable for worms but still pathogens and weed seeds get killed in vermicomposting. The most commonly used Earthworms are *Eisenia foetida*, *Eudrilus eugeniae* and *Lumbricus rubellus*. Vermicomposting can be taken up in small containers to large tanks with a thatched roof. The disadvantages are

- Worms are sensitive to heat and moisture, so timely turning over and maintenance of moisture should be ensured.
- Spicy items, meat, dead organisms, etc. can't be used for composting.
- Worms have many predators like ants, rodents, frogs, snakes, centipedes, etc.

***Figure 4: Vermicomposting***

*G. Recent Advances in Composting Technologies*

*G.1) Enclosed or In-vessel Composting*

This is the novel technology which is gaining the interest of many researchers and composters. Unlike other methods of composting it is very advanced. The whole system is closed inside a container or a tank. There is an outlet exhaust for emission of harmful gases and odor which get filtered through biofilters fitted at the exhaust unit. The aeration is provided either by rotation of the container or through aeration pumps, to maintain steady air flow rate. Since the whole system is enclosed, moisture is conserved within itself thus reducing the dependency on water. The ideal moisture content of 40-60% [19], can be maintained easily. A thermophilic condition which is favorable for aerobic thermophilic bacteria can be achieved due to the prevention of heat loss. Since the inside environment is not affected by the exterior conditions in-vessel composting can be taken up in any part of the world, irrespective of the climate of the place. The comparative evaluation of in-vessel composting system with other systems of composting is shown in Table 2.

***Table 2: Comparative Evaluation Of In-Vessel Composting System***

| Sl. No. | Parameters | In-vessel | Others |
|---|---|---|---|
| 1 | Moisture control | Yes | No |
| 2 | Temperature control | Yes | No |
| 3 | Aeration control | Yes | No |
| 4 | Exhaust air control | Yes | No |
| 5 | Climate<br>• Cold countries<br>• Warm countries | <br>Possible<br>Possible | <br>Not possible<br>Not possible |
| 6 | Re-infection | No | Yes |
| 7 | Occupational risks | No | Yes |
| 8 | Odour | No | Yes |
| 9 | Space requirement | Very less | Large |
| 10 | Skills required | No | Yes |
| 11 | Design | Yes | No |
| 12 | Time | Rapid | Slow |
| 13 | Cost | Low | High |

*G.2) Advantages of In-Vessel Composting System over Traditional Methods*

- Reduced dependency on malignant chemical fertilizers.
- Reclamation of soil health and enhancement of beneficial soil micro- and macro-organisms.
- Efficient organic waste management.
- Saving the cost of transportation and fertilizer purchase.
- Improved environmental protection.
- Income generation through selling the outcome.
- Enhanced corporate image.
- Improved relations with the nearby villagers, other industries and organizations and market advantages.

## VI CONCLUSION

With the upsurging population growth in India, there is a huge demand for plant nutrition supplements for the enhanced soil fertility. Usage of the effective composting system will reduce the uncontrolled use of chemical fertilizers which ultimately reduces the cost of cultivation. In-vessel composting is a rapid composting method and thus it can be efficiently utilized for the community-based composting at need-based compost production, which will be a key to link daily household waste with resource generation. This can also aim to achieve Swach Bharat Mission by growing up this system on a pilot scale.

## ACKNOWLEDGMENT

Authors of this study are thankful to CSIR-National Environmental Engineering Research Institute, Nagpur and Amity University Haryana, Gurgaon for providing the necessary resources for the present study.

## REFERENCES

[1] Population Reference Bureau, “World Population Data Sheet,” 2017.

[2] M. Rezaei and B. Liu, “FOOD LOSS AND WASTE IN THE FOOD SUPPLY CHAIN Maryam,” Int. Nut Dried Fruit Counc., no. July, p. 2, 2017.

[3] FAO (UN), “SAVE FOOD: Global Initiative on Food Loss and Waste Reduction,” 2016. [Online]. Available: http://www.fao.org/save-food/resources/keyfindings/en/. [Accessed: 01-Oct-2017].

[4] B. Ravi, “Food Wastage In India A Serious Concern,” CSR J., 2015.

[5] EPA US, “Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012,” US Environ. Prot. Agency, pp. 1–13, 2014.

[6] D. Gunders, “Wasted: How America is losing up to 40 percent of its food from farm to fork to landfill,” NRDC Issue Pap., no. August, pp. 1–26, 2012.

[7] R. Das Purkayastha, “Forming Community Enterprises using Vermicomposting as a tool for Socio-Economic Betterment,” Int. Conf. Econ. Bus. Mark. Manag., vol. 29, pp. 83–87, 2012.

[8] P. M. Munnoli and S. Bhosle, “Effect of soil and cow dung proportion on vermicomposting by deep burrower and surface feeder species,” J. Sci. Ind. Res. (India)., vol. 68, no. 1, pp. 57–60, 2009.

[9] G. Quiroga et al., “Effect of ultrasound pre-treatment in the anaerobic co-digestion of cattle manure with food waste and sludge,” Bioresour. Technol., vol. 154, pp. 74–79, 2014.

[10] B. D. Rounsefell, C. A. O’Sullivan, N. Chinivasagam, D. Batstone, and W. P. Clarke, “Fate of pathogen indicators in a domestic blend of food waste and wastewater through a two-stage anaerobic digestion system,” Water Sci. Technol., vol. 67, no. 2, pp. 366–373, 2013.

[11] J. I. Chang and T. E. Hsu, “Effects of compositions on food waste composting,” Bioresour. Technol., vol. 99, no. 17, pp. 8068–8074, 2008.

[12] M. Kumar, Y. L. Ou, and J. G. Lin, “Co-composting of green waste and food waste at low C/N ratio,” Waste Manag., vol. 30, no. 4, pp. 602–609, 2010.

[13] Z. Li, H. Lu, L. Ren, and L. He, “Experimental and modeling approaches for food waste composting: A review,” Chemosphere, vol. 93, no. 7, pp. 1247–1257, 2013.

[14] L. Cooperband, “The Art and Science of Composting A resource for farmers and compost producers,” Univ. Wisconsin-Madison, Cent. Integr. Agric. Syst., pp. 1–14, 2002.

[15] E. Guttmann, “Midden cultivation in prehistoric Britain: arable crops in gardens,” World Archaeol., vol. 37, no. 2, pp. 224–239, Jun. 2005.

[16] R. Ahmad, G. Jilani, M. Arshad, Z. A. Zahir, and A. Khalid, “Bio-conversion of organic wastes for their recycling in agriculture: an overview of perspectives and prospects,” Ann. Microbiol., vol. 57, no. 4, pp. 471–479, 2007.

[17] A. Singh, S. C. Srivastava, and N. Singh, “Comparative Performance and Restoration Potential of Jatropha curcas and Pongamia pinnata on Degraded Soil of North India Doctor of Philosophy in Environmental Sciences Under the joint guidance of Eco-Auditing Group,” p. 216, 2013.

[18] D. Rabee, “The rapid composting method,” Veg. Res. Inf. Cent., pp. 1–3, 1981.

[19] Robert Rynk, “On-Farm Composting Handbook,” Monogr. Soc. Res. Child Dev., vol. 77, p. 132, 1992.

[20] R. Mohee and A. Mudhoo, “Analysis of the physical properties of an in-vessel composting matrix,” Powder Technol., vol. 155, no. 1, pp. 92–99, 2005.

[21] University of Illinois Extension, “Composting for the Homeowner,” 2017. [Online]. Available: https://web.extension.illinois.edu/homecompost/science.cfm. [Accessed: 10-Oct-2017].

[22] J. K. Lekasi, J. C. Tanner, S. K. Kimani, and P. J. C. Harris, “Cattle manure quality in Maragua District, Central Kenya: effect of management practices and development of simple methods of assessment,” Agric. Ecosyst. Environ., vol. 94, no. 3, pp. 289–298, Mar. 2003.

[23] A. Bary, C. Cogger, and D. Sullivan, “What Does Compost Analysis Tell You About Your Compost ?,” p. 98371, 2002.

[24] G. Anthonis, “Standards for organic fertilizer,” Agro-Chemicals News Br., 1994.

[25] A. Hong, K. Baptist, and K. Tong, “Hong Kong Organic Resource Centre Compost and Soil Conditioner Quality Standards,” 2005.

[26] Ecoideaz, “Vermicomposting – Composting with Earthworms.” Available at: http://www.ecoideaz.com/expert-corner/vermicomposting-composting-with-earthworms. [Accessed: 11-Oct-2017].

## BIOGRAPHY

**Vivek Manyapu**: Pursuing Masters in Environmental Science and Management have been awarded Dr. A.P.J. Abdul Kalam Fellowship in the year 2017. My fields of interest are solid waste management, biogas, bio-fuel and bio-energy.

**SSWM-17**
**National Conference on Sustainable Solid Waste Management**

**Organized by:**

**Department of Civil Engineering,**
**Amity School of Engineering & Technology**
**Amity University Haryana**