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Composting physics: A degradation process-determining tool for industrial sludge

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ABSTRACT

Management of industrial sludge is a big challenge for developing countries. Composting is an economical and viable option to manage and treat an industrial sludge. However, efficient compost production requires nature of materials involved, process understanding and physics behind the process. We investigated the physical parameters during composting of solid pulp and paper mill sludge in 550 L rotary drum composter. Variation in physical parameters such as bulk density, volatile solids, moisture content, free air space, void ratio, ash content and particle density were analyzed over the period of composting. Bulk density was observed increasing, whereas free air space was showed declining trend and observed 52% in end compost. The particle density was observed to be increasing from 610 to 680 kg m^{-3}. End compost was analyzed for nutritional parameters and seen to be increasing over the period of composting. A strong relationship was found between various physical parameters. Pearson's correlation coefficient matrix was formed between free air space, bulk density, moisture content and particle density.

1. Introduction

The lignocellulosic waste is very difficult to manage as it is not easily degraded. Solid pulp and paper mill sludge (SPPMS) is one of industrial lignocellulosic biomass which has been utilized for compost production from the decade. SPPMS is generated as a result of pulp and paper mill effluent treatment. In general, per tonne of paper production generates 40–50 kg dry sludge and is a mixture of primary (70%) and secondary (30%) sludge (Bajpai, 2015; Hazarika et al., 2017). Owing to the presence of organic matter, the sludge produces greenhouse gases (CO_2 and CH_4) when disposed of in landfills. Availability of organic matter makes SPPMS a good substrate for composting. Composting process involves a natural biological decomposition of organic matter, which is carried out by naturally occurring microbes such as bacteria, fungi, actinomycetes thus converting into humus product i.e. compost (Pan et al., 2012). It is an entirely aerobic biological process that occurs under certain conditions, which allow development of thermophilic temperatures to produce compost that is free from pathogens and plant seeds and can be applied to land (Haug, 1993).

Several studies carried out on composting or vermicomposting of SPPMS showed improvement in nutrients concentration. A study carried out by Jackson and Line (1997) indicated an absence of phytotoxicity and reduction in pile volume by 45%, 31.6% increase in bulk density and 10% reduction in moisture content. The author further stated reduction of C: N ratio from 218:1 to 23:1 before mineral nutrient addition. The stability tests, the C:N ratio, and the nutrient-content during windrow composting of paper mill sludge from Virginia fiber corporation indicated that the compost was a high quality, fertile growth medium (Evanylo and Daniels, 1999). A study performed by Thyagarajan et al. (2010) on composting of pulp and paper mill industry sludge added with saw dust and cow dung revealed improvement in chemical and nutritional properties. Rotary drum composting of SPPMS indicated a reduction in bioavailability and leachability of toxic metals such as copper, iron, nickel, lead, chromium, zinc, mercury and manganese after 20 days composting period (Hazarika et al., 2017). However, such studies do not provide information about degradation process monitoring, air, and water distribution within the compost matrix, and composting physics. The composting study on SPPMS has been mostly carried out on understanding variation in heavy metals concentration, amount of gaseous emissions, and chemical and nutritional transformation during degradation process. However, composting physics behind the composting process have rarely been studied for SPPMS. The lignocellulose substrates such as SPPMS usually characterized by a slower attainment (> 45 °C) of thermophilic temperatures thus slower degradation rate and longer duration of acquired stable compost. The lesser moisture content can have adverse impacts on microbial survival rate during the composting process. This research work is pointed at understanding the composting physics during

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degradation of lignocellulosic substrate by adding cow dung (inoculum) and saw dust (bulking agents), paying particular attention to its temperature change, moisture content reduction, and other physical parameters that controls entire composting process such as bulk density, porosity, free air space, void ratio and particle density.

Composting physics plays an important role during every stage of compost production, handling, and its utilization. It includes measurements of parameters such as bulk density, porosity, moisture content, free air space, void ratio, particle density within the compost matrix during the process. Besides food to microorganism ratio, composting is highly affected by water and air availability. To keep microorganism active, it is important to monitor and to provide optimum air and water during the process (Agnew and Leonard, 2003). Author further states that sufficient amount of moisture is required for microbial transport and nutrition. To support the metabolic processes of microbes, water plays an important role which is produced by and required for microbial activity (Baeta-Hall et al., 2005). Water is the medium for the transports nutrients, chemical reactions and allows the microbes to move about (Rynk, 1992). A range of moisture content reported by Jeris and Regan (1973) is 40–65% with a preferred range of 50–60% at the start of composting. The continuity of voids is also an important factor since this influences how easily air and water will flow through the material (Rynk, 1992). The heat and mass transport processes and therefore microbial kinetics in an organic compost matrix were influenced by free air space (Jeris and Regan, 1973; Miller, 1991; Haug, 1993). Bulk density was proving to be precious physical property as it determines power requirements for turning or mixing of wastes. According to Iqbal et al. (2010), a physical parameter holds a healthy relationship between each other, i.e., a small variation in one parameter may cause adverse effects on an additional parameter and thus degradation process would be compromised. No such studies have been carried out on giving the relationship between various physical parameters during composting of SPPMS.

Therefore, the current study focuses the composting of SPPMS added with cow dung and sawdust in the ratio of 6:3:1 as optimized by (Hazarika et al., 2017). The study aims to determine (1) how the combined addition of sawdust and cow dung affects composting physics during composting of SPPMS using rotary drum composter (2) how these additions improvise the chemical and nutritional quality of the final compost; and (3) correlations between various physical parameters.

2. Materials and methods

2.1. Composting substrate and bulking agents

In the current study, industrial waste i.e. SPPMS were composted after added with sawdust and cow dung as inoculum. Experiments were carried out at Indian Institute of Technology Guwahati (IITG), Guwahati, Assam, INDIA. The substrate, SPPMS used were collected from Nagaon Paper Mill, a unit of Hindusthan Paper Corporation situated in Nagaon, Assam, India. It is situated about 70 km from IITG campus. Fresh cow dung was gathered from a nearby dairy farm. Sawdust, which was used as a bulking agent, were collected from the nearby sawmill, located in Amingaon, Guwahati, Assam, INDIA. The selected ranges of physical properties of the various experimental materials are shown in Table 1.

Table 1
Selected physical properties of various experimental raw materials.

Parameters		SPPMS	Cow Dung	Saw Dust
Moisture Content	(%)	44.2 ± 3.2	85 ± 0.5	11.4 ± 0.2
Volatile Solids	(%)	42 ± 2.7	75 ± 4.1	80 ± 1.9
pH		7.2 ± 0.01	6.8 ± 0.01	6.2 ± 0.01
Electrical conductivity	(dS/m)	0.7 ± 0.02	2.9 ± 0.02	0.6 ± 0.03
Bulk Density	(kg/m^3)	419 ± 12.8	100 ± 5.1	350 ± 8.6

2.2. Experimental setup and compost preparation technique

Rotary drum composter was used as composting technology for composting of SPPMS. It is mounted on four rubber rollers attached to a metal stand. It is cylindrical, and partially opened on both sides to provide sufficient aeration, and it is horizontally aligned. The drum is having the volume of 550 L and operated in batch mode. The composter is rotated manually with lever provided at one end. Inside angles are welded longitudinally of size 40 × 40 mm, to confirm the suitability of mixing of wastes through the rotation. Detention period for composting of SPPMS was fixed for 20 days as mentioned in the studies reported on various organic wastes using rotary drum composter reveals higher degradation and stabilization of waste (Varma and Kalamdhad, 2014; Nayak and Kalamdhad, 2014; Singh et al., 2016; Hazarika et al., 2017). Fig. 1a shows a graphic representation of a rotary drum composter used for this study.

Fig. 1a. Rotary drum composter.

The SPPMS were brought to the solid waste laboratory, IITG campus. SPPMS were dried for three days at room temperature (26 ± 2 °C) to remove excess moisture. It is then broken into smaller pieces to a magnitude such that to yield 2–4 cm. Maximum weight of 150 kg was considered for the feeding mix. Firstly, the homogenous mixture of cow dung and sawdust were prepared in the ratio of 3:1, respectively. The prepared mixture was then mixed with six parts i.e. 90 kg of SPPMS. The ratio of 6:3:1 were prepared, which was observed to be optimum for best quality compost by Hazarika et al. (2017) and used for the current study to determine the physical parameters during the composting process.

2.3. Sampling, monitoring, and analyses

2.3.1. Sampling and monitoring

Triplicate Samples were collected on day 0, 2, 4, 6, 10, 14, 18 and 20 from the center and two extremities (top, middle, and bottom) from each reactor and were mixed to give one composite sample per composter. Then each mixed samples were divided into two parts as oven-dried, ground to pass through a 212 μ soil sieve and stored in a desiccator. While another part, which is not oven-dried, were used to quantify bulk density, moisture content, and porosity. While the oven-dried samples were used for determination of chemical, nutritional and physical properties such as, pH, EC, particle density, and the contents of volatile solids (VS), total organic carbon (TOC), total Kjeldahl nitrogen (N), total phosphorus (P), and total potassium (K).

Temperatures in the composting mixtures (top, middle, and bottom layers) in rotary drum composters were monitored using a digital thermometer consisting of a temperature sensor attached to it. Temperature data were collected daily after every 4 h during the entire composting process, and readings were averaged per composting mix. Ambient temperature was also recorded using the same temperature sensor.