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Optimisation of In-Vessel Composting of Municipal Solid Wastes (MSW)

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ABSTRACT: The aim of this study is to recover nutrient resources by optimizing the chemical oxygen demand (COD) through composting Municipal Solid Wastes (MSW). The study involved 84 tests on four sets of samples, focusing on aeration period, percentage of porous materials, and moisture content. The composting process was carried out using an in-vessel system at a temperature of 70 °C for a period of 14 days. The results indicate that the best aeration period is 8 hours. The addition of porous materials should be limited to 10% of the total weight, as exceeding or reducing this amount can have a negative impact on the process. Furthermore, the research demonstrates that COD can be reduced by approximately 50% through this composting approach.

Keywords: Chemical Oxygen Demand (COD), Carbon to Nitrogen Ratio (C/N), Aeration, Composting, Municipal Solid Wastes (MSW)

1. Introduction

The rapid growth of industrial and technological advancements, along with the increasing population, has presented two significant challenges related to urban solid waste. Although several disposal methods have been proposed, each has its drawbacks, necessitating the development of more advanced approaches to address these issues. Furthermore, composting involves important parameters such as chemical oxygen demand (COD), which impact the activities of microorganisms and serve as indicators of maturity. Achieving an optimal level of COD typically leads to other optimal design parameters. Thus, this study aims to propose a sustainable composting solution by determining the optimum parameters. Simultaneously optimizing COD in the composting process, the study focuses on three design parameters: aeration period, percentage of porous material, and moisture content.

2. Research History

Composting is highly valued for its environmental versatility in the stabilization of municipal solid waste (MSW). Composting is considered an ideal technique for managing solid waste due to its ability to biologically convert organic solid wastes into stabilized organic matter (OM) with high plant nutrient content. In the present time, there is a growing significance and extensive research focused on understanding various indices associated with the composting process. This expanding knowledge base contributes to advancing our understanding and optimizing composting practices. Each year, significant research efforts are dedicated to solid waste management systems, particularly composting systems. Mahapatra et al. [1] summarised the various bins manufactured around the world that are used for the composting of organic solid waste. A notable example is the work of Shuval et al. [2] between 1981 and 1989, where they conducted a series of cost-effectiveness tests using various composting materials with different ratios. According to their findings, Shuval et al. affirmed the feasibility of co-composting wastewater sludge with various organic waste materials. However, the selection of primary ratios is significantly influenced by economic factors. Mahapatra et al. [3]

Körner et al. [2] focused on the integration of composting as a viable solution for managing the organic fractions of municipal solid waste (MSW). They highlighted that composting offers a suitable approach for treating the organic waste components within MSW. The research paper discusses various options for the collection and separation of impurities in urban areas. Additionally, it suggests a phased approach to source separation, beginning with the inclusion of hotel and restaurant waste. Furthermore, for rural areas, the implementation of home composting is recommended as a practical solution.

Onwosi et al. [4] put forth a range of composting methods that have been reported to be utilized in waste management. Furthermore, they highlighted the crucial factors such as temperature, pH, C/N ratio, moisture content, and particle size, which are considered relevant in the monitoring of the composting process. The study also delved into the implementation of suitable techniques to enhance and optimize the effectiveness of the composting process. However, certain challenges arose during composting, including the generation of leachate, gas emissions, and the lack of consistent assessment of maturity indices. The researchers addressed these difficulties and proposed strategies for their improvement. Additionally, they highlighted several innovative technologies that have the potential to enhance composting practices. In a separate study, Cofie et al. [5] presented the possibilities and performance of co-composting mixed treatment of fecal sludge (FS) and MSW, exploring the synergies between the two waste streams. The objectives of the study were to investigate the impact of different types of municipal solid waste (MSW), the mixing rate of MSW with fecal sludge (FS), and the frequency of turning on the quality of compost. Samples were collected during each turning process and analyzed for various parameters, including total solids, electrical conductivity, total volatile solids, total organic carbon, pH, ammonium and nitrate nitrogen, and total Kjeldahl nitrogen. The results indicated that the number of turning repetitions did not significantly influence temperature changes or the quality of the compost. In another study, researchers explored the co-composting performance of sewage sludge (SS) and the organic fraction of municipal solid waste (OFMSW) at different ratios [6]. The findings indicated that a higher proportion of sewage sludge (SS) facilitated the initiation of the composting process, while increasing the organic fraction of municipal solid waste (OFMSW) extended the thermophilic period and enhanced the degree of humification. However, a higher proportion of OFMSW necessitated a longer co-composting duration to ensure optimal compost maturity and quality. In another study, Cai et al. conducted four experimental series on co-composting wastewater sludge with rice husk, observing the removal of a significant portion of semi-volatile organic compounds from the compost after 56 days [7]. In their research, Lannotti et al. [8] investigated the stability of compost generated from municipal solid waste (MSW) using dissolved oxygen respirometry in a pilot-scale system. The study involved examining the changes in stability of samples at different stages of the composting process through chemical and physical tests. This methodology offers a versatile approach, serving as a straightforward quality control measure or enabling the calculation of rates for comparing efficiency within or among composting facilities. Furthermore, using an anaerobic pilot reactor, some researchers assessed a composting mixture comprising municipal solid waste, wastewater treatment sludge, wood chips, and a series of enzymes [9]. According to their study, the choice of combining materials, composting materials, and their composition ratios significantly affect the quality of the final compost product. Brinton conducted an examination of the historical appreciation of compost and emphasized the growing recognition of the importance of distinguishing compost from other recycled wastes and conventional fertilizers [10].

In a separate investigation, researchers examined the effects of incorporating different bulking waste materials, such as wood shavings, into OFMSW composting, focusing on their influence on microbial enzymatic activity and the quality of the final compost [11]. The results demonstrated that combining OFMSW with wood shavings and a microbial consortium proved to be a beneficial approach, enhancing enzymatic activity and reducing the composting time. In another research endeavor, laboratory tests were conducted using sewage sludge as a base substrate for composting [12]. The study observed characteristic parameters of the composting process, including fat content and lipolytic enzymatic activity, using aerated static lab-scale composters. The results indicated that co-composting with sewage sludge can be considered a viable option for treating solid waste, even at high proportions of up to 40%. However, it may be advisable to limit the maximum ratio to 20% to avoid prolonged composting periods. Tognetti et al. explored the impact of various municipal organic waste (MOW) on the stabilization of organic matter and the quality of compost [13]. The findings indicated that shredded treatments demonstrated faster stabilization of organic matter compared to non-shredded treatments. Addition of wood shavings significantly improved compost quality, although it led to a decrease in total nitrogen and available nutrient concentrations. In their research, Nemati et al. [14] investigated the recovery of nutrient resources through the co-composting of wastewater treatment plant sludge with Municipal Solid Wastes (MSW). Their study aimed to achieve optimal levels of chemical oxygen demand (COD) and carbon to nitrogen ratio (C/N). The researchers determined that the most favorable waste to sludge ratio for this process is 2:1. Additionally, they found that an 8-hour aeration period yields the best results. To maintain the desired composting conditions, the addition of porous materials was limited to a maximum of 15% of the total weight. Interestingly, the study indicated that sludge dewatering is unnecessary in such co-composting processes. Furthermore, Nemati et al. [14] observed that the efficiency of reducing both COD and C/N levels reached approximately 40%.

Bian et al. [15] examined the influence of matured sewage sludge (MSS) amendment on N2O emissions during aerobic co-composting of MSW. The results confirmed that MSW composting with MSS amendments increased N2O emissions during the initial stage. Zhanga et al. [16] focused on the physicochemical characteristics, such as pH and electrical conductivity (EC), in the co-composting of pine sawdust with fresh solid swine manure. The results suggested that nitrogen and phosphorus decomposition primarily occurred during the mesophilic phase, while organic carbon degradation took place during the thermophilic phase. A mixture of 30% swine manure with an initial C/N ratio of approximately 40 was found to be optimal for composting organic substrates. In a similar study, Millán [17] conducted a field trial involving the co-composting of municipal solid organic waste with wastewater treatment plants (WWTP) sludge in a municipality in Boyacá. The study aimed to identify the optimal proportion of these materials and characterize their respective properties. Yang et al. [18] investigated the composting of yard trimmings (YT) and food waste (FW), with the goal of determining the appropriate mixing ratio between the two. The results indicated that a 1:1 mixing ratio was optimal, resulting in a C/N ratio of 14.15.

3. Method

The study utilized a "Composting Optimization Laboratory Reactor" as the experimental setup. This reactor system consisted of a closed chamber housing four cylindrical vessels. To ensure precise temperature control, automatic elements and digital sensors were employed to continuously monitor the ambient temperature. The frame of the system was constructed using fiberglass sandwich panels with double galvanized facings, providing excellent insulation and minimizing heat exchange. The temperature regulation was achieved through a digital heating system, where the sensors would activate and cut off the electricity flow to the elements as the desired temperature was reached. However, due to the efficient insulation system, it took a significant amount of time for the temperature to decrease. The heat loss could be adjusted between zero to ten Celsius degrees, depending on the desired accuracy. The pilot system was equipped with a central switch, fuse, and function indicator for operational safety. Additionally, two external fans were installed in the reactor to serve as air blowers and heat-gas exhaust. This allowed the operator to select various aeration types, and the fan could be activated or deactivated using a digital timer along with a thermal sensor or its functional interval. Manual control of these fans was also possible when specific programs were not in place. In the study, the initial phase involved source separation of the municipal solid waste (MSW). The separated waste material then underwent milling to achieve an approximate size of 4 cm, which was considered suitable for composting and contributed to the rapid reduction of organic carbon content. Small wood chips, measuring approximately 1200 mm^2 in area, were added to create the necessary porosity in the composting material. Additionally, flexible PVC parts with a length of approximately 20 mm were used to further enhance the porosity. The pH value of the waste used in the study was measured to be 6.3.

4. Test series

In this study, three series of tests were designed and conducted as follows:

4.1 Series 1: Constant parameters: Temperature, Amount of additives for increasing porosity (20%), Moisture content of waste (no dewatering)

- Constant parameters: temperature: 70 °C, initial COD
- Variable parameters: aeration frequency and duration (times of aeration)
- Sampling period: every 2 days
- Test duration: 14 days
- Controlling parameters: COD variation

Aeration frequency and duration are shown in the Table 1.

Table 1 Aeration Condition

Tank No.	Aeration frequency	Aeration Duration
A_1	continuous aeration	continuous aeration
A_2	every 8 hours	20 minutes
A_3	every 16 hours	20 minutes
A_4	every 24 hours	20 minutes

4.2 Series 2: Determination of optimum amount of additives for increasing porosity

- Constant parameters: temperature, times of aeration, Moisture content of waste (no dewatering), initial COD
- Variable parameters: amount of additives for increasing porosity
- Sampling period: every 2 days
- Test duration: 14 days
- Controlling parameters: COD variation

In this series, different amount of additives were added to the samples in order to determine the optimum amount for the best level of porosity. The evaluated ratios are shown in Table 2.

Table 2 Amount of additives in each tank

Tank No.	B_1	B_2	B_3	B_4
Additives amount (by volume)	5%	10%	15%	20%

Series 3: Optimum moisture determination

- Constant parameters: temperature, times of aeration, amount of additives for increasing porosity, initial COD
- Variable parameters: moisture content of waste
- Sampling period: every 2 days
- Test duration: 14 days
- Controlling parameters: COD, and weight variation

At this stage, the optimum moisture content was determined by varying the water content of waste. The considered moisture contents are shown in Table 3.

Table 3 Moisture content in each tank

Tank No.	C_1	C_2	C_3	C_4
Moisture content	30%	40%	60%	not dewatered

4 Results

Figure 1 illustrates the results of COD control in all series of tests in a 14-day period.

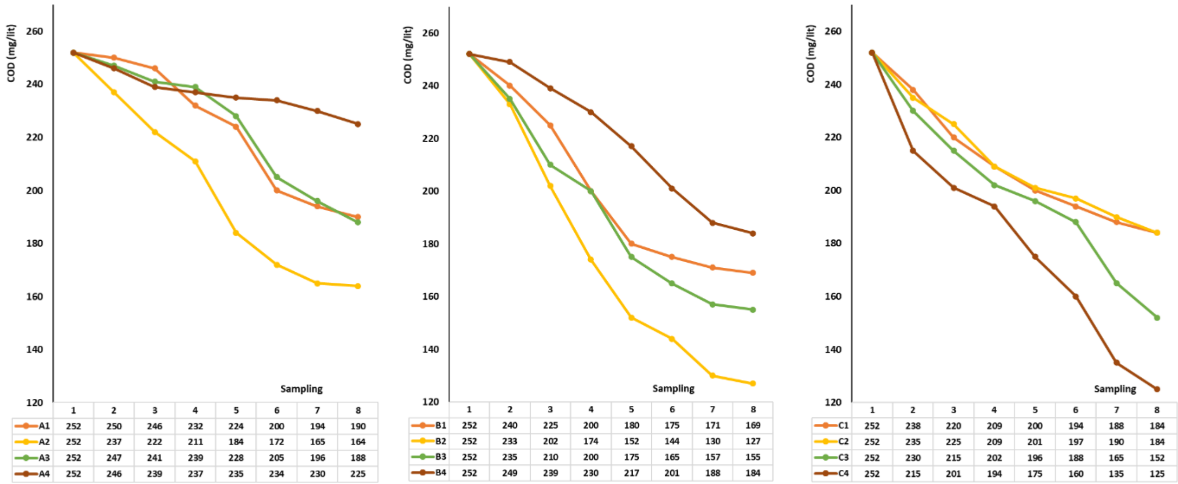

Fig.1 Variation in COD levels across different tanks after a duration of 14 days in the initial (left), second (middle) and third (right) series of tests.

In the initial test series focusing on continuous aeration, tank 1 was continuously supplied with air by keeping its door open. Since maintaining continuous humidity control was challenging, the initial moisture level was used as the determining factor. Based on Figure 1, it was observed that tank 2 achieved a 35% reduction in COD. This indicates that extending the aeration intervals by 8 hours resulted in a 20% decrease in system efficiency due to a reduction in available oxygen for the microorganisms. Interestingly, although the aeration intervals increased linearly, the efficiency reduction process was non-linearly affected. The efficiency reduction was comparable to that achieved with continuous aeration. In other words, when extended aeration was applied, biological processes were hindered due to rapid moisture loss, with a maximum reduction of 25% observed. Therefore, the optimal aeration period was determined to be 8 hours in this scenario. Figure 1 illustrates the highest rate of COD removal during 15 days of system operation occurring in tank 2, after which the rate remained relatively constant. The observed COD reduction was 50%. Any percentage of porosity-enhancing additives exceeding 10% led to a decrease in the COD removal rate. Hence, it is recommended to apply this recommended level of porosity-enhancing additives in real-scale applications. Furthermore, the addition of 20% of this material, due to its high porosity, resulted in early moisture evaporation and a reduction in system efficiency by approximately 40%.

The optimum reduction of COD was found to be 50%. Dewatering up to 60% caused a decrease in system efficiency by up to 20%. Similarly, dewatering to 40% resulted in another 27% reduction in system efficiency. This indicates the high moisture requirements of the microorganisms involved in the composting process. Notably, tank 4 exhibited the highest rate of compost COD reduction (as shown in Figure 2).

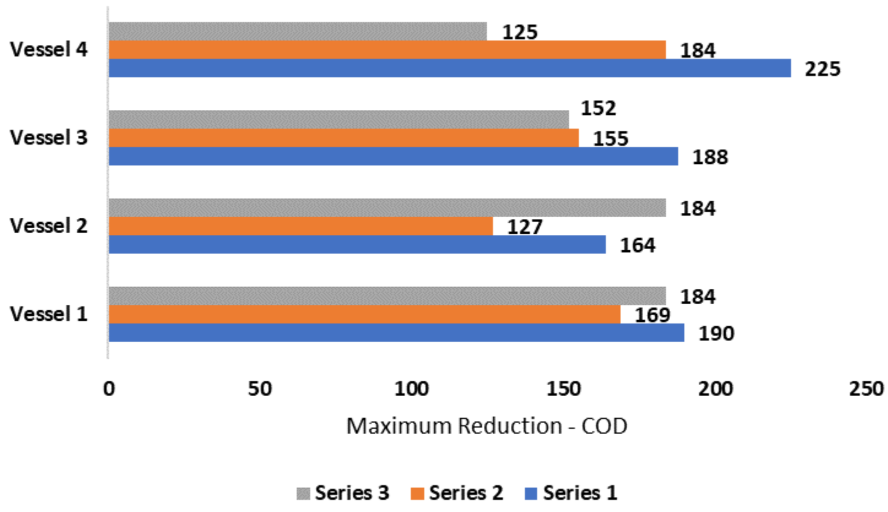

Fig 4. Comparison between COD variations in different test series

5 Conclusion

Based on the research findings, the in-vessel composting of municipal wastes yields the following results:

- Municipal wastes should not undergo dewatering during the composting process.
- When maintaining a temperature of 65 °C and applying an 8-hour aeration period, the maximum Chemical Oxygen Demand (COD) reduction in the municipal solid waste (MSW) is 50%.
- Extending the aeration intervals by 8 hours leads to a decrease in system efficiency by 20%.
- To achieve optimal results at a temperature of 65 degrees, it is recommended to include porosity producing additives in the mixture volume, accounting for 10% of the total volume.

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