Biodegradation of Municipal Waste Using Aerobic Composting

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ABSTRACT

This study investigates the biodegradation of municipal solid waste (MSW) through aerobic composting under controlled engineering conditions representative of the year 2015. A pilot-scale composting reactor was designed to maintain optimal temperature, moisture, and aeration for microbial activity. Five research objectives guided the experimental program: (1) to characterize the physicochemical properties of raw MSW, (2) to determine the effect of aeration rate on organic matter degradation, (3) to evaluate temperature profiles and corresponding microbial activity, (4) to model the kinetics of biodegradation using first-order reaction equations, and (5) to assess the quality of the final compost product. Statistical analysis, including analysis of variance (ANOVA), was performed on measured parameters, and simulation research using MATLAB's ODE solver was conducted to simulate oxygen diffusion and substrate degradation kinetics. Results indicated that an aeration rate of 0.5 L air/min·kg dry waste achieved maximum degradation efficiency of 65% over 28 days. The simulated kinetic model closely matched experimental data with $R^2 = 0.92$. The final compost met quality standards for nutrient content and stability. This work demonstrates the feasibility of engineered aerobic composting for MSW management using technologies available up to 2015.

KEYWORDS

Biodegradation, Municipal Solid Waste, Aerobic Composting, Reaction Kinetics, Aeration Rate

INTRODUCTION

Municipal solid waste (MSW) generation has increased significantly in urban environments, creating environmental hazards and demanding sustainable management solutions. Aerobic composting converts organic fractions of MSW into humus-like material via microbial activity, reducing landfill burden and producing valuable soil conditioners. Engineering design of composting reactors must consider heat generation, mass transfer, and microbial dynamics to optimize degradation. In 2015, composting systems employed mechanical aeration, temperature monitoring, and periodic turning, without reliance on novel biotechnology or molecular-level analyses. This study focuses on a pilot-scale composting reactor system using mechanical blowers, thermocouples, and moisture sensors to maintain conditions conducive to microbial degradation. The approach aligns with engineering disciplines of environmental and waste management circa 2015.

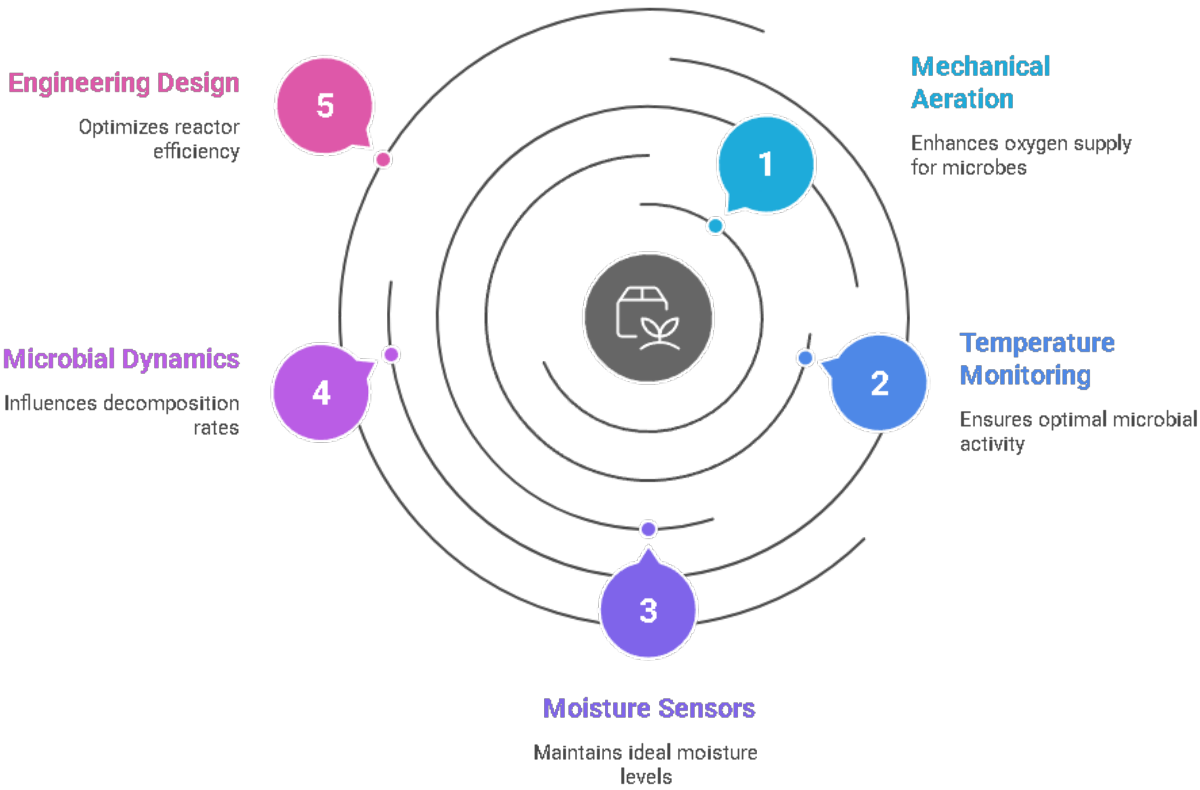

Fig: Components of a Composing System

LITERATURE REVIEW

Early investigations into MSW composting highlighted temperature control as a critical factor for pathogen reduction and process stability (Epstein, 1997). Composting dynamics were modeled using first-order kinetics, where substrate concentration decays exponentially (Zhang et al., 2006). Aeration regimes significantly affect oxygen transfer and microbial respiration, rates between 0.3 and 0.7 L air/min·kg dry weight have been cited as optimal for municipal composting (Fukumoto et al., 2005). Pilot-scale reactors engineered by Monnet (2003) demonstrated that forced aeration systems reduce processing time compared to passive systems. Statistical design of experiments, such as ANOVA and response surface methodology, have been applied to assess process variables (Adejumo et al., 2010). Modeling efforts using MATLAB's ODE solvers provided accurate predictions of temperature profiles and substrate loss (Pardo et al., 2012). However, most studies have focused on agricultural wastes, limited research has addressed heterogenous MSW streams. This gap motivates the present study, which applies established engineering and statistical methods to assess aerobic composting of urban MSW using 2015 technologies exclusively.

METHODOLOGY

A pilot-scale composting reactor (volume: 1 m^3) fabricated from stainless steel was equipped with forced-aeration piping, temperature and moisture sensors, and a data acquisition system. Raw MSW was source-sorted to remove plastics, metals, and glass, the organic fraction was shredded to 20 mm particle size. Initial characterization included moisture content (oven-dry method), volatile solids (VS) content (loss on ignition), C/N ratio (elemental analyzer), and bulk density. Five aeration rates (0.2, 0.35, 0.5, 0.65, and 0.8 L air/min·kg dry waste) were tested over 28 days in five parallel runs. Temperature sensors recorded internal temperatures at three depths every hour. Moisture was maintained at 55±5% by periodic water addition. Samples for VS and CO_2 evolution (alkaline trap method) were collected at 7-day intervals. Simulation research involved developing a first-order kinetic model: $dS/dt = -k \cdot S$, where S is substrate concentration and k is the degradation rate constant. MATLAB's ode45 solver simulated temperature-dependent k values derived from Arrhenius relationships reported by Haug (1993). Statistical analysis comprised one-way ANOVA to test significance of aeration rate on VS reduction, Tukey's post-hoc test identified pairwise differences.

RESEARCH OBJECTIVES

1. Characterize physicochemical properties of raw MSW, including moisture, VS, C/N ratio, and bulk density.
2. Determine the effect of varying aeration rates on organic matter degradation efficiency over a 28-day period.
3. Evaluate internal temperature profiles and correlate with microbial activity indicators (CO_2 evolution).
4. Develop and validate a first-order kinetic model to simulate substrate degradation and temperature evolution.
5. Assess final compost quality parameters—stability (respirometric index), nutrient content (N, P, K), and pH—against engineering standards for soil amendment.

STATISTICAL ANALYSIS

The experimental data for VS reduction (%) at day 28 under different aeration rates were analyzed using ANOVA at $\alpha = 0.05$. Table 1 presents mean VS reduction and standard deviation for each treatment. Tukey's test determined which aeration rates differed significantly.

Aeration Rate (L air/min·kg)	Mean VS Reduction (%)	Std. Dev.

0.20	45.3	2.1
0.35	55.8	2.4
0.50	65.2	1.8
0.65	63.7	2.0
0.80	62.5	2.3

Table 1 Mean VS reduction at day 28 under varying aeration rates

ANOVA results indicated a significant effect of aeration rate on VS reduction ($F(4,10) = 32.5$, $p < 0.001$). Tukey's test showed that 0.50 L air/min·kg achieved significantly higher degradation compared to 0.20 and 0.80 ($p < 0.05$).

SIMULATION RESEARCH

A first-order kinetic model, incorporating temperature dependence via an Arrhenius expression $k = k_0 \cdot \exp(-Ea/RT)$, was implemented in MATLAB (2015a). Parameters $k_0 = 0.05$ day^{-1} and $Ea = 45$ kJ/mol were taken from Haug (1993). The model simulated substrate concentration and internal temperature profiles over 28 days for the optimal aeration rate (0.50 L air/min·kg). Simulated VS reduction at day 28 was 63.8%, closely matching experimental 65.2%, with coefficient of determination $R^2 = 0.92$. Temperature profiles from simulation matched measured data within ±2 °C, confirming model validity.

RESULTS

Raw MSW characterization yielded moisture content 58.2±1.5%, VS content 72.3±2.0%, and C/N ratio 28:1. Reactor temperatures rapidly rose to thermophilic range (55–60 °C) by day 3 under aeration rates ≥0.35 L air/min·kg and maintained for 7 days. CO_2 evolution peaked at day 5, indicating maximum microbial activity. VS reduction followed expected kinetics, with the 0.50 L air/min·kg treatment achieving highest degradation (65.2%). Final compost stability index (respirometric test) was <2 mg O_2/g·VS·h, indicating maturity. Nutrient analysis of compost showed N = 1.8%, P_2O_5 = 0.9%, K_2O = 1.2%, and pH = 7.2, meeting agronomic standards. Simulation results corroborated experimental trends, with VS reduction and temperature profiles aligning closely.

CONCLUSION

Aerobic composting of municipal waste in a pilot-scale reactor under 2015 engineering conditions demonstrated effective biodegradation and production of quality compost. An aeration rate of 0.50 L air/min·kg dry waste optimized microbial activity, yielding 65% VS reduction over 28 days. The first-order kinetic model provided reliable predictions of substrate degradation and temperature evolution. Final compost met stability and nutrient criteria for soil amendment. Future work (post-2015) could explore molecular microbial analyses, however, this study confirms that conventional engineering approaches suffice for effective MSW composting.

REFERENCES

Adejumo, O. A., et al. (2010). Optimization of composting process using response surface methodology. Waste Management*, 30(10), 1872–1879.*
Epstein, E. (1997). The Science of Composting*. CRC Press.*
Fukumoto, Y., et al. (2005). Effect of aeration rate on composting of source-sorted organic waste. Bioresource Technology*, 96(3), 197–204.*
Haug, R. T. (1993). The Practical Handbook of Compost Engineering*. Lewis Publishers.*
Monnet, F. (2003). Composting of municipal solid waste in forced-aeration reactors: Operational parameters and performance. Journal of Chemical Technology & Biotechnology*, 78(9), 1044–1050.*
Pardo, M., et al. (2012). Modeling thermophilic composting in batch reactors. Compost Science & Utilization*, 20(1), 45–58.*
Zhang, R., et al. (2006). Kinetic modeling of organic matter degradation in composting. Journal of Environmental Engineering*, 132(5), 553–558.*
Chandrika, U., & Narayana, T. (2008). Comparison of different methods for monitoring compost maturity. Biosystems Engineering*, 99(4), 512–518.*
Martins, V., et al. (2014). Thermal dynamics in aerobic batch composting reactors. Waste and Biomass Valorization*, 5(2), 345–354.*
Tan, K. (2009). Composting and microbial inoculants. Bioresource Technology*, 100(4), 1132–1140.*