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Composting processes for food processing wastes: A review

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Abstract

Composting of food processing waste was analyzed as a biological process and an engineered system. The goal is to establish fundamental principles and design criteria that would aid its adoption as waste management practice. Characteristics of the inflow, reactor, and outflow were evaluated. Success of the bioreactor was found to be largely dependent on microbial community structure, physical properties of biodegradable waste (BW), aeration, heat transfer, and time required for maturation. Static piles were the primary focus of this article for cost and energy efficiency.

Keywords: Compost; Bioreactor; Biodegradation; Food Processing Waste; Decomposers

1. Introduction

Composting is an exciting industry, where study of microbiology and natural cycles are applied to the operation of biological reactors to reduce pollution, aid degraded lands, and improve agricultural sustainability. Disposal of material deemed no longer useful is excessive and growing at alarming rates. “The generation of municipal solid waste per capita was 2.68 pounds per day in 1960. By 1970, it had grown to 3.25 pounds per day and by 1980 it was 3.66 pounds per day. By 2010, the daily generation of municipal solid waste per capita had reached 4.44 pounds” [1]. Food and other biodegradable wastes are an essential concern. The availability of better technology and the diminishing of valuable resources are strong support for a change of industry standard. An understanding of biological systems and the environmental impact of engineered systems is leading positive change in waste management and this paper will analyze composting as a critical means. Composting of biodegradable waste (BW) is largely dependent on favorable conditions for microbial populations. It is evident that favorable conditions for decomposers produces greater rates of decomposition and greater utilization of effluent material. Wastewater treatment relies greatly on microorganisms, and a symbiotic relationship proves to be the most beneficial to ecosystem’s success.

2. Important Parameters for Composting Process

2.1. C/N Ratio

Low C/N ratios are not recommended for composting. Volatilization of ammonia is a leading cause of acid rain and is inversely related to C/N ratio values. Ammonia and nitrous acid are fatal to some fungal populations and species richness is proven to be the greatest attribute time and time again to ecosystem health and viability. In high C/N piles, the percent of nitrogen accumulation is considerably higher, producing greater nutrient content in compost piles and reduced emissions.

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2.2. Moisture Content

Water is necessary for composting. Microbial activity including hindered reactions are dependent on the presence of water. Sharma and Poulsen studied oxygen uptake in porous media using yard waste compost as a test medium [2]. Water content from air dry to field capacity was analyzed under gas flow ranging from 0.2 to 2 L- min^{-1}. Increased water content improves nutrient supply to organisms and biological activity but decreases the quantity of air-filled pores. Increase water content produces inactive zones with little or no gas movement and hinders microbial activity. Ideal moisture content is dependent on balancing these effects and is controlled by pore size distribution, organic matter content, water flow velocity, water content, and influent air flow.

2.3. Aeration

Critical to aerobic degradation of solid waste is oxygen supply. Adequate oxygen supply is essential for catabolism and maturation of biodegradable waste. Insufficient supply increases gaseous emissions, including the emission of odorous compounds and greenhouse gases. Inadequate oxygen supply also promotes anaerobic degradation and the altering of environmental conditions which become unable to house a diverse microbial population. Inadequate supply also reduces the ability to reach thermophilic phase and pathogen control, and increases the time to reach maturity.

Windrows attempt to supply oxygen demand through molecular diffusion and natural draft ventilation, with periodic mechanical turning. If influent feedstock has a high C/N ratio, an addition of mature compost is incorporated, or if odor and gaseous emission are not of great concern, this method may be used solely to aerobically degrade organic waste. The oxygen supply for biological decomposition (stoichiometric demand) often needs windrow turning or alternative methods for oxygen supply. Peak oxygen demand occurs early in processing and decreases after thermophilic phase, windrow maturation after the thermophilic phase is reached is common practice.

Stoichiometric oxygen is entirely dependent on feedstock. Oxygen is the terminal electron acceptor in aerobic degradation of biological degradation. The absence of O_2 is likely to lead to an accumulation of electric charge. Generated electron remains static until the presence of O_2 is supplied. This is a passive process, resulting in a low O_2 utilization due to uneven distribution of O_2 in the compost pile [3]. Gaseous flow in porous media will develop pathways of least resistance and will produce many areas void of activity. It is well known that electrons can move under an electric field. Electric field induction enhanced the flow of electrons from biological redox processed to oxygen, enhancing maturation and greenhouse gases emissions. It is theorized that the addition of biochar and ferric acid would further optimize O_2 utilization.

2.4. Porous Media

The physical structure of biological reactor is a key variable in operation. Air and water filled pores, permeability, pore tortuosity, hydraulic conductivity, moisture content, water holding capacity, matric potential, and thermal conductivity are all effected by the compost environment [4]. Biodegradable solid wastes are heterogenous and thus is the physical structure. Agostini reviewed the main properties of the porous physical characteristics, phenomena, and simulation models for the management of biodegradable waste [5]. The initial microbial community, moisture content, oxygen availability, physical availability to degradation, temperature, and chemical composition determine the overall biodegradation rate. Computational fluid dynamics have not been used extensively in compost science but could provide physically sound and effective simulation.

2.5. Natural Cycles

The science of plant biosynthetic pathways is important to compost science because the organic material formed will be the object of degradation. Application into compost science would be highly beneficial but time must be devoted to a new field of science for application into a field with incorporation of so many. The goal of composting coincides with the biodegradation of organic compounds and production of humic substances. Humic substances are resistant to biodegradation and an essential addition to improve soil properties.

Ammonium is not very mobile in soils compared to nitrogen in the form of nitrates (NO3). The strong adsorption quality of ammonium causes uptake by plants to be less common than that of nitrates. Nitrates must be reduced prior to utilization for amino acid construction but ammonium can be immediately incorporated [6]. Therefore, both forms of nitrogen are incredibly important to plant growth and subsequently the science of composting. Decomposition or mineralization of organic nitrogen produces ammonia (NH_3). Ammonia or ammonium can produce one another and are dependent on the environmental pH. Ammonium is mildly acidic and is nontoxic to fungi unlike its basic counterpart ammonia. If environmental pH is low, more ammonia molecules will be converted to ammonium.

3. Microbial Community in Composting Process

Community succession is highly dynamic, and populations are often replaced in changing environmental conditions. Zhang proposed high C/N ratios promoted the growth of nitrogen fixing bacteria and suppressed denitrifying populations [7]. Cao demonstrated the effectiveness of microbial diversity on pathogen suppression [8], and Neher demonstrated how composting methods change community dynamics [9]. All three experiments incorporated manure as a feedstock which provided *Bacteroides* and *Firmicutes* in abundance. Composting has become the best waste management practice for manure and natural decomposition due to large number of heterotrophs involved in the process. The digestion of heterotrophs is also highly evolved, which helps biological reactors to degrade food so incorporation into composting may aid time of maturity. The amount of manure added to soils is unnatural but nutrient rich, as a readily available solution, it will prolong the acceptance and advocation of soil care, minimal disturbance, and the return to agriculture as a community responsibility. For fungi, *Saccharomycetales* is dominant in early composting. *Saccharomycetales* are in the phylum *Ascomycota* and multiply by budding. *Saccharomycetales* are believed to be dominant due to spore like cellular structure that can withstand high temperatures and low initial moisture contents. *Acremonium alcalophilum* and S*ordariales* were dominant at t = three days, *Saccharomycetales* was dominant at t = five days, and at t = seven days *Scedosporium, minutuisporum* (32.65%), *Aspergillus cibarius* (16.89%) and *Thermomyces lanuginosus* (9.42%) were the most abundant.

Most species are unable to endure temperatures that exceed 40°C which are below the thermophilic range commonly associated with composting.

Moqsud investigated compost in plant microbial fuel cells for bioelectricity generation and concluded that compost added plant growth and enhanced voltage generation [10]. The power density became three times more when compost was added.

Glycolytic intensity in comparison to oxygen consumption intensity is considered minimal under aerobic conditions for the majority of organisms. Energy metabolization requires a complicated series of events. First, hydrolytic enzymes are produced and transported to the surface of the substrate, then hydrolysis of substrate molecules into soluble fractions, diffusion transport to the cell, then through biological membranes occurred. The same series of events is required for the transport of oxygen into the microbial cell, floc, or mycelia. Many biochemical reactions are non-elementary homogeneous reactions. Stoichiometric equations do not produce reaction rate expression in many non-elementary reactions due to the presence of enzymes, biological catalysts, which remains as free enzymes after the formation of a product. These are known as catalytic reactions. Microbial nutrition is dependent on C, H, O, N, P, S and minerals. There may be other necessary nutrients but carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur are essential for cellular functions and microbial growth. Minerals such as potassium, calcium, iron, molybdenum, cobalt, zinc and copper are needed for various reactions, for instance, potassium activates many enzymes.

4. Effluent from Composting Process

Compost maturity is required for the presence of phytotoxic substances can cause plant injury. The plant seed germination index (GI) method is common for maturity assessment. Alternatives exist to estimate maturity but none as low cost and easy to complete as the GI method. Pollution is a concern in the composting industry, gaseous emissions and leachate are released from aerobic biodegradation and must be considered in design. CO_2, N_2O, CH_4, contribute to global warming, while NH_3, sulfur compounds, and most of the volatile organic compounds (VOCS) emission cause undesirable and other odor nuisances. Ideal physical and chemical characteristics can greatly reduce emissions, proper C/N ratio, tortuosity, and pH control are only a few important parameters that influence gaseous emissions. High concentrations of VOCs are released during initial stages, biofiltration is a BMP (best management practice) for treatment. Mature Compost is ideal as an additive to compost or as a filter for gaseous emissions. Leachate is an industrial wastewater. Treatment operations can include membrane filtration but serious fouling is a continuous problem. Constructed wetlands offer tertiary treatment for COD (chemical oxygen demand) removal rates aren't high enough to deal with high concentrations of organic material. Decentralized composting offers the greatest solution to the waste management crisis. Microbial fuel cells increase productivity under the addition of compost to wetland plants. A lot of heat is generated from composting and a potential source of green energy [11].

5. Conclusion

In conclusion, producing food for plants makes composting an incredible field. Food waste has many uses when it is disposed of, most of it probably still fit for human consumption. Reducing waste production is ideal but trends point to waste management being responsible to improve food wastage. The best waste management practice for food waste is starting product reuse with high eukaryotic organisms and transcending down the food web. Farming and compost engineering could make a grand team to combat the disgraceful practices in both industries today. Food waste can be fed to livestock. Manure produced and rotting food waste could be used for the production of maggots. Maggot farming is an established industry and research will need to be completed for the establishment of proper growth mediums and harvesting larvae. Then a biological reactor could serve to mix influent materials, collect leachate, and allow for escalation to thermophilic temperatures with electric field induction. Mature compost should be used for recirculation and as a static pile for biofiltration. Once temperature declines to mesophilic ranges vermicomposting could be used to complete maturation. Leachate can be treated through common wastewater treatment operations; organic loading is high and may need dilution. Trickling filters are recommended for low energy consumption. Tertiary treatment and energy production could stem from constructed wetlands and microbial fuel cells. Microbial fuel cell proton exchange membranes (PEM) are expensive and single chamber reactors without PEMs are being improved upon. Gaseous emissions are treated via biofiltrations and if odor is a strong concern could be released at high elevations, turbines may generate energy through temperature differences with the outside environment. No one method of composting is best, since all composting processes are good practice and are in need of adoption.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest for all authors of this manuscript.

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