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Effect of moisture content of a wood matrix on a small-scale biodegradation system for organic solid waste

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Abstract The optimum working moisture content of a wood matrix for the garbage automatic decomposer-extinguisher (GADE) machine was investigated using a small-scale degradation reactor. A formula feed for rabbits was used as the model waste. The degradation experiment was conducted under controlled conditions such as moisture content, environmental temperature, and airflow rate. The degradation rate was estimated precisely from weight loss and the CO_2 evolution rate. The degradation rate were nearly constant at a moisture content of 30%–80% on a wet-weight basis. Microorganisms from the environment propagated in the reactor with no inoculums added. The number of microorganisms showed a trend similar to that of the degradation rate. The microorganism community changed according to the moisture content of the matrix and were considered to attain a constant degradation rate at a wide range of moisture content of a matrix.

Key words Food waste · Biodegradation · Wood particles · Moisture content · Microorganism

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Introduction

The problem of waste management has recently become more serious. Both waste reduction and recycling are being promoted to resolve this problem. With those goals in mind, the garbage automatic decomposer-extinguisher (GADE) machine was developed to process organic solid waste aerobically, especially food waste using a matrix such as wood particles or sawdust.[1–4] Microorganisms that propagate in such a matrix degrade wastes into carbon dioxide (CO_2) and water. Residues from waste such as minerals and humus accumulate in the matrix. Residual wood particles were found to be effective as an organic fertilizer after they ceased to be effective as a matrix owing to fiberization and accumulation of residues.[2,5]

To use the machines effectively, optimum operating conditions must be determined. Moisture content (MC) of the matrix is one of the main determinants of factor to microbial activity. Several studies were conducted on the optimal MC for composting. Sular and Finstein reported that when composting food waste the optimal MC was 50%–60%[6]; and Kaneko and Fujita reported that when composting model waste[7] 50%–60% was optimum as well. However, there are few reports about the optimal MC on biodegradation of organic waste using a matrix. Inoue et al. reported that the optimal MC in the biodegradation machine was lower, at 35%–45%,[3] but that was empirical data.

We therefore examined the effect of the MC of the matrix on the degradation rate to estimate optimum conditions more accurately using a small-scale degradation reactor and uniform model waste.

Materials and methods

Matrix and model waste

Wood particles used as a matrix were prepared from sapwood of Japanese cedar (*Cryptomeria japonica* (L. fil.) D.

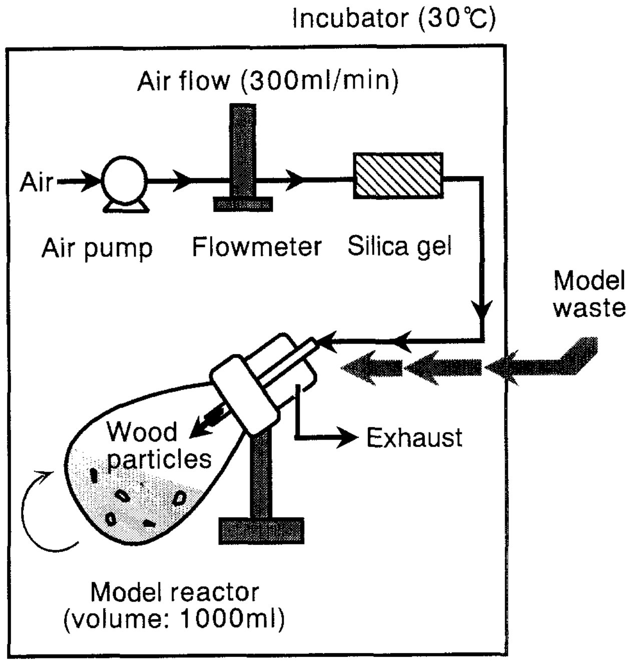

Fig. 1. Equipment

Don) and ground in a Willey Mill; particles were then sieved to a grain size of 0.5–1.0mm. The MCs of the wood particles were varied at 20%, 30%, 40%, 50%, 60%, 70%, and 80% on a wet-weight basis. A formula feed for rabbits made from alfalfa, flour, delipidated soybean, and wheat germ (Hi-Pet Co., Osaka, Japan), was applied as the model waste because its contents of crude protein, fat, fiber, and ash (19%, 2%, 10%, and 9%, respectively) were similar to actual food waste.[1,8–10] The carbon/nitrogen (C/N) ratio of the model waste was 13.9.

Equipment

A 1000-ml Kjeldahl flask was used as a small-scale degradation reactor (Fig. 1). The reactor was connected with an air pump to supply dry air through a silica gel bed at a controlled flow rate of 300 ml/min. The reactor was attached to a rotary evaporator (Tokyo Rikakikai Co., Tokyo, Japan). Each setup was kept in separate incubators adjusted to 30°C.

Degradation experiment

Initially, 40g of dried wood particles was placed in the reactors where the MCs were adjusted to 20%, 30%, 40%, 50%, 60%, 70%, and 80%, respectively. Each reactor was rotated at 30rpm for 2min every 15min. Model waste (3.5g) was added to the each of the reactors every 24h. The model waste/wood particles ratio was greater than the actual waste/wood particles ratio used in the previous study.[1,3] The MC of the wood matrix was checked using a 7-g sample from each treatment with an infrared MC meter every 24h to determine the actual moisture level. The MC of the matrix was adjusted to maintain a constant level. The measured sample was then returned to the reactor after adjusting the MC.

Each of the three experiments lasted 30 days except the experiments at 80%. The duration of the latter was shortened because the strength of the equipment could not bear the reactor weight for more than about 15 days.

Weight loss, evolved CO_2, pH, and viable microorganism count in the model waste

The total weight of the residual model waste was determined by weighing the model reactor flask (including the wood matrix) and the model waste, assuming that the matrix was not degraded. The total weight loss of the degraded model waste was then calculated by taking the difference between the original weight and the residual weight.

The concentration of CO_2 in the exhaust gas was monitored by a gas detector (GASTEC Co., Kanagawa, Japan). The rate of CO_2 evolution was calculated by taking the difference in CO_2 concentration in the inflowing air and the outflowing air, airflow rate, temperature, and gas constant, all using the equation for the ideal gas state.

The pH of the supernatant, 30ml deionized water mixed with 3g wet matrix, was measured using a pH meter.

All of the measurements were done every day, just before the new model waste was added.

A 1-g sample was removed from each treatment every 5 days and suspended in 100ml of sterile water. A 100-μl aliquot of the fluid from this suspension was then placed on a standard method agar (SMA) plate and incubated at 30°C. The number of viable microorganisms was counted following standard methods (Pharmaceutical Society of Japan, 1990). The medium was composed of yeast extract (0.25%), peptone (0.5%), glucose (0.1%), and agar (1.5%). The plates, on which about 20 colonies appeared, were selected, and the dominant microorganisms were isolated. Their cell shapes were observed using a phase-contrast microscope to determine whether they were yeast or bacteria. The bacteria were then classified as gram-positive or gram-negative using SMA-added crystal violet (5ppm).[11]

Results

Rate of weight loss and CO_2 evolution

The time series data for total weight loss, CO_2 evolution, pH, and number of viable microorganisms in the matrix at MC 50% are shown in Fig. 2, as an example. The variation in weight loss for the time charts was small. Previously it was generally believed that the stability of the biodegradation process of food waste was difficult to maintain. However, this experiment showed that degradation can be stabilized by controlling environmental conditions such as temperature, MC of the matrix, and aeration rate.

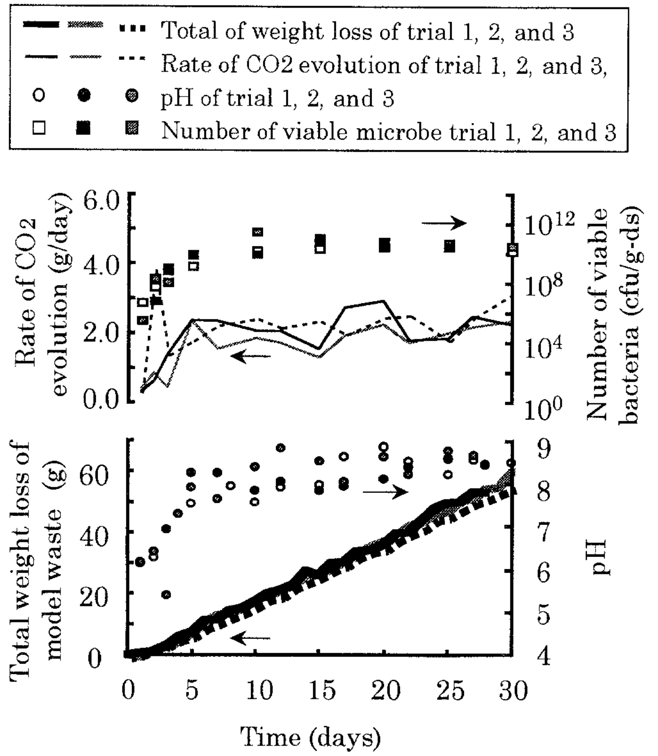

Fig. 2. Time series data for total weight loss of the model waste, rate of CO_2 evolution, number of bacteria, and level of pH of the matrix during biodegradation of model waste at a moisture content of 50% on a wet weight basis

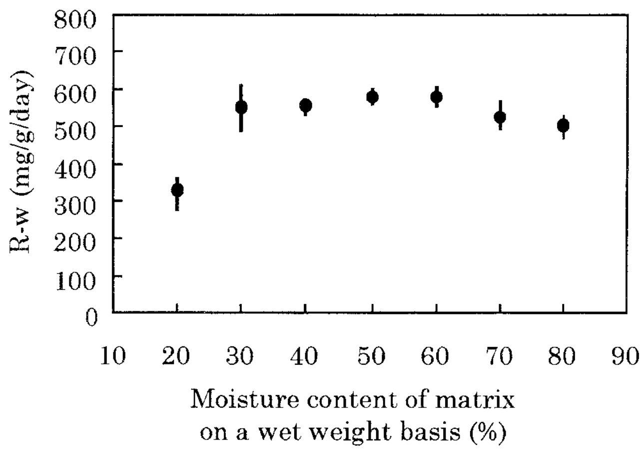

Fig. 3. Relation between the moisture content of the matrix and the ratio of weight loss of the model waste (R_{-w}) in the steady state. *Bars* show maximum and minimum values of three plots

A lag phase in the degradation test showed no weight loss in the waste for the various moisture conditions. The lag phase for the lower MC samples, however, was longer. The relation between incubation time and weight loss was linear after the lag phase. The rates of weight losses, determined from the slopes of the lines, were 1.15, 1.93, 1.93, 2.03, 2.02, 1.82, and 1.75 g/day at MC 20%, 30%, 40%, 50%, 60%, 70%, and 80%, respectively. From those figures, the rates of weight losses in the supplied waste weight (R_{-w}) were calculated to be 329, 552, 553, 579, 576, 520, and 499 mg/g at an MC of 20%, 30%, 40%, 50%, 60%, 70%, and

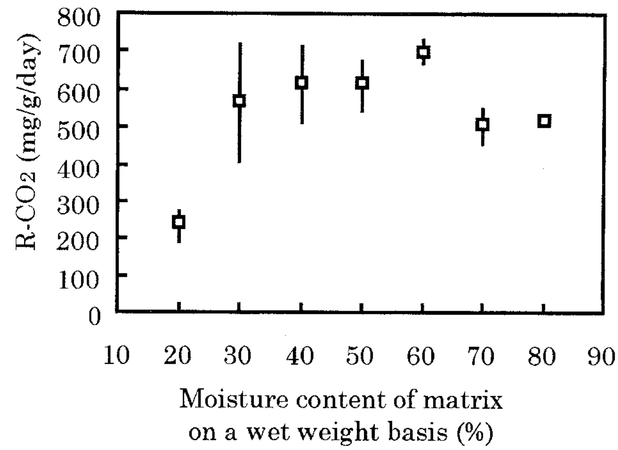

Fig. 4. Relation between the moisture content of the matrix and the rate of CO_2 evolution (R_{-CO_2}) in the steady state. *Bars* show maximum and minimum values of three plots

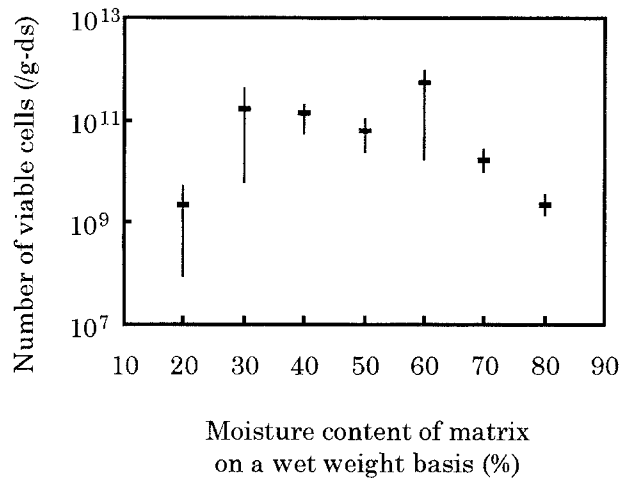

Fig. 5. Relation between the moisture content of the matrix and the number of viable microorganisms in the steady state. *Bars* show maximum and minimum values of three plots

80%, respectively (Fig. 3). The sample at the lowest MC, 20%, showed the lowest rate of weight loss, but samples at other MCs, 30%–80%, showed nearly the same rates of weight loss.

The rate of CO_2 evolution increased gradually from the initial stage and became almost constant at each moisture condition (the steady state). The constant levels were determined from the average level at steady state to be 0.84, 1.98, 2.15, 2.15, 2.44, 1.77, and 1.80 g/day at MC 20%, 30%, 40%, 50%, 60%, 70%, and 80%, respectively. From these figures the CO_2 evolution rate in the samples (R_{-CO_2}) was determined to be 241, 565, 615, 615, 698, 506, and 515 mg/g, respectively (Fig. 4). Samples at the upper and lower ends of the MC range showed lower rates of weight loss.

Viable microbial concentration and matrix pH

Growth of microorganisms was observed in all trials despite the fact that no inoculums were added. No microorganisms were detected at the initial stage of the experiments, although the number of microorganisms increased logarithmically during the early stages until a steady state was reached (Fig. 2). These was significant growth of microorganisms in the small-scale degradation reactor without any inoculums. The number of microorganisms found at various MC levels showed a trend similar to these of R_{-w} and R_{-CO_2} (Fig. 5).

The pH of the original wood particles and the raw model waste were 5.50 and 5.72, respectively. The pH of the matrix changed from acidic to alkaline at every MC condition after reaching the steady state (Fig. 2). The pH increased more quickly at the middle of the MC range. The average pH in the steady state increased from MC 20% to 50%; it was constant at 50%–70% and lower at 80% (Fig. 6).

Transition of microorganism community

The microorganism community varied with the MC of the matrix (Fig. 7). Gram-positive bacteria were dominant at the lower MC levels, except at 20%, and gram-negative bacteria appeared at higher MC levels. At the lowest MC (20%) yeast were dominant. The community also changed with experiment time at MC 60% and 70%.

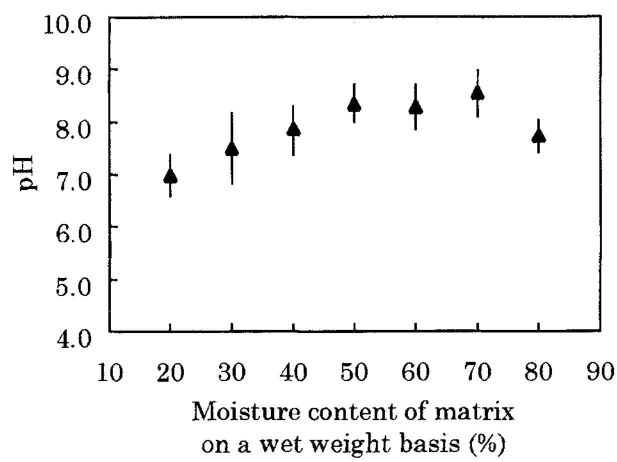

Fig. 6. Relation between the moisture content of the matrix and average pH level of the matrix in the steady state. *Bars* show standard deviation in the steady state

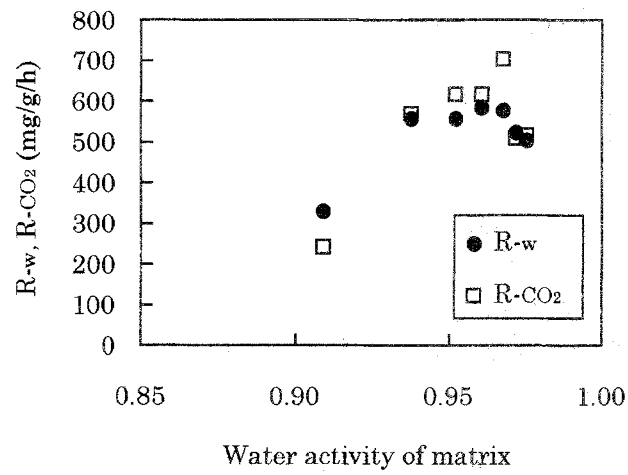

Fig. 8. Relation between the water activity of the matrix and the ratio of weight loss of the model waste (R_{-w}) and the rate of CO_2 evolution (R_{-CO_2}) in the steady state

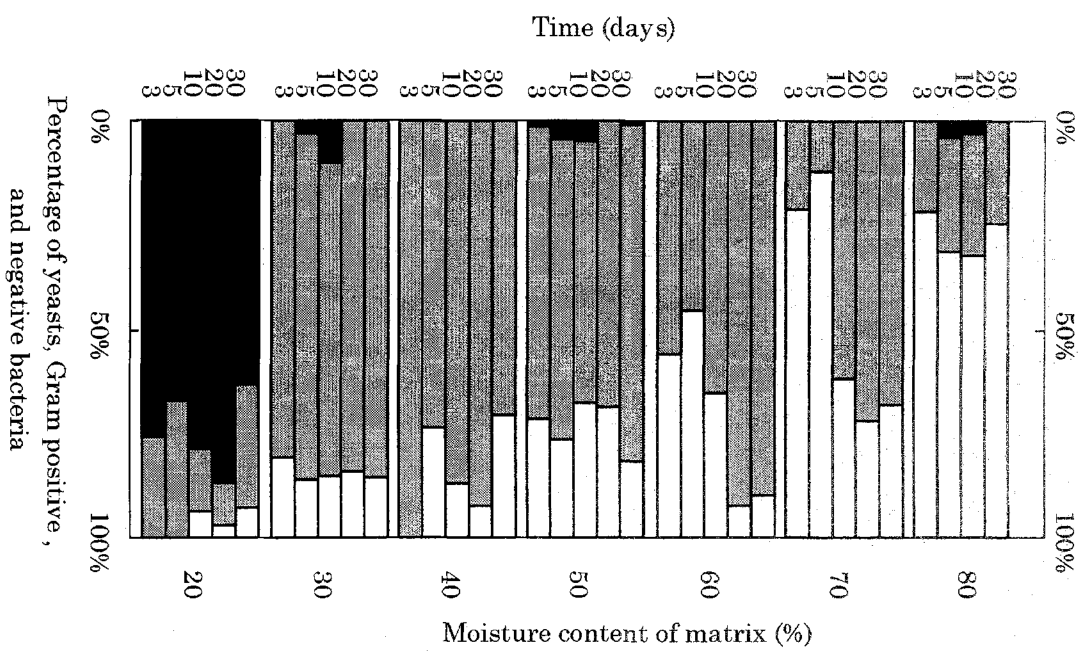

Fig. 7. Transitions of gram-stainable bacteria due to the moisture content of a matrix and elapsed time. *Dark bar*, yeast; *gray bar*, gram-positive bacteria; *white bar*, gram-negative bacteria

Discussion

The microbial community, conditioned by the MC of the matrix, is believed to affect the biodegradation of waste, as the MC is an important factor controlling microbial activity. In our experiment, an accurate estimation of the degradation rate was determined in a small-scale degradation reactor.

The results of R-$_w$ and R-$_{CO_2}$ showed the lowest MC level at 20%. R-$_w$ was nearly constant at 30%–80%, whereas R-$_{CO_2}$ was constant at 30%–60% and was lower at 70%–80%. Based on the report by Kaneko and Fujita,[12] the MCs in wood particles of 20%, 30%, 40%, 50%, 60%, 70%, and 80% converted to water activity (a_w) of 0.909, 0.938, 0.952, 0.961, 0.967, 0.972, and 0.976, respectively. In the relations between R-$_w$, R-$_{CO_2}$, and a_w, samples at the upper ends of a_w showed the lowest level (Fig. 8). Kaneko and Fujita reported that the maximum specific growth rate (μ_{max}) of microbes is proportional to a_w in the lower a_w range during composting; their data indicated that the peak μ_{max} of composting dog food and sawdust appeared at a_w 0.97.[12] Our results are consistent with these data.

The water-holding capacity is 66.1% on a wet-weight basis from our earlier study on the water retention of sawdust.[5] Water is believed to fill the spaces between the grains of wood particles at an MC of more than 70%, cutting off air to the microorganisms. An MC of 20% on a wet-weight basis is similar to the fiber saturation point. The number of microorganisms is believed to have decreased because there is little free water available to support their growth.

Inoue et al. reported that bacteria in food waste are able to adapt to a wide range of conditions, and that the bacterial community can change according to the conditions, maintaining their degradation performance without the addition of special inoculums.[13] Similar results were obtained in our study, even though the waste was sterilized before testing. It is believed that the bacteria came from the air or from the wood particles and multiplied in the reactor. The microorganism community varied with the MC of the matrix. Yeast appear to be dominant at an MC of 20%, at which the minimum a_w is lower than that required for bacterial growth. An MC of 20% in a mixture of sawdust is equivalent to an a_w of 0.909,[12] which is the minimum a_w for bacteria in general.[14] Yeasts, on the other hand, can grow at a low a_w because their minimum a_w is 0.88.[14]

The increase in pH is believed to be due to biodegradation of the model waste. Fujita et al. reported that biodegradation during composting proceeds in largely alkaline conditions and has a maximum pH of 8–9.[15] These results are similar to those of our experiment. The pH increases were caused by the generation of ammonium ions; but they decreased through the generation of organic acid under anaerobic conditions, which in turn led to a low reaction rate.[16] The pH of matrix decreased at an MC of 80%, suggesting that an MC of 70%–80% is the upper boundary of the optimal range.

It was concluded that almost equal weight losses can be obtained at the wide MC range of 30%–80 in the GADE machine using a wood matrix, and that special controls are not necessary in this range. However, an MC of more than 70% is not desirable because the biodegrading rate starts to decrease owing to a fall in aeration capacity.

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