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Project Summary

Shredded Rubber Tires as a Bulking Agent for Composting Sewage Sludge

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Shredded rubber tires were evaluated as a bulking agent for composting wastewater sludges to determine the optimum particle size and mix ratio for efficient composting. Three sludges (raw primary, anaerobically digested, and secondary biological), two amendments (sawdust and recycled compost), three sizes of shredded rubber (1.27 to 2.54 cm, 2.54 to 5.08 cm, and greater than 5.08 cm), and three shredded-rubber-chip-to-sludge mix ratios (1:1, 2:1, and 3:1) were evaluated. The smallest size rubber chip, 2:1 mix ratio, and sawdust amendment were found to be optimums.

Test results with raw primary sludge, shredded rubber, and no amendments produced undesirable odors and handling difficulties. A high initial moisture content and low carbon-to-nitrogen (C/N) ratio led to conglomeration of the sludge particles, anaerobic conditions, and the conversion of excess nitrogen into ammonia gas. Tests with all three sludges and recycled compost produced similar results.

When amended with sawdust, all of the sludges were effectively composted using shredded rubber. Because of high moisture content and low C/N ratio, all sludges required the moisture absorbency and supplemental carbon that the sawdust provided.

Heavy metal levels increased during composting with raw primary sludge and rubber chips as a result of the concentrating effect of organic matter decomposition. In addition, the shredded rubber chips contributed Zn and Fe to the finished compost. Recycling the rubber chips reduced the Zn and Fe concentrations, but they were still high after five cycles. However, the levels were not high enough to limit the use of shredded rubber in the composting of the sludge.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The static pile composting of sewage sludge has historically used wood chips as a bulking agent. Because wood chips are biodegradable and easily lost in the composting process, there is a need for recoverable, low-cost bulking agents.

Previous studies have shown that shredded rubber tires are a potential substitute for wood chips as a bulking agent. Experiments using raw sludge showed that temperatures of 55°C could be developed and maintained for pathogen destruction, but that the shredded rubber contributed Fe and Zn to the finished compost. Based on past experience, this study had four goals: (1) to determine the optimum rubber chip size and mix ratio for efficient composting; (2) to evaluate which types of sewage sludges could be composted with shredded rubber; (3) to determine if supplemental sources of carbon would be required to enhance the composting process, particularly for biological and digested sludges with low energy values; and (4) to determine the heavy metal contribution of shredded rubber and the number of reuse cycles required before a reduction in metal levels occurred.

Procedure

Three compost vessels were constructed of wood with dimensions of 1.83 by 1.83 by 1.37 m. The front wall of the vessel was hinged for access, and the vessels were insulated with styrofoam board.

The vessels had an airflow plenum at a height of 15.2 cm from the bottom for air distribution. One blower, controlled by a time clock and thermostat, pulled air through each vessel. The thermostat was located in the center of the composting mass and overrode the time clock during peak activity periods to maintain the temperature at 55°C. At the beginning of each experiment, the minimum airflow rate was set at 31 cubic meters per hr per dry metric ton (m^3/h·dt). During peak activity periods, the maximum airflow rate was 500 m^3/h·dt.

Three dewatered sewage sludges (raw primary, anaerobically digested, and secondary biological) were obtained from three local wastewater treatment plants. Shredded rubber tires that were relatively free of protruding steel belts were obtained from a local tire company. The shredded tires were classified by screening into three sizes, 1.27 to 2.54, 2.54 to 5.08, and greater than 5.08 cm. Supplemental amendments (sawdust and recycled compost) were used for moisture control and carbon sources. The amendments were used to adjust the initial moisture content of the rubber chip and sludge mixture to between 50% and 60%.

Temperature and airflow were recorded for each composting vessel. Four thermocouples at both the 0.3- and 0.6-m levels were connected in parallel to produce an average temperature reading for each level. Because the temperature of the compost vessel was controlled by a thermostat, the temperature was not used to evaluate performance.

The heavy metal (Cd, Cu, Fe, Ni, Pb, and Zn) contents of the sludge and the final compost were measured to determine any possible contribution of metals to the compost by the shredded rubber tires.

Results and Discussion

The composting experiments were grouped into five sets, and within each set were several trials. Each trial used the same sludge in each of the three composting vessels.

Trials with Raw Primary Sludge

Determination of the Optimum Rubber Chip Size

The first experimental set consisted of five trials to determine the optimum shredded rubber chip size for composting. These trials used raw primary sludge with a C/N ratio of 11 to 19, which was lower than the optimum range for composting of 25 to 30. The first three trials compared small, medium, and large rubber chips, and the last two trials compared small, medium, and mixed-size (1:1 small and medium) chips. The results were measured by reductions in moisture, volatile solids, and total carbon content, and were statistically analyzed using a Latin square design. The statistical analysis of the first three trials showed that the large rubber chips performed poorly; therefore, no further trials were conducted with the large chips. Analysis of the last two trials showed that the small rubber chip outperformed the medium and mixed-size chips. Based on these results, the small size chip was determined to be the optimum and was used for all subsequent trials.

Determination of the Optimum Rubber-Chip-to-Sludge Mix Ratio

The second experimental set consisted of three trials conducted with raw primary sludge (C/N ratio of 7 to 9) to determine the best rubber-chip-to-sludge mix ratio. Three mix ratios were compared (1:1, 2:1, and 3:1; volume basis) based on experience with the static pile composting method used in the United States. The performance of each mix ratio was statistically evaluated using moisture, volatile solids, and total carbon content data. In addition, qualitative evaluations were made from observations during loading, composting, and screening.

The statistical analysis, confirmed by field observations, identified the 1:1 mix ratio as being unsatisfactory. No statistically significant differences were found between the 2:1 and 3:1 mix ratios. These two mix ratios were approximately equal in ease of handling and composting performance, but the 2:1 mix ratio was considered optimum because fewer rubber chips were required. During loading, the 1:1 mix ratio was observed to be the stickiest and to form the most sludge balls. The 2:1 and 3:1 mixed more uniformly and formed fewer sludge balls. A test for one trial showed that the porosity of the mixture increased from 43% to 52% as the mix ratio increased from 1:1 to 3:1. Composting odors were most noticeable from the 1:1 mix ratio and least noticeable from the 3:1. Screening carryover was greatest for the 1:1 mix and pockets of wet, partially composted sludge were observed during unloading.

Contribution of Heavy Metals by Shredded Rubber Tires

Using shredded rubber tires significantly increased the concentrations of Zn and Fe. Recycling the rubber chips reduced these levels somewhat, but they were still high after five cycles. Zinc levels ranged from 900 to 1,200 mg/kg in the raw sludge and 1,400 to 2,800 mg/kg in the finished compost. Iron levels ranged from 6,900 to 14,000 mg/kg in the raw sludge, and 11,000 to 27,000 mg/kg in the finished compost. Zinc oxide, used in the manufacturing of tires, was the source of Zn in the compost. The increase in Fe was because of steel belts and rim beads found in rubber chips that had eluded magnetic separation. Although steel was infrequently observed, it caused no handling problems and appeared to be randomly distributed among the chip sizes.

In four of the first five trials, the highest levels of Zn were found in the compost that used the small chips, and the lowest levels when the large chips were used. This was probably because of the abrasion of the rubber chips during loading, unloading, and screening that resulted in small particles being incorporated into the sludge or compost matrix. The small chips had the greatest surface area per unit volume and, therefore, contributed more abraded particles to the compost samples. The greater the percentage of chips in the mix, the higher the concentration of Zn and Fe in the compost.

The percentage change in concentration of Cd, Pb, Ni, and Cu showed that increases in the level of these metals were not significant and were due to the concentrating effect of composting as organic matter was destroyed. No correlation was found between chip size and metal concentration for these metals.

Temperature

Temperature readings for the middle of the compost pile (0.6 m level) were averaged for each day. The set point temperature of 55°C was maintained for at least 3 consecutive days only about 60% of the time. There was no pattern between the temperature and the chip size or mix ratio.

A temperature profile was observed in the composting pile, highest at the bottom and lowest at the top. This was because of cool ventilation air entering the composting vessels at the top and warmed exhaust air exiting from the bottom.

Screening Efficiency

A rotary trommel screen with a 1.27-cm mesh opening was used to separate the shredded rubber from the compost. The screen removed all of the chips from the compost, but some compost was carried over into the shredded rubber. The amount of carryover was highly moisture dependent: the least amount occurred when the moisture content was 40% or less; the highest amount occurred when the moisture content exceeded 50%. Because the rubber chips did not absorb water from the sludge to lower the moisture content, sludge balls formed while mixing and were difficult to break during screening. Thus the screening efficiency was poor when the compost was wet and became more severe when the sludge balls dried.

Trials with Raw Primary Sludge Plus Amendments

The third experimental set consisted of two trials with raw primary sludge mixed with amendments (one with sawdust, the other with recycled compost) and small rubber chips.

Adding both amendments to the raw sludge lowered the moisture content of the initial mixture to the 50% to 60% range. Adding sawdust also increased the C/N ratio from 14 to 27. Reducing the moisture and increasing the C/N ratio produced a dry, screenable compost with no objectionable odors during the compost process, goals which were not achieved by adding recycled compost.

The average daily temperature at the center of each composting vessel was maintained close to the 55°C set point for both trials, but showed greater fluctuation for the recycled compost trial.

Trials with Digested Sludge Plus Amendments

The fourth experimental set consisted of two trials in which either sawdust or recycled compost was mixed with anerobically digested sludge and the small rubber chips. The anaerobically digested sludge had a moisture content of about 82%. The amount of amendment required to lower the initial mixture to the 50% to 60% range was calculated to be about equal to the volume of sludge. The rubber-chip-to-sludge-to-amendment mix ratio was 2:1:1 for both trials.

As a result of digestion, the anaerobically digested sludge had a high total nitrogen content and a low carbon content that yielded a low C/N ratio of 3 to 4, which was not favorable for composting. Therefore, a carbon source was essential.

As expected, adding sawdust to the anaerobically digested sludge increased the volatile solids content, total carbon content, and C/N ratio of the initial mixture. But, the recycled compost did not supply enough carbon for effective composting. Adding recycled compost to the anaerobically digested sludge decreased the volatile solids content and thus produced odors, but not as strong as those produced during the trials with raw primary sludge. When sawdust was used as an amendment, odors were not a problem. Also, the recycled compost trial did not compost well or uniformly. During unloading, ammonia gas was present and numerous pockets of wet, uncomposted sludge were found.

There were no problems screening the compost from the sawdust trial. The compost from the recycled compost trial was wet and formed balls during unloading and screening, resulting in a high percentage of compost staying with the rubber chips.

The average temperature at the center of each composting vessel was maintained near the 55°C set point for both trials. The temperature in the sawdust trial had less variation.

Trials with Secondary Biological Sludge Plus Amendments

The last experimental set consisted of two trials in which secondary biological sludge was mixed with either sawdust or recycled compost and the small rubber chips. With a moisture content over 85%, the amount of amendment required to lower the initial moisture content was greater than for previous trials. The rubber-chip-to-sludge-to-amendment mix ratio was 2:1:1.5.

As expected, the secondary biological sludge had a high total nitrogen content and low carbon content. The resultant C/N ratio was low (4) and a supplemental carbon source was necessary. The sawdust increased the C/N ratio from 4 to 17, but adding recycled compost only increased the C/N ratio from 4 to 9.

The 2:1:1.5 mix ratio yielded initial mixtures that had about 56% moisture content for both trials, but had different physical characteristics depending on which amendment was used. The sawdust aided the mixing of the sludge and rubber chips, the mixture had a uniform consistency that was easy to handle, and the finished compost screened well. The mixture with recycled compost appeared wet, was very sticky, and formed balls and clumps during the loading phase of the experiment. This occurred in the mixer and in the conveyor used to load the compost vessels. The formation of sludge balls and clumps also contributed to composting odors and a high amount of screening carryover.

During the composting with sawdust, no odors were detected because the moisture content was lowered into the optimal range, carbon was provided to increase the C/N ratio, and the mixing was easier. Odors were detected during composting with recycled compost, but these odors were not as strong and objectionable as those produced when composting raw primary sludge. The odors were present, even though the moisture content was in the optimal range, because the recycled compost did not prevent the formation of sludge balls and clumps or provide sufficient carbon to adequately increase the C/N ratio.

The average daily temperature measured in the center of the pile did not reach 55°C for two of the three vessels in the sawdust trial. Two of the three vessels in the recycled compost trial reached 55°C for at least 3 consecutive days.

Conclusions

Of the three rubber tire chip sizes (1.27 to 2.54, 2.54 to 5.08, and greater than 5.08 cm) and three rubber-chip-to-sludge mix ratios (1:1, 2:1, and 3:1) evaluated, the smallest size chip and the 2:1 mix ratio were found to be optimums for effective composting.

The porosity of the rubber chip and raw primary sludge mixtures were all acceptable and did not limit the composting process. Average porosities were 46%, 47%, and 50% for the 2:1 chip-to-sludge mixtures of the small, medium, and large chips, respectively.

The combination of raw primary sludge and shredded rubber produced thermophilic composting conditions. However, it also produced anaerobic conditions, undesirable odors, and handling difficulties, even at the optimum chip size and mix ratio. These problems were caused by the high initial moisture content and the balling of sludge particles during mixing. In addition, a low C/N ratio produced noticeable concentrations of ammonia gas.

Adding sawdust to the raw primary sludge and shredded rubber mixture lowered the moisture content and increased the C/N ratio and thus eliminated odors and screening problems. A minimum of one part of shredded rubber is recommended to provide sufficient porosity and structure. The quantity of sawdust required depends on the moisture content and C/N ratio of the sludge mixture; a moisture content of 55% to 60%, combined with a C/N ratio of about 25:1, successfully eliminated odors and produced a dry, stabilized compost.

Using recycled compost to lower the moisture content did not effectively eliminate odors and screening problems, probably because of the lack of carbon for increasing the C/N ratio. In addition, recycled compost was not totally effective in preventing the formation of sludge balls. Hence, recycled compost is not recommended as an amendment when using shredded rubber unless it is combined with another amendment such as sawdust.

Because of the low C/N ratio and the high moisture content of the sludges used, amendments containing available carbon, such as sawdust, were essential. When mixed with these sludges, sawdust effectively eliminated odors, screening problems, and the formation of sludge balls, and ensured composting temperatures of 55°C.

The shredded rubber contributed Zn and Fe to the compost, but repeated recycling of the rubber lowered the metal concentrations somewhat. Elevated Zn levels are expected to be found in the finished compost for the life of the shredded rubber because zinc oxide is part of the rubber matrix and will continue to be abraded from the surface during handling. On the other hand, Fe comes from the steel belts and rim beads and should eventually be completely oxidized and no longer contribute to the finished compost. The increased Zn and Fe levels do not appear high enough to limit the use of shredded rubber in the composting of sewage sludge.

When only sludge and shredded rubber were composted, all heavy metals increased in concentration because of the concentrating effect as organic matter was decomposed. However, amendments that supplied organic matter, such as sawdust, lowered the metals concentrations in the finished compost.

The use of shredded rubber tires as a bulking agent in the composting of all types of sewage sludge is recommended in combination with amendments such as sawdust, which reduce moisture content and supply carbon. In spite of the need for additional amendments, using shredded rubber tires may represent a cost advantage over the sole use of other materials. Although other materials may supply carbon and moisture absorbency as well as bulk, they are biodegradable and must be replaced more frequently than non-biodegradable shredded rubber. The cost-effectiveness of using shredded rubber as opposed to other amendments will depend on the local cost and availability of each material.

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The complete report, entitled "Shredded Rubber Tires as a Bulking Agent for Composting Sewage Sludge," (Order No. PB 87-175 535/AS; Cost: $13.95, subject to change) will be available only from:
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