Production of biodegradable plastics using activated sludge

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The majority (80%) of excess sludge from wastewater treatment plants in Japan is disposed by landfill. As a resource utilization of excess sludge, the production of biodegradable plastics using the sludge has been proposed. It is demonstrated that the sludge developed in an anaerobic/aerobic biological phosphorus removal process produced polyhydroxyalkanoates (PHA) with a high efficiency from organic acids.

Introduction

In the field of wastewater treatment, it has become a serious problem to dispose of excess sludge produced from wastewater treatment. The quantity of excess sludge from wastewater treatment facilities in Japan in 1989 was 244 million m^3 per year, and it became twice in volume in these ten years. Recently, some effective utilization methods of excess sludge such as biological composting and thermal energy recovering have been investigated to reduce the disposal volume. However, the proportion of effective utilization of sludge is still as low as 20%, and the majority (80%) of sludge is now disposed of by landfill.

Activated sludge is a biomass resource composed of many microorganisms. A wide variety of microorganisms are known to synthesize biodegradable plastics, polyhydroxyalkanoates (PHA) and accumulate it as a reserve material of carbon and energy.[1)] The microbial PHA is a thermoplastic with biodegradable and biocompatoble properties, and the products as films and fibers are degraded in soil or seawater.[2)] Recently, microbial PHA has attracted attention as an environmental friendly plastic. In 1974, Wallen and Rohwedder[3)] found that PHA were present as 1.3% of the dry weight of activated sludge. The object of this study is to develop a new technology of producing of biodegradable plastic by activated sludge.

In this communication, the authors propose a new wastewater treatment process to produce microbial PHA and discuss the productivity of PHA from organic acids by two different kinds of sludge.

General idea on PHA production by activated sludge

Figure 1 shows a scheme of the PHA production by activated sludge in the wastewater treatment plant. Organic acids such as acetic, propionic, butyric, and pentanoic acids may be produced by an anaerobic digestion of excess sludge. The produced organic acids are very suitable carbon sources for the production of PHA by microorganisms.[2)] Thus, a proposed wastewater treatment system consists of three basic plants of wastewater treatment, anaerobic digestion of excess sludge and PHA production from organic acids.

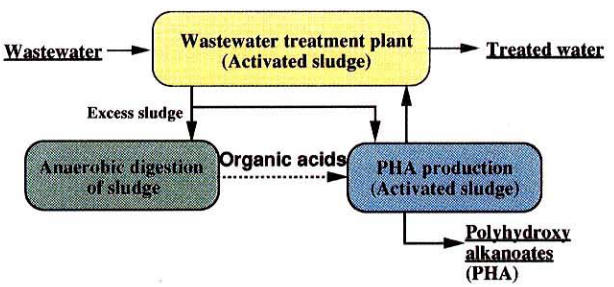

Fig. 1. Schematic flow of wastewater treatment and biodegradable plastic (PHA) production.

PHA production by aerobic and anaerobic/aerobic sludges

Two different kinds of sludge, aerobic and anaerobic/aerobic sludges were used to produce PHA from organic acids. The aerobic biological system with activated sludge is the most popular process to oxidize organic compounds in wastewater to CO_2 and to convert it into cell components. On the other hand, the anaerobic/aerobic sludge method is a process helping the growth of polyphosphate accumulating bacteria by introducing the anaerobic zone ahead of the aerobic zone to remove BOD in the conventional activated sludge process, and hence enhancing the removal of phosphate in the influent wastewater as well as the removal of carbon compounds.

Acetic acid is the main component (70%) of organic acids produced from the anaerobic digestion of sludge. Therefore, we used acetic acid as the carbon source to produce PHA by the two types of sludge in a nitrogen-free aqueous solution. Figure 2 shows the production of PHA by aerobic and anaerobic/aerobic activated sludges under aerobic conditions. Glycogen in aerobic sludge was rapidly accumulated up to 35wt% in dried sludge according to consumption of acetic acid in the wastewater, and the content of PHA was 7.8wt% after 144 h. On the other hand, anaerobic/aerobic sludge

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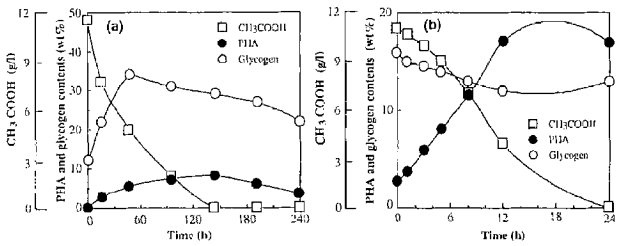

Fig. 2. Production of PHA and glycogen by different kinds of activated sludge. (a) Production of PHA by aerobic sludge from acetic acid in nitrogen-free solution under aerobic conditions at 25 °C. (b) Production of PHA by anaerobic/aerobic sludge from acetic acid in nitrogen-free solution under aerobic conditions at 25 °C.

produced preferenticaly PHA from acetic acid at a fast rate, and the maximum content of PHA reached up to 17.1wt% in dried sludge within 12 h. In contrast, glycogen was consumed during the accumulation of PHA.

Table 1 lists the result of production of PHA and glycogen by the two different kinds of sludge. Aerobic sludge produced the homopolymer P(3HB) of 3-hydroxybutyrate from acetic acid. In contrast, anaerobic/aerobic sludge produced a copolymer of 4 monomer units, 3HB, 3-hydroxyvalerate(3HV), 3-hydroxynonanoate(3HN), and 3-hydroxydecanoate(3HD). The yield of PHA from acetic acid by aerobic sludge was as low as 0.026(g/g). On the other hand, the yield of PHA from acetic acid by anaerobic/aerobic sludge was as high as 0.410(g/g). This value is close to the theoretical yield (0.56(g/g)) for the production of P(3HB) from acetic acid.

Table 1. Production of polyhydroxyalkanoates (PHA) and glycogen from acetic acid by different kinds of sludge.

Sludge	Maximum content[a] (wt%)		PHA composition[b] (mol%)				Yield[c] (g/g-Acetate)	
	PHA	Glycogen	3HB	3HV	3HN	3HD	PHA	Glycogen
Aerobic sludge	7.8	32.3	100	-	-	-	0.026	0.107
Anaerobic/aerobic sludge	17.1	16.0	89	5	1	5	0.410	-

[a] Maximum contents of PHA and glycogen in dried sludge during the incubation.
[b] Determined by GC analysis. 3HB; 3-hydroxubutyrate, 3HV; 3-hydroxyvalerate, 3HN; 3-hydroxynonanoate, 3HD; 3-hydroxydecanoate.
[c] Yields of PHA and glycogen from the acetic acid comsumed during the incubation.

In general, PHA is accumulated within cells of bacteria under growth limited conditions when an essential nutrient such as nitrogen source for growth becomes limited but are exposed to an excess carbon.[1] The liquid produced from the anaerobic digestion of sludge contains a high concentration of ammonia in addition to organic acids. Therefore, productivity of PHA by sludge may be inhibited by the presence of nitrogen sources in the digested liquid. Then, we studied the effect of nitrogen source on the production of PHA by anaerobic/aerobic sludge.

The culture solutions containing acetic acid and ammonia(0, 50, and 100 mg/l) were used for the production of PHA by anaerobic/aerobic sludge. Figure 3 shows the production of PHA from acetic acid by the sludge under aerobic conditions. The maximum content of PHA in dried sludge was little influenced by the concentration of ammonia in the culture solution. Anaerobic/aerobic sludge was found to produce biodegradable plastic, PHA, with high efficiency from wastewater containing organic acid nitrogen compounds.

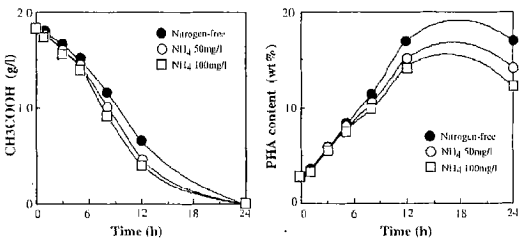

Fig. 3. Effect of ammonia on PHA production from acetic acid by anaerobic/aerobic sludge.

Conclusion

Anaerobic/aerobic activated sludge produced biodegradable plastics, PHA, with high efficiency, and a possibility was suggested that the wastewater treatment process by using anaerobic/aerobic activated sludge produces PHA.

References

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