Ethanol production from biomass using consolidated continuous solid-state fermentation system

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Bioethanol, regarded as a renewable natural resource, has been a great concern in many countries. In Japan where natural biomasses are insufficient, utilization of biological municipal solid waste (RMSW) would be beneficial for bioethanol production. These raw materials are bulky and scattered in low density. With this aim, to obtain the total production cost in Japan, an alternative approaches can produce ethanol from local raw materials and to consume the resultant ethanol in the region where it is produced, namely "locally-produced-and-locally-consumed". In conventional ethanol production systems, however, the smaller the scale facilities, the higher the capital costs and energy consumption per unit of bioethanol. Thus, a new geometrically-distributed production system that produces ethanol at a reasonable cost with a low energy consumption even in small scale need be developed.

To save the cost and input energy for bioethanol production, a consolidated continuous solid-state fermentation (CSSF) system composed of a rotating drum reactor, a humidifier and a condenser was developed. Biomasses, saccharifying enzymes, yeast and a minimum amount of water are introduced into the system. Ethanol produced by simultaneous saccharification and fermentation is continuously recovered as vapor from the headspace of the reactor while the humidifier compensates for water loss. From raw corn stalk as a biomass model, 95.43, 226.9, 458.26 and 509.64 L of ethanol solutions were recovered continuously when the ethanol content in reactor was controlled at 90-10, 50-70 and 75-85 g/km3, respectively. The residue showed a lesser volume and higher solids content than those obtained by conventional liquid fermentations. There is no cost for intensive water waste treatment and the continuous fermentation enabled the sustainability of enzyme activity and yeast in the system.

From the practical aspects, further development of the system is a strategy for prevention of yield in ethanol fermentation caused by bacterial contamination. Saccharobacterium plantarum NSC1067 was used as a contaminant model. In the CSSF, saccharification, fermentation and ethanol recovery are performed simultaneously, initial addition of external ethanol to the fermentation mixture at 50 g/kg prevented contamination and the ethanol yield reached to 0.45 g/L. In CSSF, this ethanol as the additive for preventing contamination can be recovered. That is, by recycling a portion of produced ethanol in the next batch of CSSF, it is possible to repress contamination without additional cost.

To demonstrate the advantages of CSSF, the ethanol production cost of various raw materials was estimated. The ethanol production costs on the CSSF system of a starchy food waste, off-spec rice and waste cotton were estimated to be 111, 50 and 162 yen/L, respectively. In Japan, the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF) set the target price of ethanol to 100 yen/L. For the off-spec rice, since the estimated total cost is half of the target price, a profit will be expected. The sensitivity analysis was used to analyze the critical parameters that affect the production cost of the CSSF system. As the results, the contributions of the fermentation time, and the capacity of CSSF system to the balance of payment were found to be relatively large. To reduce the production cost in future, technologies that reduce the fermentation time and increase the capacity of CSSF system are need to be developed.

From these considerations, the CSSF system was concluded to be available to reduce the production cost and energy consumption in biodiesel production process. Especially, the initial cost per unit of ethanol would be small even in small scale production of biodiesel. The results also indicated that biodiesel production from bioethanol is feasible in the future.
以上のように、本論文は、バイオマスからのエタノール生産を固体酵素間接酸酵法にて生物化学工学的観点から提案し、実施的観点から、装置論としてバイオリアクターシステム構築を、操作論として最適エタノール発酵および廃棄汚染防止手法を提案し、さらに、ホスケールにおいても効率的に行うことを可能としており、その成果は、生命先進工学の発展に大きく寄与することが大きい。よって本論文は博士論文として価値あるものと認める。