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Editorial

Current and future ABE processes

Biobutanol owing to its unique properties well competes with other biofuels and petroleum-based products. Compared to ethanol, butanol can be blended at any ratios with gasoline. Easier transportation because of its lower vapor pressure, absorption of less moisture, and lower corrosion are also among the advantages of biobutanol. Higher energy content than ethanol is another specific property of this energy carrier. Biological production of a mixture of acetone, butanol, and ethanol (ABE) from sugars and starchy materials has been industrialized in the 20th century. In the old processes, acetone was the most valuable chemical, mainly for military applications, while today butanol is the most desirable chemical, mainly as a renewable liquid fuel. Most of the old processes were stopped in 1980s due to the high price of substrates. However, recently, a new wave of interest in the process has been stimulated by soaring oil prices, unclear future of fossil fuels, and environmental concerns. The largest oil companies, e.g., British Petroleum and DuPont, are among the active investors in this field.

Compared to ethanol, ABE production is accompanied with several challenges. Namely, the concentration of ethanol at commercial scale processes is typically between 5-9%, while total concentration of produced ABE is typically between 2-4%. Thus, its separation is difficult and costly. Furthermore, ABE yield from sugars is lower than that of ethanol; thus, the feedstock type and price are very important. Also, ABE producing bacteria are strictly anaerobic, very sensitive to substrate composition and inhibitors, and also very sensitive to their own products at high concentrations.

Reliable feedstock is among the most important perquisite to an economical ABE production. Therefore, feedstock has a more important role in the economy of ABE compared to that of bioethanol. This is also ascribed to the higher feedstock consumption by ABE processes. For instance, for the production of each ton of butanol more than six tons of corn is required, while only less than three tons of corn is needed for the production of the same quantity of ethanol. Earlier processes are mainly based on sugars and starchy materials, which are directly or indirectly related to human food chains and thus, are not acceptable due to food security issues. Lignocellulosic biomasses, glycerol, algae biomass, and syngas are suggested feedstocks for ABE production.

Among the suggested feedstocks, lignocelluloses wastes are the most promising. They contain cellulosic and hemicellulosic sugars, which can be converted into glucose, xylose, mannose, and other fermentable sugars. Fortunately, unlike most of ethanol producing microorganisms, ABE producing bacteria can utilize pentoses as well as hexoses. Fermentable sugars can be produced from lignocelluloses by acid or enzymatic hydrolysis. Acid hydrolysis can be conducted either at high or low acid concentration. Expensive reactors requirement because of the highly corrosive environment, production of large amounts of gypsum, and high energy demands for acid recovery are among the negative features and high sugar yield is among the positive features of the concentrated acid hydrolysis. On the other hand, dilute acid hydrolysis can result in high yield of sugars from hemicelluloses and low yield of glucose from cellulose. Dilute acid hydrolysis has been the focus of hydrolysis for several decades and significant developments have been made.

Two-stage hydrolysis, plug flow, percolation, countercurrent, and shrinking-bed reactors are among the developed systems. However, the production of severe fermentation inhibitors, low cellulose conversion to sugar yield, severe reaction conditions (high temperature and pressure), corrosion, and the production of environmentally harmful wastewaters by dilute acid hydrolysis have resulted in a shift by researches towards an alternative hydrolysis method; enzymatic hydrolysis.

Enzymatic hydrolysis has two main disadvantages: high price of hydrolytic enzymes and low yield of sugars. The price of hydrolytic enzymes has significantly reduced during the last few years. On the other hand, development of suitable and economical processes for pretreatment is still the focus of a growing number of studies in this area. Most of pretreatments are firstly developed for bioethanol and are then used for biobutanol production.

Beside lignocelluloses, glycerol is a suitable feedstock, which can be utilized for biobutanol production. Glycerol is produced in biodiesel plants as a byproduct but is limited in quantity and its price is much higher than lignocelluloses wastes. Algae with several considerable advantages also among the candidate feedstocks, but still in the preliminary stage of development. Yet, separation and downstream processing costs of butanol production from algae are out of question. Direct conversion of solar energy and CO_2 to biobutanol by algae is still more like an idea.

ABE fermentations are conducted in batch, fed-batch, and continuous mode of operation using native and modified strains in the free and immobilized forms. The process can be further improved by product removal, as the products, particularly butanol, have severe inhibitory effects on the solvent producing bacteria. The most effective techniques are pervaporation, liquid–liquid extraction, gas stripping, vacuum fermentation, perstraction, and adsorption.

The most applied strains for ABE production are *Clostridium acetobutylicum* and *C. beijerinckii*. The ratio of acetone, butanol, and ethanol produced by the wild strains is typically 3:6:1, respectively. Mutagenesis, evolutionary engineering, genomic studies, and transcriptional analysis have been used for the overproduction of biobutanol and higher tolerance to butanol, and significant improvements in the overproduction of biobutanol have been achieved. Genetically-engineered microorganisms, including *Saccharomyces cerevisiae*, *Escherichia coli*, *Bacillus subtilis*, and *Pseudomonas putida* have also been used for ABE production; however, so far, their efficiency are not comparable with the native strains of ABE fermenting clostridia. Therefore, striving to improve clostridia strains seems more promising for the future of ABE processes.

Given the growing number of research works in this arena, it is expected that old ABE processes be revamped to the second generation biobutanol production (using lignocelluloses substrates) and a number of existing ethanol units be modernized to produce ABE in the future.

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