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The acetone-butanol-ethanol fermentation process

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Acetone-butanol-ethanol (ABE) fermentation, which was developed as an industrial process during the First World War, represents a key stage in the growth of modern industrial microbiology. The activities of micro-organisms had been exploited for thousands of years, in processes such as brewing, wine making and cheese making, but the ABE fermentation marked a step change. It differed from existing microbiological processes in requiring asepsis during operation. Traditional fermentations were robust in the sense that they can occur naturally without the need for equipment and procedures to exclude or kill all contaminating microorganisms. Contamination can still cause problems in activities such as brewing and cheese making and they benefit from high levels of cleanliness which minimise these risks, but they also have built-in antimicrobial features that help the desirable organism, (yeasts in brewing or lactic acid bacteria in cheese making) predominate over others. For example, the combination of anaerobic conditions, low pH and the production of significant concentrations of antimicrobial compounds (ethanol or lactic acid). Thus, it is possible for enthusiasts to make beer, yoghurt and cheese at home without much microbiological expertise. The ABE fermentation was not like this and, for successful operation, it needed measures to ensure a sterile medium and the exclusion of contamination on an industrial scale.

The ABE fermentation is performed by *Clostridium acetobutylicum,* an anaerobic spore-forming bacillus from the same genus as the causative organisms of botulism and tetanus. The clostridia are found in anoxic environments such as the soil and the gut. They lack a respiratory chain and obtain their ATP by fermentation of carbohydrates, amino acids and other compounds. *C. acetobutylicum* will ferment carbohydrates in the form of starch or soluble sugars to produce a mixture of acetone, butanol and ethanol, in an approximate ratio of 3:6:1, and copious quantities of carbon dioxide (60%) and hydrogen (40%). It does so in two phases: the initial acid production phase in which the organism produces ethanoic and butyric acids along with a mixture of CO_2 and H_2, followed by a solvent production phase in which sugars continue to be metabolised but acids are re-assimilated and reduced to produce acetone and butanol (**Figure 1**).

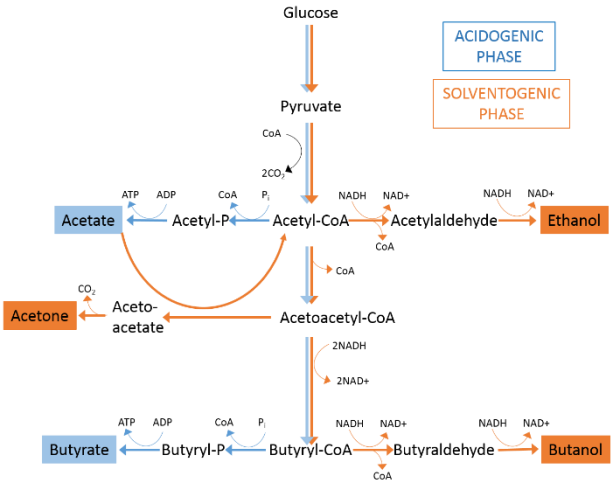

Figure 1. The ABE pathway.

Interest in the fermentation as an industrial process started around 1910. Working as part of an Anglo-French consortium, Auguste

Fernbach at the Institut Pasteur in Paris isolated a *Clostridium* species that fermented potato starch to produce acetone and butanol, but which later proved unreliable when the process was scaled up. Initially the main focus of interest was in using the butanol as a raw material for synthetic rubber production but, at the start of World War 1, attention shifted to acetone which was used as a solvent in the production of cordite, the smokeless propellant used in artillery and naval guns. Previously acetone had been obtained from the destructive distillation of wood; a source insufficient to cope with the new, high levels of demand. Chaim Weizmann at Manchester University isolated a strain of *C. acetobutylicum* which was more reliable than Fernbach's organism and could also use maize as a substrate. To demonstrate the viability of his process he ran pilot trials at a gin distillery in London surmounting numerous difficulties with unsuitable equipment and contamination along the way.

As a result, acetone production began at several sites in the UK, the largest being a plant built at the Admiralty Cordite Factory in Dorset, as well as sites nearer the source of maize, in Toronto, Canada and the mid-west of the United States. At the end of the war, the Toronto plant alone was producing nearly 200 tons of acetone a month. Demand for acetone dropped abruptly with the end of the war, but the ABE fermentation continued; now as a source of butanol, which had found a new role in the production of nitrocellulose lacquers used by the car industry.

Eventually, acetone and butanol from fermentation proved uncompetitive with petrochemical sources, and the industry largely died out in the 1950s, though it persisted a little longer in a few countries for strategic reasons.

Interest in improving the economics of the process as a source of biofuels still occasionally resurfaces, but today its real legacy lies in the expertise gained in the development of a large-scale fermentation requiring asepsis. This contributed to the later success of processes for the production of penicillin and citric acid and, from there, a host of other modern industrial processes producing enzymes, food additives and pharmaceuticals.

AUTHOR PROFILE

Martin Adams is Emeritus Professor of Food Microbiology at the University of Surrey. After a BSc at the University of Warwick, he obtained MSc and PhD degrees in Microbial Chemistry from the University of Manchester. Before joining Surrey in 1984, he spent 10 years in the Microbiology and Fermentation Section of the Tropical Products Institute in London. He is a past President of the Society for Applied Microbiology and represented them on MiSAC for many years.