Continuous, high cell density and immobilized cell reactors have been used for laboratory-scale lactic acid fermentations. Productivity and yield (100 kg/m^3) of lactic acid formation are higher in such reactors than in batch cultures. Continuous removal of lactic acid from cultures by dialysis membranes increases production rates.

Recovery of lactic acid from the fermentation broth constitutes a significant part of production cost. The use of pure sugar solutions with minimal amounts of nitrogen simplifies product recovery. A process diagram is shown in Fig. A.2. The first step is to increase the temperature of the fermenter to 80–100°C and the pH to 10–11. This procedure kills the organisms, coagulates the proteins, solubilizes calcium lactate, and degrades some of the residual sugars. The liquid is then filtered to remove biomass, and sulfuric acid is added to obtain lactic acid. Calcium sulfate is removed by filtration, and lactic acid is then concentrated. Alternatively, purification of lactic acid may be accomplished by calcium lactate precipitation. The fermenter broth is filtered and evaporated to 25% lactic acid. The calcium lactate is then crystallized and separated from the mother liquor. Several purification procedures can be performed to obtain lactic acid of different grades. These include bleaching with activated carbon, ion exchange, electrodialysis, solvent extraction, and esterification. Edible lactic acid is colorless and contains 50–65% lactic acid. Pharmaceutical applications require over 90% pure lactic acid. Traditionally, polymer-grade lactic acid had to be as pure as possible. However, recently polylactate has been obtained from industrial-grade lactic acid.

World demand for lactic acid is estimated as $150 million (100,000 tons). About 50% of the market is in food and beverage applications, which is a mature and stable market. However, niche applications of lactic acid are expected to increase its demand. These include biodegradable polymers, solvents, and cleaning agents. An annual growth of 8.6% of the lactic acid market is expected between 2000 and 2003.

Major producers of lactic acid are United States, Japan, Belgium, the Netherlands, Spain, and Brazil. China and India are also producers. The price of pure lactic acid is about $2.3/kg (2000). Derivatives of lactic acid such as calcium lactate sell at a higher price ($2.8/kg, 2000 basis). Assuming 20% profit margin, one can estimate the manufacturing price of lactic acid approximately as $1.8/kg.

A.1.3. Acetone–Butanol Production

Acetone is used mainly as a solvent for fats, oils, waxes, resins, lacquers, and rubber plastics. Butanol is used in the production of lacquers, rayon, detergents, and brake fluids; and as a solvent for fats, waxes, and resins. Butanol is a better fuel additive than ethanol because of its low vapor pressure, low solubility with water, and complete solubility with diesel fuel. Acetone and butanol (A/B) are produced from petrochemical industry intermediates. However, it is expected that the demand for cleaner processes and shortage of oil-derived products will require production by fermentation.

Clostridium species are used for acetone–butanol production. *C. acetobutylicum* is a strict anaerobe with a versatile metabolic capacity. It has amylolytic and saccharolytic enzymes to hydrolyze gelatinized starch to glucose and maltose. *C. acetobutylicum* can ferment a large number of carbohydrates such as glucose, lactose, fructose, galactose, xylose, sucrose, maltose, and starch. The fermentation products include acetone, butanol,