fermentation from cheese whey in 1982. For a plant producing 45,000 tons of solvents per year, the total capital investment including the waste-water treatment was estimated to be $28 million and the total production cost was nearly $37 million, with an annual income of nearly $53 million and an annual profit of $16 million. Nowadays, production by fermentation is not economically attractive due to low levels of product concentrations (0.7–1.5%) and high cost of product recovery. However, fermentation may be the preferred method for production of A/B if a shortage of oil products exists, or as demands for environmentally friendly processes increase.

A.2. AEROBIC PROCESSES

Aerobic bioprocesses are widely used for the production of organic acids (citric, acetic, gluconic), vitamins, antibiotics, enzymes, flavors–fragrances, amino acids. Owing to space limitations only a few examples of aerobic bioprocesses will be presented here.

A.2.1. Citric Acid Production

Citric acid present in citrus fruits was first crystalized from lemon juice in form of calcium citrate. Later on, citric acid was synthesized from glycerol. Production of citric acid from sugar solutions by aerobic bioprocesses was first realized by using *Penicillium.* Due to low yields obtained from *Penicillium, Aspergillus niger* was utilized in subsequently developed processes.

Citric acid is used as an acidulant in food, confectionery, and beverages (75%). Pharmaceutical (10%) and industrial (15%) applications are also significant. Citric acid complexes with heavy metals such as iron and copper and can be used as a stabilizer of oil and fats. In the pharmaceutical industry, citric acid can be used in antacids, soluble aspirin preparations, and as a stabilizer of ascorbic acid. Metal salts of citric acid such as trisodium citrate are used to prevent blood clotting by complexing calcium. Trisodium citrate can be used in detergents and cleaners as a cleaning agent instead of phosphates.

Aspergillus niger is the most widely used organism for citric acid production from molasses or sugar solutions. *Candida* yeast can also be used for producing citric acid from carbohydrates or *n*-alkanes, with yields as high as 225 g/l. Beet or cane molasses can be used as source of carbohydrates for citric acid production. The concentration of heavy metals such as iron and manganese must be reduced. Typical trace-element concentrations are 0.3 ppm zinc, 1.3 ppm iron, and Mn < 0.1 ppm. High concentrations of metals can be reduced with the addition of Na- or K-ferrocyanide. Additions of nitrogen, phosphate, and other inorganic salts may not be required. Utilization of pure glucose or sucrose solutions is expensive and requires additions of nitrogen (NH_4^+), phosphate, and inorganic salts. Because of its low price and nutrient-rich nature, molasses is usually preferred to pure sugar solutions.

Citric acid production is mixed growth associated, mainly taking place under nitrogen and phosphate limitations after growth has ceased. Since citric acid is a product of primary metabolism, it is produced in high concentrations only under very specific conditions. These include restricted growth, medium deficient in one or more essential elements, high sugar concentration, high dissolved-oxygen concentration, pH below 2, and