H_2SO_4 and gypsum formation; however, it may result in extraction of some impurities present in molasses. Ketones, hydrocarbons, ethers, and esters can be used as extractants. Extraction of citric acid is realized at low temperature, and the solvent is then stripped with hot water.

Almost no information is available on process economics for citric acid production because of the proprietary nature of production schemes. The demand for citric acid in 1999 was 400,000 tons ($1,400 million). It is expected to increase 3% annually through 2003.

A.2.2. Production of Bakers' Yeast

Bakers' yeast is essential to the modern baked goods with which we are familiar. The earliest production of bakers' yeast was accomplished by a Dutch process (1781), utilizing grain mash as raw material. Later on, sugar solutions and aeration were used in Germany. The process was further improved to avoid ethanol formation and to improve biomass yield. Today, bakers' yeast worldwide production is at the level of a million tons per year. The process is based on aerobic cultivation of *Saccharomyces cerevisiae* on carbohydrates.

Today the most widely used organism for baking is *Saccharomyces cerevisiae.* In the past (prior to the nineteenth century) other strains of *Saccharomyces* such as *S. uvarum* or *S. carlsbergensis* (brewers' yeast) had been used. However, *S. cerevisiae* is superior to other species of yeast for baking purposes, primarily due to its ability to generate gas (e.g., CO_2) in the dough. The most suitable yeast strains are selected in the laboratory and are stored by freeze drying.

Molasses is the most used carbon and energy source for production of bakers' yeast. It is inexpensive, rich in nutrients (nitrogen, phosphorus, and minerals), and is available year around. Other carbohydrates such as glucose, sucrose, fructose, or hydrolyzed starch can be used. Aqueous ammonia (NH_4OH), ammonium salts, or urea may be used as nitrogen sources. Phosphoric acid may also be added as phosphate source. Addition of some Mg and Fe salts may be needed. Some yeast strains require B vitamins as well as Na, K, Mg, Ca, and sulfate ions for effective growth.

A material balance for bakers' yeast formation can be written as follows:

$$\begin{aligned}&\text{Sucrose (200 g)} + NH_3\ \text{(10.3 g)} + O_2\ \text{(100.5 g)} + \text{Minerals (7.5 g)}\\ &\longrightarrow \text{Biomass (100 g)} + CO_2\ \text{(140.g)} + H_2O\ \text{(78 g)}\end{aligned} \tag{A.4}$$

Typical yields are about 0.5 gram of cells per gram of substrate and 1 g of cells per gram of oxygen. The maximum specific growth rate of yeast is 0.6 h^{-1} (doubling time of 1.2 h). The temperature and pH of the fermentation medium are controlled at 30°C and 6–7, respectively. High dissolved-oxygen concentrations (above 2 mg/l) are required to promote biomass production. High carbohydrate concentrations may provoke ethanol production even in aerobic conditions (the Crabtree effect). Ethanol is inhibitory to cell growth and reduces biomass yield.

Growth of yeast results in a highly viscous culture broth. Consequently, mechanically agitated fermenters are preferred over airlifts or aerated columns. Typical reactors have a working capacity of 50 m^3 to 350 m^3 with a height-to-diameter ratio of 3. Vigorous aeration and agitation are required to provide oxygen for biomass production. Reactors