the form of either gasohol (10% alcohol) or pure alcohol. However, the use of ethanol as fuel can be viable only if its cost is comparable to that of oil-derived fuels.

A.1.2. Lactic Acid Production

Lactic acid was first isolated from sour milk (1780) and has two optically active forms called D- and L-lactic acids. The major use of L-lactic acid is in foods (more than 50%) as an acidulant and preservative. Lactic acid is also used as a chemical intermediate to produce other chemicals and in the pharmaceutical industry. Most lactic acid is produced by fermentation.

In industry, usually a mixture of lactic acid bacteria is used to ferment a mixture of carbohydrates. A mixture of strains may result in faster fermentation rates than pure cultures. Selected organisms should grow fast, produce lactic acid with high yields and productivities, and have low nutritional requirements. Lactic acid formation is a mixed growth associated process that requires high growth rate and cell concentration. Lactic-acid-producing bacteria are classified in two major groups, homolactic (*Lactobacillus* sp., *Streptococcus* sp., *Pediococcus* sp.) and heterolactic bacteria (some *Streptococcus* sp., *Leuconostoc* sp.).

Homolactic species of *Lactobacillus* and *Streptococcus* are usually used for the industrial production of lactic acid. Homolactic bacteria use the EMP pathway to generate two moles of pyruvate from one mole of glucose that are further reduced to lactic acid, as summarized below.

$$C_6H_{12}O_6 \longrightarrow 2C_3H_6O_3 \tag{A.2}$$

The product yield over glucose is usually above 0.9 g/g. The organisms are facultative anaerobes, but generate ATP only by anaerobic fermentation. Industrially important homolactics grow at temperatures above 40°C and pH between 5 and 7. High temperature and low pH (pH < 6) reduce the risk of contamination. Homolactic bacteria can produce lactic acid from pentoses as well as hexoses other than glucose. Usually lactic and acetic acids are produced from fermentation of pentoses. Most of the lactic acid bacteria also require several B vitamins, amino acids, and phosphate. Peptides may increase cell growth rate. Fermentation yield varies, depending on substrate and the organism used.

Heterolactic fermentation is undesirable because of by-product formation. However, depending on microbial flora, energy availability, and fermentation conditions, it may occur. Heterolactic bacteria produce one mole of lactic acid, ethanol, and CO_2 from one mole of glucose as shown below.

$$C_6H_{12}O_6 \longrightarrow C_3H_6O_3 + C_2H_5OH + CO_2 \tag{A.3}$$

The theoretical lactic acid yield is 0.5 grams per gram of glucose.

Some species of *Rhizopus* (e.g., *R. oryzae*) have low nutritional requirements and can be used to produce lactic acid from carbohydrates. They have the advantage of producing stereochemically pure L-(+)-lactic acid. *Rhizopus* species can also utilize starch for the production of lactic acid.

The ideal raw material must be inexpensive, must result in high rates with high product yields and no by-product formation, should not require significant pretreatment,