2. *Formation of volatile acids:* Solubilized organic compounds are metabolized by anaerobic bacteria to produce volatile organic acids, such as acetic, butyric, formic, and propionic acids, and short-chain fatty acids. Acid-producing organisms are a mixture of facultative anaerobes, such as enteric bacteria and clostridial species, which are called *acid formers.* Alcohol formation (butanol, propanol, ethanol) also takes place to a lesser extent. The optimal temperature and pH values for this step are $T = 35°C$ and pH = 4–6. The partial pressure of H_2 in the reactor can greatly influence metabolism.

3. *Formation of methane:* Volatile acids and alcohols produced in the second stage are converted to methane and CO_2 by methanogenic bacteria, which are strictly anaerobic. Among methanogenic bacteria used for this purpose are *Methanobacterium* (nonspore-forming rods), *Methanobacillus* (spore-forming rods), and *Methanococcus* and *Methanosarcina* (a cocci group growing in cubes of eight cells). The optimal temperature and pH range for methanogenic bacteria are $T = 35°$ to 40°C and pH = 7 to 7.8.

The major biological reaction steps involved in a typical anaerobic digestion process can be represented as follows:

$$\text{insoluble organics} \xrightarrow[\text{enzymatic or acid}]{\text{Hydrolysis}} \text{soluble organics} \xrightarrow[\text{bacteria}]{\text{Acid-producing}}$$

$$\text{volatile acids} + \text{alcohols} + H_2 + CO_2 \xrightarrow{\text{Methanogens}} CH_4 + CO_2 + H_2S$$

Depending on the composition of organic waste, either enzymatic hydrolysis of insolubles (e.g., cellulosics) or methane production from volatile acids is the rate-limiting step in this reaction sequence. The concentration of H_2 is often critical in determining the rates of these processes. Hydrolysis reactions are usually carried out as a separate step. However, acid-formation and methane-formation steps can be achieved in the same reactor. Single- and two-reactor systems have been developed for anaerobic digestion. The two-step reactor scheme has been reported to result in higher reaction rates and methane yields. The operating conditions in a single-reactor system are pH = 6 to 7 and $T = 35°$ to 40°C, which result in reasonable rates of acid formation and methane generation. Typical solids residence time in an anaerobic digester is 10 to 30 days.

Cell yields in anaerobic digesters are low, and a typical value is 0.05 g cells/g COD. Cell yield also varies with substrate. Yield on carbohydrates is larger than yield on the other carbon compounds.

Changes in temperature affect the methane-formation rate more than the acid-formation rate. Although the optimal temperature is reported to be 35° to 40°C, in some cases higher removal rates are obtained at higher temperatures ($T = 55°C$), depending on the composition of the organisms. The system does not function satisfactorily at temperatures below 35°C, and the temperature of the reactors needs to be controlled for stable methane generation.

The rate of methane formation is considerably lower than the rate of acid formation and is rate-limiting. Sudden increases in organic load concentrations may cause volatile acid (VA) accumulation in the medium, decreasing pH and altering H_2 levels, which further depresses methane production. Typical soluble organics removal rates are on the