CHAPTER II
LITERATURE REVIEW

2.1 Ethanol in Thailand

Nowadays, fossil fuels are imported to Thailand more than 200,000,000 Baht per year. Moreover, the price of fossil fuels tends to increase. Therefore, ethanol industry is currently concentrated in Thailand. Ethanol is produced from cassava, molasses, corn, and sugar cane. As a result of the low price of these plants, ethanol production can increase the price of these plants and help agriculturists. In Thailand, cassava is the most used for producing ethanol because the cassava is grown about 4,000,000 ton per year, which can yield ethanol approximately 2,000,000 liters per year (http://www.teenet.chula.ac.th/forum/allmsg.asp?ID=901).

2.2 Ethanol Wastewater

Ethanol wastewater is generated from cassava fermentation with enzyme. The products from fermentation process are fractionated by a distillation column. Then, the products, ethanol, and water are separated to product tank and wastewater treatment system. Sapthip Lopburi Co., Ltd. is an ethanol production plant in Thailand. The capacity is about 200,000 liters per day. The process of ethanol production is shown in Figure 2.1.

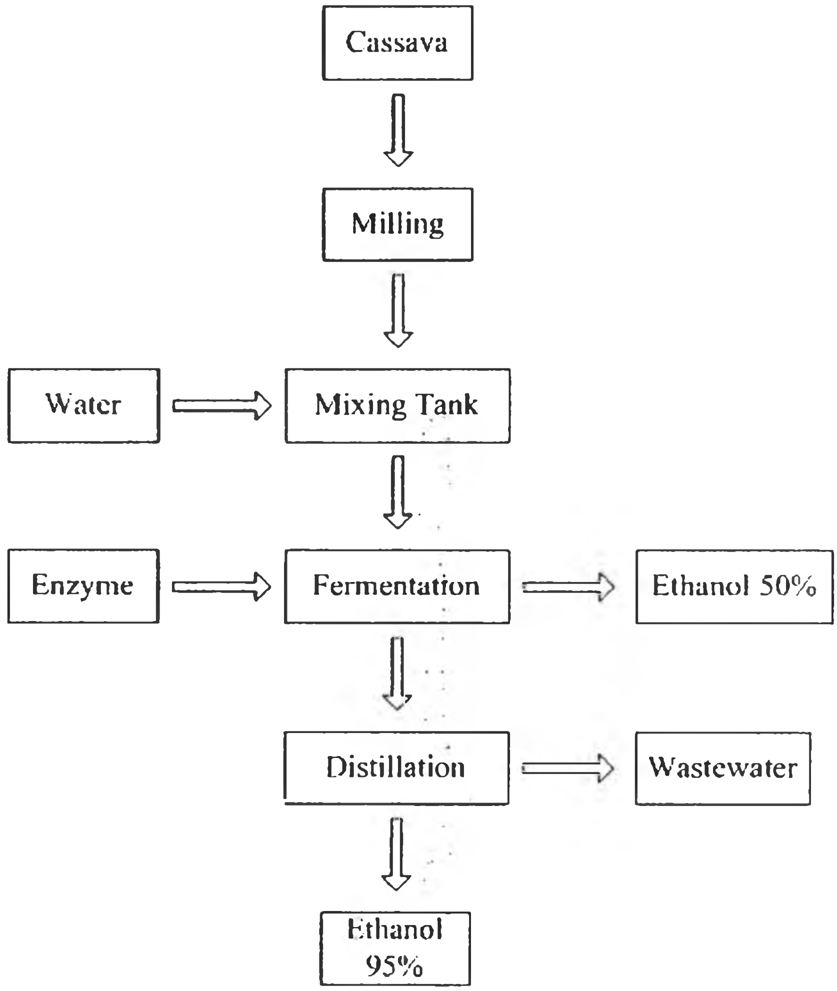

Figure 2.1 Flow diagram of ethanol production process from cassava at Sapthip Lopburi Co., Ltd.

2.3 Wastewater Treatment

2.3.1 Fundamental of Wastewater Treatment

The goal of wastewater treatment is to reduce or remove organic matter, solids, nutrients, disease-causing organism, and other pollutants from wastewater. Wastewater treatment is a multi-stage processes to clean wastewater before discharged of the environment. A common set of process that might be used are as follows.

2.3.1.1 Preliminary Treatment

Preliminary treatment is the first step in the wastewater treatment to remove or separate large or hard solid. Grinners bar screens and grit channels are examples of medium in the entering of treatment plant as treatment equipment.

2.3.1.2 Primary Treatment

Primary treatment is the second step in the wastewater treatment to separate suspended materials. Most of the materials do not have a density much different from wastewater, thus they need to be held with enough time to separate. This step allows the suspended materials to settle out at the bottom and skim off at the surface. The clarified wastewater flows to the next stage of wastewater treatment.

2.3.1.3 Secondary Treatment

Secondary treatment is a biological treatment process to remove the dissolved organic matter from wastewater. Generally, the biodegradation of the pollutants can be supplied by microorganisms. The microorganisms are added to the wastewater and adsorb organic matter from wastewater supply. Three approaches are used to accomplish secondary treatment;

- Fixed Film Systems

Fixed film systems grow microorganism on substrate, such as rocks, sand, and plastic. The wastewater is spread over the substrate, allowing the wastewater to flow past the film of microorganisms fixed onto the substrates. Organic matter and nutrients in wastewater are absorbed on the film, where microorganisms grow and thicken. Examples of fixed film systems are trickling filters, rotating biological contactors, and sand filters.

- Suspended Film Systems

Suspended film systems stir and suspend microorganism in wastewater. Orgånic matter and nutrients in the wastewater are absorbed by microorganisms, which will grow in size and number.

- Lagoon Systems

Lagoon systems are shallow basins, which hold the wastewater for several months to allow for the natural degradation of wastewater.

These systems are slow, cheap, and relatively inefficient, but can be used for various types of wastewater.

2.3.1.4 Final Treatment

Final treatment focuses on removal of disease-causing organisms from wastewater. Treated wastewater can be disinfected by adding chlorine or by using ultraviolet light. High level of chlorine may be harmful to aquatic life in receiving streams. Treatment systems often add chlorine-neutralizing chemical to the treated wastewater before draining to environment.

2.3.1.5 Advanced Treatment

Advance treatment is necessary in some treatment systems to remove nutrients from wastewater. Chemicals are sometimes added during the treatment process to help settle out or skim off phosphorus or nitrogen. Some examples of nutrient removal systems include coagulant addition for phosphorus removal and air stripping for ammonia removal.

2.3.1.6 Sludge Treatment

Sludge is generated through the sewage treatment process. For primary sludge, material that settles out during primary treatment, it has a strong odor and requires treatment prior to disposal. Secondary sludge is the extra microorganisms from the biological treatment processes. The goals of sludge treatment are to stabilize the sludge and reduce odors, remove some of the water and reduce volume, decompose some of the organic matter and reduce volume, kill disease causing organisms, and disinfect the sludge.

2.3.2 Wastewater Treatment to Remove Pollutants

Industrial wastewater usually contains pollutants both biodegradable and non-biodegradable materials. Thus, the industrial wastewater treatment can be divided into 2 major types.

2.3.2.1 Physical/Chemical Treatment

Physical/chemical treatment is used to treat the non-biodegradable wastewater. A physical process usually treats suspended, rather than dissolved pollutants. It can be dived into two processes, passive and mechanically aided. For the passive process, it allows suspended pollutants to settle down or float to the top depending on the density of suspended pollutants. On the other hand, the mechanically aided process may be used with flocculation, flotation, filtration techniques. A chemical process usually treats dissolvable metal or toxic pollutants into solid or harmless compounds. Dissolved metal pollutants can precipitate in settleable form by adding alkaline materials or organic coagulant aids, like electrolytes, to help flocculate and settle the precipitated metal. Highly toxic pollutants can be converted into harmless compounds by oxidizing them with chloride or using ozone to destroy organic chemicals.

2.3.2.2. Biological Treatment

Biological treatment is commonly used to treat domestic or combined domestic and industrial wastewater. The process keeps wastewater under controlled conditions, so that the cleansing reaction is completed before the water is discharged into the environment. Biological treatment can be divided into 2 types;

2.3.2.2.1. Aerobic Biological Treatment

Aerobic treatment systems require oxygen for microorganisms to be able to digest organic compounds in wastewater to harmless components. Sometimes, the wastewater receives pretreatment before it enters the aerobic unit. Treated wastewater leaving the unit requires additional treatment (passage through a soil absorption field) before being returned to the environment.

2.3.2.2.2. Anaerobic Biological Treatment

In anaerobic treatment, there is an absence of gaseous oxygen. The anaerobic treatment of wastewater has now emerged as an energy saving wastewater treatment technology. Organic compounds are degraded to produce biogas. Due to increasing energy cost in the aerobic treatment, the technique of anaerobic wastewater treatment has gained substantial importance.

The comparison of aerobic and anaerobic biological wastewater treatments is shown in Table 2.1.

Table 2.1 Comparison of aerobic and anaerobic biological wastewater treatments

	Aerobic treatment	Anaerobic treatment
Start up	- Short start-up period.	- Long start-up period.
Process	- Integrated nitrogen and phosphorus removal possible. - Production of high excess sludge quantities. - Large reactor volume necessary. - High nutrient requirements.	- No significant nitrogen or phosphorus removal, nutrients removal done via post treatment. - Production of very little excess sludge (5-20%). - Small reactor volume can be used. - Low nutrient requirements
Carbon balance	- 50-60% incorporated into CO_2; 40-50% incorporated into biomass.	- 95% converted to biogas; 5% incorporated into microbial biomass.
Energy balance	- 60% of available energy is used in new biomass; 40% lost as process heat.	- 90% retained as CH_4, 3-5% is lost as heat, and 5-7% is used in new biomass formation.
Residuals	- Excess sludge production. - No need for post-treatment.	- Biogas, nitrogen mineralized to ammonia. - Post-treatment required for removal of remaining organic matter and malodorous compounds.
Costs	- Low investment costs. - High operating costs for aeration, additional nutrient and sludge removal, and maintenance.	- Often moderate investment costs. - Low operating costs due to low power consumption and additional nutrients hardly required.
State of development	- Established technology.	- Still under development for specific applications.

2.4 Background of Hydrogen

Energy is one of the most important factors in the world. The world's energy requirement is fossil fuels (about 80% of the present world energy demand) (Das and Veziroglu, 2001). Fossil fuels have served as energy and convenience for transport and industry. However, the combustion of fossil fuels has negative effects on environment. When these fuels are burnt, their carbon recombines with oxygen from the air to form carbon dioxide (CO_2), resulting in carbon dioxide emission into the atmosphere, which is the primary greenhouse gas that causes global warming. Moreover, carbon monoxide, nitrous oxide, volatile organic chemicals, and fine particulates are released from the combustion of fossil fuels. When released into the atmosphere, many of these compounds cause acid rain or react with sunlight to create ground-level smog. Moreover, the recent rise in oil and natural gas prices may drive the current economy toward alternative energy sources. To avoid these problems, hydrogen has been focused for an alternative energy resource.

2.4.1 Advantage of Hydrogen

2.4.1.1 Hydrogen is Clean Fuel.

Hydrogen is the cleanest fuel that has a minimum impact on the environment. When used in a combustion engine, hydrogen burns to produce only water. Thus, hydrogen is regarded as a clean non-polluting fuel. Pure hydrogen produces only heat energy, water, and trace amounts of oxides of nitrogen when burnt. When used in a fuel cell, hydrogen combines with oxygen to form water vapor. This reaction takes place at lower temperatures, and so the only waste product from a fuel cell is water vapor.

2.4.1.2 Hydrogen is Harmless Fuel.

Hydrogen is the safest of all fuels, partly because of how light it is compared with other fuels. Gaseous hydrogen is fourteen times lighter than air and four times lighter than helium. In the event of an accidental release, it disperses rapidly upward into the atmosphere. Other fuels take longer to disperse or may spill onto the ground. Some, such as gasoline, require specialized cleanup efforts and present toxic hazards to the nearby environment.

2.4.1.3 Hydrogen is Environmentally Friendly.

Conventional energy resources can significantly produce greenhouse gases, especially carbon dioxide, which is thought to be responsible for changes in global climate. The long-term environmental benefits of using hydrogen as a fuel are enormous. Hydrogen fuel produces few pollutants when burnt, and none at all when used in a fuel cell. Hydrogen is a carbon-free fuel, and when produced using renewable energy, the whole energy system can become carbon-neutral, or even carbon-free. So, hydrogen fuel can contribute to reducing greenhouse gas emissions and can reduce the production of many toxic pollutants.

2.4.1.4 Hydrogen can Help Prevent the Depletion of Fossil Fuel.

Hydrogen can be used in any applications, in which fossil fuels are being used, such as a fuel in furnaces, internal combustion engines, turbines and jet engines, automobiles, buses, and airplanes. Nowadays, hydrogen can be directly used to generate electricity through fuel cells, which are mostly used in transportation section. So, the use of hydrogen can decrease the fossil fuel usage.

2.4.1.5 Hydrogen can be Produced from Various Sources.

The greatest advantage of hydrogen is that there are many ways to produce it, using both renewable and traditional energy sources. The most common method of hydrogen production is by reforming fossil fuels, particularly natural gas. Electrolysis is another method of hydrogen production that uses electricity to split water into hydrogen and oxygen gases. One advantage of electrolysis is that one can perform electrolysis using renewable source so that the hydrogen produced is a renewable fuel.

2.4.2 Hydrogen Production Process

2.4.2.1 Hydrogen Production from Fossil Fuels

2.4.2.1.1 Stream Reforming of Natural Gas

Stream reforming of natural gas is the least expensive method for producing and is mostly used for hydrogen production. Steam, at a temperature of 700-1,100 °C is mixed with methane gas in a reactor with a catalyst at 3-25 bar.

The reaction of this process is:

$$CH_4 + H_2O \rightarrow CO + 3H_2 \quad (2.1)$$

It is usually followed by the shift reaction:

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (2.2)$$

The percentage of hydrogen to water is 50%.

2.4.2.1.2 Thermal Cracking of Natural Gas

This is an alternative method replacing steam reforming process because of no carbon dioxide emission. H_2 can be produced via the thermal decomposition of CH_4. However, this method requires a high reaction temperature, about 2,000 °C. The reaction is shown below:

$$CH_4 \rightarrow C + 2H_2 + 75.6 \text{ kJ} \quad (2.3)$$

2.4.2.1.3 Coal Gasification

Gasification of coal is the oldest method for the production of hydrogen. However, it is almost twice as expensive to produce hydrogen from coal as from natural gas. First, reaction of coal with oxygen and steam under high pressures and temperatures to form synthesis gas, i.e. a mixture consisting primarily of carbon monoxide and hydrogen from the following reaction (unbalanced):

$$CH_{0.8} + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + \text{other species} \quad (2.4)$$

After the impurities are removed from the synthesis gas, the carbon monoxide in the gas mixture is reacted with steam via the water-gas shift reaction to produce additional hydrogen and carbon dioxide. Then, hydrogen will be obtained by a separation process.

2.4.2.2 Hydrogen Production from Water

2.4.2.2.1 Electrolysis

Electrolysis uses an electric current to split water into hydrogen at the cathode (+) and oxygen at the anode (-). If renewable energy is used to produce electricity, which is used to split the water into hydrogen and oxygen, the hydrogen will be an even cleaner form of energy. The efficiency of the electrolyzer is an important factor because the consumption of energy makes up 80-90% of the production costs at an electrolysis plant. The chemical reaction of water electrolysis is:

$$2H_2O + \text{energy} \rightarrow 2H_2 + O_2 \quad (2.5)$$

Disadvantages of this method are that it needs to have a high temperature heat source at above 2,500 K for a reasonable degree of dissociation possibility, recombination of H_2 and O_2, or end up with an explosion. H_2 from electrolysis is extremely pure, but expensive at the same time; being ten times more costly than from steam reforming of natural gas. Moreover, this method is not efficient when it comes to produce large amounts of hydrogen.

2.4.2.2.2 Photoelectrochemical Systems

Photoelectrochemical systems use semiconductor materials (like photovoltaics) to split water using sunlight. This is the cleanest way to produce hydrogen, by using sunlight to directly split water into hydrogen and oxygen. Multijunction cell technology developed by the photovoltaic industry is being used for photoelectrochemical (PEC) light-harvesting systems that generate sufficient voltage to split water and are stable in a water/electrolyte environment.

2.4.2.2.3 Thermochemical Process

The promising thermochemical process uses solar energy to heat water to around 1,000 °C. Heat from high temperature solar process is used for driving an endothermic reversible reaction that produces hydrogen (Meyers, 2001).

$$H_2O \rightarrow H_2 + 0.5O_2 \tag{2.6}$$

2.4.2.2.4 Thermolysis Process

Thermolysis uses solar energy to heat water to more than 2,000 °C, causing the water to break down directly to hydrogen and oxygen (http://www.science.org.au/nova/111/111key.htm).

2.4.2.3 Hydrogen Production from Biomass

Biomass can be used as renewable sources for hydrogen gas production (Kapdan and Kargi, 2006). It has been used as a carbon source. Hydrogen production from biomass has been given attention due to operation under mild conditions. Biomass wastes, such as agricultural and domestic wastes, may be major sources for biohydrogen production (Argun *et al.*, 2008). The major problems in biohydrogen production from wastes are the low rates and yields. Large reactor volumes are required due to the low production rate. So, it may be overcome by selecting and using more effective organisms or mixture cultures, developing more efficient processing schemes, optimizing the environmental conditions, improving the light utilization efficiency, and developing a more efficient photo-bioreactor (Kapdan and Kargi, 2006).

Hydrogen production from biomass can be classified into two categories, which are thermochemical process and biological process.

2.4.2.3.1 Thermochemical Process

1) Pyrolysis

Biomass pyrolysis is the heating of biomass at high temperature (650-800 K) and low pressure (0.1-0.5 MPa) in the absence of air (O_2) to convert into gaseous, liquid, and solid products. The main gaseous products from pyrolysis are hydrogen, carbon dioxide, carbon monoxide, and hydrocarbon gases. The liquid products are tar and oil. Solid products are mainly composed of char, carbon, and other inert materials.

2) Biomass Gasification

Gasification of biomass under partial oxidation and high temperature (above 1,000 K) with steam and oxygen gives gas and charcoal. Finally, charcoal is reduced to H_2, CH_4, CO, CO_2, and some hydrocarbons, as follow:

$$\text{Biomass} + \text{heat} + \text{steam} \rightarrow H_2 + CH_4 + CO + CO_2 + \text{hydrocarbon} + \text{char} \quad (2.7)$$

The problem of biomass gasification is the production of tar and ash; tar causes formation of tar aerosols and polymerization to more complex structures, but ash causes deposition, sintering, slagging, fouling, and agglomeration. If biomass has moisture content over than 35%, the gasification can be done under the supercritical water condition with heating water to a temperature (674 K) and compressing it over its critical pressure (22 MPa). Then, the biomass is rapidly decomposed to small molecules and gases with no tar and ash formation.

2.4.2.4 Hydrogen and Methane Production from Biological Process

Biological process uses microorganisms for converting compounds in wastes to products, such as hydrogen, carbon dioxide, volatile fatty acids, and alcohols (Kapdan and Kargi, 2006). Biological hydrogen production process mostly operates at ambient temperature and pressure (Das and Veziroglu, 2001). So, these processes require less energy and low operating cost, and are environmentally friendly. There are two types of biological process:

(1) Photo-fermentation

Photo-fermentation is the process that uses photosynthetic bacteria. Photosynthetic bacteria uses light for converting organic substances, such as acetic, lactic, and butyric acids, to hydrogen (Kapdan and Kargi, 2006). The advantages of photo-fermentation are high theoretical conversion yields, lack of O_2-evolving activity, which causes problem of O_2 inactivation of different biological systems, and ability to use wide spectrum of light and ability to consume organic substrates from wastes (Das and Veziroglu, 2001). However, the light requirement is a problem for hydrogen production rate at night.

(2) Dark Fermentation

Dark fermentation contains anaerobic bacteria, which can convert carbohydrate in organic wastes to hydrogen. The major product of anaerobic bacteria are acetic, butyric, and propionic acids. Hydrogen is produced as a by-product during conversion of organic wastes into organic acids, which are then used for methane generation (Kapdan and Kargi, 2006). So, for hydrogen production, hydrogen consumers are eliminated by heat digestion of sludge. The advantages of dark fermentation are rapid and simple operation, and hydrogen production is obtained from renewable sources or wastes (Liu *et al.*, 2007). Hydrogen production from dark fermentation seems to be more feasible than other methods in commercial processes due to attaining high hydrogen production rate than other biohydrogen production systems (Lee *et al.*, 2008).

For the degradation pathways as shown in Figures 2.2, in hydrolysis step, fermentative bacteria hydrolyze protein to amino acids and polypeptide, while lipids are hydrolyzed via β-oxidation to long chain fatty acids (LCFAs) and glycerol, and polycarbohydrates to sugars and alcohols. After that, fermentative bacteria convert the intermediates to volatile fatty acids (VFAs), H_2, and CO_2. Ammonia and sulfide are the by-products of amino acid fermentation. Hydrogen-producing acetogenic bacteria metabolise LCFAs, VFAs with three or more carbons, and neutral compounds larger than methanol to acetate, H_2, and CO_2.

Methanogens convert acetate, H_2, and CO_2 to CH_4 and CO_2 (Salminen and Lintala 2002).

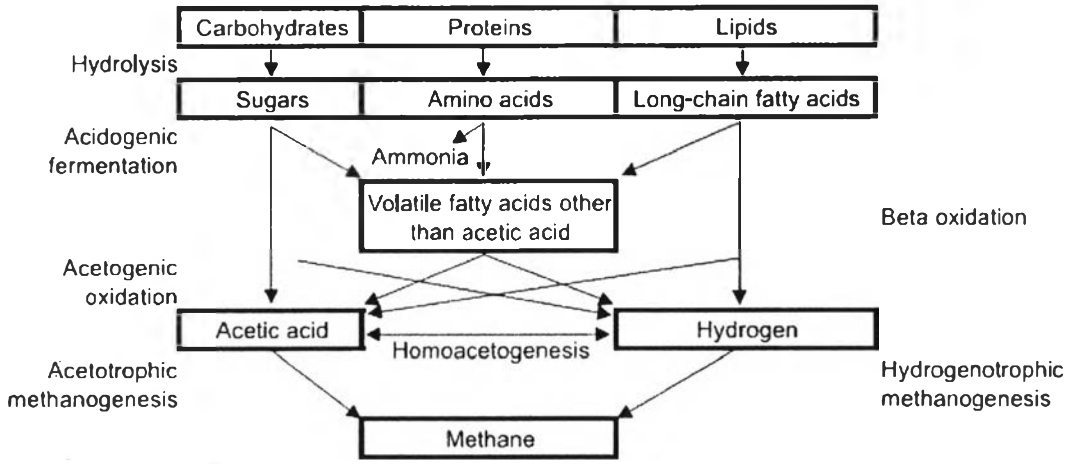

Figure 2.2 Degradation pathways in anaerobic degradation (Salminen and Rintala 2002).

2.4.3 Hydrogen Utilization

At present, environmental pollution, which affects the increase in global temperature, is of a great concern around the world, due to rapid industrialization and urbanization. So, the alternative sources of clean energy are focused. Hydrogen is highly considered because it is a clean energy source and has a higher energy content per weight than the other fuel, as shown in Table 2.2. Hydrogen can be used for various applications (Das and Veziroglu, 2001), which can be divided into following categories:

1. As a feedstock chemical, such as a reactant in hydrogenation process: hydrogen is used to produce low-molecular-weight compounds, saturated compounds, cracked hydrocarbons, or to remove sulfur and nitrogen compounds.

2. As an O_2 scavenger: hydrogen is used to chemically remove trace amounts of O_2 to prevent oxidation and corrosion.

3. As a fuel in rocket engines.

4. As a coolant in electrical generators to take advantage of its unique physical properties.

Table 2.2 Energy content per weight of different fuels (Ni *et al.*, 2006)

Fuel	Energy content (MJ/kg)
Hydrogen	120
Liquified natural gas	54.4
Propane	49.6
Aviation gasoline	46.8
Automotive gasoline	46.4
Automotive diesel	45.6
Ethanol	29.6

2.5 Anaerobic Bioreactors

Anaerobic fermentation is an excellent odor-reducing technique and also converts the degradable organic substrate to gas in a tank for use as a fuel. The organic substrates, such as glucose, sucrose, paper mill waste, municipal soild waste, food processing waste, rice winery and palm oil mill effluents, can be used for hydrogen production (Vijayaraghavan and Soom, 2006). The different types of substrate and bioreactor affect the amount of produced hydrogen. Metcalf and Eddy (2003) categorized anaerobic bioreactor into 3 groups: anaerobic suspended growth reactor, attached growth anaerobic anaerobic reactor, and upflow anaerobic sludge blanket reactor.

2.5.1 Anaerobic Suspended Growth Treatment Processes

Anaerobic suspended growth processes are classified into three types:

2.5.1.1 Complete-mix Process

For the complete-mix anaerobic digester as shown in Figure 2.3(a), the solid retention time and hydraulic retention are equal. The complete-mix digester without sludge recycle is more suitable for wastes with high concentrations of solids or extremely high dissolved organic concentrations, where it is difficult for thickening the effluent solids. Organic loading rates for this process are present in Table 2.3, as compared to anaerobic contact and anaerobic sequencing reactor processes.

Table 2.3 Typical organic loading rates for anaerobic suspended growth processes at 30 °C

Process	Volumetric organic loading, kg COD/m^3d	Hydraulic retention time (τ), day
Complete-mix	1.0-5.0	15-30
Anaerobic contact	1.0-8.0	0.5-5
Anaerobic sequencing batch reactor	1.2-2.4	0.25-0.50

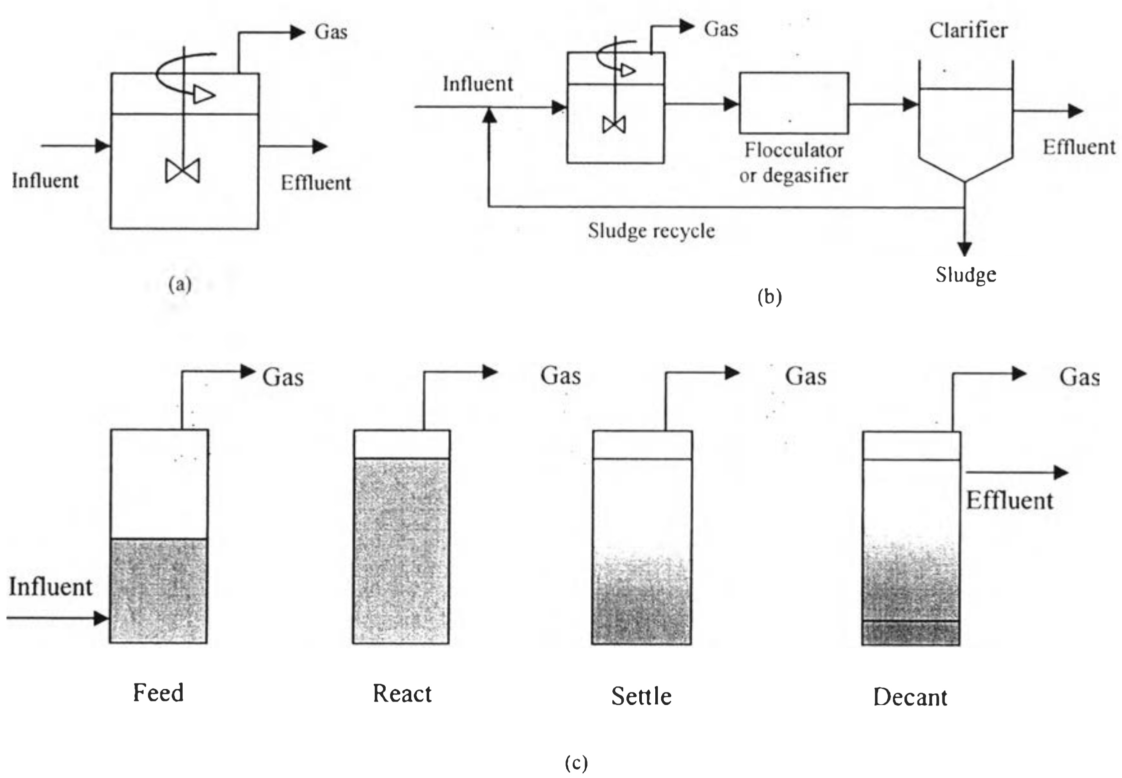

Figure 2.3 Anaerobic suspended growth processes: (a) complete-mix process, (b) anaerobic contact process, and (c) anaerobic sequencing batch reactor process.

2.5.1.2 Anaerobic Contact Process

This process, as shown in Figure 2.3(b), can overcome the disadvantages of a complete-mix process without recycle. Separated biomass is returned to the complete-mix or contact reactor, so the solid retention time (SRT) is longer than hydraulic retention time (τ). This process can reduce the anaerobic reactor volume by separating SRT and τ values. Gravity separation is the most common approach for thickening and solid separation prior to sludge recycle. In some cases, gas flotation is used for solid separation by dissolving the process off-gas under pressure. Since the reactor sludge contains gas produced in the anaerobic process and gas production can continue in the separation process, solid-liquid separation can be inefficient and unpredictable.

2.5.1.3 Anaerobic Sequencing Batch Reactor (ASBR)

This reactor, as shown in Figure 2.3(c), is typically operated under batch-mode comprising four different phases, including feed, react, settle, and decant or effluent withdrawal. The completely mixed condition is only done during the react phase to provide uniform distribution of substrate and solids.

2.5.2 Anaerobic Sludge Blanket Processes

These principal types of anaerobic sludge blanket processes include the original upflow anaerobic sludge blanket (UASB) process, anaerobic baffled reactor (ABR), and anaerobic migrating blanket reactor (AMBR). Among all of these, the UASB process is the most commonly studied because of high rate of production, (Perez *et al.*, 2006), low energy requirement, and simple operation (Metcalf and Eddy, 2003).

2.5.2.1 Upflow Anaerobic Sludge Blanket (UASB)

The basic UASB reactor is shown in Figure 2.4(a). The influent wastewater is distributed at the bottom of the reactor and travels in an upflow mode through the sludge blanket. The influent distribution system, the effluent withdrawal design, and the gas-solid separator are the critical elements of the UASB reactor design. Modifications to the basic UASB design include adding a settling tank, as shown in Figure 2.4(b), or the use of packing material at the top of the reactor, as shown in Figure 2.4(c). The key feature of this process that allows the use of high volumetric COD loadings compared with other anaerobic processes is the development of a dense granulated sludge.

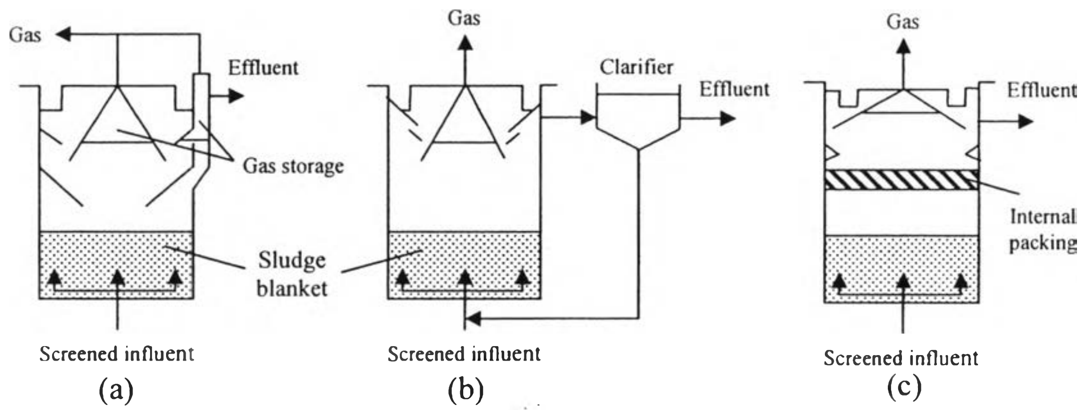

Figure 2.4 Schematic of the UASB process and some modifications: (a) original UASB process, (b) UASB reactor with sedimentation tank and sludge recycle, and (c) UASB reactor with internal packing for fixed-film attached growth, placed above the sludge blanket.

2.5.2.2 Anaerobic Baffled Reactor (ABR)

In the ABR process, as shown in Figure 2.5(a), baffles are used to direct the flow of wastewater in an upflow mode through a series of sludge blanket reactors. The sludge in the reactor rises and falls with gas production and flows but moves through the reactor at a slow rate. Various modifications have been made to the ABR to improve performance. The modifications include: (1) changes to the baffle design, (2) hybrid reactors where a settler is used to capture and return solids, or (3) packing is used in the upper portion of each chamber to capture solids.

Advantages for the ABR process include the following:

- Long solid retention time possible with low hydraulic retention time
- No special biomass characteristic required
- Compatible with various kinds of wastewaters with a wide variety of constituent characteristics.
- Stable to shock loads

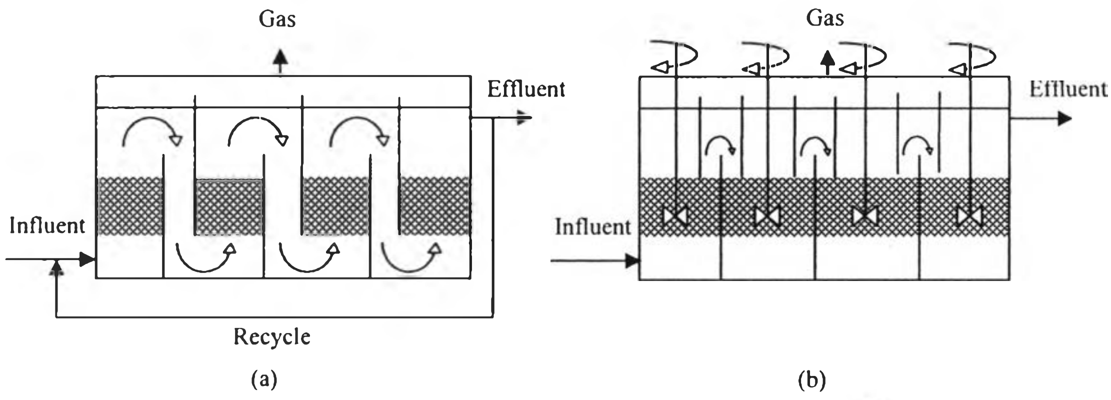

Figure 2.5 Schematic of alternative sludge blanket processes: (a) anaerobic baffled reactor (ABR) and (b) anaerobic migrating blanket reactor (AMBR).

2.5.2.3 Anaerobic Migrating Blanket Reactor (AMBR)

The AMBR process is similar to the ABR with the added features of mechanical mixing in each stage and an operating approach to maintain the sludge in the system without resorting to packing or settlers for additional solid capture, as shown in Figure 2.5(b). In this process, the influent feed point is changed periodically to the effluent side, and the effluent withdrawal point is also changed. In this way, the sludge blanket remains more uniform in the anaerobic reactor. The flow is reversed when a significant quantity of solids accumulates in the last stage.

2.5.3 Attached Growth Anaerobic Processes

Upflow attached growth anaerobic treatment reactors differ by the type of packing used and the degree of bed expansion. This attached growth anaerobic processes can be classified as following details (Metcalf and Eddy, 2003).

2.5.3.1 Upflow Packed-bed Attached Growth Reactor

Full-scale upflow packed-bed anaerobic filters are used in cylindrical or rectangular tanks at widths and diameters ranging from 2 to 8 m and heights from 3 to 13 m, as shown in Figure 2.6(a). The most common packing materials are corrugated plastic crossflow or turbular modules and plastic pall rings. A large portion of the biomass responsible for treatment in the upflow attached growth anaerobic processes is loosely held in the packing void spaces and not just attached to the packing material. Low upflow velocities are generally used to prevent the washout of the biomass. Over time, solids and biomass will accumulate in the packing to cause plugging and flow short-circuiting. At this point, solids must be removed by flushing and draining the packing.

Advantages of upflow attached growth anaerobic reactors are the compatibility with high COD loadings, relatively small reactor volumes, and operational simplicity. The main limitations are the cost of the packing material, operational problems, and maintenance associated with solid accumulation and possible packing plugging. The process is best suited for wastewaters with low suspended solid concentrations.

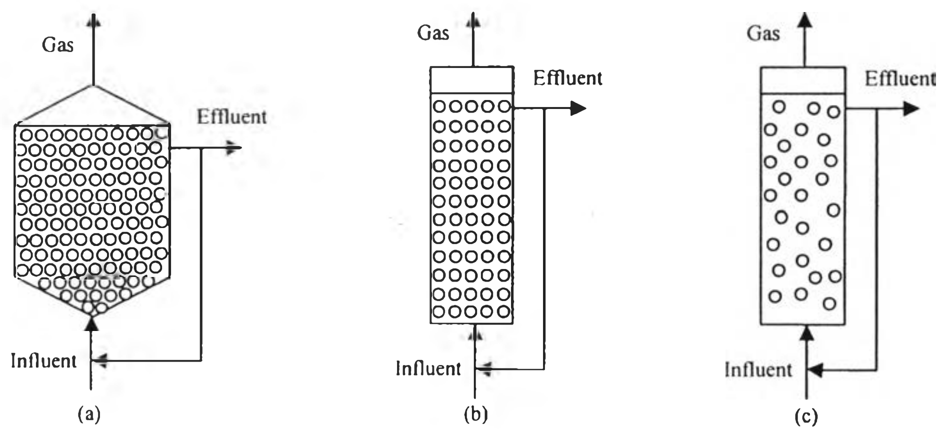

Figure 2.6 Upflow anaerobic attached growth treatment reactors: (a) anaerobic upflow packed-bed reactor, (b) anaerobic expanded-bed reactor, and (c) anaerobic fluidized-bed reactor.

2.5.3.2 Upflow Attached Growth Anaerobic Expanded-bed Reactor

The anaerobic expanded-bed reactor (AEBR), as shown in Figure 2.6(b), uses silica sand with a diameter in the range of 0.2 to 0.5 mm and specific gravity of 2.65 as the packing material to support biofilm growth. The smaller packing provides a greater surface area per unit volume. With such a small packing and void volume, the expanded-bed operation is necessary to prevent plugging. Because the expanded-bed system is not fully fluidized, some solids are trapped, and some degree of solid degradation occurs. Most applications for the AEBR treatment process have been for the treatment of domestic wastewater.

2.5.3.3 Attached Growth Anaerobic Fluidized-bed Reactor

The anaerobic fluidized-bed reactor (AFBR), as shown in Figure 2.6(c), is similar in physical design to the upflow expanded-bed reactor. The packing size is similar to the expanded-bed reactor, but the AFBR is operated at higher upflow liquid velocities of about 20 m/h to provide about 100 percent bed expansion. Effluent recycle is used to provide sufficient upflow velocity.

The advantages for the AFBR process include the ability to provide high biomass concentrations and relatively high organic loading, high mass transfer characteristics, ability to handle shock loads due to its mixing and dilution with recycle, and minimal space requirements.

2.5.3.4 Downflow Attached Growth Process

The downflow attached growth anaerobic processes, as illustrated in Figure 2.7, have been applied for treatment of high-strength wastewaters using a variety of packing materials, including cinder block, random plastic, and tubular plastic. Systems are designed to allow recirculation of the reactor effluent.

The major advantages for the downflow attached growth process, where a higher void space packing material is used, are a simple inlet flow distribution design, no plugging problem, and a simple operation.

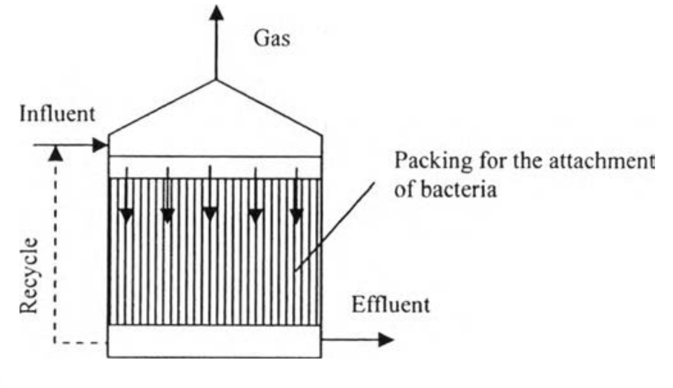

Figure 2.7 Downflow attached growth anaerobic treatment reactor.