CHAPTER 1

INTRODUCTION

1.1 GENERAL

Any industrial manufacturing process invariably results in the production of certain waste streams containing physical, chemical and biological substances that are in both soluble and insoluble forms. If this effluent stream were to be discharged into any attribute of water environment, rapid de-oxygenation would result with serious consequences of environmental degradation. Hence, any industrial waste stream requires to be treated for the removal of waste constituents to the prescribed level of acceptance, for ensuring its safe disposal into environment.

Rapid urbanization and industrialization in the developing countries pose severe problems in collection, treatment and disposal of effluents. This situation leads to serious public health problems. Increased discharge of domestic and industrial wastewater in receiving bodies and simultaneously increased withdrawal of freshwater, make it impossible to self–purifying capacity of these receiving water bodies. Decreasing assimilative capacity of water bodies, need for water conservation and growing public awareness in the maintenance of clean environment, bring to force the need for development of appropriate, cost effective and resource recovery based wastewater treatment systems.
Conventional waste management technologies commonly adopted in tropical climates, are not only expensive but also warrant exacting operation and maintenance requirements. Centralized & low cost systems for individual establishment specifically with respect to sewage treatment are now increasingly recognized as alternatives to large and sophisticated waste treatment systems. Research and development endeavor in recent years is directed towards wastewater treatment technologies which are compatible with environmental and economic conditions, appropriate for semi urban settlements, isolated communities and variety of industrial situations. Most of the developing countries suffer from severe environmental problems, shortage of energy and resources. These countries urgently need simple and inexpensive and integrated environmental protection systems, which combine wastewater treatment with recovery and reuse.

1.1.1 Statement of Problem

Most of the industries usually discharge large volumes of wastewater characterized by high concentration of Chemical Oxygen Demand (COD) or Biological Oxygen Demand (BOD), large amounts of suspended solids (SS) and various organic components including nitrogen and phosphorus. The high organic loading in the processing of wastewater creates a pollution problem to water quality when discharged to rivers and lakes.

They are the main causes of the deterioration of the quality of receiving water bodies. Therefore, it should be treated by wastewater treatment plant prior to discharge to receiving body such as rivers and lakes. All industries have the wastewater treatment that usually use anaerobic before aerobic process. Popular anaerobic processes are anaerobic pond that requires a large amount of area. Thus the anaerobic process requires less area with good performance can be applied for any type of wastewater.
Anaerobic wastewater treatment technology has been gaining a wider popularity due to its advantages over aerobic treatment, such as low initial and operational costs, low sludge production, valuable gas production. Amongst, the up flow anaerobic sludge blanket (UASB) reactor is regarded as one of the most successful anaerobic processes. The comparative characteristics between the UASB system and other systems are as shown in Table (1.1). UASB reactor has been applied to the treatment of various organic wastewaters with different COD concentrations under a wide range of temperature conditions. Since its introduction about 20 years ago, UASB has become popular in Western Europe and, more recently, in East Asia. It has been most commonly used for wastewater from various industries. The success of these reactors depends on the formation of compact, highly flocculated sludge aggregates called granules. The formation of granules gives efficient separation between the solids retention time and the hydraulic retention time. In addition, UASB produce biogas as by-product, which mostly composes of methane and carbon dioxide and traces of hydrogen sulfide and nitrogen. The produced biogas can be used for cooking, lighting.

Therefore, this research focuses on the performance of the UASB treatment of the various wastewaters for Indian climatic condition, and offer guidelines for further application of full-scale plants in the near future.

Table 1.1 Comparative characteristic between the UASB system and other systems

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Anaerobic Filter</th>
<th>Anaerobic Contact</th>
<th>Anaerobic Fluid bed</th>
<th>UASB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment</td>
<td>high</td>
<td>Moderate</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td>Operation cost</td>
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<td>Moderate</td>
<td>very high</td>
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<tr>
<td>Control</td>
<td>very simple</td>
<td>Moderate</td>
<td>difficult</td>
<td>moderate</td>
</tr>
<tr>
<td>Loading</td>
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<td>High</td>
<td>very high</td>
<td>very high</td>
</tr>
<tr>
<td>Shock load</td>
<td>good</td>
<td>Good</td>
<td>very good</td>
<td>very good</td>
</tr>
<tr>
<td>Digester size</td>
<td>small</td>
<td>Small</td>
<td>very small</td>
<td>very small</td>
</tr>
<tr>
<td>Start-up</td>
<td>simple</td>
<td>Moderate</td>
<td>difficult</td>
<td>difficult</td>
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</tbody>
</table>
The precious aquatic environment is getting polluted by the domestic and industrial wastewater and warrants urgent action to prevent further degradation. Development, selection and application of appropriate technologies for wastewater treatment are therefore the major component of such a preventive action. Important criteria to be set for the development of such appropriate environmental protection technologies and methodologies are summarized and which criteria for selection of wastewater treatment technologies is presented as follows.

1.1.2 Criteria to be set for Environmental Protection Technologies and Methodologies

- No need for dilution of the pollutants with clean water
- High efficiency of treatment
- Maximum recovery and reuse of polluting substances
- Economically viable through requirement of low capital and infrastructural cost and least operation and maintenance cost requirements.
- Simple in operation and maintenance
- Application at small as well as on big scale
- Leading to a high self-sufficiency in all respects
- Well acceptable for the local population
- No need for of central sewer
1.1.3 Important Criteria for Selecting Wastewater Treatments Technology

1. The method should provide sufficient treatment efficiency towards the removal of various categories of pollutants i.e.

- Biodegradable organic matters
- Suspended solids
- Ammonia, organic compounds
- Phosphates
- Pathogens

2. High stability against interruptions in power supply, peak loads, fluctuations in the quantity and quality of feed and ingress of toxic pollutants

3. High flexibility with respect to future extensions and possibilities of augmentation to improve the efficiency.

4. Simple in operation, maintenance and control (i.e. reduced dependency on the highly skilled operators and engineers)

5. Low land requirements

6. Long life time

7. Reduced sludge disposal and nuisance problems

8. Good possibilities to recover useful byproducts for agricultural applications
1.1.4 Biological Treatment of Wastewater

There are two basic modes of operation in the effluent treatment processes, namely aerobic and anaerobic. In the view points of efficiency, economics, energy and required engineering, the anaerobic treatment overrun the advantages of aerobic treatment. The process limitations and higher energy requirements of aerobic treatment systems make the anaerobic treatment option as viable and feasible for almost all biodegradable industrial effluent streams. Moreover, for tropical conditions like India, the application of anaerobic treatment for reducing the COD upto 85 % is in the frontline as the most effective and economic option for providing treatment to industrial liquid waste streams. Anaerobic treatment converts the wastewater organic pollutants into small amount of sludge and large amount of biogas as source of energy (Ayati & Ganjidoust 2006).

Methods of wastewater treatment in which the application of physical forces predominates are known as unit operations. Methods of treatment in which the removal of contaminants is brought about by chemical or biological reactions are known as unit processes. At the present time, unit operations and processes are combined together to provide what is known as primary, secondary, and tertiary or advanced treatment.

Biological treatment of wastewater basically reduces the pollutant concentration through microbial coagulation and removal of non-settleable organic colloidal solids. Organic matter is biologically stabilized so that no further oxygen demand is exerted by it. For domestic wastewater (i.e. sewage), the major objective is to reduce the organic content and nutrients such as nitrogen and phosphorus.

Anaerobic and aerobic biological treatment systems are conventionally adopted for the treatment of municipal wastewater. The rate of
stabilization of organic matter in case of aerobic process is high as compared to that in anaerobic process. The following anaerobic systems are conventionally adopted:

- Anaerobic lagoons
- Anaerobic activated sludge
- Anaerobic filters
- Anaerobic contact process
- Upflow anaerobic sludge blanket (USAB) reactor
- Expanded bed and fluidized bed reactor

Following conventional aerobic systems are implemented in the field:

- Activated sludge process
- Trickling filters
- Rotating biological contactors
- Differential aeration systems
- Stabilization ponds
- Aerated lagoons

Modifications in these two basic processes have resulted in the development of various other types of applied biological treatment systems. These are further categorized into following four major groups:

- Aerobic process
- Anoxic process
- Anaerobic process
- Combination of aerobic/anoxic or anaerobic processes.

Efficiency of any of the biological treatment process is basically dependent on

- Available active microbial population in the reactor
- Type of arrangement provided for contact of pollutant with the biomass
- Contact time provided for the microbial action

Various advances and improvements in anaerobic reactors to achieve variation in contact time and method of contact have resulted in development of suspended growth systems, attached growth or fixed film systems or combinations thereof.

The Upflow Anaerobic Sludge Blanket (UASB) reactor was developed in the 1970’s by Gatze Lettinga which is most suitable for regions with hot climate. As stated above, several full-scale plants have been put into operation and many more are coming up day by day. Normally wastes with moderate concentration should have the following arrangement for a UASB type treatment plant.

1. Initial pumping
2. Screening and De-gritting
3. Main UASB Reactor
4. Gas collection and conveyance
1.2 ANAEROBIC TREATMENT PROCESSES

The two types of commonly operated anaerobic processes can be classified as conventional anaerobic processes and high rate anaerobic processes.

1.2.1 Conventional Anaerobic Processes

1.2.1.1 Cesspool

It is the oldest type of anaerobic digester for the purpose of treating household wastewater. Due to its small size and lack of maintenance, only hydrolysis takes place in the tank. Dissolved organic compounds seep through the tank wall to the soil.

1.2.1.2 Septic tank

It is similar to cesspool, but it has higher efficiency. There are branches of pipes connected to the tank to increase the seepage rate. Organic compounds are degraded by acidogenesis and methanogenesis in the soil.

1.2.1.3 Anaerobic pond

The pond is in the open air and thus it must have a depth of at least 3 m to prevent oxygen from transferring down to the bottom. It is commonly made of clay and used for treating high strength wastewater from industries. In spite of its convenient operation and maintenance with low operating costs, this process requires large areas of land and the removal efficiency is not very high. Malodor may arise and biogas cannot go utilized.
1.2.1.4 Conventional anaerobic digester

It was developed to digest sludge from aerobic wastewater treatment such as activated sludge process. A single tank or two connecting tanks may be used to convert sludge into biogas. This process has a higher efficiency than the cesspool and the septic tank, but not high enough to treat wastewater from industries.

1.2.1.5 High-rate Anaerobic Processes

This process was developed to treat high strength wastewater from industries. The efficiency can be improved by increasing the number of microorganisms in the system. This can be achieved by, for example, retaining bacterial film on high surface-area media, circulating bacteria in the overflow to the digester, controlling upflow velocity to create bacterial granules and using membrane filtration.

1.2.1.6 Anaerobic Filter (AF)

It is a process that mainly consists of a column filed randomly with plastic media. Thus, the concentration of bacteria is much higher than that in conventional processes. Wastewater can be fed either at the top of the bottom of the digester. The removal efficiency of this process is very high, but the construction costs are very expensive because of the media prices. Therefore, it is suitable for a small flow treatment.

1.2.1.7 Anaerobic Fixed Film (AFF)

AFF process is quite similar to an AF process, but the media arrangements are different. The media in AFF digester are orderly arranged and fixed to solve the clogging problem in AF process.
1.2.1.8 Anaerobic Contact Process (ACP)

This process has the same general concept as an AS process, except that the reactor is sealed off from oxygen. The mixture of treated water and suspended solids flows through a clarifier for sedimentation process. Settled sludge is pumped back to the reactor. Thus, the mixed liquor suspended solids concentration (MLSS) can be as high as 20,000 mg/L. ACP and AF processes have roughly the same efficiency. But ACP has a higher operating cost and more difficult maintenance because a sludge pump and an agitator are required, while AF process has a higher construction cost due to costs of plastic media.

1.2.1.9 Upflow Anaerobic Sludge Blanket (UASB)

It is considerably a modern process. It can be applied for treatment of various types of industrial wastewater. Wastewater is introduced in the bottom of the reactor with a proper upward velocity. The bacterial granules with diameters of 1-5 mm are formed densely at the bottom later. Flocculent bacteria are floated in the upper layer and separated by the settler installed in the top of the reactor. Biomass is retained in the reactor to have the efficiency as high as AF process and ACP. The advantages of UASB process are that a clarifier is not required and, unlike ACP, an agitator is not needed. Therefore, the construction cost is lowest compared to other processes. However, the system design is very complicated. A feed distribution system and a special baffle system are necessary.

1.2.1.10 Anaerobic hybrid reactor

The hybrid reactor has been designed to improve the liquid and solid separation. In principle, this process is a combination of UASB in the bottom part and AF in the upper part using floatable media. The media used
are about 20-30% of the reactor volume and may be made of polyurethane foam polymer balls or plastic rings for the microorganisms to grow on.

1.2.1.11 Anaerobic fluidized bed

This process has the highest removal efficiency because a large biomass can be maintained with the concentrations of 15,000 – 40,000 mg/L. Bacteria, which are attached on the granule like media (less than 1 mm Diameter), are fluidized by the wastewater being pumped upward with sufficient velocity to keep a bed of media float. The Brownian movement of the media helps speed up the mass transfers of food and wastes from biochemical reactions. The upper part of the reactor has a larger diameter which makes the upflow velocity slower; therefore, bacteria-covered media drop back and knock against each other causing biofilm to be rubbed off. Since the process is difficult to operate and has a high operating cost, it is not widely used.

High-rate anaerobic processes have gained more importance due to the high efficiency. During the past 15-20 years, researchers have conducted the tests to separate acidogenesis from methanogenesis processes because these two groups of bacteria require different optimum conditions. Therefore, two-step processes have higher efficiency than single-step processes. Currently in all countries, two-step UASB processes are being used for the treatment of wastewaters.

1.2.2 Concept of UASB-Process

The UASB-reactor concept has been derived from following facts

Anaerobic sludge inherently possesses good settling properties, provided the sludge is not exposed to heavy mechanical agitation. For this
reason mechanical mixing is generally omitted in UASB-reactors. At high organic loading rates, the biogas production guarantees sufficient contact between substrate and biomass. In UASB process wastewater enters the reactor from the bottom at low velocities and flows upwards through relatively dense (granular) sludge bed and a blanket of sludge particles. The substrate comes in contact with a sludge suspension (biomass) and eventually gets digested. The gas produced bubbles through the bed and brings about an excellent mixing so that an adequate contact is made between the biomass and the substrate. A gas solid separation device is placed at the top of the UASB reactor. It allows the rising gas bubbles and a quiescent zone is created. This zone acts as a separation compartment where sludge particles carried along with upward flow of effluent settle and slide over the inclined walls of the separator and back into the reactor. A fine quality treated effluent leaves the settling compartment.

For achieving the required sufficient contact between sludge and wastewater, the UASB-system relies on the agitation brought about by the natural gas production and on an even feed inlet distribution at the bottom of the reactor.

Well settling sludge aggregates being dispersed under the influence of the biogas production are being retained in the reactor, by separating (collecting) the biogas in a gas collector system placed in the upper part of the reactor and releasing the biogas via this device from the reactor. By separating the biogas in this way, a settler is created in the upper most part of the reactor.

An important feature of UASB process is the quality of sludge with respect to settleability. A few weeks after start up of the reactor, the sludge gets converted into granular form and thus attains very good settleability.
This facilitates increase in hydraulic and organic loading potential of the reactor at reasonably low hydraulic retention time.

Essential components that need to be controlled and the main conditions to be maintained in a UASB plant are:

1. An effective separation of the biogas, from the liquid and the sludge must be accomplished

2. The anaerobic sludge should attain an early settleable form and it should develop as a granular sludge

3. For proper functioning of USAB process, the reactor needs an even distribution of the wastewater at the bottom of the reactor.

Although UASB is essentially a suspended growth reactor, it can be considered as a fixed biomass process. The essential feature of the system is the development of a sludge blanket in which the component particles are sufficiently aggregated to withstand the hydraulic shear of the upward flowing liquid without being carried upwards & out of the reactor. In addition, these shear forces must not cause the particles to break up into smaller units that could be washed out of the reactor. In other words, the sludge flocs must be structurally stable & have good settlement properties. Specific report regarding the anaerobic wastewater treatment based on biomass retention with emphasis on the UASB process has been published by Lettinga et.al.

The inlet system for the wastewater in UASBR is designed to spread the wastewater uniformly over the bed of the reactor. The lower part of the reactor is called reaction compartment. It contains a layer of active sludge. When the wastewater comes in contact with the sludge, the unstable organic matter present in the wastewater is digested anaerobically resulting in end
products which mainly consist of methane and carbon dioxide. The part above the reaction compartment is called solid-liquid-gas separator or three phase separator. In this part, the gas generated in reaction compartment is separated from the liquid and collected in the gas hood. The water flows into the settler zone where solids are made to settle down and return to reaction compartment. The treated effluent is then collected in the effluent channels and transported out of the reactor.

1.3 PLANT COMPONENTS

1.3.1 Gas Liquid Solid Separator (GLSS)

In order to achieve the highest possible sludge hold up under operational conditions, it is necessary to equip the reactor with a GLSS device (Gas Liquid Solid Separator). It is the most characteristic and most important device in the UASB reactor. The main objectives of the GLSS device are listed below. The three phase separator was designed to meet these requirements, as per the guidelines given by Lettinga & Hulshoff Pol (1991).

1. To separate and discharge biogas from the reactor.

2. To prevent the washout of viable bacterial matter as efficiently as possible.

3. To enable the sludge to slide back into the digester compartment.

4. To serve as a kind of barrier (slopper) for rapid excessive expansions a sludge blanket in to the settler.

5. To provide polish effect.

6. To prevent the washout of floating granular sludge.
No additional measures required to enhance the return of the sludge from the settler back into the digester compartment.

The following points are to be considered as guidelines for GLSS design:

1. The slope of the settler bottom should be between $45^\circ$ and $60^\circ$.

2. The surface area of the apertures between the gas collectors should be 15 and 20% of the reactor surface areas.

3. The height of the gas collector should be between 30 to 35% of reactor height.

4. A liquid–gas interface should be maintained in the gas collector in order to facilitate the release of collection of gas bubbles and to combat scum layer formation.

5. The overlap of the baffles installed beneath the apertures should be 10–20 cm in order to avoid upward flowing gas bubbles to enter the settler compartment.

6. The diameter of the gas exhaust pipes should be sufficient to guarantee the easy removal of the biogas from the gas collection cap, particularly also in the case of flaming.

1.3.2 Feed Inlet System

The feed inlet distribution system constitutes a crucial part of the reactor. To obtain a uniform distribution of the influent over the bottom of the UASB reactor, it is necessary to employ a flow-splitting device to introduce the influent flow at several points on the reactor bottom (Lettinga 1991).
It is important to plan a homogeneous influent distribution in order to prevent the development of stagnation and short circuits in the distribution systems with as many feeding chambers as inlet points.

1.3.3 Effluent Collection Devices

The treated effluent should be collected from the top of the UASB Reactor as uniformly as possible. Specifically made horizontal gutters with V-Notches will be provided at regular intervals all round peripheral distance on top of the reactors. It is recommended to provide the effluent gutters with a scum baffle to retain floating solids.

1.3.4 Sampling Ports

A sampling of the reactor content to obtain the information about the sludge concentration and microbial activity as using openings can do a function of reactor depth conveniently. A sampler is introduced via such opening and then samples can be withdrawn at any desired level of the reactor height.

The sampling ports is connected with metal cocks or airtight flexible tubes and closed with steel locks.

1.3.5 Sludge Discharge Points

It is necessary to incorporate provisions in the design to remove excess sludge from the reactor. Generally, it is provided at one half of the reactor height from the bottom.

At large and in specific too, the conventional anaerobic digesters do suffer with the system efficiency for want of microbial count and retention of active biomass. The idea of retaining the active biomass (30 – 50 kg/m$^3$),
independent of Hydraulic Retention Time, in the non-attached concepts, stimulated the interest on up flow anaerobic sludge blanket, as modified suspended growth, anaerobic digester for treating high COD industrial waste streams.

In tropical conditions like in India, UASBR is already proved to offer COD removal upto 80%, for upto higher organic loading rate of 12 kg COD/m$^3$ d. The active biomass retained in the sludge blanket, almost immobilized in the blanket in contrast to the requirement of fills for microbial attachment, is the major breakthrough in the optimized design of UASBR for treating industrial waste streams.

The reaction kinetics of UASBR significantly favors its application for the treatment of high COD or BOD waste streams.

The contemporary advantages of anaerobic treatment system like low biomass production, less nutrient requirement, less energy requirements, methane production etc., are inherited in a much higher scale in the UASBR systems.

The VFA production and pH problems are well controlled in the UASBR with the active, enriched biomass in the blanket.

Tolerance to variation in the Hydraulic and Organic Loading Rates is excellent.

Performance of UASB Wastewater Process refers to the removal efficiency of Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Total Dissolved Solids (TDS), Nitrogen and Phosphorous.

Biogas Production refers to by-product gas generated from UASB process mostly composed of methane and carbon dioxide and traces of
hydrogen sulfide and nitrogen. In this research, the volume of biogas production measured by substitution in water.

1.4 UASBR AN ALTERNATIVE TO CONVENTIONAL ANAEROBIC REACTOR

1.4.1 Advantages

The UASB system has high efficiency and able to feed with loading of 50 kgCOD/m$^3$ d. It does not need a mixer, packing media and settling tank. The building and operating costs are low. It can deal with loads and able to halt operations for long period of time.

1.4.2 Disadvantages

The start up process is complicated and needs experienced personnel. The system is not suitable for wastewater with high SS; however, it could be remedied by using a two-stage process. It is not suitable for low volume of wastewater. Also, the design of the system is more complex than other systems.

The anaerobic treatment technology for domestic wastewater is as old as wastewater treatment itself. The first ever-engineered treatment system for domestic waste stream is Mouras Automatic Scavenger in France established by the end of the last century. The septic tank and imhoff tank are its modifications respectively in England and Germany, which have seen wide applications worldwide and in fact, continuing still.

The shortfalls and lacuna of these systems were overcome with anaerobic lagoons, which then got developed as digesters, as full-fledged engineered systems of anaerobic treatment. The anaerobic digesters were classified into several types of the reactors and incorporated with certain
specific plant components and system supports and are referred to in different terminologies. The Up flow Anaerobic Sludge Blanket Reactor is one such system, which has seen tremendous field applications for treating domestic and industrial waste streams.

The success of UASBR for treating domestic waste stream is proven and well established. Quite interestingly, the scientific world is continuously exploring and evaluating the process kinetics and plant components of UASBR for treating biodegradable industrial waste streams.

The UASBR was tried with several process modifications and redefined with up graded plant components by many researchers and engineers. The successful history of UASBR for treating industrial waste streams like Pharmaceuticals, Starch, Pulp, etc., is highly encouraging.

1.4.3 Anaerobic Processes in the UASB Reactor

There are 4 phases of anaerobic digestion in an UASB reactor

Hydrolysis, where enzymes excreted by fermentative bacteria converts complex, heavy, un-dissolved materials (proteins, carbohydrates, fats) into less complex, lighter, materials (amino acids, sugars, alcohols).

Acidogenesis, where dissolved compounds are converted into simple compounds, (volatile fatty-acids, alcohols, lactic acid, CO₂, H₂, NH₃, H₂S) and new cell-matters.

Acetogenesis, where digestion products are converted into acetate, H₂, CO₂ and new cell-matters.

Methanogenesis, where acetate, hydrogen plus carbonate and methanol are converted into CH₄, CO₂ and new cell-matters.
1.4.3.1 Degradation of organic matters

The total degradation of organic matters consists of three stages, usually described as follows:

**Hydrolysis**

In the initial stage, complex molecules such as carbohydrates, polysaccharides, lipids and proteins are hydrolyzed into utilizable substrates by extracellular enzymes. For example, carbohydrates are hydrolyzed into glucose by amylase and proteins are hydrolyzed into amino acids by protease. As for fats and lipids, with the result of glycerol and fatty acids, they are hydrolyzed very slowly by lipase and enterase respectively. Hence the hydrolysis might be regarded as a limiting step (including methane production) for a waste containing considerable amount of lipids and other slowly hydrolyzing compounds.

**Acid Formation**

These hydrolysis products are further fermented into various intermediates, mainly volatile fatty acids (VFA) such as acetic acid (CH$_3$COOH), propionic acid (CH$_3$CH$_2$COOH), and butyric acid (CH$_3$CH$_2$COOH). The other intermediates, i.e., organic acids, alcohols, hydrogen (H$_2$), carbon dioxide (CO$_2$), ammonia (NH$_3$) and sulfide ion (S$^2$) are also found in this state. This results from the reaction of a hardly separable group of fast growing facultative and obligate anaerobic acidifying bacteria or ‘acid formers’. The acid production rate is high compared to the methane production rate, which may lead to accumulation of acids and a subsequent drop in pH-value.

**Methane Production**

During this stage, methane (CH$_4$) is produced by slowly growing obligately anaerobic bacteria or ‘methane formers’. McCarty suggested that
most of the methane is produced from propionic and acetic acid. This stage is a very slow process which is a rate-limiting step of anaerobic digestion. Methane formers are generally known as very sensitive to disturbances. They account for the main COD reduction of the effluent, and work well at a pH of about 7. So it is a cause to the instability if there are considerable increases in intermediate products in the digesters; thus good pH control is absolutely necessary.

Figure 1.1 (Kaviyarasan 2014) shows the complete degradation of organic matter to carbon dioxide and methane involves four, not two, groups of bacteria. The new concept of syntropism in anaerobic cultures enables better understanding of the way these organisms are metabolically dependent upon each other for survival. Namely, the fast growing acid-forming group (minimum doubling time of 2-3 hours at 35°C ) accounts for converting complex organic matter to intermediate products, primarily acetic, propionic, and butyric acids. Then the second microbial group, the acetogenic bacteria, takes hold of these fatty acids and other compound producing acetic acid, hydrogen and carbon dioxide.

Figure 1.1 Flow diagram of Bio-gas production from UASB Reactor
These reactions can be illustrated by the simplest form of sugar, glucose, as follow:

\[ C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2 \]  (1.1)

\[ C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2 \]  (1.2)

\[ C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + H_2O \]  (1.3)

\[ CH_3CH_2COOH + 2H_2O \rightarrow CH_3COOH + CO_2 + 3H_2 \]  (1.4)

\[ CH_3CH_2CH_2COOH + 2H_2O \rightarrow 2CH_3COOH + 2H_2 \]  (1.5)

The terminal methane group comprises the methanogens effectively utilizing acetic acids and those utilizing the mixture of hydrogen and carbon dioxide. Namely, the slow growing acetoclastic methane bacteria (minimum doubling times of 2 – 3 days at 35°C) are responsible for converting acetic acid into methane and carbon dioxide according to the reaction:

\[ CH_3COOH \rightarrow CH_4 + CO_2 \]  (1.6)

And the hydrogen-utilizing methane bacteria are responsible for converting the mixture of hydrogen and carbon dioxide into methane gas according to the reaction:

\[ 4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \]  (1.7)

It can be seen that almost all of described above hydrogen is utilized by this latter methane group. Regarding the trace concentration of hydrogen availability in the systems, we have recently known that these forms of control, as described above are regulated by the trace of hydrogen through the digest. The H_2 are obviously sped up by high concentrations of hydrogen.
Usually the reactions are the conversion of hydrolysis products into acetic acid.

If the concentration of hydrogen is increased, e.g. during surge loads, it can slow down the overall rate of acid production. Moreover, it can further reduce the acid load by diverting some part of the acid products towards butyric acid by producing one mole of butyric acid instead of two moles of acetic acid. Sometimes events proceed further and trigger accumulation of hydrogen; the bacteria will response by putting the hydrogen into formation of propionic acid. The hydrogen also controls the rates at which propionic and butyric acids are subsequently reversed into acetic acid. This provides the methanogenic bacteria with the prime substrate for methane production. Thus, we can say that the trace concentration of hydrogen regulates not only the fatty acid productions but also the rate of methane formation in the digestion control.

1.4.3.2 Denitrification

Nitrates in wastewater are reduced by facultative denitrifying bacteria under anaerobic conditions provided a source of carbon is available. This group of bacteria is heterotrophic organisms i.e., *Pseudomonas, Achromobacter, Bacillus and Microoccus*. They obtain energy for growth from the biochemical reaction between nitrates and organic matter. Namely, nitrates (NO\(^3\)) are presumably reduced to nitrites (NO\(^2\)), and then reduction of nitrites occurs. Reduced of nitrite carried all the way to ammonia (NH\(_3\)) by a few bacteria, but most of them carry the reduction to nitrogen (N\(_2\)) gas which escape with the digester gas produced. For example, when methanol is used as the carbon source, nitrate is converted to nitrogen as the following equation:
NO\textsuperscript{3} + 5CH\textsubscript{3}OH → N\textsubscript{2} + 5CO\textsubscript{2} + 7H\textsubscript{2}O + OH\textsuperscript{-} + Energy \hspace{1cm} (1.8)

1.4.3.3 Sulfate reduction

In the absence of dissolved oxygen and nitrates, Sulfates can be served as a source of oxygen (or electron acceptor) for anaerobes called sulfate-reducing bacteria. This group of bacteria is also routinely found in the digester i.e., Desulfovibrio, Desulfotomaculum. The biochemical reactions of sulfate are shown in the following Equation (1.9).

\[
\text{SO}_4^{2-} + \text{organic matter} \rightarrow \text{S}_2^{2-} + \text{H}_2\text{O} + \text{CO}_2
\] \hspace{1cm} (1.9)

Sulfides produced from the reaction may exist in a soluble or insoluble form, depending upon the action with which they become associated. At the normal digester pH level, metal sulfides can precipitate to form in a black colloid in solution. The remaining soluble sulfides form hydrogen sulfide (H\textsubscript{2}S) that some extent can be released as a gas called “rotten egg gas” to the biogas production.

1.4.3.4 Microbial aspects

The microorganisms responsible for acidogenesis are well known as the acid formers or sometimes called “non-methanogens”. These groups of bacteria always consist of both facultative and obligately anaerobes. We can commonly find them in natural environment such as sewage sludge, organic sediments and the remen of cud chewing animals. They are found in gram-negative facultative rods, gram-positive cocci, endospore-forming rods and gram-positive asperogenous rods. This is similar to the result from the experiment with the separate upflow anaerobic reactor by some researches. The microorganisms observed in the acid reactor were reported to be white in appearance, consisting of rod shape bacteria with variable lengths; and young
cells (just after division) were gram-negative, whereas older cells were gram-positive.

The methanogenic microorganisms are fastidious anaerobes which have strictly requirements for redox potential and oxygen absence. The methanogens are unusual in that they are composed of many species with very different cell morphologies. They are reported in various types of cocci, rods, or even filamentous shapes, found in both gram negative and gram positive. Moreover, it cannot locate single colonies of methanogens in purified agar due to the fact that they often grow with the non-methanogen contaminants. They are in black and smell of hydrogen sulfide after treating with HCl.

1.4.3.5 Biogas

The end products obtained from organic destruction in anaerobic process is “biogas”. This is often referred to as a mixture of methane (CH$_4$) and carbon dioxide (CO$_2$) plus traces of other gases, i.e., hydrogen (H$_2$), nitrogen (N$_2$), ammonia (NH$_3$), and hydrogen sulfide (H$_2$S), etc., Table 2.2 shows the typical gases which are always measured in the stable digester. It can be seen that methane is the major portion in the composition of product gas. McCarty estimated that approximately 70% of methane came from acetic acid formation. At present, the two theoretical methane productions are accepted as follow:

\[
\text{CH}_3\text{COOH} \rightarrow \text{CH}_4 + \text{CO}_2 \quad (1.10)
\]

\[
\text{CO}_2 + 8\text{H} \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \quad (1.11)
\]

1.4.4 Anaerobic Digestion Process

Using biological anaerobic treatment has more advantages over aerobic treatment. It provides lower nutrient demand, lower bacteria
production, and lower energy demand. The process also generates biogas, mainly methane, which can be utilized as fuel. However, there are also disadvantages. The bacteria in the process have slow growth rate resulting in a long startup period for the system. The system is not capable of adapting to changes in wastewater quantity, BOD, temperature and other surrounding changes. The system also gives off the malodorous hydrogen sulfide gas, which reacts with metals and turns the effluent into a black color.

Lettinga stated that classification of anaerobic treatment of organic process depends on loading rate of organic matter, which is determined by the amount of bacterial sludge in the reactor.

Also, the classification depends on contact between the wastewater and the bacteria.

Methods for maintaining a high amount of bacteria in the reactor for a long period of time are as follow:

- Maintaining the bacteria by using packing material or media in the reactor to capture the bacteria as they form a sheet of film such as the Anaerobic Filter.

- Maintaining the bacteria by using immobilization process by using the mechanism of bacterial contact on the packing material or media such as the Fluidized Bed or Fixed Film Expanded Bed System.

- Maintaining the bacteria by using the sludge blanket process such as the Upflow Anaerobic Sludge Blanket System.
1.5 **UPFLOW ANAEROBIC SLUDGE BLANKET REACTOR**

The interest in anaerobic wastewater treatment processes in practice is sharply increasing all over the world. This increased popularity for anaerobic wastewater treatment can partly be attributed to the fact that AWWT combines a number of important principal advantages with low if any inseparable drawbacks. However, the main reason for the breakthrough of anaerobic wastewater treatment presumably should be found in the development – and successful application of new, simple and low cost high-rate anaerobic treatment processes, Upflow Anaerobic Sludge Blanket (UASB) process. Moreover the enormous potentials of anaerobic treatment are rapidly becoming recognized in an extending circle.

The loading potentials of an anaerobic wastewater treatment system are primarily dictated by:

a. The amount of viable sludge which can be retained in the anaerobic reactor, and

b. The contact that can be achieved between the incoming wastewater and the sludge.

Contrary to aerobic treatment processes the loading potentials of the process are not limited by the supply of any required reagent/ingredient. If more sludge can be retained higher loads can be applied, provided a sufficient contact between sludge and wastewater can be maintained.

The UASB reactor is one of the reactor types with high loading capacity. It differs from other processes by the simplicity of its design. UASB process is a combination of physical & biological processes. The main feature of physical process is separation of solids and gases from the liquid and that of biological process is degradation of decomposable organic matter.
under anaerobic conditions. No separate settler with sludge return pump is required, as in the anaerobic contact process. There is no loss of reactor volume through filter or carrier material, as in the case with the anaerobic filter and fixed film reactor types, and there is no need for high rate effluent recirculation and concomitant pumping energy, as in the case with fluidized bed reactor.

1.5.1 Essential Features of UASB Reactor System

Basically the upflow anaerobic sludge blanket reactor is divided into three distinct zones, namely sludge bed, sludge blanket, and solid-liquid-gas separator. The sludge in this reactor is kept in dynamic motion by two factors, namely: (a) Controlling the wastewater flow in upward direction at the bottom, and (b) The produced blogs in sludge bed is able to push up sludge particles in upward direction. The flow of the wastewater entering the reactor is always let in through the distributor in order to avoid the short-circuiting of flow. The wastewater is initially fed into the reactor by ensuring that the incoming flow is uniformly distributed across the entire cross-sectional area of the reactor in order to promote efficient substrate utilization by the microbial population, and to prevent short-circuiting through the sludge bed zone. The wastewater entering the reactor passes through the sludge bed zone. The biological sludge is formed by the active biological solids which along with the suspended particles of waste are retained in the reactor by settling and thickening properties of the anaerobic (active biological solids) sludge.

Waste stabilization occurs as the waste passes up through the sludge bed. Solids concentrations in the sludge bed may reach as high as 100-150 g/L reported that these high concentrations in the bed were due mainly to the development of a highly developed granular sludge (consisting of active biomass or bacteria), which has superior settling properties. Mechanical
mixing of any kind in the sludge bed zone should be kept to a minimum (except during initial start-up periods), since it is possible to erode some of the granular shaped sludge particles.

The sludge bed zone has been described as a perfectly mixed region, which can actually be divided into smaller sub-regions. The first sub-region encountered in the sludge bed is the area around the influent ports, which is considered to be a perfectly mixed region. The rest of the sludge (except for dead space regions), is considered a transition region between the initial bed zone and the sludge blanket zone. Gas production by the biological solids results in gas bubbles, which produce mixing throughout the bed and eventually eliminate any initial dead space regions. One reason for considering the sludge bed, as less than a perfectly mixed zone, is that some of the influent bypasses the sludge bed zone via channels formed in the bed. The sludge bed zone is responsible for 80 to 90 percent of the waste degradation occurring in the reactor while occupying roughly only 30 percent of the reactor volume.

The next zone encountered by the waste stream is the sludge blanket section, which occupies about 70 percent of the total reactor volume and contains solid concentrations of an order of magnitude lower than the sludge bed. The sludge blanket zone is considered ideally mixed and consists of highly flocculated sludge. The free rising gas bubbles in the blanket (originating from the sludge bed) cause mixing, and because the liquid residence time is essentially longer compared to the time required for the gas bubbles to reach the reactor top, very good mixing conditions exist.

1.5.2 Upward Velocity

The upward velocity creates a constant selection pressure for microorganisms, which can adhere to each other to form granules, which
settle well. The granules can be several millimeters in diameter and can accumulate in the reactor in large amount.

The admissible maximum liquid surface load for granular sludge is approximately 3 m/h as on average over a day. The same is 1 m/h in the case of soluble waste streams and 1.25 m/h for partially soluble wastewater, under which conditions most of the granular sludge will be retained in the reactor. The high superficial velocities may result in the wash out of granular sludge particles.

The resulting anaerobic degradation process typically is responsible for the production of biogas (CH$_4$ and CO$_2$). The biogas bubbles rise up to the liquid gas interface under the phase separator.

### 1.5.3 Process Microbiology

The microorganisms of most general importance to environmental biotechnology are the prokaryotes. Very little is gained by dividing their descriptions between the Bacteria and Archaea. Since, functionally, their similarities are greater than their differences. Indeed, until the development of genetic phylogeny, the collection of micro-organisms within these two domains was simply called bacteria. Also, the bacteria and Archaea generally are found together and often participate together to bring about the destruction or mineralization of complex organic materials, such as the formation of methane from the decay of dead animals and plants. The Bacteria ferment and convert complex organic materials into acetic acid and hydrogen, and the Archaea convert the acetic acid and hydrogen into methane gas. The organisms must work closely together, as in an assembly line, in order to bring about the destruction of the organic matter.
1.5.4 Process of Granulation

The efficiency in producing methane and eliminating organic matter of the system will increase when the amount of bacteria increases. The UASB system has high amount of bacteria measured in MLSS or MLVSS, much higher than other types. The reason is that the bacteria are in granular form. Therefore, in the operation of the UASB system for maximum efficiency, the bacteria granules must be nurtured. Once the bacterial granules are present, the system operation is not too complicated. In general, however, it is difficult to find bacterial granules, so the start up process will use bacterial sludge from other systems. These bacteria are lighter in weight and the process of the transformation into the heavier granular form can be explained in 3 steps as follows:

1.5.5 Wash-out Stage

This is the first step in the transformation, i.e., start up process. The loading rate is low, being less than 2 kg COD/m$^3$d or sludge loading lesser than 0.3 kg COD/kgVSSd. In this step, loss of the lightweight bacteria will occur with the wash out at the same time as increasing the amount of bacteria in the system as more nutrients enter.

1.5.6 Transition Stage

This is the beginning of granule formation. However, the levels are low and the granules are small in size. The loading rate depends on the characteristic of the wastewater. In this stage, large amounts of biogas will be produced and carry the lightweight bacteria out of the system. This is actually beneficial to the system as the granular bacteria will have a chance to grow and increase in numbers. However, it should not allow the rate of lightweight
bacteria loss to be greater than the rate of granular bacteria increase as the system might fail.

1.5.7 Progressive Granulation Stage

This is the step where the granules increase in size and numbers in the reactor tank. The loading rate will be higher and the system will be able to accept higher and faster organic loading rate.

1.5.8 Types of Granules

Bacteria granules in the UASB system consist of many types of bacteria depending on the operation of the system and characteristics of wastewater. The granules are classified as follows:

1.5.8.1 Sarcina granules

It consists of methanosarcina which occurs when there is overloading. The organic acid levels would accumulate to more than 1000 mg/L at pH is lower than 6. These sarcina granules have low methane production activity.

1.5.8.2 Rod-type granules

It consist of short rods of about 3mm in length. The VS is as high as 90% which can be found in reactors of UASB systems treating certain wastes such as sugar beet wastewater and potato waste. These bacteria are methanotrix soehgenii.

1.5.8.3 Filamentous granules

It consists of long strands of bacteria with 5 mm length. Inside are mostly inert carrier material, therefore the VS level is much lower than the
first two types. UASB systems with filamentous granules have the highest efficiency. The conditions are controlled to eliminate any accumulation of organic acid in which the levels would be lower than 1000 mg/L.

1.5.8.4 Spiky granules

It occurs when the wastewater contains high concentrations of calcium. The granules can consist of CaCO$_3$ as high as 60%. These spiky granules have diameter of 1 mm and width of 0.5 mm. The settling velocity is as high as 90 m/h, most of the bacteria are long strands, and these granules have low activity because of the coating of CaCO$_3$ on the bacterial granules.

1.5.9 Operation Control Parameters

Each type of anaerobic wastewater treatment process will have operational control parameters which depend on properties of wastewater and mechanisms of microorganism in each process. For UASB process, the influent wastewater must be free from toxic substances and adjusted for the microorganisms, such as the pH and nutrients. As for the mechanisms of the microorganisms in the process, apart from controlling the balance of the acidogenic and methanogenic bacteria, the high number of bacteria in the system must be maintained. The parameter that controls the number of bacteria in the reactor tank is the sludge settle ability, which depends on the organic loading rate and the hydraulic loading rate. Therefore, the main parameters used to control the operation in UASB system is the organic loading rate and hydraulic loading rate.

1.5.9.1 Organic loading rate

It is an important parameter that affects the efficiency in digesting organic matter, settling of the bacterial sludge and producing biogas in the
reactor tank. The influent should have a lower organic loading rate than the highest rate of organic digesting by the bacterial sludge.

**1.5.9.2 Hydraulic loading rate**

It is related to mixing in the lower sludge layer. From denitrification process experimented in the reactor tank, it is found that the wastewater will flow through the space created by cracks between the bacterial sludge in the lower layer. This short circuiting effect lowers the treatment efficiency. This could be solved by applying feed inlet distribution evenly to the whole area at the bottom of the reactor tank. For operating treatment plants, one inlet would cover areas of 5-10 m² and for large pilot plants the inlet would cover areas of 1-2 m². If the feed inlet distribution system is evenly spaced, the organic loading rate will be high.

**1.5.10 UASB System Design Criteria**

As mentioned, the UASB system will have high efficiency when the bacterial sludge is in granular form. Whether granular bacterial sludge will form or not depends on the size and shape of the reactor tank. The design criteria for UASB system as follows:

Feed mode: It is very important to the fermentation process. For low COD values, the feed mode should be continuous feeding. If the COD is high (more than 10000 mg/L), it is advised the feed mode should be intermittent pulse feeding. To increase the mixing in the granular layer and distribute the wastewater evenly over the cross-sectional area, there should be a feed inlet pipe for every 1 m² of area.

Recycling effluent back into the reactor tank: It is done for several reasons. The first is to dilute the influent which is high in organic loading, to
aid in the mixing process and to adjust the pH of the influent. In the case of low organic loading rate or wastewater with low organic matter, it may not be necessary to recycle the effluent.

Dilution: It is done to lower the toxicity of the wastewater. The startup period of the system should be done with dilution. However, dilution will increase the volume of the effluent, which will add to the cost to the next steps in the process. Therefore, dilution should be avoided if not necessary.

Flow pattern: It is important to the creation of granular bacterial sludge. If the flow pattern is not suitable, then the bacterial granules will not be formed or the layer might float and wash out of the reactor tank and the reactor tank will be out of balance. The flow pattern should have the following criteria:

Hydraulic loading rate >0.25-0.4 m/h and <2 m³/m²h

Biogas flux >0.15-0.3 m³/m²h

Sludge hold up: Even though volume of bacterial sludge is desirable to increase biogas productivity and treatment efficiency, both the lower layer and the upper layer should not reach as high as the settler, otherwise the bacterial sludge will be washes out. Therefore, during operating, it should monitor the level of the bacterial sludge layer to determine the volume of sludge that needs to be removed.

Gas-solid separator: This is attached at the top of the reactor tank and may have various shapes. The design of the gas-solid separator is as important as the design of other parts of the reactor. The general design criteria are as follows
- The slope of the inclined wall of the settler = 50°
- Should be a baffle under the settler to prevent biogas loss
- Surface loading in settler <0.7 m³/m²h
- Average flow through the aperture (V) <2 m/h

**Single Stage or Two-Stage System:** Most of the general design criteria will use a single stage system. Wastewater which consists of dissolved organic matter (flour) should use a two-stage system. This is done in order to hydrolyze the solid organic matter and convert to organic acids in the acid reactor tank before the conversion to biogas in the methane reactor, which is the second tank in the UASB system. The acid reactor tank should be 1/5 to 1/7 of the methane reactor tank. In case of scarce information, it is necessary to conduct an experiment by designing a two-stage system.

**Design loading:** Design loading is generally in the range of 5-18 kg COD/m³d. However, it can be higher depending on the characteristics of the wastewater. Therefore, bench scale experimentation is very important. In the case of high organic loading and high toxicity, it may be necessary to initiate pilot scale experimentation to acquire reliable data.

**1.5.11 UASBR - Performance Controlling Factors**

The wastewater flows upward through a sludge blanket composed of biologically formed granules or particles and the treatment occurs when the wastewater comes into contact with the granules. The gases like methane, carbon-dioxide produced under anaerobic conditions causes internal circulation, which helps in the formation and maintenance of the biological granules. The factors that could affect the performance of UASBR during start-up and subsequent steady state behaviour are
1. Organic and Hydraulic loading rate

2. Sludge production

3. Biogas production

4. Temperature of wastewater

5. Toxic compounds

1.5.12 Start-up of UASBR

Factors that have the most influence on the duration of the startup period of a UASBR treating wastewater are the quality and quantity of seed sludge and the operational conditions. For any wastewater, the start-up of an anaerobic plant is a time consuming and sometimes rather difficult process, due to the fact that a large bacterial mass, adapted to the particular characteristics of wastewater, has to develop. If overloading occurs during this period, acid fermentation can become predominant over methanogenic fermentation, resulting in souring of the reactor contents.

The correct microorganism population will develop during the start-up time as a result of the growth of microorganisms capable of converting organic material into methane. From the instant when the microorganisms are full, the sludge mass in the reactor will remain basically constant and the daily mass of sludge generated becomes equal to the daily mass of sludge discharged with the effluent.

In order to enable to characterize the performance of the UASBR during start-up and the subsequent steady-state behaviour, the effect of the anaerobic treatment on the following parameters should be investigated.

1. Extent of sludge accumulation
2. Organic matter concentration expressed in BOD and COD
3. Concentration of settleable and suspended solids
4. pH, alkalinity and VFA concentration
5. Concentration of nutrients

1.6 STEADY STATE BEHAVIOR

Once the reactor is completely filled up with sludge, there are basically two methods to deal with the sludge production of the system.

1. Discharge sludge periodically, so that the concentration of settleable solids in the effluent will remain as low as possible.

2. Operate the reactor at its maximum sludge hold up, consequently accepting the wash-out of excess sludge. Relatively high concentration of settleable solids will then be present in the effluent.

The amount of excess sludge present in the effluent will constitute a considerable fraction of the effluent BOD, COD and TSS concentrations. At the steady state of sludge hold-up the total daily flux of settleable solids in the effluent is equal to the daily sludge production rate. Therefore, to evaluate the performance of a UASBR, it is important to know whether the reactor is operated at its maximum sludge hold-up, or under conditions where settleable solids concentration is minimized by applying periodic excess sludge discharge, before the maximum hold-up is attained.

If the UASBR is the only biological treatment unit, it is important to keep the effluent COD and TSS concentrations as low as possible, and consequently to apply periodic discharge of the excess sludge. On the other
hand, if some kind of post treatment is employed, periodic sludge discharge becomes less important and in some cases even counter productive. The SVI of the sludge can be calculated from the values of the volumetric and gravimetric concentrations of settleable solids present in the raw effluent of a UASBR in which regular sludge discharge regime is not applied. The steady-state behaviour of UASBR depends on the following main operational variables.

1. Hydraulic retention time
2. Volumetric loading rate

1.6.1 Hydraulic Retention Time

Hydraulic Retention Time (HRT) is an important factor in any biological reactor or process. It is evident from various studies that the COD, BOD and TSS removal efficiencies depend on applied retention time. The optimum retention time is to be applied depends on the desired results and whether or not any post-treatment is applied.

The treatment efficiency can also be correlated with the applied upflow velocity.

\[ V_i = \frac{Q_i}{A} \]
\[ = \frac{Q_i H}{V_r} \]
\[ = \frac{H}{(HRT)} \]

1.6.2 Volumetric Loading Rate

This parameter indicates the daily COD, BOD or TSS load per unit of reactors volume.
1.7 SCOPE OF THE STUDY

A laboratory-scale UASB reactor was constructed and fed with various synthetic wastewaters in two different ambient temperatures at the Environmental Laboratory of the As-Salam college of Engineering and technology, Aduthurai, Tamilnadu. The hydraulic retention time were varied as 5.21, 2.60, 1.74, 1.30 and 1.04 days corresponding to five different influent flow rates of 4.80, 9.60, 14.40, 19.20 and 24.00 L/d, respectively. The parameters of pH, temperature, BOD, COD, TSS, TDS, Volatile fatty acid (VFA) and biogas production were determined according to the Standard Methods (1999). VFA determined according to Wastewater Analysis Manual. Biogas production was measured by water substitution method.

Limitation of Study

The study was used synthetic wastewaters to assure the stability and consistency of the process parameters.

1.8 INDUSTRIAL WASTE STREAMS

Any industrial effluent is specific to the concerned manufacturing process and materials involved. Ironically, most of the waste streams from agro based industries, pharmaceuticals, pulp and paper etc., do have very significant biodegradability in the range of 0.4 to 0.6.

Anyhow, the inhibiting factors like pH variations, heavy metals, toxic chemicals etc., are present invariably in these waste streams. The conventional anaerobic treatment options and their process or reaction kinetics are not suitable for efficient handling of such waste streams.
The effluent from sugar, dairy brewery and tannery are characteristically biodegradable with significant level of inhibitions.

1.8.1 Sugar Industrial Wastewater

1.8.1.1 Manufacturing process

The Manufacturing process of sugar is relatively a complex process. The sugar cane is first washed with fresh water and then it is shredded using shredding machine in the Mill house and sent for crushing to extract the juice from the sugar cane. About 93% of the juice is extracted and the fibrous residue left over is called as Bagasse. The extracted juice is screened for removing the floating impurities. After screening, milk of lime is added to increase the pH to 7.6 to 7.8 in order to prevent from inversion and to aid clarification by coagulating the colloidal impurities along with the addition of a coagulant aid.

The mixture is pre heated using high-pressure steam and allowed to settle. The clarified juice is bleached and sent for evaporation, where the juice reclaimed. The residue results in pressmud. The concentrate juice after evaporation is fed into a multiple effect evaporator, where the sugar is further concentrated. Now the concentrated syrup known as masscurite is passed into a crystallizer. The crystal and syrup is separated in the Centrifuge systems. The spent liquor is collected as molasses and the sugar crystals are collected and dried as Sugar. A flow diagram showing the manufacturing processes of sugar industry and sources of wastewater generation in Figure 1.2.
1.8.2 Dairy Industrial Wastewater

1.8.2.1 General

The dairy industry wastewaters are primarily generated from the cleaning and washing operations in the milk processing plants. It is estimated that about 2% of the total milk processed is wasted into drains. Dairy wastewaters are characterized by high biological-oxygen demand (BOD) and chemical oxygen demand (COD) concentrations, and generally contain fats, nutrients, lactose, as well as detergents and sanitizing agents. Dairy effluents decompose rapidly and deplete the dissolved oxygen level of the receiving streams immediately resulting in anaerobic conditions and release of strong foul odours due to nuisance conditions. Different processes like cleaning, sanitization, heating, cooling, floor washing, which directly implies that the requirement of water is huge, hence giving rise to large amount of
waste waters produced which is estimated to be 2% of the total milk production.

Due to the high pollution load of dairy wastewater, the milk-processing industries discharging untreated/partially treated wastewater cause serious environmental problems. Dairy wastewaters are generally treated using biological methods such as activated sludge process, aerated lagoons, trickling filters, sequencing batch reactor (SBR), anaerobic sludge blanket (UASB) reactor, anaerobic filters, etc.

A flow diagram showing the manufacturing processes of dairy industry and sources of wastewater generation in Figure 1.3.

1.8.2.2 Manufacturing processes

In the dairy plants, the milk is received from collection tankers on checking for volume, temperature and flavor. The milk is then pumped to the plant reactors. The actual processing of raw milk begins with separation or clarification. The clarification will essentially skim the milk sediments and leukocytes away. This will have another system support to control the fat content in the raw milk. This process is also understood as standardizing.

The milk is then sent to pasteurizer, where all pathogenic bacteria will be removed. This is accomplished by heating the milk for 150°F for 30 minutes or 166°F for 15 sec. There are at least two basic methods of pasteurization, batch or continuous and could be achieved in varied types of equipments.

Essentially, the pasteurized milk is what the product known as ‘Processed Milk’. Anyhow, further downstream processes like
Homogenization and vitamin fortification are being carried out to further add value to the milk, in different brand names.

Figure 1.3 Effluents generation from various units of milk processing

DS-Detergents and Sanitizing Agents, WW-Wash Water, ST-Steam, CW-Cooling Water
1.8.2.3 Milk products

The cream separator produces cream and skimmed milk, from which many dairy products are made. The milk products are many and are drawn under varying condition of operation. They are butter, buttermilk, ghee, whey, casein, paneer, ice cream etc. The dry milk powder is also now being produced by evaporating the raw whole milk or processed or pasteurized milk.

1.8.3 Brewery Industrial Wastewater

1.8.3.1 Manufacturing process

Malting

The purpose of the malting is to render soluble starches which are contained in the seed of the barley. First, a controlled germination is induced by steeping of the barley in water. The grain is spread on the floor during this period. It may last for a week or ten days. Germination is arrested by drying. Malt may be roasted if a dark beer is to be produced. Final temperature is between 80°C and 110°C. Malt is sieved and milled into grist.

Mashing

The object of mashing is to convert the starches of the malt into fermentable sugar.

The temperature profile to be followed is as given below.

Pre-mashing : 43 - 45°C
Heating to : 45 – 52°C for 10 min.
Rest at : 52°C for 15 min.
Heating to : 52 – 67°C for 15 min.
**Rest at** : 67°C for 20 min.

**Heating to** : 67 - 71°C for 5 min.

**Rest at** : 71°C for 17 min. or till conversion

**Heating to** : 71 - 76°C for 5 min.

**Lautering**

Mash is filtered in a lautertun. Clarified mash is called as the wort. It is fed into the brew kettle, where it is heated to boiling point. Depending upon type of beer to be produced, wort may be boiled for not less than an hour and occasionally as long as two and half hour. Heat is supplied by steam (external heat boiler). Copper is traditionally used in the manufacturing of the kettles because it conducts electricity efficiently. Stainless steel is also used because it is easier to clean.

Hops are added at this stage in extract and pellet form. This brings delicate flavor and aroma to beer. After brewing, the spent hops are removed by whirlpool. The hopped wort is then cooled before being passed to the fermentation vessel.

**Wort Boiling**

- Pre-heating is started after collecting 70 to 76 HL wort in the wort boiler.
- 80 HL wort is collected in the wort boiler and boils.
- Hop Extract is added after the start of the boiling.
- Whirl floc addition is done after the end of the boiling, before transferring to whirlpool.
• Initial hop pellets are added just after the boiling starts and sugar addition is done 20 min. before the end of the boiling.

• Boiling time is 80 to 90 min.

**Whirlpool**

The whirlpool is done to remove the proteins and the hops. It works on the principle of centrifugal force. It is also used to remove the tannin. If it is present it results in the formation of Haze which is harmful.

1) The whirlpool is kept clean for the wort transfer. Inspect before use.

2) A rest period of 30 to 40 minutes is allowed.

3) The wort is transferred through the wort cooler to wort receiver.

**Fermentation & Lagering**

Tanks are cleaned and sterilized with caustic soda and disinfectant before taking into operation. Details of cleaning are maintained in Fermentation Log book. Wort from brew house at prescribed temperature is collected. Details about wort receipt are recorded.

During wort collection, yeast is also pitched into the Fermenter. Details about yeast pitching are recorded. During fermentation, wort undergoes various changes. Basic details of fermentation like gravity attenuation and temperature are recorded. Samples are given to QA and feedback obtained. After fermentation, the beer (green beer) is lagered at prescribed temperature. Samples are given to QA Lab for QA. A flow diagram showing the manufacturing processes of brewery industry and sources of wastewater generation in Figure 1.4.
1.8.3.2 Sources of brewery waste

In the manufacturing of brewery, the wastewater was generated in the following processes.

1. Wort flirtation
2. Wort boiling
3. Fermentation
4. Clarification

1.8.4 Tannery Industrial Wastewater

1.8.4.1 General

Tanning is one of the oldest industries in the world. With the growth of population and the resultant increasing demand for leather and its products, large commercial industries have been established. Tanning is the chemical process that converts animal hides and skin into leather and related products. The transformation of hides into leather is usually done by means of tanning agents and the process generates highly turbid, colored and foul smelling wastewater.

1.8.4.2 Manufacturing processes

The production processes in a tannery can be split into four main categories:

(1) Hide and skin storage and beam house operations
(2) Tan yard operations
(3) Post-tanning operations and
(4) Finishing operation.

The manufacturing of leather can be divided mainly into two parts; beam house operations and tanning process. In beam house operations, the removal of dirt and blood by washing is the first step after which the hides are then soaked in water for softening and removal of salts. After the removal of
salts, fatty tissue is removed by fleshing. Liming is done to swell the hides for the better penetration of tanning agents and hair removal. Chemical dissolution of the hair and epidermis with an alkaline medium of sulfide and lime takes place. During liming, a high concentration of sodium sulfide, lime and organic matter is delivered to the effluent. Hides are then neutralized with acid ammonium salts and treated with enzymes to remove the hair remnants and to degrade proteins. This results in a major part of the ammonium load in the effluent. Pickling is usually done to prepare the hides for tanning. The pH value of hides is adjusted by addition of acids (mainly sulfuric acid). Salts are added to prevent the hides from swelling. Tanning is the reaction of the collagen fibers in the hides with tannins, chromium, alum or other chemical agents. Alums, syntans, formaldehyde, glutaraldehyde and heavy oils are used as tanning agents. Based on the tanning agents, tanning operations are further divided into vegetable tanning and chrome tanning. Vegetable tanning is usually done in series of vats by using natural organic substances.

Treatments of various wastewaters have become more important due to diminishing water resources, increasing wastewater disposal costs, and stricter discharge regulations that have lowered permissible contaminant levels in waste streams. Many methods were carried out for the treatment of wastewater form tannery industries including biological, oxidation and chemical processes.

A flow diagram showing the manufacturing processes of tannery industry and sources of wastewater generation in Figure 1.5. (Varsha Midha 2008)
Figure 1.5 Process flow diagram of manufacture of Tannery
1.9 NEED FOR THE STUDY

Invariably, all industries have two serious environmental issues viz., pollution hazards to environment through effluent discharge and acute energy shortage. To compensate these two issues, anaerobic digestion of agro-industrial effluents is an environment friendly approach. This anaerobic digestion is of positive environmental value since it combines waste stabilization with net fuel production. Energy conversion of organic matter by the anaerobic digestion is often advantageous than thermo-chemical and or aerobic-biochemical routes.

The present study on evaluation of UASBR as anaerobic treatment system for industrial waste water with different strength for Indian climatic condition will cater the specific demand for process optimization techniques and engineering design of the UASBR.

1.10 OBJECTIVES OF THE STUDY

In the last 25 years, the use of UASB reactor for the treatment of industrial waste streams has seen quantum increase. However, waste specific reaction kinetics, biochemical process optimization, principles and standards for engineering design of UASBR are not evaluated sufficiently. The knowledge on these aspects of UASBR based effluent treatment plants is the immediate requirement and demand.

The present investigation has been undertaken with the objectives of performance evaluation and system study on UASBR for treating industrial waste streams for temperature variations keeping the following under its purviews:
1. To experiment and evaluate the performance of a laboratory model of UASBR, in terms of its efficiency in the removal of Chemical Oxygen Demand, Volatile Suspended Solids and production of Biogas under the influence the varying organic loading rates and hydraulic retention time, for waste streams from sugar, dairy, brewery and tannery industries.

2. To choose the appropriate pre & post treatment systems and to analyze the nutrients removal efficiency.

3. To analyze the performance of UASBR with variations in temperature.

4. To achieve the effective usage of UASB reactor and to determine the rate of biogas production from UASB reactor.

5. Determination of factors influencing the efficiency of UASBR and investigate the relationship of VLR Vs COD removal, OLR Vs COD removal, and HRT Vs COD removal.

Therefore, this research focuses on the feasibility and the performance of the UASB treatment of various industrial waste streams and offers guidelines for further applications of full scale plants in the near future.