"PERFORMANCE STUDY OF UASB AND EGSB REACTOR FOR INDUSTRIAL WASTE WATER TREATMENT"

A Major Project Report
Submitted in Partial Fulfillment of the Requirements
For the Degree of

MASTER OF TECHNOLOGY

IN
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Certificate

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This is to certify that the Major Project entitled *"Performance Study of UASB & EGSB Reactor for Industrial Waste Water Treatment"* submitted by Bhargav Makwana (05MCH003), towards the partial fulfillment of the requirements for the award of Degree of Master of Technology in Chemical Engineering (Environmental Process Design) of Nirma University of Science and Technology is the record of work carried out by her under my supervision and guidance. The work submitted has in my opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of my knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Nomenclature

Abbreviations and Symbols

COD	Chemical Oxygen Demand
T	Temperature
HRT	Hydraulic Retention Time
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solid
VFA	Volatile fatty acid
TSS	Total suspended solids
Mg/L	Milli gram per litter
UASB	Up flow Anaerobic sludge Blanket reactor
EGSB	Expanded Granular Sludge Bed reactor

Abstract

The main objective of the project on "Performance study of UASB (Up flow Anaerobic Sludge Blanket) reactor and EGSB (Expanded Granular Sludge Blanket) reactor for industrial waste water treatment" of production of effective COD reduction for waste water. The objective of this work to study the application of UASB and EGSB reactors inoculated with flocculent biomass for the degradation of textile waste water at mesophilic temperature. In order to study the influence of the pH , alkalinity, VFA (Volatile Fatty Acid) , and the organic load on the both reactor behaviors.

Initially the reactors were fed with waste water from textile industry . It' s initial COD was 1305 mg/l . During EGSB reactor experiment the initial COD was 1150 mg/l so organic load (glucose and milk powder) was added for increased COD up to 1300 mg/l. In such project I was also studied the effect of pH and volatile fatty acid (VFA)on both reactors operation. It was noted that at high concentration of volatile fatty acid affect on methanogenic activity and it also affect on biogas production because survival of methanogenic bacteria are difficult at higher volatile fatty acid concentration. In such project municipal sewage used for develops the anaerobic bacteria.

The sewage sludge from the sludge digestion tank used as seeding material for the study, which was obtained from the Pirana sewage treatment plant. The raw textile waste water for the study was collected from Arvind textile mills. Laboratory analysis were carried for Chemical Oxygen Demand (COD), pH, Volatile fatty acid (VFA), Alkalinity, MLVSS and TSS. The start up of experiment was performed continuously by running the UASB & EGSB reactor at a temperature of 29 ^{0} C and 35 ^{0} C respectively. During the experimental programme the pH observed to be in neutral range. During the project 70 % COD reduction was achieved in UASB reactor and 90 % COD reduction was achieved in EGSB reactor.

It was also observed that methanogenic activity higher at pH between 7 to 8.25. EGSB reactor is good for COD reduction as compared to UASB reactor but economically UASB reactor is better than EGSB reactor because in EGSB reactor operation continuously supply of electricity is required for waste water recycling.

CHAPTER 1
INTRODUCTION

The essential features of UASB reactor system is the presence of a very active sludge blanket at the bottom of the reactor. The UASB takes the advantages of the fact that with proper physical and chemical conditions, anaerobic sludge can be flocculated and formed into granules which have excellent settling properties. In the reactor, the microbes attach themselves to each other or to small particles of suspended matter to form granules.[8]

The main elements of the reactor are the influent distribution system at the bottom of the reactor and a three phase separator equipped in the upper part. The influent is distributed over the bottom and mixed with the anaerobic sludge bed by the influent distribution system. The organic compounds are removed from the wastewater as it rises to the top of the reactor and are converted mainly into biogas and some new sludge. The biogas produced during this process increases the contact between the sludge and feed . The gas formed and feed flow cause sufficient agitation to keep the sludge bed particles moving around to keep the bed fully mixed. Some particles are lifted up above the sludge blanket, but as they loose the entrapped gas, they settle back. The anaerobic sludge and the gas are separate from the treated effluent in the three phase separator. The separator acts to separate the gas produced from the dispersed sludge particles. This is very important for the retention of sludge in the reactor.[11]

1.1. Principles:

The UASB reactor is initially with digester sludge and then feed in the up flow mode. After few months of operation a very concentrated sludge bed develops near the bottom. This sludge is very dense and granular in nature with high settling velocities. Individual particles may grow to diameters of 1-5 mm in the absence of shearing forces induced by mixing. Development of this palletized sludge depends upon the characteristics of the wastewater and on the seed sludge used when starting the reactor.

Above the sludge bed is a blanket zone or more diffuse growth with lower particles settling velocities at concentration between 15-30 kg VSS / m^3 COD removal occurs throughout the entire bed and blanket reaction zone and the system is self mixed by rising gas bubbles.[3] The bubbles which are produced in the reactor are removed by submerged gas collector. During the start up when gas production is minimal it may be desirable to provide additional mixing by gas recirculation.[7]

In the region around the above and three phase separator solid – liquid separation takes place in quiescent settling zone. All surface in the settling zone are constructed with steep slopes to allow settled solids to return to the bed blanket region.[4]

1.2. Birth of UASB Reactor

The UASB process was first developed by Gatze Lettinga and colleagues in the late 1970's at the Wageningen University (The Netherlands). Inspired by publication of Dr. Perry Mcarty, Lettinga's team was experimenting with anaerobic concepts. The anaerobic filter is a high rate anaerobic reactor in which biomass is immobilized on an inert porous support material. During experiments with the anaerobic filter, Latina had observed that in addition to biomass attached on the support material, a large proportion of the biomass developed into free granular aggregates. The UASB concept crystallized during a trip Gatze Lettinga made to South Africa, where he observed at an anaerobic plant treating wine vinasse, that sludge was developing into compact granules.[11]

1.3. Project objective

The main objective of the project are produce biogas and effective reduction of COD in both UASB and EGSB reactor and check the reactor is better for reduction of COD and production of biogas.

1.4. Project methodology

Experimental design performance parameters selected for evaluating the treatment efficiency of the UASB set up in the institute are:

- COD reduction
- Biogas production

- Optimum organic load
- Optimum hydraulic retention time

Factors affecting the UASB performance are:

- pH
- Temperature
- Organic loading rate

1.5. Application of UASB reactor in industries

Anaerobic UASB treatment is now becoming a popular treatment method for industrial waste water because of it's effectiveness in treating high strength wastewater and because of its economic advantages. Initially UASB was used for treating wastewater from:

- Food industry
- Textile industry
- Dairy waste water
- Beverages industry
- Pulp and paper industry
- Breweries
- Distilleries and fermentation industry

But recent times the application of these technologies are expanding t in treatment of

- Chemical and petrochemical industry
- Landfill leachates

CHAPTER 2
LITERATURE REVIEW

2.1. CONCEPT OF ANAEROBIC TREATMENT

The major sources of water pollution are sewage effluents and industrial effluents. Wastewaters typically contain a number if contaminants that need to be removed, or at least significantly reduced in concentration. These contaminants can be classified as follows:

- Immiscible floating materials
- Suspended solids
- Soluble no hazardous organic materials
- Soluble hazardous materials
- Soluble inorganic materials
- Volatile materials

These all materials impart h high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of wastewaters, which are generally higher that the Bureau of Indian Standard (BIS) permissible limits. Thus there is need of prior treatment of these effluents before their disposal. The choice of possible sequence of specific treatments depends on the type and concentration of contaminants. In general two types of biological processes are widely used for wastewater treatment.[12] the first type are aerobic processes in which the microbes use oxygen dissolved in waste liquors. The second type is anaerobic processes in which the microorganisms do not have access to freely dissolved oxygen, nor to other energetically favorable electron acceptors such as nitrate ions. In such circumstances microorganisms can use the carbon in the organic molecules as electron acceptor. The most widely used engineered anaerobic process in wastewater treatment is that of sludge digestion, however, more sophisticated plants have been used for treating soluble, agricultural and industrial wastes and anaerobic systems have been investigated for treating settled municipal wastewaters.

The choice between aerobic and anaerobic processes for wastewater treatment has tendered to favors the former because the systems were considered to be more reliable, more stab le and better understood. However, anaerobic processes have served clear advantages. The disadvantages of aerobic biological ; treatment include high cost, aeration requirement, inability to transfer oxygen at the rate sufficient to satisfy the oxygen demand of the system etc.[8] It has been observed that anaerobic processes generate less sludge than aerobic process. The cost of sludge management can be significant due to the high moisture content (90-99.7%) of waste biological sludge's.[13] Aerobic processes are likely to yield between 0.5 and 1/5 kg of biomass (sludge) solids for each kg. of BOD removed. Moreover, anaerobic processes produce methane rich gas (biogas) which can be used as requirements of anaerobic processes. Thus, the anaerobic treatment is energy yielding process rather than energy requiring. Other advantages of anaerobic digestion over aerobic stabilization include low sludge production, low nutrient requirement, high loading and intermediate operation possible etc (Webb. 1983). The biogas generated can be used to supply energy. Besides its role for fuel substitutes for energy requirements, biogas has several social and economic advantages over the existing traditional fuel. Also it has been estimated that 3330 million M3 of biogas can serve purpose of 20446 million liters of kerosene (Ramachandran & Sinha, 1993). Thus, anaerobic treatment has been found to be an attractive alternative to aerobic treatments process. The reports are available on the anaerobic treatment of waste waters of various industries such as sugar, distillery, pulp and paper (Sastry et.al., 1990; Jain & Mishra, 1989; Hall & Cornacchi, 1987 and Dangcong & Qiting, 1993).

Anaerobic treatment processes invariably involve a wide variety of organisms which show a great complexity of interactions. The overall process of anaerobic digestion can be represented as the conversion of organic waste, consisting mainly of proteins, lipids and carbohydrates, into methane and carbon dioxide. In general terms, three groups of micro-organism can be identified in terms of the nutrients they use.[12]

- Hydrolytic organisms which break down the complex molecules like carbohydrates, proteins & facts etc. in the wastewater and produce small molecules.

- Hydrogen and acid producing organisms which mainly utilize the products of catabolism off the hydrolytic organisms.
- Methanogens, organisms which produce methane.

On the basis of the above, the anaerobic treatment/ digestion process is divided into three major phases:

- Hydrolysis
- Acid production stage
- Methane production stage

2.2. Hydrolysis

In this phase, many hydrolytic organisms play a major role. The size and composition of the microbial population will depend upon the concentration and composition of the input. Typically mesophilic sludge may contain 10^5 - 10^9 hydrolytic organisms m1-1. Some of the common genera encountered in anaerobic digesters are Clostridium spp., Eubacterium spp. And Lactobacillus spp. The hydrolysis and liquefaction of the large organic molecules is carried with the help of extracellular enzymes secreted by these organisms.[17] These exo-enzymes include a range of proteases, amylases, cellulases,pectinases and lipase required to hydrolyse the available nutrient [8] . The only common input into anaerobic digesters which is rather recalcitrant to hydrolysis is lignin. The breakdown of lignin is relatively slow and, in many anaerobic processes most of the lignin remains intact during anaerobic digestion.[8]

Carbohydrates catalyze the hydrolysis of glycidic bonds. For e.g. Starch and glycogen. are hydrolyzed to disaccharide by the action of amylases. The disaccharides are then cleaved to monosaccharides by a glyconsidase. The enzyme specificity depends ion the nature of the glycosidic bond, the monosacharide involved and the size of the heterocyclic ring. Cellulase and chitin degrade the structural polysaccharides cellulose and chitin. Lipases and esterase hydrolyze fats and lipids. Proteolytic enzymes, proteases,

catalyze the cleavage of the peptide bonds of proteins. Again, these enzymes are also somewhat specific.

2.3. Acid protection stage

The initial degradation products formed after the hydrolysis and liquefaction of organic molecules are utilized by the micro-organisms, providing they are able to pass into the cell through the cytoplasmic membrane. This membrane selectively regulates the flux of nutrients, ions and waste products in and out of the cell. It is believed that the various proteins embedded in the membe\rane act as carries for specific substances or types of molecules. The typical metabolic pathway for the degradation of monosaccharides is Embden-meyerhof-Parnas pathway of glycol sis. The end product of glycolysis in yeast is ethanol, and in bacteria is acetic acid and carbon dioxide is evolved in either case.[21]

The anaerobic degradation of long-chain fatty acids proceeds primarily viz B-oxidation, in which two carbon atoms at a time split from the chain. The sequence shows the removal of one acetate unit which combines with reduced coenzymes. Acetic acid can then either be liberated from in a subsequent reaction or the acetate can be transferred to other functional compounds. It is suspected that proteolytic species of Clostridium are largely responsible for that anaerobic decomposition of amino acids. Some other species of bacteria which participate in the acid production stage such as Bacillus sp., Pseudomonas sp. and Micrococcus sp. Have also been isolated from anaerobic digesters (Bisseli , 1975).The C.O.D. removed during these hydrolysis and fermentation steps is very low. Although some carbon dioxide is formed, the process consists largely of breaking down large molecules into one or two carbon units. The growth yield of fermentative cells is also low due to the small net production of A.T.P. by substrate phosphorylation.

2.4. Methane production stage

In this phase a highly specialized group of bacteria commonly referred to as the methane producing bacteria (Methanogens) degrade the low – molecular – weight acids produced in the acid production stage to methane and carbon dioxide. These organisms

have the unique ability to couple organic oxidation to reduction of carbon dioxide. It has been reported that the Methanogens are generally present in low numbers and the typically Methanogens concentrations in mesophilic seqage slue is or the order of 10^6 – 10^8 cell ml^{-1} .Taxonomically, the Methanogens constitute a diverse group of organisms belonging to several genera and are distinguishable according to composition of their DNA. The four genera (Methanobactyerium, Mathanobacillus. Methanococcus, Methanosarcina) of anaerobic bacteria are known to produce methane gas. The range of compounds that serve as energy sources for the Methanogens is very limited. H_2 and CO or acetic acid is the most common substrate used. But format, methanol, methylamines and ethylamines are also utilized by some.[8]

In the absence of hydrogen the reaction is:

$CH_3COOH \rightarrow CH_4 + CO_2$

If hydrogen is available the carbon dioxide is reduced to methane:

$CO_2+4H_2 \rightarrow CH_4+2H_2O$)

In the overall process of the anaerobic conversions of organic material into methane there is an interaction between the fermentative (acid forming) bacteria and the Methanogens in the form of interspecies hydrogen transfer.

2.5. FACTORS AFFECTING THE ANAEROBIC PROCESS

Many investigators have studied the ranges and optimum conditions for anaerobic digestion. Widespread application of the anaerobic process has been hampered as it is assumed that it is being easily affected by different factors. Further development of anaerobic process technology is dependent on a better understanding of the factors associated with the stability of the biological process involved (Clark et. al., 1978). The process instability is usually indicated by a rapid increase in the concentration to volatile acids, with a consequent decrease in methane gas production. the acclimation period has also been reported to effect the process.[22]

2.5.1. Temperature

Digestion and gas production can occur over a wide range of temperatures as long as the temperature is relatively constant. Once a temperature range is established and the micro-organisms have become adapted fluctuation can result in process upset. The anaerobic digesters can be operated at psychophysically (<20C), mesophilically (20-45^{o}C), or thermophilically (50-70^{o} C). The main advantage if using thermophilici temperature is that the rate of the digestion is higher at these elevated temperatures. Other advantages include shorter solids retention times, better sludge dewatering characteristics and increased destruction of pathogenic organism. However, experience has shown that themophilic processes are less stable and small fluctuations in temperature leads to great fluctuations in performance. Thermophilic operations must also provide superior mixing to ensure better heat distribution and more uniform feeding thus adding additional cost.[14]

For these reasons, most anaerobic digestion processes operate at mesophilic temperatures (30-40^{o} C). This provides a reasonably high rate of digestion, an ability to respond to a wide range of substrates by allowing for broad species diversity and the heat input required is sufficiently low to remain cost – effective. Although, the sludge digesters are operated in the mesophilic range, methanogensis can also occur as lower temperatures. However, decomposition is considerably slower at lower temperatures (Stevens and Schulte, 1979).[8]

2.5.2. Hydrogen ion concentration (pH)

The hydrogen ion concentration (pH) also plays a very important role in the efficiency of anaerobic treatment processes. During acid production stage, the fall in pH can inhibit the growth and metabolism of the micro-organisms present and the digestion process can come to a halt. For methane producing bacteria, optimum pH ranges of 6.9-7.2, 6-4-7.2 and 6.6-7.6 have been reported. The non-methanogenic organisms are not nearly as sensitive and are able to function in a range of pH from 5 to 8.5. Process pH results from the interaction of the carbon dioxide – bicarbonate buffering system present with the volatile fatty acids and ammonia formed by the process. It is important that there be sufficient buffering capacity for the acids produced in order that they do not lower the pH to a level upsetting to the methane bacteria.[22] there has been considerable debate

concerning the toxicity of the ammonia and volatile acids themselves, independent of pH. Current thinking is that only the unionized volatile acids in the concentrations range 30-60 mg/I are toxic. And process inhibitions by ammonia result from excessive concentrations of free ammonia rather than ammonium ions (Hobson and Shaw, 1976).

2.5.3. Nutrients

All organisms have requirements for a broad spectrum of minerals. In addition to the major elements (carbon, hydrogen, oxygen, nitrogen phosphorus, sulphuric, magnesium, potassium and calcium), a wide variety of micro (trace) – elements are also required. The Methanogens particularly need iron, zinc, manganese, nickel, molybdenum and cobalt many of which act as cofactors for enzymes or are part of the prosthetic groups of enzymes. It is often necessary to add nitrates (or ammonium ions) and phosphates to industrial wastes. Sulfate is inhibitory only in the respect that the sulfate reducing bacteria complete with the Methanogens for hydrogen. If the incoming sludge is deficient in any one of the macro – or micro-elements or if these are present only in a form that cannot be utilized by cells, then the performance of the digester will be greatly impaired. Sometimes the vitamins (which act as cofactors is enzyme catalyzed reactions) and amino acids are required to be present in the incoming sludge as some microorganisms are unable to synthesize these biochemical's.

2.5.4. Moisture

In studying the effect of various moisture concentrations in solid wastes, i.e. in landfills, it was found that maximum methane production occurred at moisture concentrations (De Walle and Chian 1976) between 80 to 99 % . On the other hand, if the excess moisture (rainfall) contains dissolved oxygen, the methanogens will be inhibited.[7]

2.6. Upflow anaerobic sludge blanket (USAB) reactor

It was developed in the Netherlands in the 90's by Lettinga and the co-workers (Bachmanna, et.al., 1985). The essential features of UASB reactor system design are the three phase separator, proper influents distribution, head space, and effluent draw off

facilities. The key to successful operation of the UASB is to keep the very active sludge blanket at the bottom of the reactor. The UASB takes the advantage of the fact that with proper physical and chemical conditions, anaerobic sludge can be flocculated and formed into granules which have excellent settling properties, in the reactor, the microbes attach themselves to each other or to small particles of suspended matter to form conglomerate of granules. [6]

The UASB reactors is initially seeded with acclimatized sludge and then fed in up flow mode. The influent is distributed over the bottom and mixed with the anaerobic sludge bed & during process the organic compounds are removed from the wastewater as it rise to the top of the reactor and are converted mainly into biogas and some new sludge. The mixing is kept by the biogas formed and feed flow. Moreover, the biogas produced that 273-450 M^3 . Of water is required per ton of paper produced, that consequently, generate 300 M^3 as waste water (Subrahmanyam and Hannmanulu, 1976). These effluents are dark brown in color and associated with high biochemical oxygen demand (BODS), chemicals oxygen demand (COD), which are much higher that Bureau of Indian Standard (BIS) permissible limits. Thus, these effluents require proper treatment prior to disposal. Several anaerobic configurations for the treatment of effluents of various pulp and paper mills with their advantages and disadvantages have been discussed (Lee et.al., 1989) .[3] The most commonly used configurations for anaerobic treatment so far is the monophasic digestion system in which the acidogensis and methanogensis, which are quite different

2.6.1. Advantage of UASB reactor

- Low production of waste biological solids
- Waste biological sludge is a highly stabilized product that ,as a rule, can be easily dewatered
- Low nutrient requirements
- No energy requirement for aeration
- Production of methane, which is a useful end product
- Very high loading rates can be applied under favorable conditions
- Active anaerobic sludge can be preserved unfed for many months

2.6.2. Limitations of UASB reactor

- Anaerobic digestion is a rather sensitive process
- Relatively long periods of time are required to start up the process, as a result of the slow growth rate of anaerobic bacteria
- Anaerobic digestion is essentially a pretreatment method an adequate post treatment is usually required before the effluent can be discharge into receiving waters

2.7. Problems associated with up flow Anaerobic Sludge Blanket reactor

2.7.1. Start Up

To achieve high treatment efficiencies at high loading rates the formation of a highly settleable and active sludge in the UASB reactor is of it's almost importance. Granular type of sludge is reported to have these properties. The first granular are observed 4-6 weeks after the start of the experiments, but various factors are involved in the granulation process.

2.7.2. Factors affecting the granulation process

As bacterial granulation must be primarily governed by bacterial growth, the granulation process will be affected by the followings:

2.7.2.1. Environmental conditions

- The availability of essential nutrients, because growth condition should be optimal
- The temperature since the specific activity of methanogenic sludge is highly temperature dependent
- The pH which should be in the optimal range (6.5-7.8) and
- The type of wastewater with regard to the composition of the waste, biodegradability of the organic matter, the presence of finely dispersed non biodegradable organic and inorganic matter, the ionic composition and the presence of inhibitory compounds.[24]

2.7.2.2. The type of the seed sludge

With respect to its specific to its specific activity its settle ability and the nature of the inert fraction. Two types of digested sewage sludge behave differently when used as seed in the treatment of medium strength waste water.

Theoretically any medium containing the proper bacterial flora can be used as seed sludge for a UASB reactor. Possible seed material is digested manure, fresh water sediments, septic tank sludge, digested sewage sludge from anaerobic treatment plants.

- The process condition applied during the start up
- The procedure followed in increasing the loading rate, e.g. the extent of overloading and the allowed wash out of suspended solids
- The amount of seed sludge used

During start up the gas production is limited and the feed distribution system is of more importance for the sludge / substrate contact. To shorten the start up period a large number of feed inlet points are therefore desirable.

2.7.2.3. Sludge washout

All start up experiments carried out in UASB reactors reveal a very significant washout of sludge during the initial start up phase of the process and consequently a deep depression is developed in the retained amount of seed sludge. Due to the washout of the sludge ingredients a considerable fraction of the net bacterial growth occurring during the initial phase of the startup is also lost with the effluent.

To prevent the formation of a deep depression in the retained sludge the following measures are proposed:

1. The selection of the right type of seed sludge.
2. Adjusting the waste water composition.
3. The addition of nutrients or vitamins, if necessary to assure growth condition
4. Proper management

During the start up long periods of over and under loading must be prevented. Upper loading rates lead to the development of voluminous sludge. Over loading is detrimental because of the gas production that will occur in the separator, which will hamper the settlement of the sludge.

Sludge wash out during the operation of the process is closely connected to the amount of finely dispersed sludge present in the reactor. Concerning the washout of sludge three situations should be distinguished:

(a) The top of the sludge blanket remains well below the effluent weir of the reactor. Under such circumstances, sludge wash out is considerably less than sludge accretion from growth. This is even truer because the sludge lost with the effluent generally will not consist completely of bioactive matter. A considerable part of the effluent suspended solid may originate from suspended solids supplied with the influent solution; this has been particularly observed for sugar beet campaign waste. Moreover, strong indications have been obtained that a majority of the bioactive sludge can be recovered from the effluent by plain sedimentation.

(b) The sludge blanket reaches the effluent weir under steady loading condition. In this situation the wash out of sludge and the accretion of sludge by growth will range over a similar order of magnitude per unit of time.

(c) An excessive expansion of the sludge blanket may occur as results of a shock loading or due to suddenly deteriorating conditions high concentrations of finely dispersed poorly flocculating matter. Under such circumstances a temporary drastic washout of the sludge may occur and last until a few steady beds has been established.

2.8. Foaming

Excessive foaming has been encountered in the relatively poor treatment efficiencies, due to overloading or nutrient deficiency, and at very high gas production rates. Difficulties may be expected in the wastes that are relatively rich in proteins, such

as potato starch wastewater. Foaming could be effectively depressed by adding anti foaming agents to the feed solution.

2.9. Process failure and remedies

As with any biological process, UASB reactor system is subjected to resulting from unstable operation and toxic materials influent to the process. Instability in the process occurs when the series of microbiological reactions become uncoupled. Acid formers out produce acid consumers and a sharp rise in volatile acid results.

2.10. Process failure indicators

1. Volatile acid concentration increases
2. Bicarbonate alkalinity drops
3. PH falls
4. Excess SS in effluent
5. Gas production rates drops
6. Percentage of CO_2

Probable Cause of Process Failure;

1. Hydraulic overload
   - Increase feed flow
   - Excessive sludge production
   - scum accumulation
   - Alkalinity washout
2. Organic overload
   - increase sludge production
   - Increase feed concentration
   - Change in feed characteristics
   - To rapid start up
3. Toxic overload
   - Heavy metals
   - Detergents

- Cations
- Sulphides

4. Solution often
- Excess of mixing
- Adjust alkalinity
- Clean reactor
- Restart reactor

2.11. What are sludge granules?

Sludge granules are at the core of UASB and EGSB technology. A sludge granule is an aggregate of microorganisms forming during wastewater treatment in an environment with a constant up flow hydraulic regime. In the absence of any support matrix, the flow conditions create a selective environment in which only those microorganisms, capable of attaching to each other, survive and proliferate. Eventually the aggregates form into dense compact biofilms referred to as "granules" (see Figure 1. below). Due to their large particle size (generally ranging from 0.5 to 2 mm in diameter), the granules resist washout from the reactor, permitting high hydraulic loads. Additionally, the biofilms are compact allowing for high concentrations of active microorganisms and thus high organic space loadings in UASB and EGSB reactors. One gram of granular sludge organic matter (dry weight) can catalyze the conversion of 0.5 to 1 g of COD per day to methane. In layman terms that means on a daily basis granular sludge can process its own body weight of wastewater.[25]

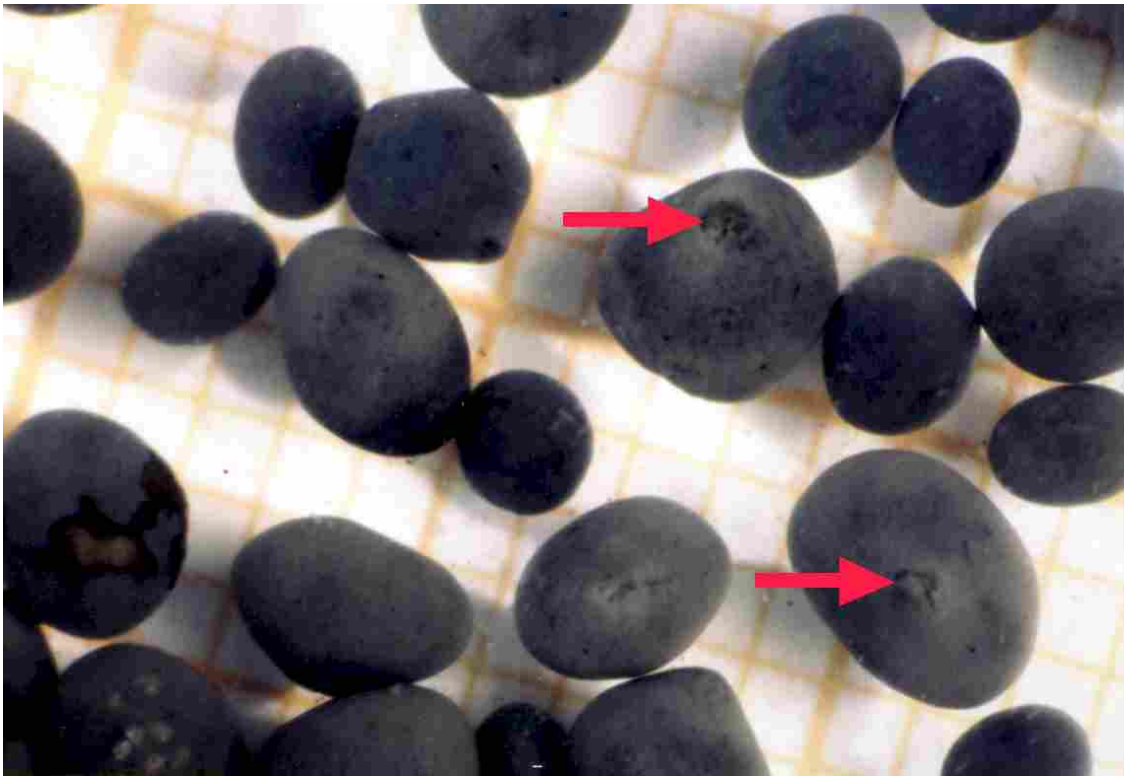

FIG 2.1 Granular sludge [25]

2.12. Granulation process:

The process of granular sludge formation is one of the most interesting and enigmatic questions when attempting to understand the fundamentals of anaerobic granular sludge technology. There are many theories, ranging from extracellular polysaccharide slime to calcium as key players in the initial aggregation process. However, the most promising theory is the "spaghetti" theory (proposed by Dr. W. Wiegant) in which filamentous microorganisms become entangled in one another analogous to the formation of fungal pellets as shown in Figure.2. Below. In support of theory is the fact that the methanogens known as *Methanosaete,* which are better adapted for low substrate concentrations (a condition desired for wastewater treatment), happen to be filamentous microorganisms. The initial pellets ("spaghetti balls") of *Methanosaete* can serve as a surface of attachment or support matrix for other microorganisms involved in the anaerobic degradation process. For the attachment of diverse microorganisms to the pellet, perhaps slime layers and calcium may play an important role.[22]

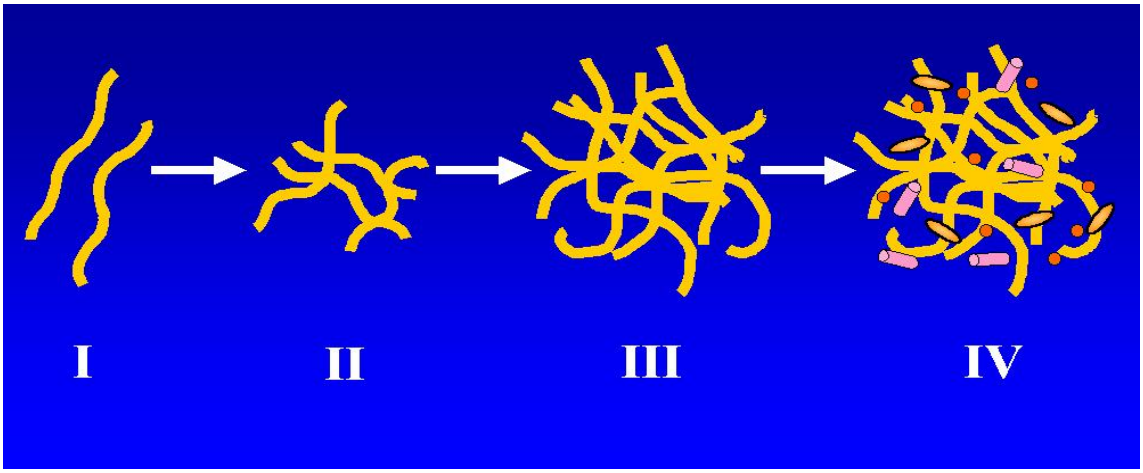

Figure 2. 2.Granulation process [25]

(I) Disperse methanogens ;

(II) Floccule formation via entanglement;

III) Pellet formation and;

IV) Mature granules, with attachment of other anaerobic microorganisms onto The palette

2.13 Anaerobic wastewater treatment

Anaerobic wastewater treatment is the biological treatment of wastewater without the use of air or elemental oxygen. Many applications are directed towards the removal of organic pollution in wastewater, slurries and sledges. The organic pollutants are converted by anaerobic microorganisms to a gas containing methane and carbon dioxide, known as "biogas" (see Figure 2.3 below). [25]

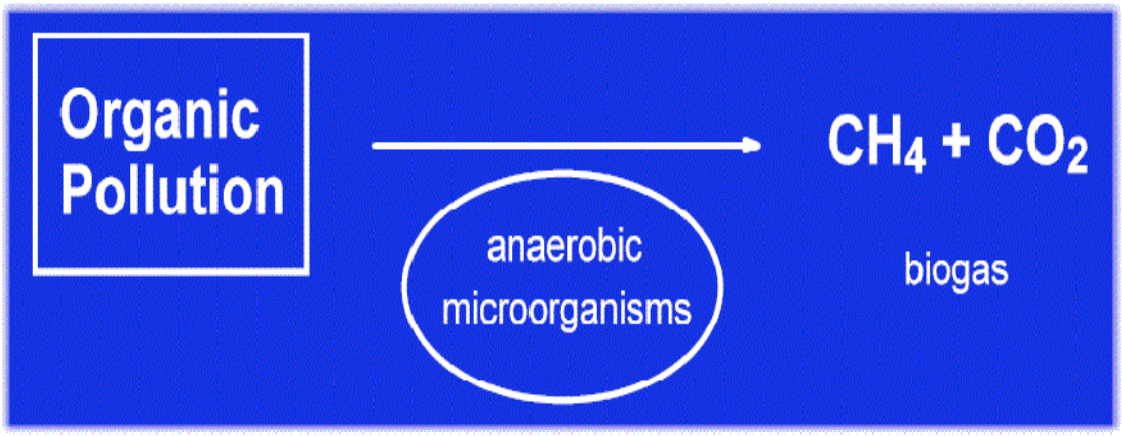

Figure 2.3.Biogas production[25]

2.14.COD Balance in Anaerobic and Aerobic process

In the wastewater engineering field organic pollution is measured by the weight of oxygen it takes to oxidize it chemically. This weight of oxygen is referred to as the "chemical oxygen demand" (COD). COD is basically a measure of organic matter content or concentration. The best way to appreciate anaerobic wastewater treatment is to compare its COD balance with that of aerobic wastewater treatment, as shown in fig.2.4 below.[25]

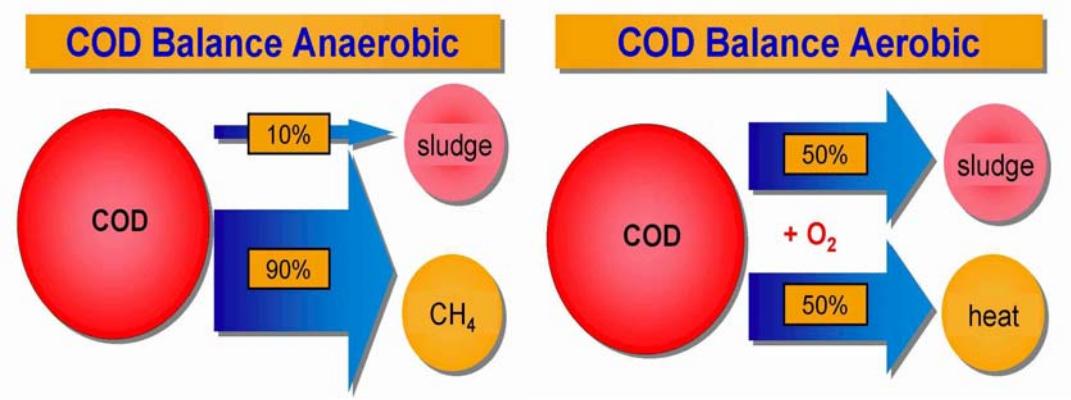

Figure 2.4. COD balance in Anaerobic and Aerobic process[25]

2.14.1. Anaerobic Treatment:

The COD in wastewater is highly converted to methane, which is a valuable fuel. Very little COD is converted to sludge. No major inputs are required to operate the system.[1]

2.14.2. Aerobic Treatment:

The COD in wastewater is highly converted sludge, a bulky waste product, which costs lots of money to get rid of. An aerobic wastewater treatment facility is in essence a "waste sludge factory". Elemental oxygen has to be continuously supplied by aerating the wastewater at a great expense in kilowatt hours to operate the aerators.[1]

Most environmental engineers are aware that anaerobic processes are used to stabilize sludge such as a sludge digester at a municipal treatment plant. Less fully appreciated is the fact that "high rate" anaerobic wastewater treatment technologies can also be utilized to treat dilute to concentrated liquid organic wastewaters (distillery, brewery, paper manufacturing, petrochemical, etc). Even municipal wastewater (sewage)

can be treated in tropical countries with "high rate" anaerobic technologies. "High rate" anaerobic treatment is a mature technology. At least 1200 full-scale plants have been documented world-wide for the treatment of industrial effluents (the actual number is estimated at 2500).

2.15. "High Rate" Anaerobic Treatment:

High rate anaerobic treatment systems refer to bioreactors in which the sludge retention time (time for sludge biomass solids to pass through system) is separated from the hydraulic retention time (time for liquid to pass through system). The net effect is that slow growing anaerobes can be maintained in the reactor at high concentrations, enabling high volumetric conversion rates, while the wastewater rapidly passes through the reactor. The main mechanism of retaining sludge in the reactor is immobilization onto support material (microorganisms sticking to surfaces, *e.g.* filter material in the "anaerobic filter") or self-aggregation into pellets (microorganisms sticking to each other, *e.g.* sludge granules).[25]

Other Applications High rate "anaerobic wastewater treatment is not limited to removal of bulk organic pollution in wastewater. There are a number of established and emerging technologies with various applications such as:

- Sulfate reduction for the removal and recovery of heavy metals and sulfur
- Denitrification for the removal of nitrates to
- bioremediation or the breakdown of toxic priority pollutants to harmless products

2.16. Sulfate reduction

Sulfate reducing bacteria can be utilized to convert sulfate (SO_4^{2-}), sulfite (SO_3^{2-}) to sulfide (SO^{2-}) as shown in Fig.5. The bacteria utilize electron-donating substrates present in wastewater (organic pollution) or added substrates for the reduction of sulfate. The substrates are either partially oxidized (*e.g.* to acetate) or fully oxidized to carbon dioxide. Sulfate behaves as an alternative electron acceptor to support anaerobic respiration. The formation of biogenic sulfide is the first step in biotechnological processes directed at the removal and recovery of sulfur or heavy metals. [25]

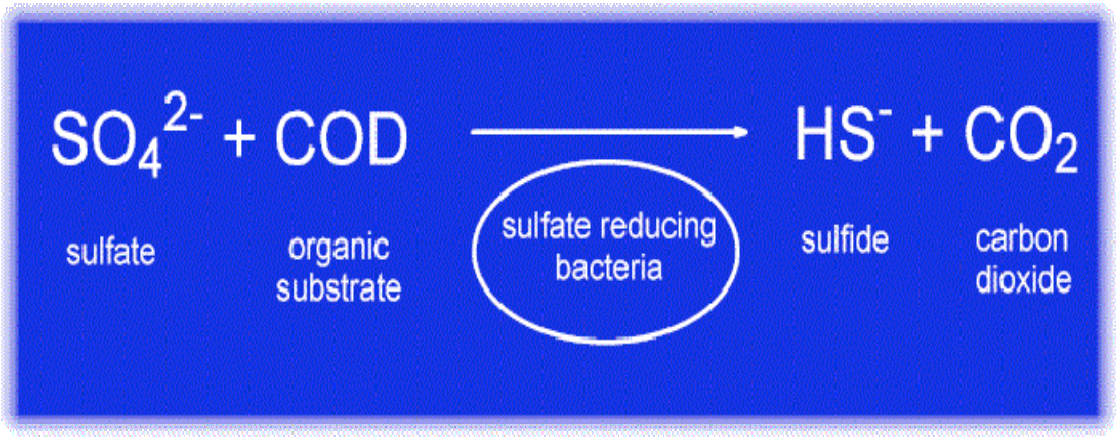

Figure 2.5. Sulfate reduction process, resulting in the formation of biogenic sulfide.[25]

2.17. Heavy metal removal and recovery:

Biogenic sulfides form highly insoluble precipitates with heavy metals (such as copper or zinc). Thus the sulfides can precipitate soluble heavy metals in wastewater streams or polluted groundwater as shown in Fig.2.6 the resulting metal sulfides precipitates can be removed. Since the metals ions are highly concentrated in the precipitate, they can be recycled back into industry for reuse.[25]

Figure 2.6. Precipitation of heavy metals by biogenic sulfides.[25]

2.18. Sulfur removal and recovery:

Biogenic sulfides can be partially reoxidized under microaerophilic conditions (low oxygen concentrations) by chemotrophic bacteria to form insoluble elemental sulfur (S^0) as shown in Fig.7. The elemental sulfur sedimented from the wastewater and can be

collected for reuse in industry. A microaerophilic sulfoxidation reactor is typically placed as a post-treatment to a sulfate reducing bioreactor in order to remove and recover sulfur. Sulfoxidation reactors can also be used to clean gas streams which contain hydrogen sulfide (H_2S).[19] Piles of elemental sulfur are shown in Fig.2.7

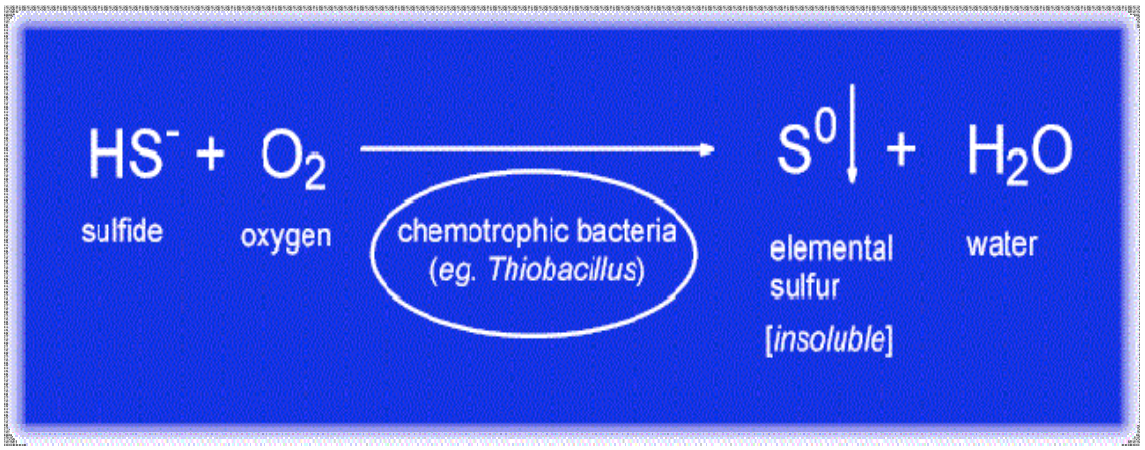

Figure 2.7 Sulfur removal and recovery[25]

CHAPTER 3
UASB AND EGSB REACTOR PARAMETER

3.1. UASB and EGSB Reactor Parameter

- Material of construction : acrylic sheet tube
- Volume of the reactor : 75 liter
- Height of the reactor : 2.38 meter
- Bottom area of the reactor : 0.020 m^2
- Height of sludge bed : 1.88 meter.

3.2 GSL (Gas Solid Liquid) separator Parameter

- Maximum velocity through aperture, m/d = 50
- Area of aperture = 0.006 m^2
- Shape of aperture area = circular
- Diameter of aperture, m = 0.10
- Angle of inclination= 45^0
- Diameter of deflector, m =0.15
- Height of deflector = 0.075

3.3.Construct material for UASB and EGSB reactor

In the anaerobic conditions of an UASB and EGSB reactor, there is a risk of corrosion in two main situations:

- Some H_2S gas can pass the GSL separator and accumulate above the water level in the top of the reactor. This will be oxidized to sulphate by oxygen in the air to form Sulphuric Acid that will in turn cause corrosion of both concrete and steel.
- Below the water level: Calcium Oxide, (CaO), in concrete can be dissolve with by Carbon Dioxide, (CO_2), in the liquid in low pH conditions. [23]

To avoid these problems, the material used to construct the UASB and EGSB reactor should be corrosion resistant, such as stainless steel or plastics, or be provided with proper surface coatings, (e.g. coated concrete rather than coated steel, plastic covered with impregnated hardwood for the settler, plastic fortified .

3.4.Internal three-phase GSL device

Installed at the top of the tank, the GSL device constitutes an essential part of an UASB and EGSB reactor with following functions.[3]

- To collect, separate and discharge the biogas formed.
- To reduce liquid turbulences, resulting from the gas production, in the settling compartment.
- To allow sludge particles to separate by sedimentation, flocculation or entrapment in the sludge blanket.
- To limit expansion of the sludge bed in the digester compartment.
- To reduce or prevent the carry-over of sludge particles from the system.

3.5. Operation

3.5.1.Operation criteria for UASB and EGSB reactor :

The optimum pH range is from 6.6 to 7.6 The wastewater temperatures should not be < 5 °C because low temperatures can impede the hydrolysis rate of phase 1 and the activity of methanogenic bacteria. Therefore in winter season, methane gas may be needed to heat the wastewater to be treated in the reactor.[25]

Always maintain the ratio of COD : N : P =1000:7: 1 If there is a deficiency of some of these nutrients in the wastewater nutrient addition must be made to sustain the micro-organisms. Chemicals that are frequently used to add nutrients (N, P) are $NH_4H_2PO_4$, KH_2PO_4, $(NH_4)_2CO_3$...

Suspended solid (SS) can affect the anaerobic process in many ways:

- Formation of scum layers and foaming due to the presence of insoluble components with floating properties, like fats and lipids.
- Retarding or even completely obstructing the formation of sludge granules.
- Entrapment of granular sludge in a layer of adsorbed insoluble matter and sometimes also falling apart (disintegration) of granular sludge.
- A sudden and almost complete wash-out of the sludge present in reactor
- Decline of the overall methanogenic activity of the sludge due to accumulation of SS

Therefore, the SS concentration in the feed to the reactor should not exceed 500 mg/l In phase 2 and 3 the pH will be reduced and the buffer capacity of wastewater may have to be increased to provide alkalinity of 1000 – 5000 mg/l $CaCO_3$.

3.6. Start-up of UASB and EGSB reactor

An UASB and EGSB reactor requires a long time for start-up, e.g. from 2 – 3 weeks in good conditions (t > 20 ^{0}C) and sometimes the start-up can take up to 3 – 4 months. In start-up process, hydraulic loading must be 50% of the design hydraulic loading.[17]

The start-up of the UASB and EGSB reactor can be considered to be complete once a satisfactory performance of the system has been reached at its design load.

CHAPTER 4

EXPERIMENTAL ON UASB REACTOR

4.1. Experimental Set Up of UASB reactor

4.1.1 Influent Collection System

The influent tank is connected with 2 pipe line, one that is used for influent inlet to the UASB at the bottom of the Reactor and other for dilution water. The capacity of the influent collection tank is 200 liter in which influent waste water is collected.

Figure: 4.1.1. Influent collection system

4.1.2.UASB reactor for waste water treatment

Fig 4.2 shows that the diagram of UASB reactor which is connected with influent pipe at the bottom, treated effluent pipe line , exit gas pipe line, it also consists of GSL separator at the top for the separation of exit gas, treated effluent and solids biomass.

Figure 4.1.2 UASB Reactor

4.1.3. Exit effluent collection system

For collection of treated effluent a exit system is kept beside of UASB reactor, the volume of this collection system is 35 liter. Laboratory Analysis Were carried out for Chemical Oxygen demand (COD), pH, Volatile Fatty Acids (VFA), Total Suspended Solids (TSS), Alkalinity & MLVSS.

Figure : 4.1.3 Exit effluent collection system

4.2.Experimental procedure for UASB reactor

The laboratory bench scale experiments were carried out in UASB reactor. A venturi type gas deflector is attached on the top of the reactor, which is used to invert the gas bubble to conical gas separator and to facilitate the settling of the biomass. The GSL separator which is installed in the upper part of the reactor and the end of which is connected to gas collection device.

The sewage sludge from the sludge digestion tank used as seeding material for the study, which was obtained from the Pirana sewage treatment plant. The raw textile waste water for the study was collected from Arvind textile mills. Laboratory analysis were carried for Chemical Oxygen Demand (COD), pH, Volatile fatty acid (VFA), Alkalinity, MLVSS and TSS. The start up of experiment was performed continuously by running the UASB reactor at a temperature of 29 ^{0} C. Granulation was observed in the UASB reactor about 38 days from reactor stabilization. During the experimental programme the pH observed to be in neutral range.

CHAPTER 5
RESULTS ANALYSIS & DISCUSSION FOR UASB (UP FLOW ANAEROBIC SLUDGE BLNKET) REACTOR

5.1. VFA Test (Volatile Fatty Acid)

During the UASB reactor experiments the concentration of Volatile Fatty Acid decreased from 640 mg/l to 304 mg/l .During experiments run 1 (day 1 to 18) VFA decreased from 640 mg/l to 524 mg/l . During experiments run 2 (day 20 to 38) the VFA further decreases from 520 mg/l to 440 mg/l. During experiment run 3 (day 39 to 53) the VFA decreased from 432 mg/l to 304 mg/l. Low concentration of VFA favor the anaerobic operation and it is observed that the methanogenic activity affected by VFA concentration. If VFA level is high than it affect on COD reduction efficiency. The variation in the concentration of VFA during the UASB reactor operation are shown in table 5.1.

VFA are produced more in waste water rich in carbohydrates. If VFA production is more pH is neutralized by increasing alkalinity should be less than 0.1, when VFA increases pH drops in such cases , feeding of new material is stopped until the pH and VFA are stabilized, if any day it is observed that VFA : Alkalinity ratio is less than 1:2 feeding should be stopped for the day and add bicarbonate alkalinity to bring the ratio 1:2.

5.2. Alkalinity Test

During the experiment of UASB reactor the alkalinity also played an important role in COD reduction. Alkalinity may vary from 625 mg/l to 850 mg/l .

During experiments run 1 (day 1 to 18) the alkalinity increased from 625 mg/l to 695 mg/l. During experiments run 2 (day 20 to 38) the alkalinity further increased from 705 mg/l to 780 mg/l. During experiment run 3 (day 39 to 53) the alkalinity increased from 785 mg/l to 890 mg/l. For the satisfactory performance of the anaerobic operation the concentration of VFA within 250 mg/l and the ratio of VFA to alkalinity should be

less than 0.1.The alkalinity variation during the experiments with time are shown in table 5.1.

Day	**Volatile Fatty Acid (VFA) mg/l**	**Alkalinity (mg/l)**
1	640	625
2	620	635
3	600	645
5	584	630
6	580	620
9	572	645
10	564	650
11	556	660
12	548	665
13	540	670
16	532	675
17	524	685
18	520	695
20	512	705
21	500	715
23	492	720
25	484	730
28	476	735
31	468	745
33	460	750
35	452	760
36	440	775
38	432	780
39	416	785
41	400	805
43	380	825
45	372	835
47	360	850
48	348	855
50	324	865
51	320	880
53	304	890

Table 5.1. VFA (Volatile Fatty Acid) mg/l and Alkalinity (mg/l) variation during the Time (days)

The variation in alkalinity and Volatile fatty acid concentration during the UASB reactor operation within the time in days are shown in fig.5.1 and fig.5.2 respectively.

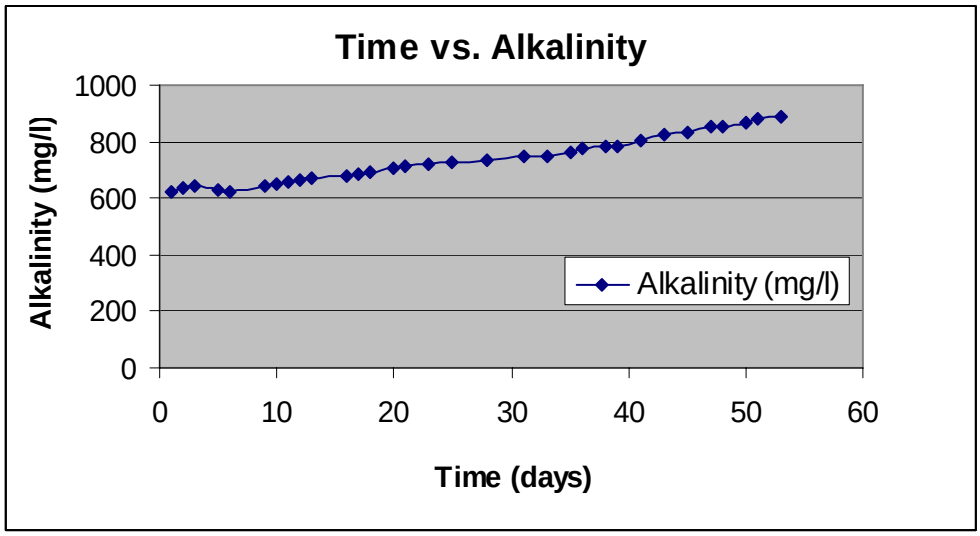

Figure 5.1.Plot for Time (days) vs. Alkalinity (mg/l)

The change in Volatile Fatty Acid during the experiments with time is shown in figure 5.2. During the experiments it was also studied that in variation of VFA in mg/l. For effective operation of UASB reactor the VFA level is low as possible as 250 mg/l. High concentration of volatile fatty acid affect the anaerobic process it is also affect the methanogenic activity . If volatile fatty acid concentration is high then COD reduction efficiency is low and production of biogas is also less.

During the experiments of UASB reactor the concentration of VFA decreased day by day.

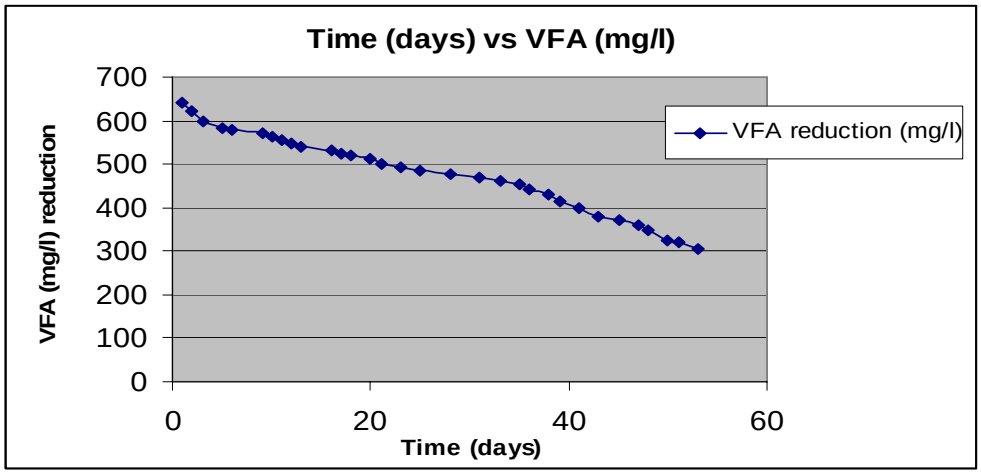

Figure 5.2 Plot for Time (days) vs. VFA (mg/l)

5.3.TOTAL SUSPENDED SOLID TEST

The Total Suspended Solid s present in the waste water of UASB reactor are given in the table 5.2. During the experiments the variation in total suspended solid (TSS) was also studied . pH also plays an important role in anaerobic process for production of biogas and high COD reduction efficiency .Normally it is reported that methanogenic activity is higher at pH between 7 to 8. The variation in TSS and pH during the UASB reactor operation are shown in table 5.2.

Day	pH	TSS (mg/l)
1	7.11	225
2	7.17	221
3	7.21	223
5	7.15	220
6	7.07	215
9	7.22	215
10	7.26	213
11	7.29	200
12	7.31	195
13	7.30	190
16	7.32	182
17	7.33	180
18	7.36	179
20	7.38	178
21	7.41	174
23	7.43	172
25	7.48	170
28	7.52	165
31	7.61	161
33	7.63	159
35	7.67	158
36	7.68	151
38	7.72	149
39	7.75	141
41	7.83	137
43	7.91	133
45	7.95	129
47	8.03	121
48	8.05	117
50	8.11	107
51	8.17	101
53	8.20	98

Table 5.2 TSS (mg/l) and pH during the UASB reactor operation

The graph for Time (days) vs. pH and Time (days) vs. TSS (mg/l) are shown in figure 5.3 and figure 5.4.

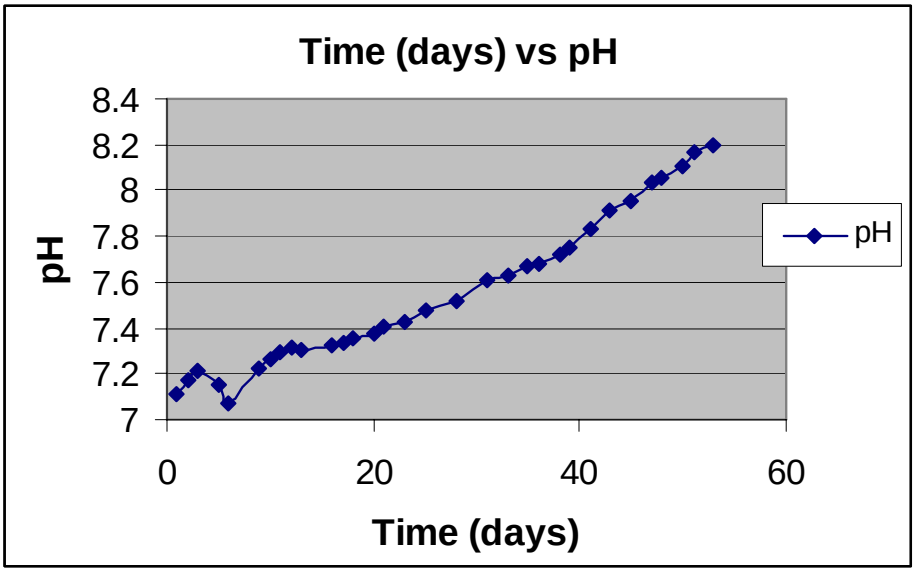

Figure 5.3.Time (days) vs. pH

The graph for Time (days) vs. Total Suspended solid (TSS) in mg/l are shown in figure 5.4

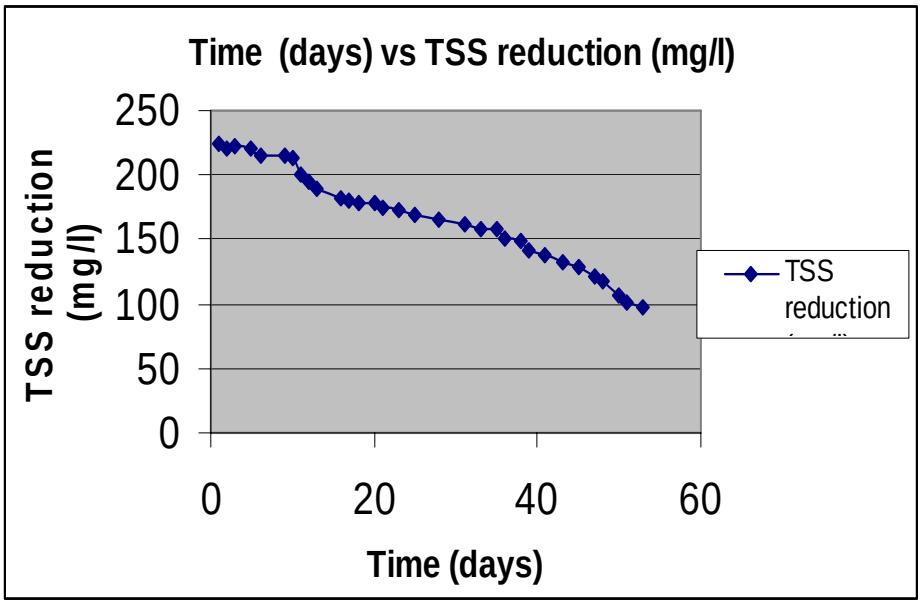

Figure 5.4. Time (days) vs. Total Suspended solid (TSS) in mg/l

5.4.Characteristics of biomass in UASB reactor

it was studied that the behaviors of biomass by checking the MLSS and MLVSS. levels were high at bottom of the reactor and it's level were low at top of the reactor as compared to bottom of the reactor. MLVSS plays an important role in anaerobic process. If MLVSS level is high than higher COD reduction efficiency achieved. The MLVSS (mg/l) and MLSS (mg/l) are shown in table 5.3.

Days	MLVSS (mg/l)	MLSS (mg/l)
1	15100	19711
2	15425	20080
3	15550	20520
5	15670	20890
6	15720	21950
9	15825	22050
10	15910	22485
11	15930	22630
12	16025	22795
13	16230	22860
16	16650	23951
17	16830	24020
18	17020	24520
20	17330	25890
21	17345	27396
23	17530	29862
25	17670	30987
28	17830	32568
31	17920	33696
33	18025	34596
35	18110	35966
36	18290	36951
38	18570	37898
39	19120	39854
41	19425	42632
43	19890	43990
45	20020	45882
47	20250	47955
48	20450	49232
50	20995	51242
51	21075	52455
53	21580	53221

Table 5.3.MLVSS (mg/l) and MLSS (mg/l) during the UASB reactor experiment

The variation in MLVSS and MLSS during within time is shown in Fig.5.5 and Fig.5.6. The Time (days) vs. MLVSS (mg/l) plot and Time (days) vs. MLSS (mg/l) plot are shown in Figure 5.5 and Figure 5.6 respectively.

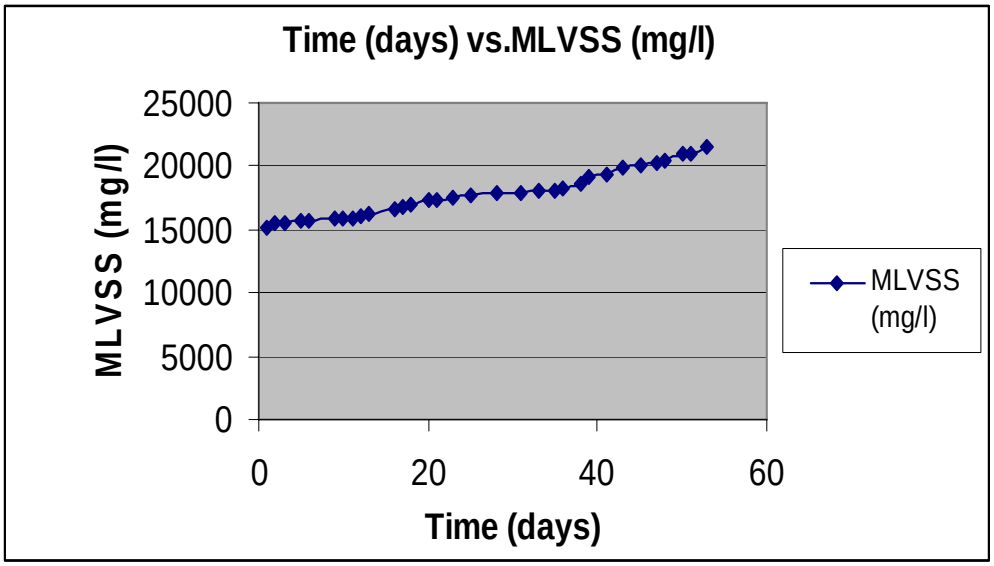

Figure 5.5 Plot for Time (days) vs. MLVSS (mg/l)

Time (days) vs. MLSS (mg/l) plot are shown in Figure 5.6.

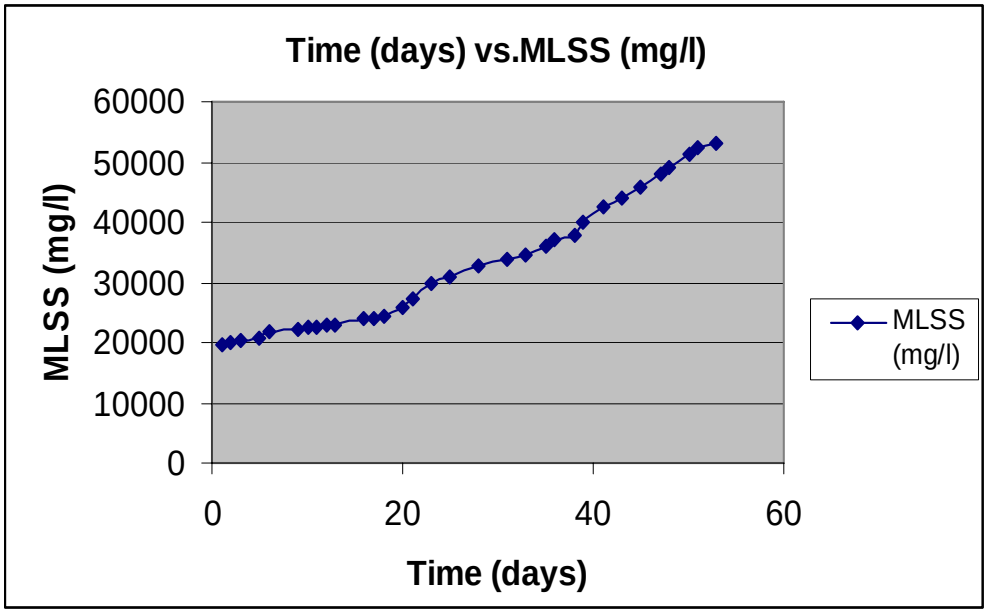

Figure 5.6 Plot for Time (days) vs. MLSS (mg/l)

During the UASB reactor experiments for treatment of industrial waste water maximum 70% COD reduction was achieved .The day by day COD reduction efficiency are shown in Table.5.4.Also the organic loading rate in kg/day during the operation are shown in Table.5.4.

Days	Organic Loading Rate(kg/day)	COD reduction efficiency in %
1	0.005	32
2	0.006	33.5
3	0.007	34
5	0.008	34.5
6	0.009	36
9	0.010	37
10	0.011	39
11	0.012	41
12	0.013	43
13	0.014	44
16	0.015	45
17	0.016	46.5
18	0.017	47
20	0.018	48
21	0.019	48.5
23	0.020	49
25	0.021	51
28	0.022	52
31	0.023	54
33	0.024	55
35	0.025	57
36	0.026	58
38	0.027	60
39	0.028	62.5
41	0.029	63
43	0.030	64.5
45	0.031	65
47	0.032	66
48	0.033	66.5
50	0.034	67
51	0.035	68.5
53	0.036	70

Table 5.4 Day by day COD reduction Efficiencies and Organic loading rate during the UASB reactor operation

Plot graph for **Time (days) vs. COD reduction efficiencies** are shown in **fig. 5.7**.

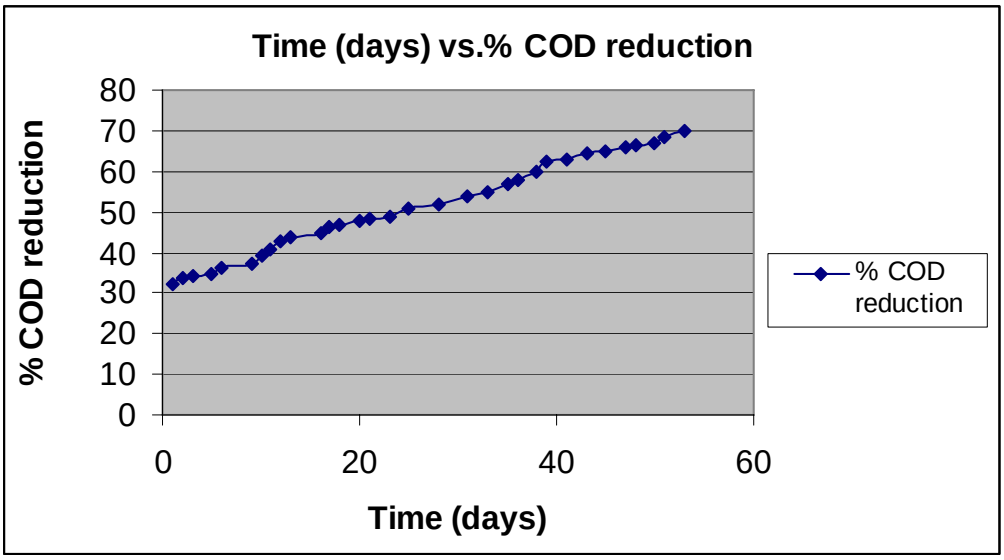

Figure 5.7 Time (days) vs. COD reduction efficiencies

The overall results of UASB reactor are shown in table 5.5. In such Table we also see that the MLVSS , VFA (Volatile Fatty Acid as CH_3COOH), pH, Alkalinity, and Total Suspended Solids (TSS) and %COD reduction day by day during the experiments of UASB reactor for treatment of waste water.

5.5. The experimental results of UASB reactor

Experiment run 1	Day	TSS (mg/l)	MLVSS (mg/l)	VFA mg/l	pH	Alkalinity mg/l	%COD reduction	Organic Loading Rate kg/day
	1	225	15100	640	7.11	625	32	0.005
	2	221	15425	620	7.17	635	33.5	0.006
	3	223	15550	600	7.21	645	34	0.007
	5	220	15670	584	7.15	630	34.5	0.008
	6	215	15720	580	7.07	620	36	0.009
	9	213	15825	572	7.22	645	37	0.010
	10	210	15910	564	7.26	650	39	0.011
	11	208	15930	556	7.29	660	41	0.012
	12	205	16025	548	7.31	665	43	0.013
	13	201	16230	540	7.30	670	44	0.014
	16	198	16650	532	7.32	675	45	0.015
	17	196	16830	524	7.33	685	46.5	0.016
	18	193	17020	520	7.36	695	47	0.017

Expe. run 2	20	191	17330	512	7.38	705	48	0.018
	21	189	17345	500	7.41	715	48.5	0.019
	23	187	17530	492	7.43	720	49	0.020
	25	185	17630	484	7.48	730	51	0.021
	28	183	17705	476	7.52	735	52	0.022
	31	179	17830	468	7.61	745	54	0.023
	33	176	17920	460	7.63	750	55	0.024
	35	173	18025	452	7.67	760	57	0.025
	36	170	18110	440	7.68	775	58	0.026
	38	168	18290	432	7.72	780	60	0.027
Experiment run 3	39	165	18570	416	7.75	785	62.5	0.028
	41	161	19120	400	7.83	805	63	0.029
	43	160	19425	380	7.91	825	64.5	0.030
	45	156	19890	372	7.95	835	65	0.031
	47	151	20050	360	8.03	850	66	0.032
	48	143	20450	348	8.05	855	66.5	0.033
	50	140	20995	324	8.11	860	67	0.034
	51	137	21075	320	8.17	880	68.5	0.035
	53	133	21580	304	8.20	890	70	0.036

Table 5.5. Experimental results for UASB reactor operation

CHAPTER 6
INTRODUCTION OF EGSB REACTOR

EGSB means Expanded Granular Sludge Blanket reactor. It is modified form of UASB which is used for treatment of wastewater, degradation of waste done anaerobically and generation of methane possible as a by product.

6.1 What is sewage?

The term 'sewage' refers to the wastewater produced by a community, which may originate from three different sources: (a) *domestic wastewater,* generated from bathrooms and toilets, and activities such as cooking, washing, etc.; (b) *industrial wastewater,* from industries using the same sewage system for their effluents (treated or not), and (c) *rain-water,* particularly in the case of sewer systems constructed for both wastewater and storm-water (combined systems). [9]

6.2 What are anaerobic bacteria?

Anaerobic bacteria can sustain and reproduce in the absence of air. They utilize sulfates and nitrates compounds for energy and their metabolism are substantially reduced. To remove a given amount of organic material in an anaerobic treatment system, the organic material must be exposed to a significantly higher quantity of bacteria and detained for a much longer period of time. Anaerobic bacteria release hydrogen sulfide as well as methane gas, both of which can create hazardous conditions. The advantage of using the anaerobic process is no need of electromechanical apparatus.[11]

6.3 Commercial Installation and Technologies

The growth of commercial anaerobic installations in the world over the last 30 years. As the figure shows, there are currently more than 1500 commercial anaerobic installations. This does not include hundreds of non-commercial (i.e., consultant or owner-designed) installations, such as anaerobic lagoons.

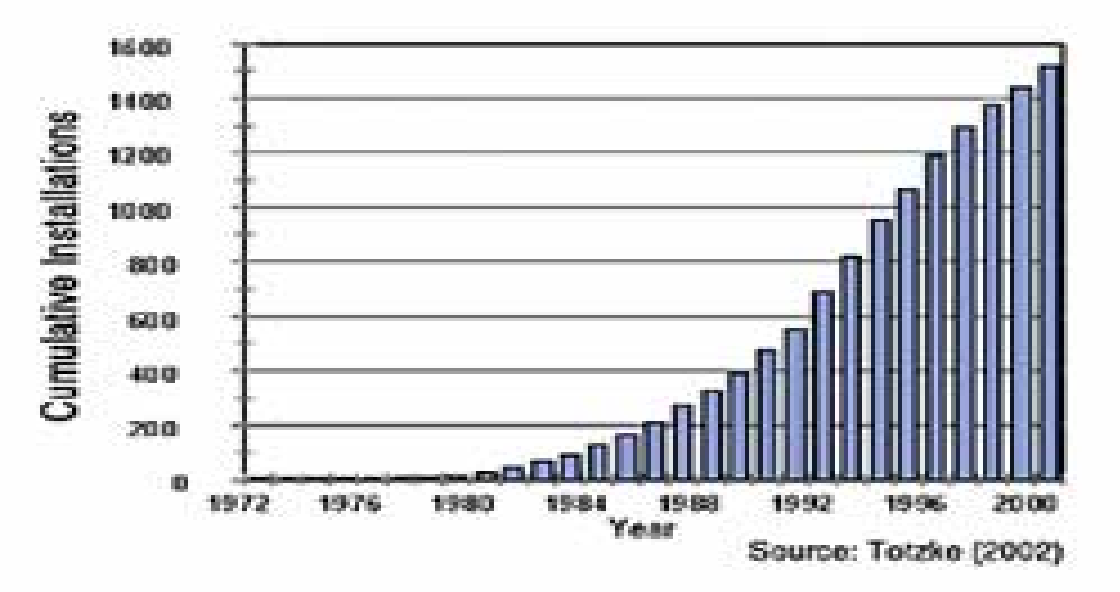

Fig 6.1 Commercial anaerobic installations

Several anaerobic technology configurations have been developed over the last 30 years or so. Some process configurations have been researched and described in the literature, but have not had significant commercial application; some of these include newer systems that have not yet achieved commercial success. In other cases, older technologies, which were commercially successful in the past, now have more limited use as they are replaced by more evolved and advanced technologies.[9]

The focus in research and development of anaerobic processes has been on maximizing biomass retention and substrate-to-biomass contact two objectives that have been challenging to combine. For example, improving biomass-to-substrate contact typically means more mixing and biogas production, which can lead to washing out the biomass unless special design considerations are used to counteract this washout.[10]

Anaerobic systems can be categorized according to the type of biomass they depend on and how that biomass is retained in the system. Suspended-growth processes are systems where the bacteria grow and are suspended in the reactor liquid. Typically, suspended-growth systems have sludge that is considered to be 'granular' or 'flocculent' in nature (oftentimes both granular and flocculent sludges coexist in a reactor). Attached-growth processes utilize either fixed film or carrier media (which is suspended in the liquid) for the bacteria to grow on and attach to.

Granular sludge-based systems include the up flow anaerobic sludge blanket (UASB) reactor, the BIOPAQ® Internal Circulation (IC) Reactor and the Biobed® Expanded Granular Sludge Bed (EGSB) reactor. Granular sludges exhibit high settling velocities and activity rates that reduce the required reactor volume and increase the organic loading rate. Thus, these processes are considered to be high-rate systems. The factors that create the formation of a good granular sludge are complex and have been studied for the last two decades or more by several academic researchers and anaerobic system vendors. These factors are varied but principally relate to wastewater characteristics, system configuration and loading condition. Typically, the granular sludge is retained in the system by specially designed gas-liquid-solids separation devices, which are often proprietary equipment.[12]

Low-rate suspended-growth anaerobic systems, such as the ADI-BVF® reactor and anaerobic contact process are effective at retaining flocculent (non-granular) sludge due to lower organic and hydraulic loading rates than the high-rate systems mentioned above. These low-rate systems are particularly effective when treating wastewaters that do not granulate well or have substances that effect the retention of granules at high loading rates (i.e., high concentrations of fat, oil or grease (FOG), total suspended solids (TSS), COD, salts, total dissolved solids, calcium, etc., in the wastewater).[12]

Attached-growth processes include expanded/fluidized bed reactors and fixed-film processes. In an expanded/fluidized bed reactor, suspended carrier media (such as sand or porous inorganic particles) are used to develop an attached film. Fixed film processes, as the name would suggest, rely on the bacteria attaching to a fixed media, like rocks, plastic rings, modular cross-flow media, etc. Some systems, such as the anaerobic hybrid process, combine suspended- and attached-growth processes in a single reactor to utilize the advantages of both types of biomass.

In some cases, a particular type of wastewater has been treated successfully by several different types of anaerobic technologies. In other cases, experience has shown that a particular technology is more appropriate (i.e., more cost-effective, stable and/or efficient) for certain wastewaters than others.[9]

6.4 The Biobed® EGSB Reactor

The Biobed® EGSB reactor is another more recently developed granular sludge-based system. The EGSB utilizes the same operating principles as the UASB but differs in terms of geometry, process parameters and usually, construction materials. The EGSB has a substantially smaller footprint, and tanks are usually 12 to 18 meters in height, typically consisting of fiberglass-reinforced plastic (FRP) or stainless steel (Zoutberg and Flick, 1999). Loading rates are typically in the range of 10 to 25 kg COD/m3/d.[12]

6.5 The BIOPAQ® IC Reactor

The BIOPAQ® IC reactor is another example of a commercial high-rate granular sludge-based system. Wastewater with low TSS and FOG can be processed through the reactor in as little as a few hours, depending on the strength of the waste. Locations where space is at a premium can be particularly suitable for high-rate technology, with its small footprint and silo-like design. Typical volumetric organic loadings range from 15 to 35 kg COD/m3/d. The IC reactor has been particularly effective for treating wastewaters from the beverage, brewery and paper industries.[11]

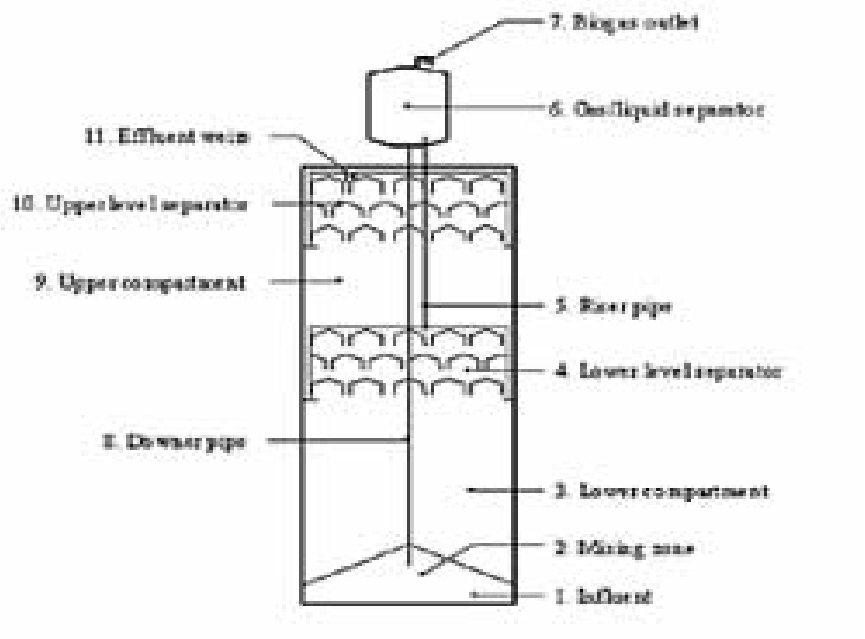

Fig: 6.2 Schematic of BIOPAQ IC reactor.

Fig: 6.2 Photo of a BIOPAQ IC reactor at a Kraft pulp mill in the USA

The influent is pumped into the reactor via a distribution system, where influent and recycled sludge/effluent are well mixed. The first reactor compartment contains an expanded granular sludge bed, where most of the COD is converted to biogas. The biogas produced in this compartment is collected by the lower level separator and is used to generate a gas lift by which water and sludge are carried upward via the "riser" pipe to the gas/liquid separator located on top of the reactor. Here the biogas is separated from the water/sludge mixture and leaves the system. The water/sludge mixture is directed downwards to the bottom of the reactor via the concentric "downer" pipe, resulting in the internal circulation flow. The effluent from the first compartment is post-treated in the second, low-loaded compartment, where any remaining biodegradable COD is removed. The biogas produced in the upper compartment is collected in the top 3-phase separator, while the final effluent leaves the reactor via overflow weirs.[13]

6.6 Anaerobic Fluidized Bed Reactor

The anaerobic fluidized bed reactor uses an inorganic carrier, such as sand or other type of particle, that provides sufficient area for bacterial growth, as well as weight to help hold the bacteria in the reactor. The reactor tank is tall and cylindrical, and recirculation rates are relatively high to fluidize the sludge and provide good biomass-to-substrate

contact. Fluidized bed reactor technology is similar to the granular sludge-based systems mentioned above in that it is best applied to high-strength wastewaters low in TSS and FOG concentration.[18]

One commercially successful fluidized bed reactor is the Ana flux process. This reactor uses a natural porous inorganic particle that has a very high surface area for bacterial growth. A triple-phase separator at the top of the reactor is used to separate liquid, biogas and solids. The solids are transferred from the separator back into the reaction chamber of the tank by gravity or pump. The Ana flux reactor can be applied at loading rates of 60 kg COD/m3/d or more if a separate acidogenic stage is also included ahead of the reactor.

6.7 Anaerobic Filter Reactor

The anaerobic filter is a fixed-film technology. Instead of depending on the growth of granular sludge with good settling characteristics or bacterial attachment to a suspended carrier, biomass becomes attached to fixed media in the reactor. Several different reactor configurations (up flow, down flow and hybrid) and types of media (random pack, cross-flow, pall rings, etc.) have been employed with the process. [18]

The volumetric organic loading to the anaerobic filter is typically in the range of five to 15 kg COD/m3/d. Similar to previously mentioned processes, the anaerobic filter is primarily used for removal of soluble organics and has similar loading limits in terms of FOG (< 100 mg/l) and TSS (< 15 percent of COD) concentrations.[12]

6.8 Anaerobic Hybrid Reactor

Figure 6.3 Schematic diagram of Hybrid reactor

The hybrid reactor is a combination of suspended- and fixed-film growth processes. Typically, the upper 50 to 70 percent of the reactor is filled with cross-flow plastic media that serves as the fixed-film zone (or anaerobic filter section). The lower 30 to 50 percent is the suspended-growth zone (or UASB section). A schematic diagram of the ADI-Hybrid reactor is provided as an example of such technology that is available commercially (see **Figure 6.3**).

Organic loading rates are typically in the range of five to 15 kg COD/m3d. Similar to the other high-rate systems described previously, this process is used primarily for soluble organics removal and has similar constraints in terms of influent FOG and TSS concentrations.

The hybrid reactor has been particularly suitable for wastewaters where the development of granular sludge has proven to be difficult, such as in some chemical industries. The attached growth on the media in the upper portion of the reactor together with the formation of a granular or flocculent sludge bed in the lower section helps concentrate biomass in the system, thus promoting better process stability and higher performance. The cross-flow media also serves as an effective gas-liquid-solids separator, further enhancing the biomass retention abilities of the process.[17]

6.9 Low-Rate Anaerobic Reactor

An example of a low-rate anaerobic technology that is available commercially is the ADI-BVF® reactor. This process consists of a suspended-growth reactor, with typical loadings in the range of 0.5 to 3 kg COD/m3/d. The lower volumetric loading rate allows the reactor to retain non-granular flocculent biomass and to treat wastewaters that have higher COD, TSS and FOG than can be handled by high-rate processes. As such, the process is particularly effective for treating wastewaters, such as potato processing, dairy and cheese, yeast and distillery.

The BVF® reactor can be constructed of in-ground, lined concrete and/or earthen basins or in above-ground concrete or steel tanks. The system utilizes a flexible insulated geomembrane cover.

The larger volume of the system means that it occupies more land area; however, the larger volume retains a large amount of biomass, which gives the process more stability and robustness than higher rate systems. Furthermore, the system can operate at lower temperatures than other processes and generates less waste sludge on a dry weight basis.

In many cases, up-front clarification is not necessary, thereby eliminating the added capital and operating costs associated with primary solids handling. Activated sludge from downstream aerobic polishing processes can be digested in the BVF reactor, eliminating sludge dewatering equipment, lowering waste sludge production and operating costs and simplifying the overall sludge handling/disposal process.[23]

6.10 Applications of EGSB [22]

Anaerobic EGSB treatment is now becoming a popular treatment method for industrial wastewater, because of its effectiveness in treating high strength wastewater and because of its economic advantages. It is modified form of UASB for treating wastewater from:

- ⇒ Sugar industry
- ⇒ Breweries
- ⇒ Beverage industry
- ⇒ Distilleries and fermentation industry

⇒ Food industry,

⇒ Pharmaceutical industry

⇒ Pulp and paper industry

⇒ Chemical and petrochemical industry effluents.

⇒ Textile industry.

Application	COD (mg/l)	COD load (Kg/m3/d)	COD Reduction(%)
Brewery	2500-9500	15-25	70-90
Soft drink	1000-5000	15-25	70-90
Beat sugar	300-20000	10-30	70-90
Potato Processing	2500-7500	10-20	80-85
Potato Starch	4500-22000	10-25	80-85
Candy	5000-15000	15-25	85-90
Yeast	10000-20000	10-20	60-80

Table 6.1 Application of EGSB Vs COD removal

(www.shi.co.pi./updated on15june2005)

6.11 Benefits and Applications

Anaerobic treatment is a biological process that utilizes a mixed culture of bacteria in the absence of free oxygen to remove organic matter that is present in the wastewater. The overall process yields a useful byproduct in the form of biogas, primarily methane (CH_4) and carbon dioxide (CO_2).

This unique feature means that much of the available energy in the wastewater is converted to a gaseous form, resulting in very little energy left for new cell growth. In a nutshell, three significant benefits are associated with this process, namely the production of biogas energy, much less biosolids waste and a low energy requirement for the treatment process, in addition to these benefits [24]

- Less nutrients required;
- System can be shut down for extended periods without serious deterioration; and
- Can handle organic shock loads effectively.

As with any process, however, anaerobic treatment does have certain drawbacks, including the following:

- Anaerobic treatment cannot achieve surface water discharge quality without post-treatment;
- Reduced sulfur compounds are produced, which need to be properly addressed in terms of corrosion, odor and safety; and
- Longer start-up period.

A straight comparison between anaerobic and aerobic treatment clearly illustrates the operating benefits that could be realized with anaerobic treatment. This is shown in **Table 6.1**, for a given biodegradable chemical oxygen demand (COD) waste load.

In many cases, the optimum wastewater treatment configuration is an anaerobic process followed by aerobic polishing (for final biochemical oxygen demand (BOD) reduction and/or sulfide oxidation).

This configuration typically guarantees that the benefits of anaerobic and aerobic treatment are realized while minimizing their respective limitations. [18]

Achievable removals are very much dependent on the type of wastewater being treated. Reactor configuration also affects removals, with the lower rate systems typically achieving somewhat better COD and BOD removals than high-rate systems.

In many ways, anaerobic treatment can be considered to have matured significantly over the past thirty years. Many full-scale applications have been recorded and can be drawn from to anticipate potential problems or future difficulties. As a result, piloting for many applications may not be essential. Today, this is normally the case for brewery applications, potato plants, starch production, recycle paper mills, sugar beet plants and dairies.[23]

Of course, no two industrial plants are alike. This is particularly true within some sectors more so than others (pulp mills, yeast plants, chemical plants and pharmaceutical applications). Within these particular areas, as well as in unusual applications, piloting is

The internal mixing was not optimal in a UASB reactor treating sewage at temperatures ranging from 4 to 20°C. This produced dead space in the reactor, leading to a reduction in the treatment efficiency. In order to improve the sludge-wastewater contact and use the

entire reactor volume efficiently a better influent distribution was required. Different feed inlet devices, more feed inlet points per square meter or higher superficial velocities have been proposed as solutions.[21]

The use of effluent recirculation combined with taller reactors (or a high height/diameter ratio), resulted in the expanded granular sludge bed (EGSB) reactor, where a high superficial velocity is applied. In this reactor concept, the up flow liquid velocity (>4m/h $^{-1}$) causes the granular sludge bed to expand, eliminating dead zones and resulting in better sludge-wastewater contact. However, a direct relationship between up flow velocity and substrate consumption could not be found, and the granule size and inner structure seem to play a more relevant role in fully expanded EGSB reactors. [17]

Accumulation of flocculent excess sludge between the sludge granules is also prevented. Soluble pollutants are efficiently treated in EGSB reactors but suspended solids are not substantially removed from the wastewater stream due to the high up flow velocities applied. Recirculation of the effluent dilutes the influent concentration, but it was extensively proven that low strength wastewater can efficiently be treated in EGSB reactors. However, recirculation is not needed for sewage treatment. Influent dilution may also allow the treatment of toxic compounds in these reactors.[19] In UASB reactors, the sludge bed behaves more or less as a static bed, but in fully expanded EGSB reactors, it is considered as a completely mixed tank. Compared to UASB reactors, higher organic loading rates (as gCOD meter^{3}d^{-1}) can be accommodated in EGSB systems. Consequently, the gas production is also higher, improving even more the mixing inside the reactor. The exact mixing pattern cannot be generalized, and it must be evaluated in each reactor by assessing the reactor hydrodynamics. In tall reactors, the gas loading (in^{3}m^{-2}h $^{-1}$) and the hydrostatic pressure at the bottom can be higher than in short reactors and the effect of these parameters on the performance of the process also have to be considered.

6.12 Growth of biomass

6.12.1 Types of bacterial strain

The Methanogens are having two common physiological characteristics, namely growing strictly anaerobically and producing methane as the exclusive final product of energy metabolism .In contrast to their significantly similar energy metabolism, methanogens inhabit extremely diverse environments, including freshwater and marine sediments the ,digestive and intestinal tracts of animals and anaerobic waste digesters. So far, 28 genera of methanogens have been described. The majority of rod-shaped methanogens are affiliated to the order Methanobacteriales, which consists of three mesophilic genera (Methanobacterium, Methanobrevibacter and Methanosphaera) and two thermophilic or hyperthermophilic genera (Methanothermobacter and Methanothermus). All methanogens grow on a H_2/CO_2 gas mixture; in addition, many of them utilize format and some grow on a few other simple alcohols. [9]

The anaerobic digester is a compatible surrounding for the growth of mesophilic methanogens and Methanobacterium strains constitute the main microbial flora, which play an important role in the anaerobic degradation of organic compounds as the terminal metabolic groups When surveying the microbial communities of two mesophilic methane-producing (EGSB) reactors, we isolated 11 strains of rod-shaped methanogens that produced methane from H_2/CO_2. vitamins, yeast extract, peptone, acetate, etc. [15]

6.12.2 Source of biomass

Granular sludge was sampled from a psychrophilic (10–12°C) EGSB reactor, which had been treating a VFA mixture of varying composition at volumetric loading rates of 10–12 g COD l^{-1} d^{-1} for 306 days. The substrate consisted of a partly neutralized (pH 6.5) VFA mixture composed of acetate, propionate and butyrate in the ratio 1:1.5:1.8 in the period 0–205 days, in the ratio 3:1:1 in the period 206–237 days, in the ratio 1:3:1 in the period 238–268 days, and in the ratio 3:1:1 in the period 269–306 days, based on COD. The reactor performance and physical–chemical characteristics of the sludge have been reported previously.[18]

CHAPTER 7

EXPERIMENTAL ON EGSB REACTOR

7.1. Experimental Set Up of EGSB reactor

7.1.1 Influent Collection System

The influent tank is connected with 2 pipe line, one that is used for influent inlet to the EGSB at the bottom of the Reactor and other for dilution water. The capacity of the influent collection tank is 200 liter in which influent waste water is collected.

Figure: 7.1.1. Influent collection system

7.1.2.EGSB reactor for waste water treatment

Fig 4.2 shows that the diagram of EGSB reactor which is connected with influent pipe at the bottom, treated effluent pipe line , exit gas pipe line, it also consists of GSL separator at the top for the separation of exit gas, treated effluent and solids biomass.

Figure 7.1.2.EGSB reactor

7.1.3. Exit effluent collection system

For collection of treated effluent a exit system is kept beside of UASB reactor, the volume of this collection system is 35 liter. Laboratory Analysis Were carried out for Chemical Oxygen demand (COD), pH, Volatile Fatty Acids (VFA), Total Suspended Solids (TSS), Alkalinity & MLVSS.

Figure : 7.1.3 Exit effluent collection system

7.2.Experimental procedure for EGSB reactor

The laboratory bench scale experiments were carried out in EGSB reactor. A venturi type gas deflector is attached on the top of the reactor, which is used to invert the gas bubble to conical gas separator and to facilitate the settling of the biomass. The GSL separator which is installed in the upper part of the reactor and the end of which is connected to gas collection device.

The sewage sludge from the sludge digestion tank used as seeding material for the study, which was obtained from the Pirana sewage treatment plant. The raw textile waste water for the study was collected from Arvind textile mills. Laboratory analysis were carried for Chemical Oxygen Demand (COD), pH, Volatile fatty acid (VFA), Alkalinity, MLVSS and TSS. The start up of experiment was performed continuously by running the EGSB reactor at a temperature of 34 ^{0} C. Granulation was observed in the EGSB reactor about 24 days from reactor stabilization. During the experimental programme the pH observed to be in neutral range.

CHAPTER 8
RESULTS ANALYSIS & DISCUSSION FOR EGSB (EXPANDED GRANULAR SLUDGE BED) REACTOR

8.1. VFA Test (Volatile fatty acid)

During the EGSB (Expanded Granular Sludge Bed) reactor experiments the concentration of Volatile Fatty Acid decreased from 500 mg/l to 244 mg/l .During experiments run 1 (day 1 to 18) VFA decreased from 500 mg/l to 380 mg/l . During experiments run 2 (day 20 to 38) the VFA further decreases from 376 mg/l to 292 mg/l. During experiment run 3 (day 39 to 53) the VFA decreased from 288 mg/l to 244 mg/l. Low concentration of VFA favor the anaerobic operation and it is observed that the methanogenic activity affected by VFA concentration. If VFA level is high than it affect on COD reduction efficiency. The variation in the concentration of VFA during the EGSB reactor operation are shown in table 8.1.

VFA are produced more in waste water rich in carbohydrates. If VFA production is more pH is neutralized by increasing alkalinity should be less than 0.1, when VFA increases pH drops in such cases , feeding of new material is stopped until the pH and VFA are stabilized, if any day it is observed that VFA : Alkalinity ratio is less than 1:2 feeding should be stopped for the day and add bicarbonate alkalinity to bring the ratio 1:2.

8.2. Alkalinity Test

During the experiment of EGSB reactor the alkalinity also played an important role in COD reduction. Alkalinity may vary from 690 mg/l to 930 mg/l .

During experiments run 1 (day 1 to 18) the alkalinity increased from 690 mg/l to 790 mg/l. During experiments run 2 (day 20 to 38) the alkalinity further increased from 795 mg/l to 855 mg/l. During experiment run 3 (day 39 to 53) the alkalinity increased from 860 mg/l to 930 mg/l. For the satisfactory performance of the anaerobic operation the concentration of VFA within 250 mg/l and the ratio of VFA to alkalinity should be

less than 0.1. The alkalinity variation during the experiments with time are shown in table 8.1.

Day	**Volatile Fatty Acid (VFA) mg/l**	**Alkalinity (mg/l)**
1	500	690
2	480	700
3	476	730
5	468	735
6	460	740
9	444	745
10	440	750
11	432	755
12	420	760
13	412	770
16	404	780
17	400	785
18	380	790
20	376	795
21	364	800
23	352	810
25	340	815
28	332	820
31	324	825
33	320	830
35	312	840
36	300	850
38	292	855
39	288	860
41	284	865
43	280	870
45	276	880
47	268	890
48	260	900
50	252	910
51	248	925
53	244	930

TABLE 8.1. VFA (Volatile Fatty Acid) mg/l and Alkalinity (mg/l) variation during the Time (days)

The variation in alkalinity and Volatile fatty acid concentration during the EGSB reactor operation within the time in days are shown in fig.8.1 and fig.8.2 respectively.

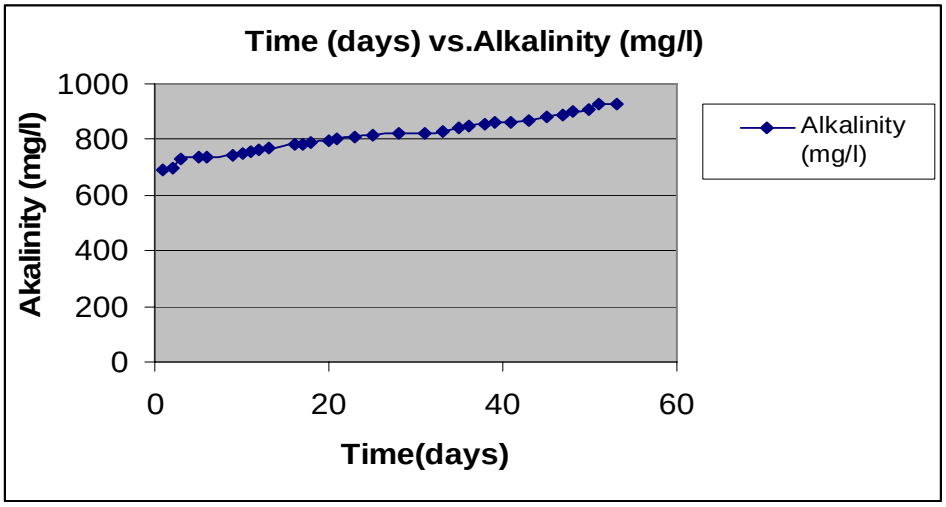

Figure 8.1.Plot for Time (days) vs. Alkalinity (mg/l)

The change in Volatile Fatty Acid during the experiments with time are shown in figure 8.2. During the experiments it was also studied that in variation of VFA in mg/l. For effective operation of EGSB reactor the VFA level is low as possible as 250 mg/l. High concentration of volatile fatty acid affect the anaerobic process it is also affect the methanogenic activity . If volatile fatty acid concentration is high then COD reduction efficiency is low and production of biogas is also less. During the experiments of EGSB reactor the concentration of VFA decreased day by day.

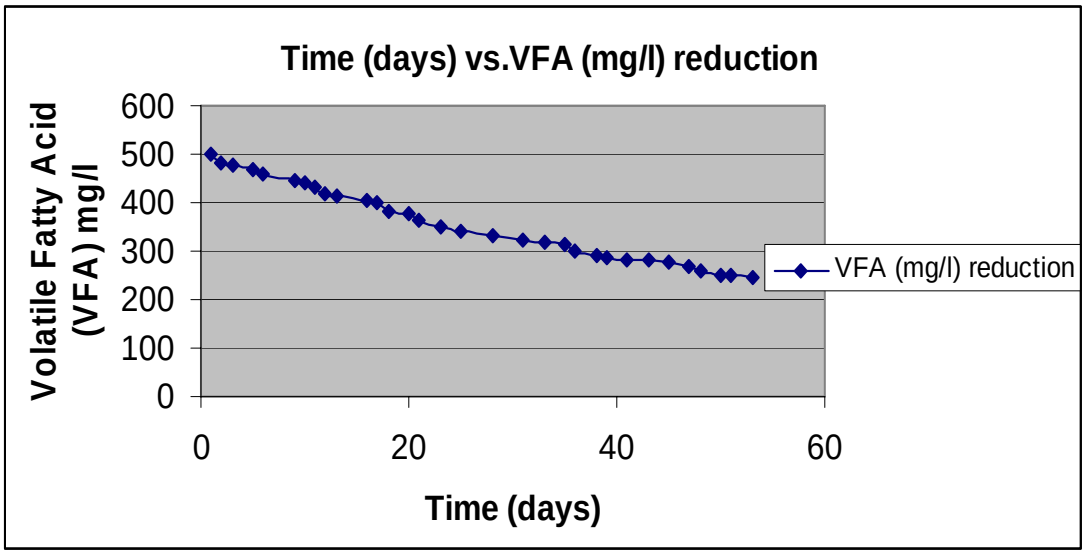

Figure 8.2 Plot for Time (days) vs. VFA (mg/l)

8.3.TOTAL SUSPENDED SOLID AND pH TEST

The Total Suspended Solid s present in the waste water of EGSB reactor are given in the table 8.2. During the experiments the variation in total suspended solid (TSS) was also studied . pH also plays an important role in anaerobic process for production of biogas and high COD reduction efficiency .Normally it is reported that methanogenic activity is higher at pH between 7 to 8.

The variation in TSS and pH during the EGSB reactor operation are shown in table 8.2. Also plotted graph for Time (days) vs. TSS (mg/l) and Time (days) vs. pH .

Day	pH (EGSB)	TSS (mg/l)
1	7.35	4200
2	7.37	4150
3	7.49	4100
5	7.51	4250
6	7.57	4025
9	7.60	4010
10	7.61	3970
11	7.63	3950
12	7.65	3930
13	7.67	3925
16	7.68	3850
17	7.86	3820
18	7.89	3726
20	7.90	3652
21	8.01	3320
23	8.03	2431
25	8.05	2163
28	8.07	2010
31	8.10	1965
33	8.15	1852
35	8.17	1762
36	8.20	1633
38	8.23	1652
39	8.27	1562
41	8.30	1465
43	8.41	1413
45	8.45	1403
47	8.47	1325
48	8.51	1310
50	8.63	1256
51	8.67	1240
53	8.89	1225

Table 8.2 TSS (mg/l) and pH during the EGSB reactor operation

Graph for Time (days) vs. pH and Time (days) vs. TSS (mg/l) are shown in figure 8.3 and figure 8.4.

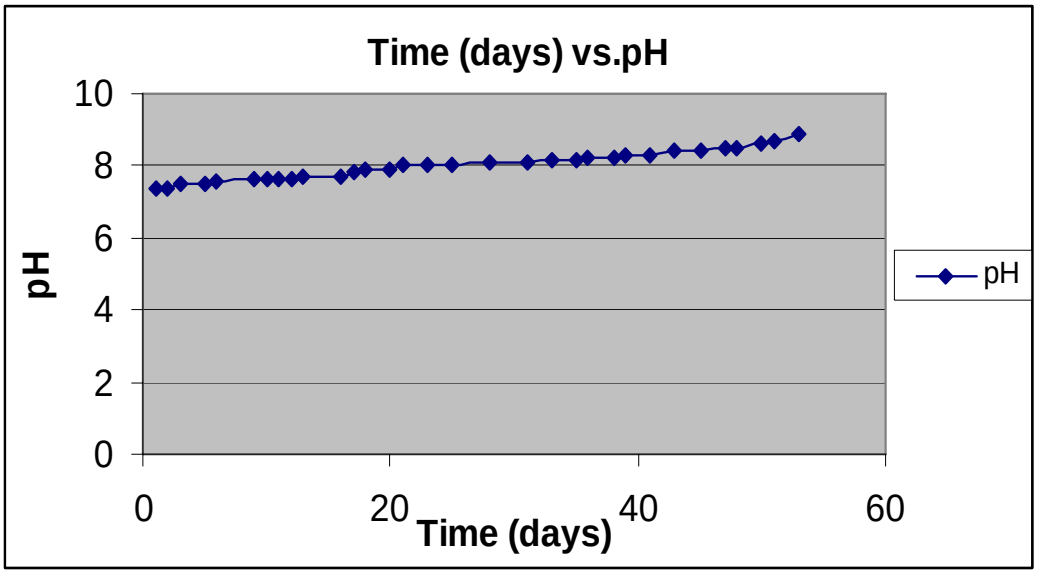

Figure 8.3.Time (days) vs. pH

The graph for Time (days) vs. Total Suspended solid (TSS) in mg/l are shown in figure 8.4.

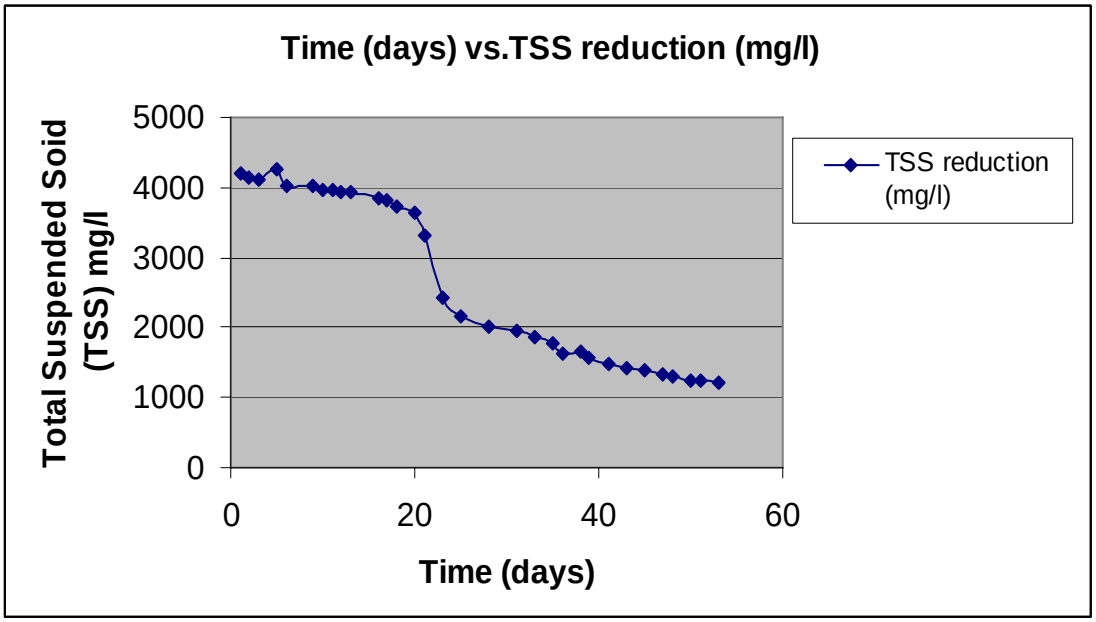

Figure 8.4. Time (days) vs. Total Suspended solid (TSS) in mg/l

8.4.MLVSS TEST

During the experiments it was also studied that the behaviors of biomass by checking the MLVSS .MLVSS also plays an important role in anaerobic process . If MLVSS level is high than higher COD reduction efficiency achieved.

The MLVSS (mg/l) during the operation are shown in table 8.3.

Days	MLVSS (mg/l)
1	23500
2	23770
3	23825
5	23910
6	24025
9	24180
10	24560
11	24710
12	24990
13	25070
16	25875
17	26100
18	26730
20	27750
21	27900
23	28320
25	28760
28	31520
31	34010
33	34760
35	35130
36	36780
38	37520
39	38325
41	39220
43	41370
45	42870
47	45765
48	46780
50	48910
51	50010
53	52045

Table 8.3.MLVSS (mg/l) and during the EGSB reactor experiment

The variation in MLVSS during within time are shown in Fig.8.5.

The Time (days) vs. MLVSS (mg/l) plot and plot are shown in Figure 8.5.

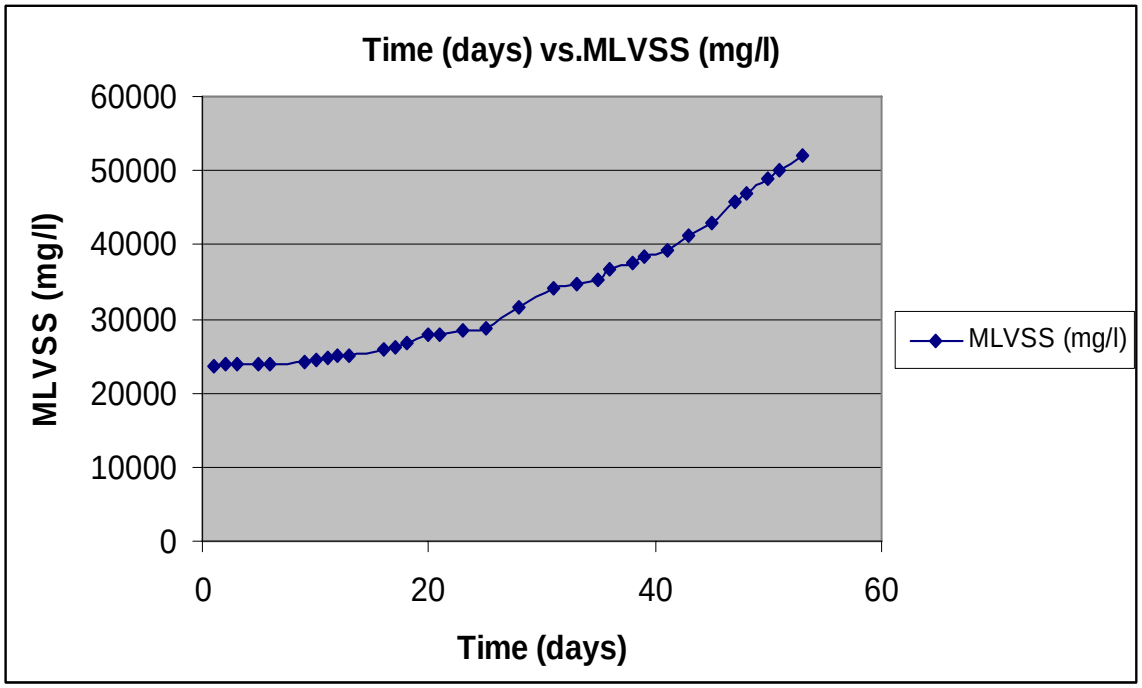

Figure 8.5 Plot for Time (days) vs. MLVSS (mg/l)

During the EGSB reactor experiments for treatment of industrial waste water maximum 90% COD reduction was achieved .The day by day COD reduction efficiency are shown in Table 8.4.Also the organic loading rate in kg/day during the operation are shown in Table.8.4.

Days	Organic Loading Rate(kg/day)	COD reduction efficiency in %
1	0.005	51
2	0.006	53
3	0.007	55.5
5	0.008	57
6	0.009	60
9	0.010	61
10	0.011	64
11	0.012	65
12	0.013	67
13	0.014	67.5
16	0.015	68
17	0.016	68.5
18	0.017	69
20	0.018	71
21	0.019	72
23	0.020	73
25	0.021	74.5
28	0.022	75
31	0.023	76
33	0.024	77
35	0.025	77.5
36	0.026	78
38	0.027	80
39	0.028	81
41	0.029	82
43	0.030	83
45	0.031	83.5
47	0.032	84
48	0.033	85
50	0.034	86
51	0.035	88
53	0.036	90

Table 8.4 Day by day COD reduction Efficiency and Organic Loading rate during the EGSB reactor operation

Also Plot graph for Time (days) vs. COD reduction efficiencies are shown in fig. 8.6.

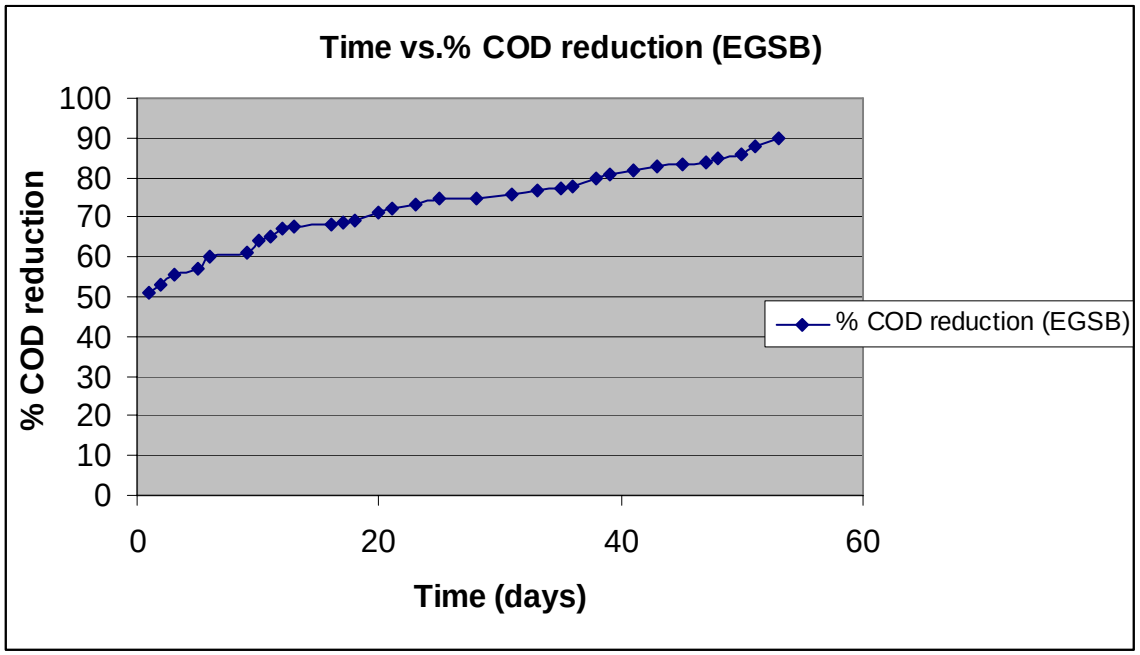

Figure : 8.6 Time (days) vs. COD reduction

The overall results of EGSB reactor are shown in table 8.5 In such Table we also see that the MLVSS , VFA (Volatile Fatty Acid as CH_3COOH), pH, Alkalinity, and Total Suspended Solids (TSS) and %COD reduction day by day during the experiments of EGSB reactor for treatment of waste water.

8.5 EXPERIMENTAL RESULTS FOR EGSB REACTOR

Experiment run 1	Day	TSS (mg/l)	MLVSS (mg/l)	VFA mg/l	pH	Alkalinity mg/l	%COD reduction	Organic Loading Rate kg/day
	1	4200	23500	500	7.35	690	51	0.005
	2	4150	23770	480	7.37	700	53	0.006
	3	4100	23825	476	7.49	730	55.5	0.007
	5	4025	23910	468	7.51	735	57	0.008
	6	4010	24025	460	7.57	740	60	0.009
	9	3970	24180	444	7.60	745	61	0.010
	10	3950	24560	440	7.61	750	64	0.011
	11	3930	24710	432	7.63	755	65	0.012
	12	3925	24990	420	7.65	760	67	0.013
	13	3850	25070	412	7.67	770	67.5	0.014
	16	3820	25825	404	7.78	780	68	0.015
	17	3726	26100	400	7.86	785	68.5	0.016
	18	3652	26730	380	7.89	790	69	0.017
Expe. run 2	20	3320	27750	376	7.90	795	71	0.018
	21	2431	27900	364	7.91	800	72	0.019
	23	2163	28320	352	8.03	810	73	0.020
	25	2010	28760	340	8.05	815	74.5	0.021
	28	1965	31520	332	8.05	820	75	0.022
	31	1852	34010	324	8.07	825	76	0.023
	33	1762	34760	320	8.10	830	77	0.024
	35	1633	35130	312	8.15	840	77.5	0.025
	36	1652	36780	300	8.17	850	78	0.026
	38	1562	37520	292	8.20	855	80	0.027
Experiment run 3	39	1465	39220	288	8.23	860	81	0.028
	41	1413	41370	284	8.27	865	82	0.029
	43	1403	42870	280	8.30	870	83	0.030
	45	1325	45765	276	8.41	880	83.5	0.031
	47	1310	45890	268	8.45	890	84	0.032
	48	1299	46780	260	8.47	900	85	0.033
	50	1256	48910	252	8.50	910	86	0.034
	51	1240	50010	248	8.61	925	88	0.035
	53	1225	52045	244	8.65	930	90	0.036

Table 8.5 . Experimental results for EGSB reactor operation

CHAPTER 9

COMPARISION OF UASB AND EGSB REACTOR RESULTS

In such chapter we see the various parameters likes MLVSS, COD reduction efficiencies , pH, TSS (Total Suspended Solid) , Volatile Fatty Acid (VFA), Alkalinity etc. for UASB and EGSB reactor and compare it .

9.1 Comparisons of MLVSS and VFA for UASB and EGSB reactor

In Table 9.1 we se that MLVSS and VFA level in both reactor during the experiments.

Day	MLVSS(mg/l) (UASB)	VFA (mg/l (UASB)	MLVSS(mg/l) (EGSB)	VFA(mg/l) (EGSB)
1	15100	640	23500	500
2	15425	620	23770	480
3	15550	600	23825	476
5	15670	584	23910	468
6	15720	580	24025	460
9	15825	572	24180	444
10	15910	564	24560	440
11	15930	556	24710	432
12	16025	548	24990	420
13	16230	540	25070	412
16	16650	532	25875	404
17	16830	524	26100	400
18	17020	520	26730	380
20	17330	512	27750	376
21	17345	500	27900	364
23	17530	492	28320	352
25	17670	484	28760	340
28	17830	476	31520	332
31	17920	468	34010	324
33	18025	460	34760	320
35	18110	452	35130	312
36	18290	440	36780	300
38	18570	432	37520	292
39	19120	416	38325	288
41	19425	400	39220	284
43	19890	380	41370	280
45	20020	372	42870	276
47	20250	360	45765	268
48	20450	348	46780	260
50	20995	324	48910	252
51	21075	320	50010	248
53	21580	304	52045	244

Table 9.1. MLVSS and VFA levels in both UASB and EGSB reactor experiments

Now figure 9.1 and figure 9.2 shows the plot for Time vs. MLVSS (mg/l) and Time vs. VFA (mg/l) for both UASB and EGSB reactor experiments.

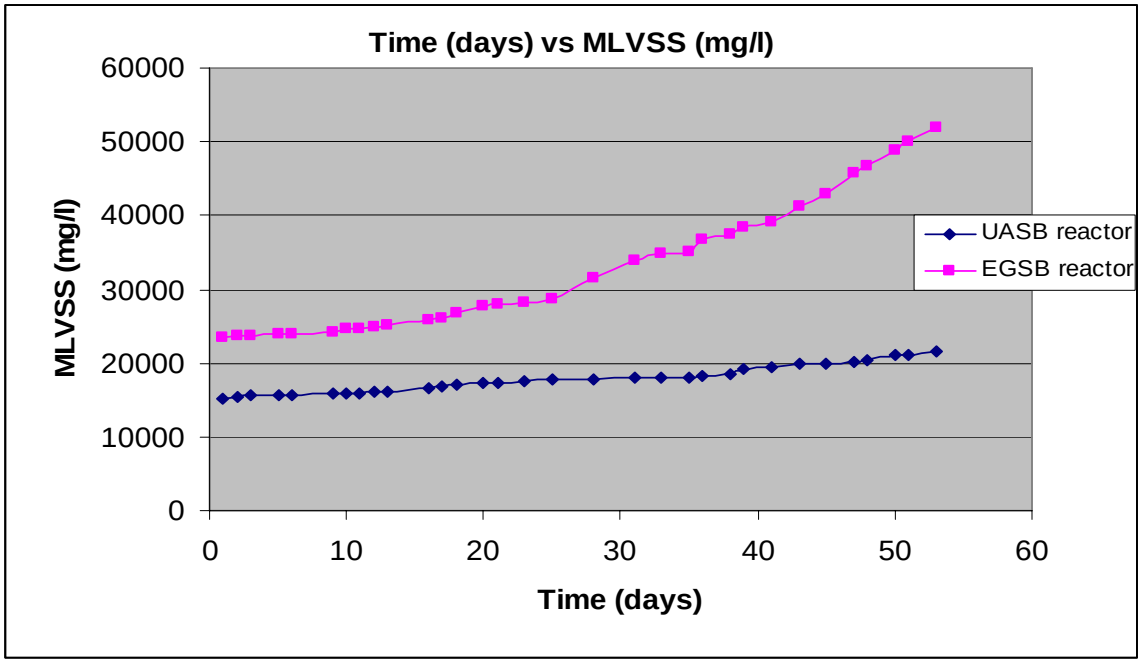

Figure 9.1.Time (days) vs. MLVSS (mg/l) for both UASB and EGSB reactor

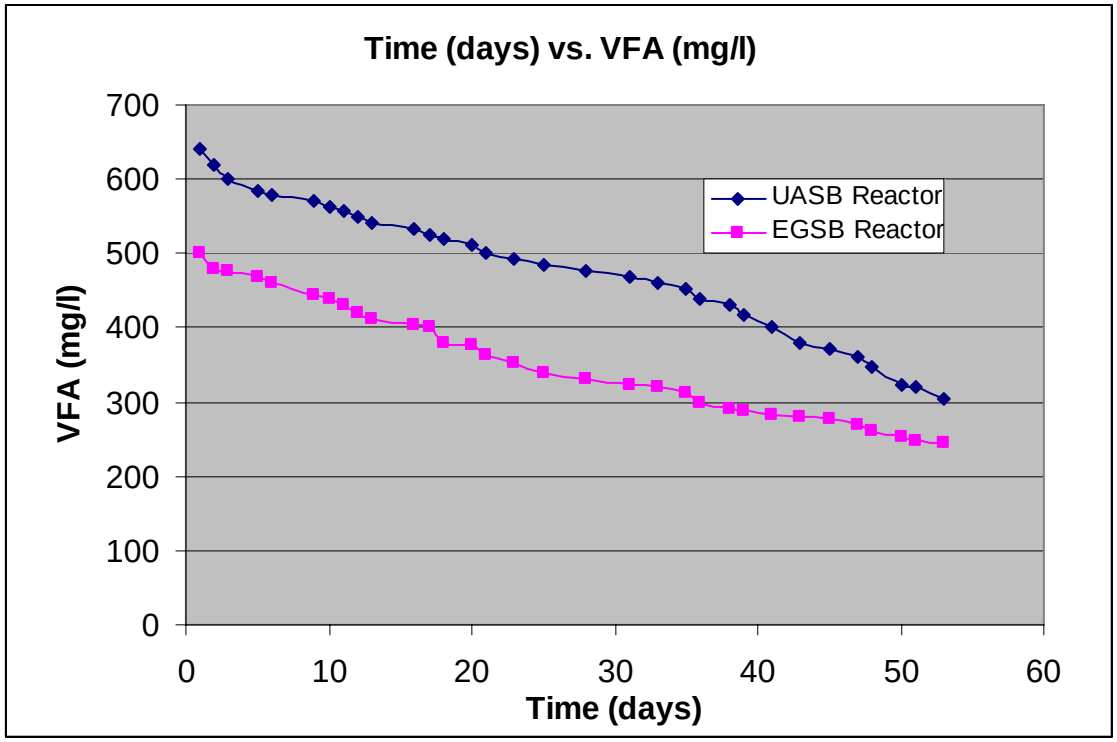

Figure 9.2.Time (days) vs. VFA (mg/l) for both UASB and EGSB reactor

9.2 Comparisons of pH and alkalinity for UASB and EGSB reactor

Now the experimental results of pH and alkalinity for both UASB and EGSB reactor during the treatment of waste water are shown in Table 9.2.

Day	pH (UASB)	Alkalinity mg/l (UASB)	pH (EGSB)	Alkalinity mg/l (EGSB)
1	7.11	625	7.35	690
2	7.17	635	7.37	700
3	7.21	645	7.49	730
5	7.15	630	7.51	735
6	7.07	620	7.57	740
9	7.22	645	7.60	745
10	7.26	650	7.61	750
11	7.29	660	7.63	755
12	7.31	665	7.65	760
13	7.30	670	7.67	770
16	7.32	675	7.78	780
17	7.33	685	7.86	785
18	7.36	695	7.89	790
20	7.38	705	7.90	795
21	7.41	715	7.91	800
23	7.43	720	8.03	810
25	7.48	730	8.05	815
28	7.52	735	8.05	820
31	7.61	745	8.07	825
33	7.63	750	8.10	830
35	7.67	760	8.15	840
36	7.68	775	8.17	850
38	7.72	780	8.20	855
39	7.75	785	8.23	860
41	7.83	805	8.27	865
43	7.91	825	8.30	870
45	7.95	835	8.41	880
47	8.03	850	8.45	890
48	8.05	855	8.47	900
50	8.11	860	8.50	910
51	8.17	880	8.61	925
53	8.20	890	8.65	930

Table 9.2. pH and alkalinity for both UASB and EGSB reactor experiments

Now the change in pH and alkalinity with time (days) for both UASB and EGSB reactor during the experiments are shown in fig.9.3 and fig.9.4.

The time(days) vs. pH graph for UASB and EGSB reactor are shown in fig.9.3.

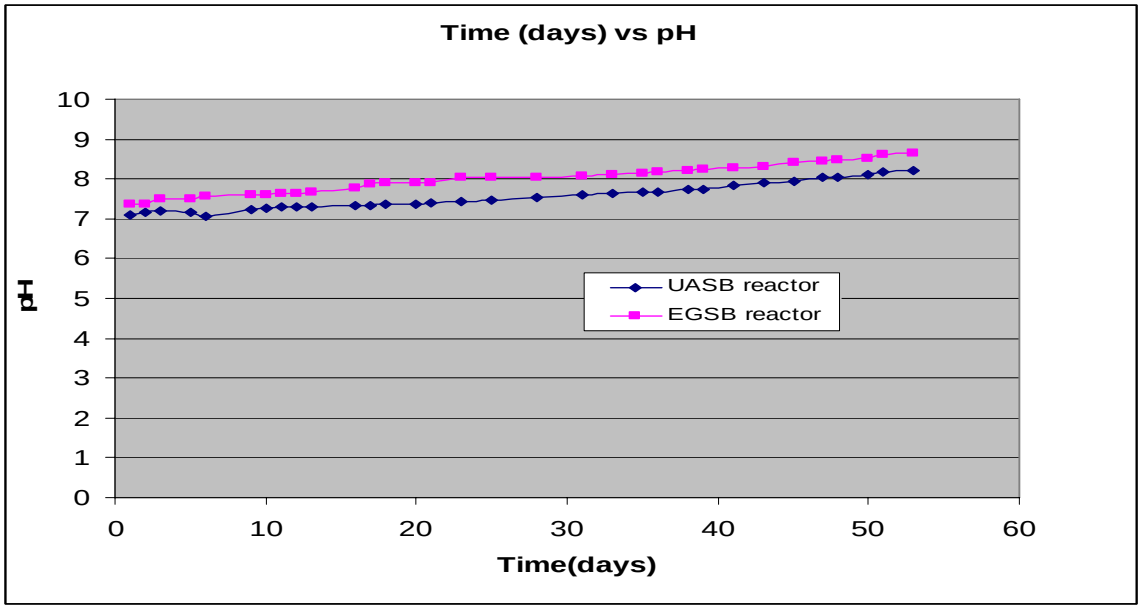

figure 9.3. Time(days) vs. pH graph for UASB and EGSB reactor

Now the time (days) vs. alkalinity graph for both UASB and EGSB reactor are shown in figure 9.4.

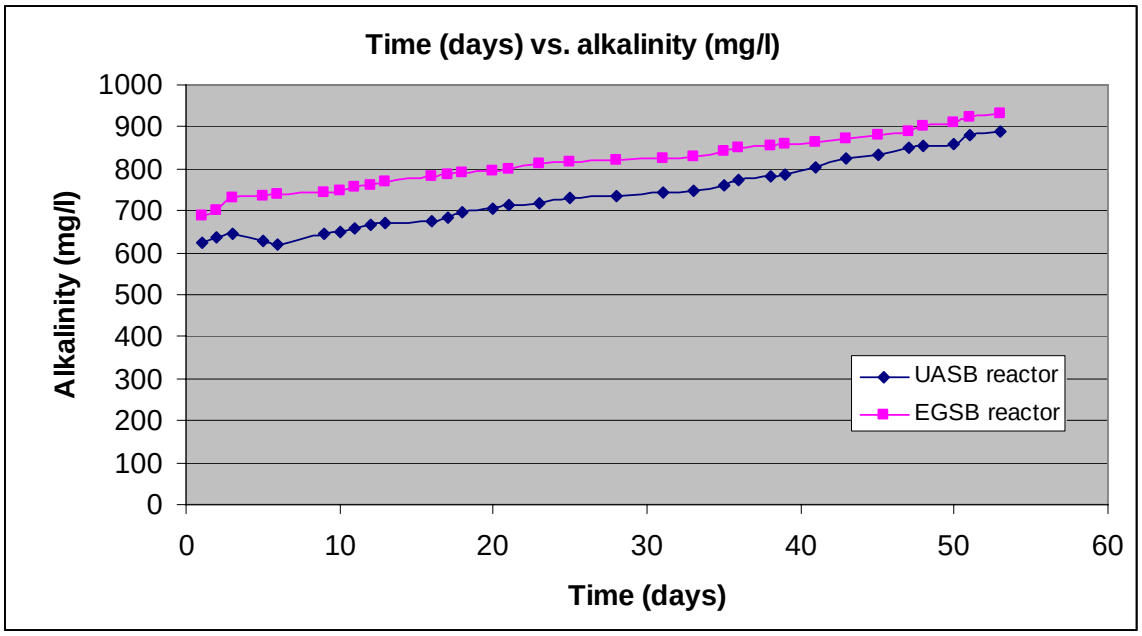

figure 9.4. Time(days) vs. alkalinity (mg/l) graph for UASB and EGSB reactor

9.3 Comparisons of TSS and %COD reduction for UASB and EGSB reactor

The COD reduction efficiencies, organic loading rate (kg/day) **,** and total suspended solid in mg/l (TSS) during the UASB (Up flow Anaerobic Sludge Blanket) reactor and EGSB (Expanded Granular Sludge Bed) are shown in Table 9.3.

Day	TSS (mg/l) (UASB)	TSS (mg/l) (EGSB)	%COD reduction (UASB)	%COD reduction (EGSB)	Organic Loading Rate kg/day
1	225	4200	32	51	0.005
2	221	4150	33.5	53	0.006
3	223	4100	34	55.5	0.007
5	220	4025	34.5	57	0.008
6	215	4010	36	60	0.009
9	213	3970	37	61	0.010
10	210	3950	39	64	0.011
11	208	3930	41	65	0.012
12	205	3925	43	67	0.013
13	201	3850	44	67.5	0.014
16	198	3820	45	68	0.015
17	196	3726	46.5	68.5	0.016
18	193	3652	47	69	0.017
20	191	3320	48	71	0.018
21	189	2431	48.5	72	0.019
23	187	2163	49	73	0.020
25	185	2010	51	74.5	0.021
28	183	1965	52	75	0.022
31	179	1852	54	76	0.023
33	176	1762	55	77	0.024
35	173	1633	57	77.5	0.025
36	170	1652	58	78	0.026
38	168	1562	60	80	0.027
39	165	1465	62.5	81	0.028
41	161	1413	63	82	0.029
43	160	1403	64.5	83	0.030
45	156	1325	65	83.5	0.031
47	151	1310	66	84	0.032
48	143	1299	66.5	85	0.033
50	140	1256	67	86	0.034
51	137	1240	68.5	88	0.035
53	133	1225	70	90	0.036

Table 9.3. TSS (total suspended solid) in mg/l, COD reduction efficiencies organic loading rate during the UASB and EGSB reactor operation

The TSS (Total Suspended Solid) variation during the experiments are shown in graph time vs. TSS for UASB and EGSB reactor operation are shown in figure 9.5.

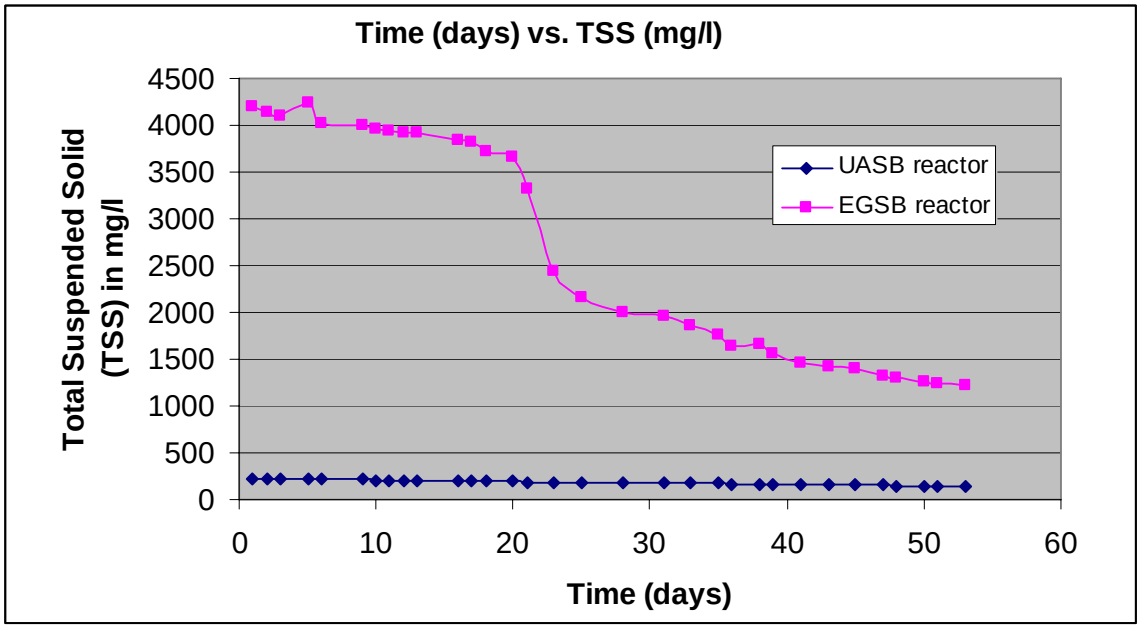

Figure 9.5.Time vs. TSS for UASB and EGSB reactor operation

COD reduction efficiencies for both UASB and EGSB reactor are shown in Table 9.3. Time (days) vs. COD reduction efficiencies graph for UASB and EGSB reactor are shown in figure 9.6.

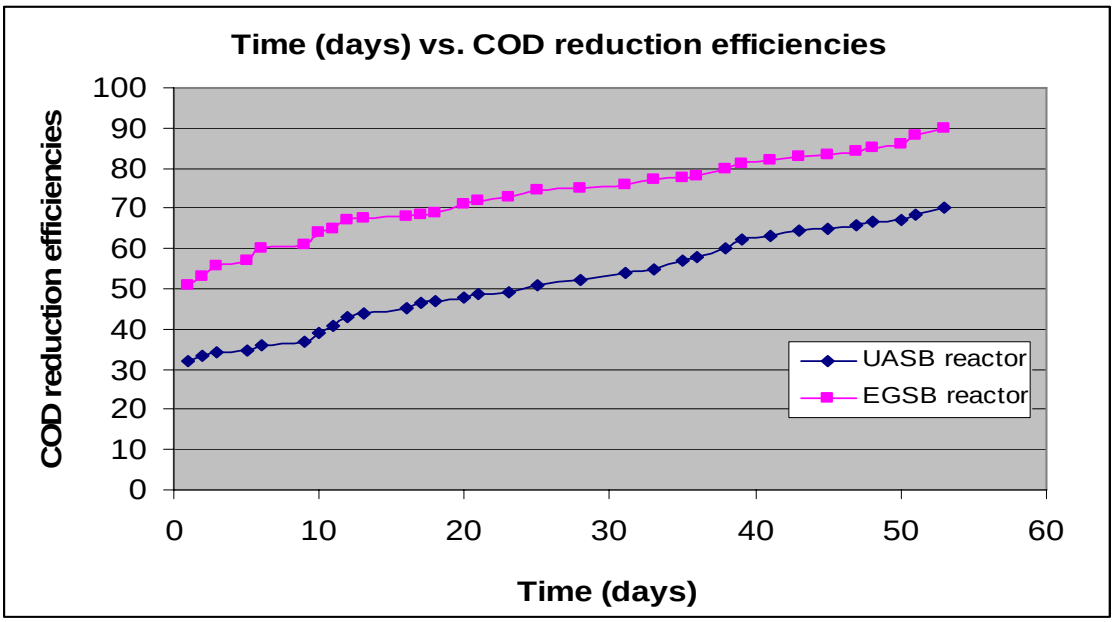

Figure 9.6.Time (days) vs. COD reduction efficiencies graph for UASB and EGSB reactor

CHAPTER 10
OPERATING COST OF EGSB REACTOR

Cost factor is very important in each operation. In UASB (Up flow Anaerobic Sludge Blanket) reactor energy is not require where as in EGSB (Expanded Granular Sludge Bed) reactor pump is require for effluent recycle. In such project 0.5 hp capacity pump was used in EGSB reactor experiment for recycling of effluent.

Normally 0.5 hp capacity pump require 9 unit electricity per day. In EGSB reactor Continuous recycling require for expand the granular. Now EGSB reactor was completed in 63 days.

So, total energy used in EGSB reactor = (9 * 63) unit
= 567 unit

Now the cost for 1 unit electricity = Rs. 4

So, the total operating cost in EGSB reactor = Rs. (4 * 567)
= Rs. 2268

So, economically UASB is better than EGSB reactor. Because in UASB reactor experiment operation cost is 0.

CHAPTER 11
CONCLUSION

Such project was carried out for treatment of textile waste water . In such project my objective was biogas production . During the project work lot of biogas was generated but it's collection was much difficult. So I was changed my objective and than my focus on COD reduction for both UASB (Up flow Anaerobic Sludge Blanket) and EGSB (Expanded Granular Sludge Bed) reactor operation. I was studied both reactor at pH between 7 to 8.25 because anaerobic activity was better at that ph level.

In such project also studied the various parameters and it' effect on COD reduction efficiencies. Laboratory analysis were carried out for Chemical Oxygen demand (COD), pH, Volatile Fatty Acids (VFA), Total Suspended Solids (TSS), Alkalinity & MLVSS.

The initial COD of textile waste water was 1305 mg/l .During the UASB reactor experiments 70% COD reduction efficiency was achieved.

In both reactor COD reduction efficiency was increased day by day . In such experiments organic loading (glucose and milk powder) was applied . During the experiment it was observed that COD reduction efficiency decreased with increased VFA (Volatile Fatty Acid) in mg/l. Higher concentration of VFA affect the anaerobic process it's also affect the methaogenic activities. It was also observed that the COD reduction efficiencies increased with increased MLVSS (mg/l) .

In UASB reactor maximum 70% COD reduction efficiency was achieved at pH 8.20 and MLVSS concentration was 21580 mg/l. In EGSB reactor maximum 90% COD reduction efficiency was achieved at pH 8.65 and MLVSS concentration was 52045 mg/l.

Both reactor given good results in effective COD reduction. But in EGSB reactor microbes growth was rapid compare to UASB reactor because in EGSB reactor effluent was recycled continuously. Also MLVSS level in EGSB reactor was also doubled compared to UASB reactor and VFA (Volatile Fatty Acid) in mg/ l was low in EGSB reactor as compared to UASB reactor.

However economically UASB reactor is most suitable than EGSB reactor because in EGSB reactor pump is require for recycle purpose. Where in UASB reactor energy was not used. In EGSB reactor experiment an operating cost was Rs.2268 where as operating cost in UASB reactor was 0. So economically UASB is better than EGSB reactor for treatment of textile waste water.

In EGSB reactor COD level was decrease from 1300 mg/l to 130 mg/l. Normally TSS level in EGSB reactor was high because in such reactor waste water recycle from top to bottom and in bottom part of the reactor sludge was collected for growth of microbes. These sludge was lift up due to recycle in EGSB reactor so the TSS level was high in such reactor.

CHAPTER 12
SCOPE FOR FUTURE WORK

In this project of **"performance study of UASB (Up flow Anaerobic Sludge Bed) and EGSB (Expanded Granular Sludge Bed) reactor for industrial waste water treatment"** excellent results outcome from both reactor in COD reduction. However my objective was production of biogas in such project lot of biogas was generated but it' s collection was difficult.

UASB (Up flow Anaerobic Sludge Bed) and EGSB (Expanded Granular Sludge Bed) reactor are widely used now a day in each chemical industries like textile industries, petrochemical industries, Food industry, Dairy waste water, Beverages industry, Pulp and paper industry, Breweries, Distilleries and fermentation industry. In such project I was selected textile waste water for treatment but it's initial COD value was low as 1305 mg/l. So I was added glucose and milk powder for increased the COD value because my objective was production of biogas and it require high COD value waste water.

UASB and EGSB both reactor are also capable for remove phenol, HCHO and cyanide. So it is also possible that remove such compound in UASB or EGSB reactor. Also check the MLVSS and VFA concentration for remove of phenol and cyanide.

Also UASB reactor in series for COD reduction of industrial waste water treatment possible such project will study for different industries waste water like petrochemical industries, pharmaceutical waste water, Pulp and paper industry, Breweries, Distilleries and fermentation industry. Also EGSB reactor in series provide excellent results for treatment of industrial waste water.

The UASB can also combine with trickling filter which gives the combination of anaerobic plus aerobic treatment. Also study the pH and alkalinity effect on the both reactor performance for treatment of waste water treatment.

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APPENDIX : A

CHEMICAL OXYGEN DEMAND

A.1.Theory

Chemical Oxygen Demand is the oxygen require for the chemical oxidation of organic matter by strong chemical oxidant ($K_2Cr_2O_7$) under acidic condition. The degree of oxidation depends upon the type of substance, ph value, temperature, reaction time and the concentration of oxidizing agent.

The main disadvantage of this test is that oxygen is also consumed by oxidation of inorganic substance such as nitrites, chlorides,sulphides, reduced metal ions. Also some of the organic materials like amino acids, ketones, or saturated carboxylic acids, benzene, pyridine etc are not oxidized by dichromate. Consequently this test is a poor measure of strength of organic wastes unless all these factors are considered.

One of the chief limitations of COD test is its inability to differentiate between biologically inert organic matter. In addition it does not provide any evidence of the rate at which biologically active material would be stabilized under condition that exist in nature.

The major advantages of COD test is the short time required for evaluation. The determination can be made in about three hours rather than 5 days require for measurement of BOD.

A.2. Practical Relevance of Experiment and Application of Data:

COD test can often be interpreted in terms of BOD values after sufficient experience has been accumulated to establish reliable correlation factors. The COD test is used extensively in the analysis of industrial waste water. The test is widely used in the operation of treatment facilities because of the speed with which the results can be obtain.

A.3. Application of COD Data in Environmental Engineering Practices:

1. The COD test is used extensively in the analysis of industrial wastes.
2. It is particularly useful in design to determine and control the losses in sewer system.
3. This test is widely used in place of BOD test in operation of treatment facilities because of the speed with which the results can be obtained.
4. It is useful to asses the strength of the wastes which contain toxins and biologically resistant organic substances.
5. The ratio of BOD to COD is useful to asses the amenability of the waste for biological treatment.
6. BOD/COD >0.8 indicates highly biodegradable waste and BOD / COD <0.3 indicates biologically inert waste.

A.4.Principle:

The organic matter present in the sample gets oxidized completely by $K_2Cr_2O_7$ in the presence of H_2SO_4 to produce CO_2 and H_2O. The excess $K_2Cr_2O_7$ remaining after the reaction is titrated with Standard Ferrous Ammonium Sulphate as titrant and Ferrion as indicator. The colour change is from green to red wine. The dichromate consumed gives the oxygen required for the oxidation of the organic matter.

A.5.Apparatus :

Reflux apparatus consisting of 250 ml Erlenmeyer flask or standard glass tubes with ground glass neck or equivalent condenser to fit within the ground glass neck of tubes of flask.

1. Heating plate to produce at 9 watts/sq.in. of heating surface a equivalent of insure adequate boiling of the contents of the refluxing flasks.
2. Glass beds.
3. Titration flask.
4. Pipette and Burette.

A.6.Reagents:

1. Standard potassium dichromate solution 0.25 N
2. Standard Ferrous Ammonium Sulphate titrant (0.1N)
3. Sulphuric acid reagent
4. Silver sulphate ($AgSO_4$)
5. Mercuric sulphate
6. Ferrion indicator

A.7.Procedures:

1. Place 0.4 gram $HgSO_4$ in the reflux flask.
2. Add 4 ml sample.
3. Add 10 ml standard potassium dichromate solution and several preheated glass bends in refluxing flask.
4. Slowly mix 30 ml of conc. Sulphuric acid containing silver sulphate to the flask.
5. Connect flask with condenser tube.
6. Mix the contents thoroughly before heating.
7. Reflux the sample for a minimum period of 2 hours.
8. Allow it to cool down and wash condenser with distilled water.
9. Dilute the sample with distilled water to make up to 150 ml cool down to room temperature.
10. Titrate excess dichromate with standard ferrous ammonium sulphate using 2 to 3 drops of ferrion indicator.
11. The end point of titration is indicated by colour change from blue green to reddish brown.(even thought the blue green colour may reappear with in minutes)
12. Reflux the blank in the same manner using distilled water instead of sample.

A.8. Calculation:

$$\text{COD of sample in mg/lit} = \frac{(A-B) \times N \times 8000}{\text{ml of sample taken}}$$

Where, A = ferrous ammonium sulphate used for blank

B = ferrous ammonium sulphate used for blank

N = Normality ferrous ammonium sulphate used

Source

1.Maiti, " Handbook of methods in Environmental Studies", Analysis of Water & Effluents , Pg. No. 60-66.

APPENDIX : B

TOTAL SUSPENDED SOLIDS

B.1. Theory:

The suspended solids in waste water may consists of organic matter or inorganic matter. The organic material retained on filter on evaporation at 105^0 C gives the quantity of total suspended solids.

B.2. Application of total suspended solid data:

1. The suspended solids parameter is used to measure the quality of waste water influent and effluent.
2.The suspended solid determination is extremely valuable in the analysis of polluted water.
3. It is used to evaluate the strength of domestic waste water.
4.It is used to determine the efficiency of treatment units.

B.3.Principle:

Total suspended solids are determined as the residue left on gooch crucible or a glass fiber filter after drying in oven.

B.4. Apparatus:

1.Oven
2.Dessicators
3.Whatman filter paper no. 44
4. Funnel and other glassware

B.5.Procedures:

1. Weigh a clean and dry Whatman filter paper no.44. Let this weigh=W1
2. Clean and oven dry the glass funnel at temperature = 105^0 C.

3. Shape and place the Whatman filter paper no. 44 into the funnel.
4. Pour known volume of sample into the funnel slowly and allow it to filter.
5. After filteration carefully remove the filter paper and dry it in an oven at 105^0C for one hour
6. Cool the filter paper in desiccators and weigh it as W2.
7. The increase in weight gives the quantity of suspended solids for the volume of sample.

Suspended solids (mg/l) = (Increase in weight in (mg) * 1000)/ ml of sample

Source

1. Maiti, " Handbook of methods in Environmental Studies" , Analysis of Water & effluents, Pg. No.144-145.

APPENDIX: C

VOLATILE FATTY ACID

C.1. Principle:

Volatile fatty acid are classified as water soluble fatty acids that can be distillate at atmosphere pressure this techniques recovers acids containing up to six carbon atom .The VFA are determined by heat distillation following by titration of condensate with a strong base such as NaOH using phenolphthalein as an indicator.

C.2. Apparatus:

1.Centrifuge, with head to carry 50 ml tubes or 250 ml tubes.
2. Distillation assembly : distillation flask, 500 ml capacity ,condenser, adaptor.

C.3.Reagents :

1.Sulphuric acid (0.1 N)
2.Standard NaOH titrant (0.1 N)
3. Phenolphthalein as an indicator

C.4.Procedures:

1. Take 200 ml sample and centrifuge filter it.
2. Collect supernatant and place exactly 100 ml supernatant liquor in a 500 ml distillation flask.
3. Add 100 ml distilled water few glass beds or similar material to prevent bumping and 5 ml H_2SO_4.
4. Mix well so that acid does not remain in the bottom of flask.
5. Connect distillation flask to a condenser and adapter and distill at the rate of about 5 ml / min.

6. Discard first 15 distillate.
7. collect exactly 150 ml distillate in a 500 ml conical flask.
8. Titrate the distillate with 0.1 N NaOH titrant using phenolphthalein as an indicator. At the end point the color changes to pink.

C.5. Calculation:

VFA as acetic acid , mg/l = (ml NaOH * N* 60000)/ml of sample

Source

1.Maiti, " Handbook of methods in Environmental Studies" , Analysis of Water & effluents, Pg. No. 210- 214.

APPENDIX: D
ALKALINITY TEST

D.1.Theory:

Alkalinity is a measure off all the substances in water which have the ability to react with the acids in water and "buffer" the ph. That is the power to keep the ph from changing. Pure water would have a pH of 7 and therefore has no alkalinity. Alkalinity is important for aquatic life because it protects or "buffer" much as a Tumsor Alka Seltzer does in your stomach. It keeps the pH from changing and makes the water less affected by factors such as acid rain or acid spills. The main source of alkalinity in water are rocks which contain carbonates or bicarbonates and respiration. Limestone is a good example of this type of rock. Water with a total alkalinity of 100-200 ppm is considered to be the best water for fish and aquatic organisms.

D.2. Reagents:

The reagents used in testing the alkalinity of water are as follows : Phenolphthalein indicator solution , Methyl Purple Indicator solution. Methyl orange Indicator solution, Standard Sulphuric Acid (N/50)

D.3.Procedure with methyl orange

1. Measure 100 ml of the clear sample into an evaporating dish or Erlenmeyer flask.
2. Add 4 drops of phenolphthalein indicator. If a pink or red color develops, phenolphthalein alkalinity is present .
3. Fill the burette with the acid and add to the sample slowly just until the pink color disappear.
4. record the ml of acid is used.
5. Now add 2 to 4 drops of methyl orange indicator.
6. Continue titration adding the acid in 0.5 ml portion until the reddish color that appears where the acid hits the sample begins to persist.
7. Then continue the addition more slowly, about 3 drops at a time until the first pinkish tinge is seen throughout the sample.

D.4. Procedure with methyl purple

1.Measure 100 ml of the clear sample into an evaporating dish or Erlenmeyer flask.

2.Add 4 drops of phenolphthalein indicator, if a pink or red color develops, phenolphthalein alkalinity is present.

3. Fill the burette with acid and add to the sample slowly just until the pink color disappears.

4.record the ml of acid used.

5. Now add 2 to 4 drops of methyl purple indicator.

6.Continue titration adding the acid in 0.5 ml portion until a greenish tint appears where the acid hits the sample. The color will change from green to gray and then to purple. The appearance of the purple tint marks the end point. Record the total ml of acid require to reach this point . This includes the ml of acid used in the phenolphthalein alkalinity titration and that used in that used in methyl purple titration.

Source : http://www.enercon /testing/Testing DF/ET-001.pdf