DOWNLOAD PDF ANAEROBIC TREATMENT IN TROPICAL COUNTRIES (WATER SCIENCE TECHNOLOGY)

Chapter 1 : Faculty and Staff Biography Profile

In developing tropical countries, where the conventional aerobic processes are not extensively used because of the costs involved, the direct utilization of new anaerobic treatment technology becomes even more attractive.

 Abstract The upflow anaerobic sludge blanket UASB reactor has been recognized as an important wastewater treatment technology among anaerobic treatment methods. The objective of this study was to perform literature review on the treatment of domestic sewage using the UASB reactor as the core component and identifying future areas of research. The merits of anaerobic and aerobic bioreactors are highlighted and other sewage treatment technologies are compared with UASB on the basis of performance, resource recovery potential, and cost. The comparison supports UASB as a suitable option on the basis of performance, green energy generation, minimal space requirement, and low capital, operation, and maintenance costs. The main process parameters such as temperature, hydraulic retention time HRT , organic loading rate OLR , pH, granulation, and mixing and their effects on the performance of UASB reactor and hydrogen production are presented for achieving optimal results. The quantity and strength of wastewater are governed by the size and socioeconomic condition of the population of the area [2]. The composition of sewage varies greatly and its characterization is important for determining the size and designing of treatment plant [3]. Table 1 provides an overview of characteristics of municipal sewage in various cities of the world. Characteristics of sewage in different cities of the world. Anaerobic treatment is preferred to treat municipal wastewater because of its merits over conventional treatment methods [1]. These advantages are i its ability to treat high COD loads and withstand fluctuation in the influent, ii biogas formation, and iii effective treatment of wastewater in a short period of time [4]. Anaerobic reactors reduce pollution load and provide good stabilization of solids. Furthermore, depending on the design of a UASB reactor, a high sludge hold-up time can be obtained so that the excess sludge needs to be discharged only once every three to four years [5]. The comparison of aerobic and anaerobic technologies is given in Table 2. Comparison of aerobic and anaerobic treatment methods. The major achievement in the development of anaerobic treatment was the introduction of high rate reactors in which biomass retention and liquid retention were not interlinked [5]. Among the various anaerobic wastewater treatment technologies, upflow anaerobic sludge blanket UASB reactors have achieved considerable success and these reactors have been applied to treat a wide range of effluents such as sugar, pulp and paper, dairy, chemical, potato starch, bean balancing, soft drinks, fish processing, noodle processing, yeast production, slaughterhouse, and coffee processing industries [6 â€" 8]. It is primarily used for the treatment of highly concentrated industrial wastewaters [7 â€" 9]; however, it can also be used for the treatment of low strength wastewater such as municipal wastewater with relatively lower contaminant strength [10 â€" 14]. As compared to aerobic technologies anaerobic treatment systems such as UASB are being encouraged because of several advantages, including plain design, uncomplicated construction and maintenance, small land requirement, low construction and operating cost, low excess sludge production, robustness in terms of COD removal efficiency, ability to cope with fluctuations in temperature, pH and influent concentration, quick biomass recovery after shutdown, and energy generation in the form of biogas or hydrogen [1 , 9 , 15 â€" 19]. These characteristics make UASB a popular wastewater treatment option [20 , 21] and a large number of researchers have recommended UASB technology for the treatment of sewage wastewater in tropical and subtropical regions [10 â€" 12 , 14 , 22 â€" 24]. It is particularly appealing in tropical countries where the comparatively high ambient temperature is nearly optimum for the mesophilic methanogenic bacteria [11 , 13]. Significant efforts were made in the past twenty years to ascertain the mass transfer and kinetic processes going on in the reactor. In this study, the advantages and disadvantages of anaerobic and aerobic bioreactors are highlighted and comparison is made of UASB with other sewage treatment methods to state their feasibility and efficiency in domestic wastewater treatment and identify possible future areas of research. The effects of main process parameters, temperature, HRT, OLR, pH, granulation, and mixing on the performance of UASB reactors and hydrogen production are provided for optimal growth of bacteria and performance of the system. Appropriate posttreatment options are also identified to be potentially used in developing countries having appropriate climate conditions. Upflow Anaerobic Sludge Blanket Reactor Process Wastewater to be treated is introduced from the bottom of the reactor and it flows upward through a blanket of biologically activated sludge, which is generally in the form of granular aggregates. The sludge aggregates have very good stability and do not get washed out under practical conditions and therefore provide good treatment efficiency when the wastewater comes in contact with the granules [25]. The gases methane and carbon dioxide produced under anaerobic conditions cause internal mixing, which helps in the formation and maintenance of biological granules. However, some of the gas produced in the sludge blanket is attached to the granules, and a gas-liquid-solid separator GLSS is added on the top of the reactor for the effective segregation of gas, liquid, and granules. In GLSS, the gas surrounded particles strike with the bottom of degassing baffles and fall back into the sludge blanket and the treated water flows out of the reactor [21 , 26 , 27]. There is lower gas production in sewage as compared to high strength wastewater, which leads to less circulation of gas to support the formation of biological granules. Therefore, control of channeling is important for weaker wastewaters like sewage [6 , 13]. Treatment Potential of UASB Process UASB technology has been effectively used for the treatment of a wide range of wastewaters but is generally inhibited by incomplete biodegradability of complex wastewaters [10 , 28]. The UASB technology has been found to be very effective for the treatment of wastewater with a high content of carbohydrates. Carbohydrate rich organic wastewater, such as starch or canning industry wastewater is easily digested by microbes and is thus a nutrient-rich starting material for anaerobic hydrogen production. Upflow anaerobic sludge blanket UASB reactor has therefore turned out to be one of the most popular designs for the treatment of wastewaters from food processing industries. Anaerobic reactors have the ability to withstand variations in wastewater quality and complete shutdown of reactor in off season [28 , 29]. The microbial distribution in granules was found strongly dependent on the thermodynamics of degradation and kinetics of particular substrates. The results reveal that granules are developed through evolution process and not through random aggregation of suspended microbes [29]. Moreover, as supported by experimental evidence biogranules degrading carbohydrates are more resistant than suspended sludge to the toxicity of hydrogen sulfide, heavy metals, and aromatic pollutants in wastewater [30]. About half the organic matter content in domestic wastewater is attributable to black water having a major portion of nutrients. A number of full-scale plants are operational and several others are at present under construction, especially in tropical or subtropical areas [33 , 34]. Table 3 summarizes the advantages and disadvantages of UASB reactor. Basic concept of UASB technique is to build up anaerobic sludge that has good settling characteristics [1] and that can hold highly active bacterial aggregation without the requirement for immobilization on a support material [35]. About UASB reactors are installed worldwide showing the widest application of this technology out of total of approximately other anaerobic applications which include anaerobic contact filter, Expanded Granular Sludge Bed EGSB reactor, hybrid reactor, and fluidized bed. About half of these installations out of are in tropical and subtropical regions [38]. Table 4 shows the performance of UASB reactors as compared to other technologies. On the basis of overall low investment and O and M costs, satisfactory COD, BOD, and TSS removal, and energy generation potential, this technology is suitable as compared to other technologies especially in developing countries. New research studies in this area have proven the successful operation of this system to treat low strength wastewater [12 , 39]. The concentration of COD in domestic wastewater is usually low and suspended solids are high along with low methane yield that requires initial hydrolysis to convert the suspended solids into soluble substrate. Hydrolysis is commonly the limiting step at low temperature setting. Therefore, the UASB reactors for domestic wastewater treatment having high level of suspended solids are practicable only at higher temperature which may require an outside heat source [32 , 40]. Better process understanding and operational knowledge on granules structure have made it possible to apply high organic loads and resulted in reducing startup time and providing a more sustainable operation [40 , 41]. Its performance in the world proves it to be a consistent and efficient system for wastewater treatment [1]. Advantages and disadvantages of UASB reactor technology. Performance comparison of UASB with other wastewater treatment technologies. Resource Recovery Potential Anaerobic technologies have the ability to recover the chemical energy of organic carbon in wastewater as methane, hydrogen, and electricity. In UASB reactor, solids are captured and organic matter is converted into biogas consisting largely of methane and carbon dioxide. Organically bound nitrogen is transformed to ammonium and sulfate is reduced to hydrogen sulfide. Moreover, sludge generation is low and sludge produced is highly stable with good dewaterability characteristics [42]. Under aerobic conditions, there is a complete loss of biomass energy in low value heat during the oxidation of organic matter, whereas under anaerobic degradation process, the original energy of the biomass is not changed. Depending on the extent to which anaerobic conversion is permitted, this energy is captured in the form of methane, hydrogen, other gases, or liquid compounds such as alcohols. Energy recovery is an old process which exists as alcohol fermentation and is now renewed by the production of biofuels from organically rich substrates [43]. In terms of carbon foot print, anaerobic wastewater treatment is more advantageous, based on the relative efficiency of the aerobic system Table 2. The recovery of dissolved methane in effluents in an economic way makes anaerobic wastewater treatment favorable in reducing carbon foot print for all wastewater strengths [44 , 45]. CH_4 produced in the reactor should always be used for energy production and methane dissociation in the effluent and sulfate reduction must be examined. As a result the benefits of energy production are reduced significantly. In case of high sulfate or sulfite content, sulfate reducing bacteria compete with the methanogens for methanogenic substrates and therefore the amount of methane generated is decreased [3]. In the United States and other developed countries, methane generated from anaerobic digestion is combusted for energy production, at large treatment plants, and is at least flared and converted to CO_2 at smaller plants [47]. Increased biogas production, efficient biogas usage, and in turn decreased addition of external fossil will lead to reduction of carbon footprint of a wastewater treatment plant [48]. The major problem in hydrogen production from biological processes is the low production rates and hydrogen yield at a large scale. Present research on hydrogen fermentation is directed towards determining culture details, beneficial substrates, conditions affecting microbial conversions, sequential fermentation, combined fermentation, mixed culture fermentation, optimizing enrichment, and stability of acidogenic sludge and reaction kinetics [49 , 50]. On the other hand, HLa and HPr are undesirable and consuming hydrogen pathways [51]. Potential of hydrogen production is now being realized by using domestic wastewater in anaerobic reactors [52 , 53]. Similarly, Paudel et al. The operational conditions play a crucial role in hydrogen production. A pH of about 5. For both high rate hydrogen production and organics removal, organic acids generated in effluent can be methanized in a methanogenic reactor after hydrogenic reactor and energy generated from hydrogen may be utilized in posttreatment units where anaerobic reactor is the core technology for sewage treatment [53]. Use of inoculum previously adapted to hydrogen production greatly enhances hydrogen rate and yield as compared to nonadapted one. In mixed culture, hydrogen producing bacteria may consume the hydrogen produced and they need to be removed to curtail hydrogen consumers and enrich hydrogen producers [52 â€” 54]. Previous studies do not show an optimal range of HRT and OLR in fermentative hydrogen production due to varying environmental process parameters or ranges of the variables reported in literature. The optimum temperature for hydrogen production through dark fermentation depends on the type of hydrogen producing bacteria and carbon source used [55]. Hydrogen producing bacteria belong to mesophilic and thermophilic groups and generally rate of hydrogen production increases with increase in temperature through thermophilic bacteria compared to mesophilic bacteria [56]. Mu and Yu [57] demonstrated that hydrogen could be generated continuously and steadily from an acidogenic-granule-based UASB reactor at varying concentration of substrate 5. They found that H_2 partial pressure in biogas decreased with increasing substrate concentration; however it was not affected by the change of HRT in a range of

6â€”22 h. The rate of hydrogen production increased with increasing substrate concentration but decreased with increasing HRT with a hydrogen yield in the range of 0. Furthermore, research is underway on directly producing electric current from electrons released in anaerobic fermentation. These electrons are scavenged at an anode and with the use of cathode under oxidizing conditions electric current is generated which can be used in decentralized plants directly without any further conversion process [58 , 59]. Posttreatment Requirements The UASB reactors do not warrant the removal of remaining organic matter, nutrients, and pathogens. Therefore, posttreatment of anaerobically treated wastewater is usually required in order to improve the quality of effluent in accordance with the irrigation standards. This has been successfully done by conventional systems such as maturation ponds, waste stabilization ponds, polishing ponds, constructed wetlands, rotating biological contactors, moving bed biofilm reactor, downflow hanging sponge [60 â€” 62], and advanced oxidative processes AOPs [63 , 64]. Polishing ponds are natural systems mainly for removal of solids which have been effectively used for the posttreatment of upflow anaerobic sludge blanket UASB effluents. They are mainly used as maturation ponds for the removal of pathogens, nitrogen, and remaining organic matter from the UASB reactor effluent [65]. The use of sequential anaerobic-aerobic technology such as UASB-activated sludge for municipal wastewater treatment combines the benefits of both systems in an economical arrangement. The combined system is energy efficient, less sludge producer, and relatively less complex for domestic wastewater treatment as compared to other options. An added advantage is the biological oxidization of the dissolved methane; however, the overall greenhouse gas reduction will depend on the energy consumption of aerobic step [44 , 66]. The UASB and posttreatment system can be applied consecutively or in an integrated manner. Effect of Different Parameters on the Efficiency of UASB Reactor The efficiency of UASB reactors is regulated by a large number of factors including wastewater characteristics, acclimatization of seed sludge, pH, nutrients, presence of toxic compounds, loading rate, upflow velocity , hydraulic retention time HRT , liquid mixing, and reactor design that affect the growth of sludge bed [16 , 67 â€” 69].

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Chapter 2 : Full-Scale application of the UASB technology for sewage treatment

Based mainly on papers presented at the 'VI Latin-American Workshop and Seminar on Anaerobic Digestion' held in Recife, Brazil, in November , this text approaches the perspectives of anaerobic treatment of wastewaters in developing countries.

Anaerobic respiration Many microorganisms affect anaerobic digestion, including acetic acid-forming bacteria acetogens and methane-forming archaea methanogens. These organisms promote a number of chemical processes in converting the biomass to biogas. Anaerobes utilize electron acceptors from sources other than oxygen gas. These acceptors can be the organic material itself or may be supplied by inorganic oxides from within the input material. Therefore, common practice is to introduce anaerobic microorganisms from materials with existing populations, a process known as "seeding" the digesters, typically accomplished with the addition of sewage sludge or cattle slurry. For the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts, or monomers, such as sugars, are readily available to other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore, hydrolysis of these high-molecular-weight polymeric components is the necessary first step in anaerobic digestion. Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules, such as volatile fatty acids VFAs with a chain length greater than that of acetate must first be catabolised into compounds that can be directly used by methanogens. Here, VFAs are created, along with ammonia, carbon dioxide, and hydrogen sulfide , as well as other byproducts. Acetogenesis The third stage of anaerobic digestion is acetogenesis. Here, simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, as well as carbon dioxide and hydrogen. Here, methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. These components make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pHs and occurs between pH 6. Configuration[edit] Anaerobic digesters can be designed and engineered to operate using a number of different configurations and can be categorized into batch vs. More initial build money and a larger volume of the batch digester is needed to handle the same amount of waste as a continuous process digester. Above this level is considered high solids content and can also be known as dry digestion. A multistage process utilizes two or more reactors for digestion to separate the methanogenesis and hydrolysis phases. In a batch system, biomass is added to the reactor at the start of the process. The reactor is then sealed for the duration of the process. In its simplest form batch processing needs inoculation with already processed material to start the anaerobic digestion. In a typical scenario, biogas production will be formed with a normal distribution pattern over time. Operators can use this fact to determine when they believe the process of digestion of the organic matter has completed. There can be severe odour issues if a batch reactor is opened and emptied before the process is well completed. A more advanced type of batch approach has limited the odour issues by integrating anaerobic digestion with in-vessel composting. In this approach inoculation takes place through the use of recirculated degasified percolate. After anaerobic digestion has completed, the biomass is kept in the reactor which is then used for in-vessel composting before it is opened [28] As the batch digestion is simple and requires less equipment and lower levels of design work, it is typically a cheaper form of digestion. In continuous digestion processes, organic matter is constantly added continuous complete mixed or added in stages to the reactor continuous plug flow; first in â€” first out. Here, the end products are constantly or periodically removed, resulting in constant production of biogas. A single or multiple digesters in sequence may be used. Examples of this form of anaerobic digestion include continuous stirred-tank reactors , upflow anaerobic sludge blankets , expanded granular sludge beds , and internal circulation reactors. The anaerobic process is very slow, taking more than three times the normal mesophilic time process. Mesophilic systems are, therefore, considered to be more stable than thermophilic digestion systems. In contrast, while thermophilic digestion systems are considered less stable, their energy input is higher, with more biogas being removed from the organic matter in an equal amount of time. The increased temperatures facilitate faster reaction rates, and thus faster gas yields. Operation at higher temperatures facilitates greater pathogen reduction of the digestate. In countries where legislation, such as the Animal By-Products Regulations in the European Union, requires digestate to meet certain levels of pathogen reduction there may be a benefit to using thermophilic temperatures instead of mesophilic. For example, certain processes shred the substrates to increase the surface area or use a thermal pretreatment stage such as pasteurisation to significantly enhance the biogas output. The pasteurisation process can also be used to reduce the pathogenic concentration in the digesate leaving the anaerobic digester. Pasteurisation may be achieved by heat treatment combined with maceration of the solids. Solids content[edit] In a typical scenario, three different operational parameters are associated with the solids content of the feedstock to the digesters: Unlike wet digesters that process pumpable slurries, high solids dry â€” stackable substrate digesters are designed to process solid substrates without the addition of water. The primary styles of dry digesters are continuous vertical plug flow and batch tunnel horizontal digesters. Continuous vertical plug flow digesters are upright, cylindrical tanks where feedstock is continuously fed into the top of the digester, and flows downward by gravity during digestion. In batch tunnel digesters, the feedstock is deposited in tunnel-like chambers with a gas-tight door. Neither approach has mixing inside the digester. The amount of pretreatment, such as contaminant removal, depends both upon the nature of the waste streams being processed and the desired quality of the digestate. Size reduction grinding is beneficial in continuous vertical systems, as it accelerates digestion, while batch systems avoid grinding and instead require structure e. Continuous vertical dry digesters have a smaller footprint due to the shorter effective retention time and vertical design. The thickness of the material may also lead to associated problems with abrasion. High solids digesters will typically have a lower land requirement due to the lower volumes associated with the moisture. Low solids digesters require a larger amount of land than high solids due to the increased volumes associated with the increased liquid-to-feedstock ratio of the digesters. There are benefits associated with operation in a liquid environment, as it enables more thorough circulation of materials and contact between the bacteria and their food. This enables the bacteria to more readily access the substances on which they are feeding, and increases the rate of gas production. Using a single stage reduces construction costs, but results in less control of the reactions occurring within the system. Acidogenic bacteria, through the production of acids, reduce the pH of the tank. Methanogenic bacteria, as outlined earlier, operate in a strictly defined pH range. Another one-stage reaction system is an anaerobic lagoon. These lagoons are pond-like, earthen basins used for the treatment and long-term storage of manures. In a two-stage digestion system multistage , different digestion vessels are optimised to bring maximum control over the bacterial communities living within the digesters. Acidogenic bacteria produce organic acids and more quickly grow and reproduce than methanogenic bacteria. Methanogenic bacteria require stable pH and temperature to optimise their performance. The organic material is then heated to the required operational temperature either mesophilic or thermophilic prior to being pumped into a methanogenic reactor. The initial hydrolysis or acidogenesis tanks prior to the methanogenic reactor can provide a buffer to the rate at which feedstock is added. Some European countries require a degree of elevated heat treatment to kill harmful bacteria in the input waste. Notably, it is not possible to completely isolate the different reaction phases, and often some biogas is produced in the hydrolysis or acidogenesis tanks. Residence time[edit] The residence time in a digester varies with the amount and type of feed material, and with the configuration of the digestion system. The plug-flow nature of some of these systems will mean the full degradation of the material may not have been realised in this timescale. In this event, digestate exiting the system will be darker in colour and will typically have more odour. In this manner, a UASB system is able to separate solids and hydraulic retention times with the use of a sludge blanket. They also allow excess material to be continuously extracted to maintain a reasonably constant volume within the digestion tanks. The degree of the inhibition depends, among other factors, on the concentration of the inhibitor in the digester. Potential inhibitors are ammonia, sulfide, light metal ions Na, K, Mg, Ca, Al , heavy metals, some organics chlorophenols, halogenated aliphatics, N-substituted aromatics, long chain fatty acids , etc. Two-stage, low solids, UASB digestion component of a mechanical biological treatment system near Tel Aviv ; the process water is seen in balance tank and sequencing batch reactor , Feedstocks[edit] Anaerobic lagoon and generators at the Cal Poly Dairy, United States The most important initial issue when considering the application of anaerobic digestion systems is the feedstock to the process. Almost any organic material can be processed with anaerobic digestion; [46] however, if biogas production is the aim, the level of putrescibility is the key factor in its successful application. Feedstocks can include biodegradable waste materials, such as waste paper, grass clippings, leftover food, sewage, and animal waste. Xylophalgeous anaerobes lignin consumers or using high temperature pretreatment, such as pyrolysis, can be used to break lignin down. Anaerobic digesters can also be fed with specially grown energy crops , such as silage , for dedicated biogas production. In Germany and continental Europe, these facilities are referred to as "biogas" plants. A codigestion or cofermentation plant is typically an agricultural anaerobic digester that accepts two or more input materials for simultaneous digestion. Material rich in easily digestible sugars breaks down quickly, whereas intact lignocellulosic material rich in cellulose and hemicellulose polymers can take much longer to break down. Sewage and manure are not, however, the material with the most potential for anaerobic digestion, as the biodegradable material has already had much of the energy content taken out by the animals that produced it. Therefore, many digesters operate with codigestion of two or more types of feedstock. For example, in a farm-based digester that uses dairy manure as the primary feedstock, the gas production may be significantly increased by adding a second feedstock, e. Drier, stackable substrates, such as food and yard waste, are suitable for digestion in tunnel-like chambers. Tunnel-style systems typically have near-zero wastewater discharge, as well, so this style of system has advantages where the discharge of digester liquids are a liability. The wetter the material, the more suitable it will be to handling with standard pumps instead of energy-intensive concrete pumps and physical means of movement. Also, the wetter the material, the more volume and area it takes up relative to the levels of gas produced. The moisture content of the target feedstock will also affect what type of system is applied to its treatment. To use a high-solids anaerobic digester for dilute feedstocks, bulking agents, such as compost, should be applied to increase the solids content of the input material. This ratio is the balance of food a microbe requires to grow; the optimal C: N ratio is 20â€” If the feedstock to the digesters has significant levels of physical contaminants, such as plastic, glass, or metals, then processing to remove the contaminants will be required for the material to be used. It is with this understanding that mechanical biological treatment plants are designed. The higher the level of pretreatment a feedstock requires, the more processing machinery will be required, and, hence, the project will have higher capital costs.

Chapter 3 : Anaerobic technology for fish processing wastewater treatment: a cost saving approach.

Anaerobic biological treatment systems represent a sustainable technology for treating industrial waste streams, which relies on the formation of syntrophic microbial communities in either suspended or immobilized forms.

Amol Lomte Veena Vyas Paper no. This led to growing interest in developing new or modifying existing anaerobic wastewater treatment technologies. Having a lot of advantages such as less energy and very small sludge formation as compared to conventional wastewater treatment methods, anaerobic treatment is the obvious choice nowadays. A simple septic tank method is being used from ancient times. Since then there have been significant advances in reactor design. Among these UASB technology is the most widely used trend in recent years. UASB offers a continuous operation with large loading rates in short retention times. Gas generated in the form of methane can be used for energy generation. This paper reviews all the designs of UASB reactor and their suitability for application in tropical and subtropical regions. An attempt has been made to resolve most of the existing challenges in design as well as operation of UASB by reviewing recent work in this area. Introduction Developing countries like India have shown a huge rise in its infrastructure development this decade. This implies a significant increase in small as well as large scale industries. Water has always been the source for such developments since ancient times. All the major cities and industries have always thrived near natural sources of water. This produces a large amount of wastewater which cannot be used for any other purpose. In the early years, when industrial development was comparatively less, wastewater was directly disposed in the surrounding. With a huge industrial and urban development today, direct disposal of wastewater without any treatment is causing environmental as well as health hazards. This has resulted in contamination of land, water resources and air. To prevent this, government has imposed consent limits for the quality of wastewater being released. This varies depending on the type of industry. Due to this, the importance of water treatments methods has increased a lot. There are two basic types of water treatment methods, aerobic and anaerobic. Aerobic treatment involves degradation of wastewater into sludge using oxygen from air whereas anaerobic treatment involves degradation wastewater without using any oxygen to produce methane, carbon dioxide and a little amount of sludge. Anaerobic treatment has a lot of advantages over aerobic treatment which is shown in table 2. Wastewater consent limits Sr. Advantages of anaerobic over aerobic process Sr. Parameter Aerobic Anaerobic No. Following are some of the benefits and drawbacks of anaerobic wastewater treatment over conventional aerobic methods as given by Lettinga et al [1]. Very low production of excess sludge. Low nutrients are required for bacterial culture. No energy requirements in the form of aeration. Methane is produced which can be used as a fuel. This process can frequently handle high loads. Anaerobic sludge can be preserved without any feed for months before causing any serious deterioration. Nitrogen is retained in the water which can be beneficial for the purpose of irrigation. Anaerobic bacteria particularly methanogens are very susceptible to inhibition by a large number of compounds. The start-up of the process is slow which can be avoided by using adapted seed sludge. This process requires an adequate post treatment for the removal of remaining BOD, nitrogen and odorous compounds. McCarty noted that anaerobic treatment technologies are in practice from as early as Some of the most common anaerobic reactors used in the industry are septic tanks in old times, upflow anaerobic sludge blanket UASB reactor, expanded granular sludge bed reactor which is adaptation of UASB reactor, etc [2]. UASB is a high rate reactor system without any moving parts. It may be cylindrical or rectangular in shape. Above the baffles is a settling zone where a dome or funnel is inserted in inverted manner. This is used for collecting the gas produced in the reactor. Reactor is sealed at both ends to maintain anaerobic conditions. A typical schematics of UASB reactor is shown in figure 1. Schematic of UASB reactor [3]. However there are some limiting factors. Presence of certain components in the influent has inhibitory effect on the process. Excess of volatile fatty acids, which lacks in alkalinity in the influent, leads to acidification of the reactor causing reactor failure in case of high load reactors. This can be avoided by dilution of influent or by adding alkalinity. High concentration of suspended solids reduces settleability of sludge leading to biomass washout. For this upflow velocity needs to be monitored. All the limitations due to influent composition can be avoided by using suitable pretreatment methods. There are some operational limitations like delay in startup and granule formation. Startup time decides the effectiveness and stability of UASB. This depends on characteristics of water, operating parameters and growth of microbial population in sludge. The reactor cannot be operated at full design organic loading rates before an acclimatization period to inoculate the seed sludge. This can be speeded up by using pretreated sludge inoculum. The choice of best inoculum source depends on toxicity and biodegradability test of wastewater [4,5]. Some nutrients can also be added in order to increase the stability of the reactor. Besides all this UASB alone cannot remove pathogens and coloring agents from the wastewater, hence significant post treatments are suggested for further treatment. Over the time, many flaws have been noticed in the design of early UASB reactor models. Later, a central sparger like assembly was suggested at the bottom for uniform distribution of water inside the reactor. However, special care should be taken to prevent clogging of pores of the sparger by sludge particles. It separates sludge granules from gas, allowing it to settle. Various new designs for GSS have been suggested to optimize its function so that the upflow velocity of wastewater can be increased without causing sludge washout. Normal GSS causes accumulation of solids in the upper part of the reaction vessel and entrapment and loss biogas through treated effluent exit. Alternate system proposed to prevent this is made up of three deflector plates attached to a central axle, 0 alternately positioned 1. Influent wastewater moving up will make a spiral movement, retaining the solids and separating the gas produced [6]. Another design suggests the inner tube type GSS. It consists of three inner tubes of conical shape through which gas bubbles pass creating a down flow stream on the outside which enhance the settling of sludge particles. Downstream is formed due to the density difference between inside and outside liquids. This type of arrangement rapidly separates sludge particles from rising gas bubbles, preventing formation of scum layer in the gas collection compartment [7]. A UASB reactor coupled with others of same or different types have shown promising increase in the overall efficiency. Usually, UASB reactor is often followed by another post treatment method but many have employed the pretreatment methods as well. The reactor itself can also be used as a single stage or double stage reactor [8]. This acts as a three phase separator where gas is collected at the top, liquid is withdrawn from the side at the top and solids in the form of granules are settled down at the bottom. Settling of solids downward and at the same time, formation of gas bubbles moving upward maintains the suspension zone within the reactor. This enhances the contact between microorganisms and wastewater molecules. Due to granulation in UASB reactor, the solids and hydraulic retention times can be manipulated independently and effectively, reducing the treatment times from days to hours [9]. Another advantage of UASB reactor includes no need of temperature control as heat is released during methanogenesis. This heat is sufficient to maintain mesophilic conditions inside the reactor. This is applicable in tropical regions only where room temperatures are 0 always above 20 C. Once fed or inoculated, it does not need any nutrients to be provided. However addition of nutrients may increase performance of the reactor. As a very little amount of sludge is produced, it can be withdrawn after a much longer period of time while a small portion may be recirculated. Some of them are explained below. Domestic Wastewater Treatment For more than years, septic tanks have been widely used for onsite anaerobic pretreatment of sewage. A significant development was achieved in the last two decades by applying upward flow and introducing GLS separator device at the top which resulted in UASB septic tank system. These reactors are operated at HRTs in the range of hours. Sugar industry Wastewater Treatment Sugarcane industry plays a vital role in social economics of rural agriculture based areas. Effluent generated in sugar mills when disposed directly causes pollution of surface or ground water. If this effluent is directly released for irrigation, it affects the soil fertility, plant growth and seed germination. It also affects soil micro flora [11]. Hence treatment of sugar industry effluent attains a high significance. Sugar industry effluents have high organic concentration hence they are very suitable to be used as a substrate in UASB reactor [18]. High concentration of carbohydrates corresponds to readily fermentative sugars. It also contains nitrogen and phosphorous essential for cultivation of microorganisms.

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Terminology[edit] The term "sewage treatment plant" or "sewage treatment works" in some countries is nowadays often replaced with the term wastewater treatment plant or wastewater treatment station. Alternatively, sewage can be collected and transported by a network of pipes and pump stations to a municipal treatment plant. This is called a "centralized" system see also sewerage and pipes and infrastructure. Origins of sewage[edit] Main article: Sewage Sewage is generated by residential, institutional, commercial and industrial establishments. It includes household waste liquid from toilets , baths , showers , kitchens , and sinks draining into sewers. In many areas, sewage also includes liquid waste from industry and commerce. The separation and draining of household waste into greywater and blackwater is becoming more common in the developed world, with treated greywater being permitted to be used for watering plants or recycled for flushing toilets. Sewage mixing with rainwater[edit] Sewage may include stormwater runoff or urban runoff. Sewerage systems capable of handling storm water are known as combined sewer systems. This design was common when urban sewerage systems were first developed, in the late 19th and early 20th centuries. Heavy volumes of storm runoff may overwhelm the sewage treatment system, causing a spill or overflow. Sanitary sewers are typically much smaller than combined sewers, and they are not designed to transport stormwater. Communities that have urbanized in the midth century or later generally have built separate systems for sewage sanitary sewers and stormwater, because precipitation causes widely varying flows, reducing sewage treatment plant efficiency. Some jurisdictions require stormwater to receive some level of treatment before being discharged directly into waterways. Examples of treatment processes used for stormwater include retention basins , wetlands , buried vaults with various kinds of media filters , and vortex separators to remove coarse solids. Industrial wastewater treatment In highly regulated developed countries, industrial effluent usually receives at least pretreatment if not full treatment at the factories themselves to reduce the pollutant load, before discharge to the sewer. This process is called industrial wastewater treatment or pretreatment. The same does not apply to many developing countries where industrial effluent is more likely to enter the sewer if it exists, or even the receiving water body, without pretreatment. Industrial wastewater may contain pollutants which cannot be removed by conventional sewage treatment. Also, variable flow of industrial waste associated with production cycles may upset the population dynamics of biological treatment units, such as the activated sludge process. Overview[edit] Sewage collection and treatment is typically subject to local, state and federal regulations and standards. Treating wastewater has the aim to produce an effluent that will do as little harm as possible when discharged to the surrounding environment, thereby preventing pollution compared to releasing untreated wastewater into the environment. Primary treatment consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment. Some sewage treatment plants that are connected to a combined sewer system have a bypass arrangement after the primary treatment unit. This means that during very heavy rainfall events, the secondary and tertiary treatment systems can be bypassed to protect them from hydraulic overloading, and the mixture of sewage and stormwater only receives primary treatment. Secondary treatment removes dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous , water-borne micro-organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro-organisms from the treated water prior to discharge or tertiary treatment. Tertiary treatment is sometimes defined as anything more than primary and secondary treatment in order to allow ejection into a highly sensitive or fragile ecosystem estuaries, low-flow rivers, coral reefs, Treated water is sometimes disinfected chemically or physically for example, by lagoons and microfiltration prior to discharge into a stream , river , bay , lagoon or wetland , or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes. Simplified process flow diagram for a typical large-scale treatment plant Process flow diagram for a typical treatment plant via subsurface flow constructed wetlands SFCW Pretreatment[edit] Pretreatment removes all materials that can be easily collected from the raw sewage before they damage or clog the pumps and sewage lines of primary treatment clarifiers. Objects commonly removed during pretreatment include trash, tree limbs, leaves, branches, and other large objects. The influent in sewage water passes through a bar screen to remove all large objects like cans, rags, sticks, plastic packets etc. The solids are collected and later disposed in a landfill, or incinerated. Bar screens or mesh screens of varying sizes may be used to optimize solids removal. If gross solids are not removed, they become entrained in pipes and moving parts of the treatment plant, and can cause substantial damage and inefficiency in the process. It also includes organic matter such as eggshells, bone chips, seeds, and coffee grounds. Pretreatment may include a sand or grit channel or chamber, where the velocity of the incoming sewage is adjusted to allow the settlement of sand and grit. Grit removal is necessary to 1 reduce formation of heavy deposits in aeration tanks, aerobic digesters, pipelines, channels, and conduits; 2 reduce the frequency of digester cleaning caused by excessive accumulations of grit; and 3 protect moving mechanical equipment from abrasion and accompanying abnormal wear. The removal of grit is essential for equipment with closely machined metal surfaces such as comminutors, fine screens, centrifuges, heat exchangers, and high pressure diaphram pumps. Grit chambers come in 3 types: Vortex type grit chambers include mechanically induced vortex, hydraulically induced vortex, and multi-tray vortex separators. Given that traditionally, grit removal systems have been designed to remove clean inorganic particles that are greater than 0. During periods of high flow deposited grit is resuspended and the quantity of grit reaching the treatment plant increases substantially. It is, therefore important that the grit removal system not only operate efficiently during normal flow conditions but also under sustained peak flows when the greatest volume of grit reaches the plant. Equalization basins may be used for temporary storage of diurnal or wet-weather flow peaks. Basins provide a place to temporarily hold incoming sewage during plant maintenance and a means of diluting and distributing batch discharges of toxic or high-strength waste which might otherwise inhibit biological secondary treatment including portable toilet waste, vehicle holding tanks, and septic tank pumpers. Flow equalization basins require variable discharge control, typically include provisions for bypass and cleaning, and may also include aerators. Cleaning may be easier if the basin is downstream of screening and grit removal. Air blowers in the base of the tank may also be used to help recover the fat as a froth. Many plants, however, use primary clarifiers with mechanical surface skimmers for fat and grease removal. Primary treatment[edit] Primary treatment tanks in Oregon, USA In the primary sedimentation stage, sewage flows through large tanks, commonly called "pre-settling basins", "primary sedimentation tanks" or "primary clarifiers ". Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank where it is pumped to sludge treatment facilities. Secondary treatment Secondary treatment is designed to substantially degrade the biological content of the sewage which are derived from human waste, food waste, soaps and detergent. The majority of municipal plants treat the settled sewage liquor using aerobic biological processes. To be effective, the biota require both oxygen and food to live. The bacteria and protozoa consume biodegradable soluble organic contaminants e. Secondary treatment systems are classified as fixed-film or suspended-growth systems. Fixed-film or attached growth systems include trickling filters , constructed wetlands , bio-towers, and rotating biological contactors , where the biomass grows on media and the sewage passes over its surface. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems. Tertiary treatment[edit] The purpose of tertiary treatment is to provide a final treatment stage to further improve the effluent quality before it is discharged to the receiving environment sea, river, lake, wet lands, ground, etc. More than one tertiary treatment process may be used at any treatment plant. If disinfection is practised, it is always the final process. It is also called "effluent polishing. These lagoons are highly aerobic and colonization by native macrophytes , especially reeds, is often encouraged. Small filter-feeding invertebrates such as Daphnia and species of Rotifera greatly assist in treatment by removing fine particulates. Biological nutrient removal[edit] Biological nutrient removal BNR is regarded by some as a type of secondary treatment process, [2] and by others as a tertiary or "advanced" treatment process. Wastewater may contain high levels of the nutrients nitrogen and phosphorus. Excessive release to the environment can lead to a buildup of nutrients, called eutrophication , which can in turn encourage the overgrowth of weeds, algae , and cyanobacteria blue-green algae. This may cause an algal bloom , a rapid growth in the population of algae. The algae numbers are unsustainable and eventually most of them die. The decomposition of the algae by bacteria uses up so much of the oxygen in the water that most or all of the animals die, which creates more organic matter for the bacteria to decompose. In addition to causing deoxygenation, some algal species produce toxins that contaminate drinking water supplies. Different treatment processes are required to remove nitrogen and phosphorus. Nitrogen removal[edit] Nitrogen is removed through the biological oxidation of nitrogen from ammonia to nitrate nitrification , followed by denitrification , the reduction of nitrate to nitrogen gas. Nitrogen gas is released to the atmosphere and thus removed from the water. Nitrification itself is a two-step aerobic process, each step facilitated by a different type of bacteria. Denitrification requires anoxic conditions to encourage the appropriate biological communities to form. It is facilitated by a wide diversity of bacteria. Sand filters, lagooning and reed beds can all be used to reduce nitrogen, but the activated sludge process if designed well can do the job the most easily. This can be, depending on the waste water, organic matter from feces , sulfide , or an added donor like methanol. The sludge in the anoxic tanks denitrification tanks must be mixed well mixture of recirculated mixed liquor, return activated sludge [RAS], and raw influent e. Sometimes the conversion of toxic ammonia to nitrate alone is referred to as tertiary treatment. Over time, different treatment configurations have evolved as denitrification has become more sophisticated. An initial scheme, the Ludzackâ€"Ettinger Process, placed an anoxic treatment zone before the aeration tank and clarifier, using the return activated sludge RAS from the clarifier as a nitrate source. Influent wastewater either raw or as effluent from primary clarification serves as the electron source for the facultative bacteria to metabolize carbon, using the inorganic nitrate as a source of oxygen instead of dissolved molecular oxygen. This denitrification scheme was naturally limited to the amount of soluble nitrate present in the RAS. Nitrate reduction was limited because RAS rate is limited by the performance of the clarifier. The "Modified Ludzakâ€"Ettinger Process" MLE is an improvement on the original concept, for it recycles mixed liquor from the discharge end of the aeration tank to the head of the anoxic tank to provide a consistent source of soluble nitrate for the facultative bacteria. In this instance, raw wastewater continues to provide the electron source, and sub-surface mixing maintains the bacteria in contact with both electron source and soluble nitrate in the absence of dissolved oxygen. Many sewage treatment plants use centrifugal pumps to transfer the nitrified mixed liquor from the aeration zone to the anoxic zone for denitrification. At times, the raw or primary effluent wastewater must be carbon-supplemented by the addition of methanol, acetate, or simple food waste molasses, whey, plant starch to improve the treatment efficiency. Bardenpho and Biodenipho processes include additional anoxic and oxidative processes to further polish the conversion of nitrate ion to molecular nitrogen gas. Use of an anaerobic tank following the initial anoxic process allows for luxury uptake of phosphorus by bacteria, thereby biologically reducing orthophosphate ion in the treated wastewater. Even newer improvements, such as Anammox Process, interrupt the formation of nitrate at the nitrite stage of nitrification, shunting nitrite-rich mixed liquor activated sludge to treatment where nitrite is then converted to molecular nitrogen gas, saving energy, alkalinity, and secondary carbon sourcing. Phosphorus removal is important as it is a limiting nutrient for algae growth in many fresh water systems.

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The AH reactor with granular sludge was efficient in the removal and conversion of the anaerobically biodegradable COD. The PTF was mainly efficient in the removal of particles, which were not removed in the anaerobic two-step. Decreasing the HLR from Also, at HLR of Moreover, such a system represents a high-load and a low-cost technology, which is a suitable solution for developing countries. INTRODUCTION High-rate anaerobic systems represent low-cost and sustainable technology for domestic sewage treatment, because of its low construction, operation and maintenance costs, small land requirement, low excess sludge production and production of biogas. Although anaerobic treatment plants have been successfully operated in tropical countries, the process up till now did not applied at countries with moderate and low temperatures. At such temperature, the chemical oxygen demand COD removal is limited and a long hydraulic retention time HRT is needed for one-step system for providing sufficient hydrolysis of particulate organics Zeeman and Lettinga, [1]. Several investigators Wang, [2], Elmitwalli et al. Recently, Elmitwalli et al. In the AF reactor, vertical sheets of reticulated polyurethane foam RPF with knobs were applied as packing material. A sludge bed was not allowed to develop in the reactor. So, all biomass retained in the reactor was attached to the RPF sheets. Also, Elmitwalli et al. Based on these results, the use of an AF reactor with vertical sheets of RPF with knobs followed by an AH reactor with granular sludge, was considered as an appropriate process configuration for the anaerobic treatment of raw domestic sewage at low temperatures. Despite the advantages of the anaerobic treatment, the anaerobic effluent still needs post treatment for removing the remaining COD, nutrient and pathogen. The post treatment system for the anaerobic effluent should be, like the anaerobic pre-treatment, a high-rate, low-cost and sustainable technology. Various high-rate aerobic systems have been proposed for post-treatment, such as submerged aerated biofilter Collivignarelli et al. The application of such high-rate systems need high-investment, operation and maintenance costs and replacement of mechanical equipment, like aerators, recirculation pumps, and RBC shaft and bearing Mba et al. A trickling filter represents a high-rate system with low-cost, when it is operated by gravity without wastewater recirculation i. Based on these considerations, vertical sheets of RPF with knobs were selected for this research. RPF media are characterised by a high specific surface area, viz. Moreover, the vertical orientation of the RPF sheets with knobs allows the wastewater and biomass to move through the reactors and consequently clogging of the filter medium is prevented Elmitwalli et al. The media in the three reactors were vertical sheets of RPF with knobs. The diameter of both the AF and the AH reactor was 0. The media of the trickling filter were three vertical sheets of RPF with knobs. Each sheet had a height of 1. The volume of the PTF settler was 0. The wastewater temperature in the AF and AH reactors was controlled at 13oC by recirculating thermostated water through a tube placed around the reactors. The trickling filter was operated at ambient temperature and the wastewater temperature ranged between oC. The trickling filter was operated for 36, 44 and 37 days at hydraulic loading rates HLR of 41, Sewage The system was fed with domestic sewage originating from the village Bennekom, The Netherlands. The sewage Table 2 is collected in a combined sewer system. Raw samples were used for CODt, 4. For determining the particles size distribution PSD of raw sewage and the effluent of each reactor, the wastewater COD was measured for raw samples and samples after filtration at filters with pore size of E-coli measured for raw and paper-filtered samples was analysed according to Havelaar and During [22]. Statistical comparison of the performance of the reactors between different HRTs was done as described by Elmitwalli et al. Schematic diagram of the experimental set-up. Characteristics of the domestic sewage used in the experiment. Standard deviation is presented in brackets. COD removal and conversion The results in Table 3 show the concentration of different COD fractions and removal efficiencies at the treatment of domestic sewage in the system. Most of the CODt was mainly removed in the two-anaerobic steps, which led to a substantial decrease of the organic loading on the aerobic step PTF reactor. The results showed that the anaerobic treatment resulted in a removal of the large particles and the effluent mainly contained colloidal and dissolved organics. The aerobic PTF process removed mainly the colloidal particles from the aerobic effluent and the removal dissolved COD was limited Fig. The excess sludge production in PTF reactor had a concentration of 1. Particles size distribution for the raw sewage and the effluent of each reactor, when the PTF was operated at HLR of Nutrients N and P removal Table 4 shows the concentration of the nutrients at the treatment of domestic sewage in the system. The decrease of the HLR from E-coli removal Table 5 presents the E-coli concentration at the treatment of domestic sewage in the system at HLR of The results showed that E-coli present in domestic sewage is mainly associated with colloidal particles. The removal of E-coli was limited in the anaerobic system less than 1 log and mainly associated with the removal of suspended particles. The PTF removed E-coli by about 2 log. Therefore, the whole system reduced E-coli in domestic sewage from Therefore, the AH reactor methanogenic reactor with granular sludge efficiently removed and converted at 13oC the anaerobically biodegradable COD. The PTF removed the fine particles, which have limited removal in the anaerobic treatment Wang, [2], Elmitwalli et al. Also, the PTF worked as a polishing-step that guaranteed a stable effluent quality. Moreover, the effluent of such system is a valuable product for restricted irrigation WHO, [25] and fertilisation, especially for regions suffering from the lack of water resources, like Middle East and for closing water and nutrients cycle. At HLR of The Role of anaerobic digestion of domestic sewage in closing the water and nutrients cycle at community level. Integrated anaerobic and aerobic treatment of sewage. Low temperature treatment of domestic sewage in upflow anaerobic sludge blanket and anaerobic hybrid reactors. 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anaerobic contractor & Anaerobic Filter are used mostl y in sub-tropical countries. The literature of sustainability assessments of w astewater treatment systems lists indicat ors as shown in.

The composition and dimensions of the plant are given below see also Fig. The gas is stored in a gasholder and flared. Materials and general design The tank of the UASB reactor of the pilot plant was made of gabions, sealed with cement. The inside structures gas-liquid-solids GLS separators were made of galvanised steel. This construction method was not quite applicable in the full-scale plant, since corrosion of the metal parts would occur and the tank would be insufficiently water tight. For the internal parts polyester GRP , in situ poured concrete, prefab concrete and stainless steel were viable possibilities. After performing a cost comparison, concrete tanks with prefab concrete inside structures were selected. Special attention was given to guarantee a smooth surface of the concrete. Additives were applied to reduce the susceptibility of the concrete for corrosion and its permeability for gas. The UASB tanks are equipped with one inlet per 2. To obtain such a minute distribution, the incoming wastewater is distributed over three splitter boxes in series, the first consisting of one box with four outlets, the second step is formed by four boxes of 9 outlets each and the 36 final boxes have 16 outlets each. The design of the final influent splitter boxes is such that dragging of air by the influent into the reactor, which would be disatrous for the anaerobic biomass Vieira, , is prevented. This resulted in a settling compartment only 1. Steeper angles would lead to unnecessarily deep settlers. More details on the design were presented by others Collazos, Scum control In the Bucaramanga pilot plant it was experienced that heavy scum formation occurred in the open gas compartment of the UASB reactors, while in the closed gas chambers of the Cali pilot plant only a slight accumulation was noticed Schellinkhout, personal observation, unpublished. Based on these observations, inthe full-scale plant, a two-step approach was chosen. First, it was assumed that if the sum was frequently mixed with the reactor contents and protected from desiccation, degradation of its grease, proteins and solids would eventually occur. Second, in case this mixing would happen to be insufficiently effective, the gas collectors should be accessible to remove the scum. Therefore, a gas injection system was installed on each gas collector to allow periodic injection of gas just below the scum, at both extremes of the gas collectors removable covers were placed. The suggerstion fo sprinklers Lettinga and Hulshoff Pol, was found not feasible, since sprinklers are susually only effective for the abatement of foam rather than scum, and they could hinder a free passage from one extreme to the other of the collector dome. Scum formed in the settling compartment is allowed to leave the reactors and is eventually collected in the inlet distribution channel of the lagoons, the latter thus functioning as an Integrated Scum Accumulation Device ISAD , from where it is removed periodically. The gas collectors prove to be quite gas tight; the porosity of the concrete is almost nil. The concrete GLS separators show some problems though, since escape of gas takes place through the joints, causing turbulence in thje settler. Behaviour and experiences during start up Loading and performace From October 30, , one reactor was operated at full load, viz. The second reactor was taken into operation on January 12, , at the same loading rate. The start up was performed without inoculum, since experience had demonstrated that was well possible Schellinkhout et al. The first four months of operation produced results that are still below the ones obtained in the pilot plant. These somewhat unexpected results should be attributed to sludge wash-out, caused by turbulence in the settling compartments. The origins of this phenomenon will be described below. Coliorms and nutrients were not analyzed; neither methanogenic activity nor gas production were determined, unfortunately, since appropriate equipment was not available yet. It is expected that these activities can start in March ; the results will be published later. When using prefab concrete, two aspects resulted to cause difficulties: The joints between the elements of the upper dome of the gas collector were sealed with 15 mm neoprene sheets. This proved to be adequate. The lower elements, however, were not sealed in this way, and gas bubbles seeping through the joints passed into the settling compartment, causing heavy turbulence and moving sludge to the outlet weirs. In March, these joints were sealed with a kit and the consult leading the gas to the upper dome was improved. In the design of the GLS separator, an overlap in the aperture between the digesting and the settling comparment of 15 cm was provided. Nevertheless, gas bubbles were noted to pass thorough the aperture into the settler, withdrawing sludge to the effluent weirs. Ths phenomenon proved to be caused by the thickness of 10 cm of the GLS separator plates used. Small gas bubbles reaching the rim of the upper plate see Fig. Large bubbles, however, cannot pass quickly due to the obtuse angle of the rim. The bubble will break up and part of it will pass into the settler. This problem will be solved by installing an extra sheet, directing the gas away from the aperture. Odur nuisance A major problem of all treatment plants, including anaerobic plants, is the emission of odour. In the Bucaramanga plant, especially during start up when the UASB effluent was not well stabilized, odour emission occurred. Also, the biogas when disposed of into the air represented much odour. To reduce smell nuisance it was experienced that flaring the excess biogas was effective. It is experienced that in the sunny, warm climate of Bucaramanga, sludge drying beds hardly emit any small, but during the filling procedure some emission occurs. Therefore, the beds will not be covered an action that would hamper the de-watering process seriously. Still it is recommended to locate sludge dewatering on the part of the site away from the houses. Sludge handling After four months of operation, no excess sludge was produced. Nevertheless, some experiments were undertaken with drying some sludge samples on the beds. Cost and personnel The cost of the whole project, including extension of the sewage intercepter system by 30 km, is USD 5. The plant itself costs USD 2. These are real costs under Colombian conditions, where equipment is more expensive than in Europe or North America, but labour considerably cheaper. The plant is operated by a staff of 4 operators, 4 assistants and 1 head of the plant. Running costs are USD 1. There are some extra costs for energy for illumination and for renning the small maintenance equipment. Conclusion The expectation that anaerobic technology, and more specifically the UASB concept, would contribute to a cost-effective and efficiente solution of environmental problems in tropical climates has only been reinforced by the experiences of the full-scale plant in Bucaramanga, in spite of some initial problems. Other cities in Colombia are preparing similar solutions. Prefab concrets is an attractive material for constructing UASB reactors in many South American Countries, since it is durable, widely available and relatively cheap. The Bucaramanga experience has demostrated, however, that this material: The project was funded by own resuorces and loans of the Colombian government and of the Inter American Development Bank. 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Anaerobic treatment technology rizing a specialized workshop held on anaerobic sewage treatment (held in). The authors stated that anaerobic sewage treatment has great potential - especially in tropical climates.