Anaerobic Digestion: A Review

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Abstract- *Under anaerobic conditions, organic pollutants in wastewater are degraded by microbes producing methane and carbon dioxide. The degradation process is effective compared to the more conventional aerobic processes and produces only 5-10% of sludge. This saves considerably on cost associated with the sludge disposal. Among anaerobic technologies, the most popular ones is the upflow anaerobic sludge blanket (UASB). In the UASB process, the waste to be treated is introduced in the bottom of the reactor. The wastewater flows upward through a sludge blanket composed of biologically formed granules or particles. Treatment occurs as the waste comes in contact with the granules. Among the main applications for UASB are in the beverage, brewery, food and tannery industries*.

Keywords- Anaerobic granular sludge, Chemical Oxygen Demand, Environmental biotechnology, Sludge bed reactor, UASB.

I. INTRODUCTION

The attractive concept of combing waste(water) treatment and the production of valuable compounds from a low a value heterogeneous feedstock does not need to be clarified to those working on the anaerobic digestion process. Anaerobic digestion for the production of methane containing biogas can be regarded as the classic example of a resource recovery process that combines wastewater treatment or solids stabilization with effective conversion of biodegradable organic carbon to a valuable product: methane containing biogas. Methane containing biogas can directly be used for electricity and/or heat production, or upgraded to natural gas quality. Other resources that can be recovered from waste (water) are nutrients like nitrogen and phosphorus, and specific trace metals. Overall it is evident that anaerobic digestion can be considered a mature technology that is widely applied for organic waste valorization. (14). A UASB reactor is essentially a variant of the classical expanded bed reactor. In it, wastewater flows upward through a column of a sludge bed, followed by a column of less dense sludge blanket. The sludge, in turn, consists of minute biosolids or 'granules', each of which sports a bacterial film. The constantly expanding, settling and resuspending sludge granules bring the bacterial films in contact with the up flowing wastewater, resulting in the anaerobic digestion of the latter(1).

Up-flow anaerobic sludge bed (UASB) reactor can be considered the most popular system of secondary treatment due to its several advantages comparing to other systems as conventional anaerobic digesters, considering that UASB reactor has the gas collection as additional part on which it will reduce the effect of releasing gas emissions into atmosphere as it occurs in conventional ponds. UASB reactor has probably designed to treat high concentration of wastewater .Various researches have widely been conducted in the field of wastewater treatment within employing UASB reactor (13). The UASB process has several advantages over other anaerobic processes. It is simple to construct and operate and is able to tolerate high organic and hydraulic loading rates. The key feature of the UASB process that allows the use of high volumetric COD loadings compared to other anaerobic processes is the development of dense granulated sludge . This has made it possible for the UASB to enhance the quality and the development of sludge with high specific activity and superior settling properties.

A typical UASB plant design consists of a biological reaction zone and a sedimentation zone. The organic compounds in the influent are converted to CH2 and CO2 in the reaction zone as the flow passes upward through the bed of activated sludge. The gas and sludge is separated by the gas-solid-liquid separator device. In the UASB reactor, the substrate degradation occurs mainly in the lower part of the reactor due to the presence of a high concentration of active anaerobic sludge, effective mixing (due to the upward escape of the gas produced) of the incoming waste flow with the partially purified liquor present in the upper part of the reactor and occurrence of colloidal particles and other specific wastes, and the precipitation, sedimentation, and/or entrapment of such undissolved matter (2).

The fact that methane is a poorly water soluble compound directly contributes to the attractiveness of the process. No or limited downstream processing is required to enable the utilization of methane containing biogas for electricity and heat production in a combined heat and power plant. Technologies are furthermore available for upgrading of the biogas to natural gas quality for introduction in the natural gas grid. Even though liquid end-products offer intrinsic advantages as well , they require energy intensive downstream processing for water removal through distillation in case of bioethanol production, or other biorefinery based product recovery technologies as required for example for lipid recovery from algae. A second advantage related to the production of a gaseous end product is the lower energy requirements for bioreactor operation compared to active aeration in aerobic processing of waste. In anaerobic wastewater treatment reactors such as the UASB reactor or anaerobic slurry reactors, no mechanical mixing is required since adequate mixing is established through biogas production. Furthermore, oxygen supply through aeration adds significantly to the electricity consumption for aerobic treatment process: composting of solids or aerobic wastewater treatment.

At present, owing to the concerns related to depleting fossil fuels and thus increasing energy prices, as well as to the ongoing concerns related to greenhouse gas emissions that are linked to fossil fuel consumption, anaerobic high-rate treatment receives renewed interest worldwide. Depending on the loading potentials of the various high-rate reactors and the anaerobic treatability of the wastewater, the energy potential of anaerobic reactor can be easily estimated. The expected energy output and CO2 emission reduction when anaerobic high-rate treatment is applied, meanwhile the generated CH4 is used inside the industry instead of fossil fuel derived electricity. Any intermediate value can be derived by linear interpolation (12). In recent years, it has furthermore been recognized that an alternative approach to anaerobic processing of biomass is to aim for production of organic acids and/or alcohols instead of methane containing biogas. Direct recovery of these water soluble products of biomass fermentation or post-processing to obtain other molecules (e.g. polyhydroxyalkanoates, or medium chain length fatty acids) may result in the production of more valuable end-products of the resource recovery process. Alternatively, biomass processing can aim for other gaseous products like molecular hydrogen or direct generation of electricity in microbial fuel cells (14).

II. OBJECTIVE

It should be recognized that besides the formation of sludge granules, erosion also takes place in the sludge bed under the influence of friction forces to which the sludge flocs are exposed in particular at high mixing intensities. The sludge particles would gain sufficient mechanical strength when proper environmental conditions are maintained at the start up. Gas re-circulation provides mechanical agitation at the gas-liquid interface in the digester compartment and is useful to prevent an accumulation of biodegradable waste solids in the lower part of the reactor and/or to ensure a good contact between bacteria and the substrate even at low gas production rates or high hydraulic loading rates. Under proper conditions active anaerobic sludge can be preserved unfed for many months without deterioration.

As the liquid upflow velocity, organic loading rate, hydraulic retention time, etc play important roles in the performance of a UASB reactor. The presence of inert particles serving at surfaces on which bacteria can adhere is clearly advantageous. Nevertheless, the particles should be well settleable, if not it may cause unwanted sludge wash-out (3).

The start-up of UASB reactors is a complicated process and a number of factors, including wastewater characteristics, acclimatization of seed sludge, pH, nutrients, presence of toxic compounds, loading rate, upflow velocity (Vup), hydraulic retention time (HRT), liquid mixing and reactor design affect the growth of sludge bed (4).

The temperature considerably influences the growth and survival of microorganisms. Although anaerobic treatment is possible at all three temperature ranges (psychrophilic, mesophilic and thermophilic), low temperature usually leads to a decline in the maximum specific growth rate and methanogenic activity Methanogenic activity at this temperature range is 10–20 times lower than the activity at 35 degree C, which requires an increase in the biomass in the reactor (10–20 times) or to operate at higher sludge retention time (SRT) and hydraulic retention time (HRT) in order to achieve the same COD removal efficiency as that obtained at 35 degree C

The upflow velocity (Vup) is directly related with HRT and plays an important role to entrap suspended solids. A decrease in Vup entails an increase in HRT, which boosts suspended solids' (SS) removal efficiency of the system (4).The required good contact between the sludge and wastewater in UASB reactors generally is accomplished by feeding the wastewater as uniformly as possible over the bottom of the reactor. Also the increased up-flow velocity results in a better contact between the sludge particles and the pollutants. Mechanical mixing is not applied in UASB reactors(12).

III. ANAEROBIC DIGESTER

The sludge bed reactor concept is based on the following ideas:

1. Anaerobic sludge has or acquires good sedimentation properties, provided the process is operated correctly.

Small particles or slowly settleable sludge will be washed-out from the system.

2. The required good contact between the sludge and wastewater in UASB reactors generally is accomplished by feeding the wastewater as uniformly as possible over the bottom of the reactor. Also the increased up-flow velocity results in a better contact between the sludge particles and the pollutants. At VLRs exceeding 5 kg COD m-3 - day-1, mixing of sludge and wastewater is brought about by biogas turbulence. Mechanical mixing is not applied in UASB reactors.
3. With wastewaters containing biodegradable inhibitory compounds, the hydrodynamic mixing is additionally achieved by applying a liquid recirculation flow. As a result, a more completely mixed flow pattern is acquired and stratification of the substrate and intermediate products over the height of the reactor is minimized, thereby minimizing potential inhibition.
4. The wash-out of the active sludge aggregates is prevented by separating the produced biogas using a gas collection dome installed at the top of the reactor. In this way, a zone with relatively little turbulence is created in the uppermost part of the reactor, in fact functioning as an in-built secondary clarifier (12).

For treatment of feedstocks with a high solid content such as manure, sewage sludge, OFMSW, or agro-industrial residues, anaerobic digestion competes with aerobic composting. Both type of processes have advantages and disadvantages:

1. Energy consumption for active aeration of the composting process makes the energy demand of the aerobic process significantly higher.
2. Off-gas treatment of aerobic composting is required to minimize ammonia emissions,
3. Feedstock subjected to anaerobic digestion need to be increased in temperature to 70 _C for some time for hygienization purposes if reuse of the digestate in agriculture is required. The temperature increase required in composting is achieved through oxygen respiration lowering the energy demand of aerobic composting process.
4. Volume reduction through drying of the material in the aerobic composting process is an asset of this process. Depending on the water content of the feedstock, anaerobically digested material often requires energy intensive dewatering before transport.

Up flow anaerobic filter process (UAF) is the most significant high-rate anaerobic treatment reactor developed in Netherlands. This type of bioreactor contains a medium, i.e., a microbial support .Granulated microorganisms exist either in suspension or attached forms within the medium; hence, a high-density microbial population is retained in the reactor and creating a hybridization of microbial adhesion. To avoid short-circuiting flow through the packed column, a distributor is fitted at the bottom to provide a homogeneous up flow of wastewater. At the top, treated waste water and the biogas produced are separated by a free board .

Anaerobic fluidized-bed (AFB) reactor, in this reactor, the medium to which the microbes adhere is fluidized within the reactor. Anaerobic microbes grow on the surface of the medium, expanding the apparent volume of the medium, that is, why its name designated as an expanded bed reactor. In this reactor, the bacterial attachment is either in non-fixed or mobile carrier particles, which consist of fine sand, quartzite, alumina, granular activated carbon, etc. In AFB reactor, good mass transfer results from less clogging and less short-circuiting due to the occurrence of large pores through bed expansion, and high specific surface area of the carriers due to their small size. Due to these, FB reactors are highly efficient. However, long-term stable operation appears to be problematic

Anaerobic baffled reactor (ABR) is a simple rectangular tank, with physical dimensions similar to a septic tank, and is divided into different equal compartments, by means of partitions from the roof and bottom of the tank. The liquid flow alternately upward and downward between the partitions, and on its upward passage the waste flows through an anaerobic sludge blanket. Hence, the waste is in an intimate contact with active biomass. This reactor appears to be able to treat high solids contents, and hence may be an alternative to AF.

Anaerobic contact process (AC), modern AC systems are very effective for relative highly suspended solids. An alternative way of sludge retention was found by applying inert support material into the bioreactor on which the anaerobic organisms can adhere. Even so, AC effluents require a subsequent treatment step in order to comply with effluent restrictions

Expanded granular sludge bed (EGSB reactor) is the family of UASB reactors. It has been objectively developed to improve the substrate– biomass contact within the treatment system by means of expanding the sludge bed with a high up flow liquid velocity ([4 m/h) which intensifies hydraulic mixing and results in better performance and stability than the

UASB. The high up flow liquid velocity in the reactor is achieved through the application of a high effluent recirculation rate. As a result of high velocity, granular sludge bed will be in an expanded or fluidized state in the higher regions of the bed which results an excellent contact between the wastewater and the sludge. Compared to UASB reactors, higher organic loading rates can be accommodated in EGSB systems. Consequently, the gas production is also higher.

Anaerobic filter (AF) called packed bed, is the earliest and simplest types of design, typically consists of a tall reactor filled with media, in which biomass is retained on the attachment of a biofilm to the solid or stationary carrier material for entrapment of sludge particles and formation of very well settling sludge aggregates. The organisms are growing either on the attached media or in a suspended form, within the interstices of the media. The wastewater to be treated is usually passed upward through the filter, and exits through a gas siphon .

Developed countries, like USA and Australia, extensively used anaerobic lagoons for treating their slaughterhouse wastewater due to its low operational and maintenance costs and high efficiency in reducing polluting charges. However, anaerobic lagoons cause odor problems and emission of methane, major contributors to greenhouse gas with a heat-trapping capacity of 20 to 30 times to that of carbon dioxide. But now, sophisticated anaerobic reactors were developed in Europe and Asia to increase treatment efficiency. Among these, a high-rate anaerobic contact (AC) reactor was applied in full scale in UK for treating slaughterhouse wastewater. Generally, dairy industries generate strong wastewaters characterized by high BOD and COD concentrations. One phase anaerobic digestion process involves degradation of organic matters by microorganisms in the absence of oxygen and leads to biogas, mixture of carbon dioxide and methane and biomass formation . Two-phase anaerobic treatment is particularly suitable for wastewaters that contain high concentrations of organic matters, such as diary wastewaters. Numerous research studies carried on the anaerobic acidogenesis of dairy wastewaters indicate better treatment efficiencies were achieved on dairy effluents, namely cheese, fresh milk, and milk powder/butter factories, using a small-scale mesophilic two-phase system.

Several studies showed that application of anaerobic digestion processes are successful to treat brewery wastewater. Another laboratory scale of anaerobic digestion processes indicates that brewery solid and wastewaters in combination together are also a good alternative for cogeneration of renewable energy. Anaerobic co-digestion is an advanced technology that takes advantage of complementary substrates to increase the methane yield of those substrates of brewery wastes. Brewery wastes (BW) is first used as co-substrate and co-digested with its solid wastes in batch mode at mesophilic conditions and finally achieved the maximum methane production. At the top of the UASB-reactor, Lamella separator should be installed for separation of the treated wastewater, biogas, and sludge .The brewery factory should extend its treatment using sequencing batch reactor. In general, for better removal of both organic matter and nutrients from brewery wastewater, SBR is very useful as post-treatment because of its high removal efficiencies for both organics and nutrients (15).

Palm Oil Mill Effluent can be treated anaerobically to breakdown organic matters while releasing biomethane and sometimes, biohydrogen. Lipids are suitable substrates for high-rate anaerobic wastewater treatment. BioHydrogen is a promising energy carrier of the future: It is a promising clean fuel as it is ultimately derived from renewable energy sources, environment friendly ,since it burns to water gives high energy yield (142 MJ/kg), and can be produced by less energy-intensive processes and has a great potential to be an alternative fuel. Cellulose and starch containing biomass can be used as a reliable and renewable raw material for hydrogen gas production. Due to the nature of Palm Oil Mill Effluent, with high cellulose and lingo cellulosic material, it takes a long time to degrade the organic substances and has a potential as a substrate for generation of hydrogen.

Biohydrogen fermentation can be realized by three main categories:

(a) Dark fermentation (b) Photo fermentation (c) Dark photo fermentation. Research in dark fermentation, for hydrogen production, is on the increase in recent years due to its potential importance in our economy and has presented a promising route of biohydrogen production compared to photosynthetic routes. The major advantages of dark fermentation are high rate of cell growth, no light energy requirement, no oxygen limitation problems and ability to run on low capital cost. A variety of bacteria such as E. coli, Enterobacter aerogenes, and Clostridium butyricum are known to ferment sugars and produce hydrogen, using multienzyme systems. Since these ‘‘dark fermentation’’ reactions do not require light energy, so they are capable of constantly producing hydrogen from organic compounds throughout the day and night. Compared with other biological hydrogen production processes, fermentative bacteria have high evolution rates of hydrogen (16).

One of the first continuous flow anaerobic reactors was designed in 1905 by Karl Imhoff, who developed a single flow through tank for enhanced settling and concomitant digestion of the settled solids. The innovative Imhoff tank was particularly applied for municipal wastewaters and is still functional in various parts of the world, particularly in warm climate regions. Sludge bed systems played a key role in the acceptance of high-rate anaerobic reactor systems for the treatment of industrial wastewater. UASB reactors and expanded bed related systems are applied at a large variety of industrial sites, offering cost-effective solutions to comply with legislative constraints in combination with a complementary technology. Reduced costs for treatment and bio-energy recovery lowers the threshold to indeed implement industrial wastewater treatment on the industrial premises. Onsite treatment of these wastewaters opens perspectives for resource recovery (bio-energy, process water) and reuse in the industrial process. Such development is regarded important for developing the so-called 'green industrial approach'.

Decades of development of high rate anaerobic reactor systems expanded the application potential enormously, currently also including the more extreme type of wastewaters. For conditions where sludge immobilization or granulation cannot be guaranteed, novel high-rate reactors equipped with advanced sludge retentions systems may offer the appropriate solution. Following this development, the authors feel that any industrial wastewater containing biodegradable organic pollutants should be treatable with a high-rate anaerobic reactor system. In the meantime, the upflow sludgebed technology remains the working horse of anaerobic high-rate treatment. In the end, the anaerobic high-rate reactor should sustain its lifetime, treating organically polluted wastewater, meanwhile converting the wasted organics in a valuable fuel (12).

IV. UASB

The UASB reactor operates as suspended growth system where microorganisms attach themselves to each other or to small particles of suspended matter to form agglomerates of highly settleable granules that forms an active sludge blanket at the bottom of the reactor. The gas formed causes sufficient agitation to keep the bed fully mixed. In the UASB process, the waste to be treated is introduced in the bottom of the reactor. The wastewater flows upward through a sludge blanket composed of biologically formed granules or particles. Treatment occurs as the waste comes in contact with the granules. The gas produced under anaerobic conditions cause internal circulation which helps in the formation and maintenance of the biological granules. Some of the gas produced within the sludge blanket becomes attached to the biological granules . The free gas and the particles (with the attached gas) rise to the top of the reactor. The particles that rise to the surface strike the bottom of the degassing baffles which release attached gas bubbles. The degassed granules drop back to the surface of the sludge blanket. The gases released from the granules are captured in the gas collection domes located in the top of the reactor(2).

It is simple in construction and in operations and is able to tolerate high organic and hydraulic loading rates. A typical UASB plant design consists of a biological reaction zone and a sedimentation zone. The organic compounds in the influent are converted into methane and carbon dioxide in the reaction zone as the flow passes upward through the bed of activated sludge.

The gas and sludge is separated by the gas-solid-liquid separator device. In the UASB reactor, the substrate degradation occurs mainly in the lower part of the reactor due to the presence of a high concentration of active anaerobic sludge, effective mixing of the incoming waste flow with the partially purified liquor present in the upper part of the reactor and occurrence of colloidal particles and other specific wastes, and precipitation and sedimentation or entrapment of such undissolved matter.

In the UASB reactor, higher loading rates at low detention times could be applied as the result of high settleability and presumably of the high specific activity of the granules of about 1-3mm in size. It is reported that performance of high rate anaerobic sludge bed reactors has significantly increased by locating the packing material to the top 25–30 %of the reactor(12). A comparison of fluidised bed reactor (FBR) and UASB reactor showed that the high rate FBR technology did have limited success, and this may be partly due to the practical problems of controlling the attachment of biofilms to the carrier material. On the other hand, the high rate UASB technology which relies on the growth of granular sludge and a three phase separator (gas-liquid- solid) has been a commercial success in over 500 installations treating a wide range of industrial effluents throughout the world (2).

In fact the UASB reactor are suitable for treating food industry wastewaters, since they can treat large volume of wastewaters in a relatively short period of time. Removal of nitrogen and phosphorus from diary wastewater has recently gained significant attention due to more strict environmental regulations, so current research efforts clearly seem to focus on nutrient removal from dairy waste effluents is worth investigating(11).

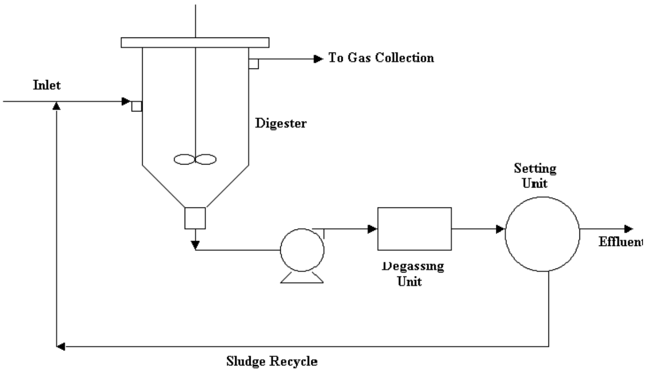

Figure 1 Flow-sheet for Anaerobic Digestion of liquid wastes

V. CONCLUSION

Anaerobic sludge bed technology for industrial wastewater treatment reveals the following:

1. Anaerobic sludge bed treatment technology has been successfully applied to a wide spectrum of industrial wastewaters at full-scale as a consolidated technology.
2. Anaerobic high-rate treatment technology is a cost-effective alternative providing energy saving, reduction in sludge production, operation at high organic loadings, compact footprint, and net energy production. These characteristics make anaerobic sludge bed technology feasible and sustainable for the treatment of virtually all organically polluted industrial wastewaters.
3. Although the key mechanism of sludge bed technology is immobilization of microorganisms, various modern anaerobic high-rate reactors employ flocculent biomass which is retained in the system by advanced (gas–)liquid–sludge separation devices. In such reactors, sludge separation is brought about by in-built flotation units or advanced tilted plate settlers. Alternatively, membrane separation is employed, ensuring complete biomass retention without any necessity for granulation.
4. The intensive research conducted on anaerobic sludge-bed systems using laboratory-scale reactor systems and which include molecular techniques and mathematical modeling resulted in the development of new reactor configurations, and applications of full-scale sludge bed systems, enabling the treatment of very complex wastewaters from chemical industries.
5. As a waste-to-energy technology, high-rate anaerobic sludge (bed) systems enable renewable energy production, and nutrient rich effluent production for irrigation purposes in agricultural fields. Therefore, this technology significantly contributes to achieve the so-called ‘‘environmentally friendly’’ industrial production concept.

The up-flow anaerobic sludge fixed film (UASFF) reactor configuration has combined the advantages of both UASB and Up-flow anaerobic fixed film (UAFF) reactors. This kind of reactor is efficient in the treatment of dilute to high strength wastewaters at low to high Organic Loading Rates . The packing medium in the hybrid reactor plays an important role in giving a better performance to the UASB reactor such as increasing solids retention by dampening short circuiting, improving gas/liquid/solid separation, and providing surface for biomass attachment (17).

REFERENCES

[1] R Sanjeevi, Tasneem Abbasi* and S A Abbasi :Centre for Pollution Control and Environmental Engineering, Pondicherry (Central) University, Pondicherry 605 014, India

[2] (2) K. Karthikeyan
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[4] WEIMIN Wu, JIcuI Hu, XIASHENG GU, YIZHANG ZHAO, HUI ZHANG and GUOGUAN Gu : Cultivation of anaerobic granular sludge in uasb reactors with aerobic activated sludge as seed .

[5] Hina Rizvi a , Nasir Ahmad b , Farhat Abbas a, *, Iftikhar Hussain Bukhari c, *, Abdullah Yasar d , Shafaqat Ali a , Tahira Yasmeen a , Muhammad Riaz :Start-up of UASB reactors treating municipal wastewater and effect of temperature/sludge age and hydraulic retention time (HRT) on its performance

[6] Robbert kleerebezem and Mark CM van Loosdrecht : Mixed culture biotechnology for bioenergy production

[7] Yu Liu* , Hai-Lou Xu, Kuan-Yeow Show : Anaerobic granulation technology for wastewater treatment

[8] Dawen Gao, Lin Liu, Hong Liang and Wei-Min Wu : Aerobic granular sludge: Characterization,mechanism of granulation and application of wastewater treatment.

[9] K. Karthikeyan, J. Kandasamy : Upflow Anaerobic Sludge Blanket Reactor(UASB) in wastewater treatment.

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[12] C. Elangovan and A. S. S. Sekar*
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*Deptt. of Civil Engineering , Alagappa Chettiar College of Engineering and Technology, Karaikudi-630 004, T. N., India

[13] Celebrating 40 years anaerobic sludge bed reactors for industrial wastewater treatment
J. B. van Lier . F. P. van der Zee .
C. T. M. J. Frijters . M. E. Ersahin

[14] S. A. Habeeb, AB. Aziz Bin Abdul Latiff, Zawawi Bin Daud, Zulkifli Bin Ahmad Faculty of Civil and Environmental Engineering, University Tun Hussein Onn Malaysia (UTHM). A review on granules initiation and development inside UASB Reactor and the main factors affecting granules formation process

[15] Robbert Kleerebezem . Bart Joosse .
Rene Rozendal . Mark C. M. Van Loosdrech t. Anaerobic digestion without biogas

[16] E. Alayu1 • Z. Yirgu2 . Advanced technologies for the treatment of wastewaters from agro-processing industries and cogeneration of by-products: a case of slaughterhouse, dairy and beverage industries

[17] Anwar Ahmad • Rumana Ghufran •
Zularisam Abd. Wahid. Bioenergy from anaerobic degradation of lipids.in palm oil mill effluent

[18] Seyyed Mohammad Emadian1, Mostafa Rahimnejad2*, Morteza Hosseini2 and Behnam Khoshandam1 . Investigation on up-flow anaerobic sludge fixed
film (UASFF) reactor for treating low-strength bilge water of Caspian Sea ships