Original Research Article

Treatment of Effluent with an Anaerobic Aerobic Effluent Treatment System

ABSTRACT

Today energy and clean water is a requirement in all societies worldwide to run productive processes. This affects the natural environment negatively and requires to establish more environmentally sustainable processes to decrease dependency and preserve the natural environment. Hub

In this research approach a laboratory anaerobic aerobic effluent treatment system was designed, built, and started up with wastewater. After start-up the system was operated with prepared milk waste, liquid cow manure and wastewater at a hydraulic retention time of 3 days and 6 days.

The laboratory anaerobic aerobic system was able to degrade the chemical oxygen demand, total solids and total suspended solids of all three influent liquids up to 95% and 98% for the 3-day and 6-day hydraulic retention time.

Maximum total solids removal was 87.89% and 92.43% for the 3-day and 6-day hydraulic retention time.

Total suspended solids removal yielded a maximum of 99.87 and 99.93% for the 3-day and 6-day hydraulic retention time.

The anaerobic sludge blanket reactor of the system operated at a temperature of 38°C and a pH between 7.5 and 8.2 achieved a biogas CH_4 content of 65% ± 5% and a maximum total biogas production of 2.23 ml/h for the milk waste at a 3-day hydraulic retention time and a minimum biogas production of 1.36 ml/h for the waste water the 3-day and 6-day HRT respectively.

The operation of the designed laboratory anaerobic aerobic effluent treatment system showed that it is capable of reducing the effluent loading of a variety of waste streams as well as produced biogas that can be converted into bio-energy.

Keywords: Anaerobic, Aerobic, biogas, co-digestion, digestion, effluent, energy production, fermentation, manure, sludge blanket reactor, waste water

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1. INTRODUCTION

The two most significant challenges facing our world in the future pertain to energy and clean water.

Today, energy is required in all societies over the world to run productive processes and provide basic human needs [1]. Fossil fuels show for years the tendency of being a highly politically and used influencing source [2]. The Russian Ukraine war that started February 24th, 2022 showed the dependency of Europe on fossil fuels (oil and gas) with increases fossil fuel costs and supply shortages, being Russia as one of the world's top 3 crude and the world's second largest natural gas producer [3].

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Without clean water life is not sustainable. Water pollution affects local wildlife and has negative environmental affects, eutrophication, bacterial growth in drinking water, algal blooms from released phosphorus from agricultural application and underperforming decentralized wastewater systems can interrupting tourism and create dead zones in bodies of water resulting in the destruction of valuable fisheries [4-6].
humans equally and we all should work on minimizing and perhaps eliminating waste and water pollution [2].

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Sustaining the natural beauty and quality of our water bodies is today's biggest challenge with ever growing urban and suburban developments including growing industrial production sites close to urban and suburban developments [2].
Fossil fuel advantages are their ease of storage, transportation and availability when needed in comparison to renewables such as solar and wind which lack short and long-term storage technologies and therefore need to be able to direct transfer into electrical power grid [7].
Produced biogas from either energy crops or bio-based waste products can be stored, converted into liquid fuel or electricity when needed [8]. Waste products for biogas production might include municipal wastewater residues, agricultural, municipal, or industrial biological waste materials that are collected. This waste material can be converted into biogas with anaerobic digestion (AD) processes which are known since the 10th century BC and have been practiced in ancient China over 3000 years ago [9].
Today, biogas produced by AD has become an alternative, carbon-neutral, renewable fuel that can be easily generated from local, low-cost organic materials [10-12].
AD reactor technology is designed to treat a specific range of biomaterials [8]. For treating liquid waste flows, reactor designs must maximize substrate-to-biomass contact and biomass retention simultaneously by maximizing the contact between substrate and biomass [13].
In recent years, bio-based waste materials have become a energy source for biogas production. However, the implementation of large agricultural operations led to the production of excess manure that cannot be put on local fields due to over fertilization with negative impacts on nearby water bodies [14].
Processing of agricultural, municipal and industrial supernatant could be done by using an aerobic up flow sludge blanket reactor.
The following **Error! Reference source not found.**. By Doelle, et. al. [8] shows a typical layout of a up flow sludge blanket reactor. A basic layout includes a vertical cylindrical formed tank. The liquid anaerobic digestible material enters the system via a pump from the bottom and products exit the tank at the top (up flow). The influent material gets distributed across the whole reactor diameter with an influent distribution system and mixed up with the biocenosis of anaerobic bacteria and higher cellular creatures. Bacteria in biocenosis cooperate with each other to improve their different nutritional requirements and bind together to create flocs, the so-called bio-sludge. During digestion of the biodegradable substances of the influent, bacteria produce mostly biogas, water and propagate into new bacteria biomass. From the sludge produced and released products flow up to the top of the reactor and separate into liquid and gaseous products. The effluent or so-called digestate contains then mostly water, undigested constituents and with the up flow carried smaller parts of bacterial material. With operational optimized flow conditions, it is ensured to retain the bulk of the sludge in the reactor to avoid washing out bacteria. At the top of the reactor collected gas could then be transferred to further gas processing systems. To improve the degradation capability of the up-flow sludge blanket reactor, a recirculation loop may be implemented. This enables bacteria to break down more difficult degradable constituents and improves the nutrient distribution and gas release in the sludge blanket with additional mixing [1, 15].

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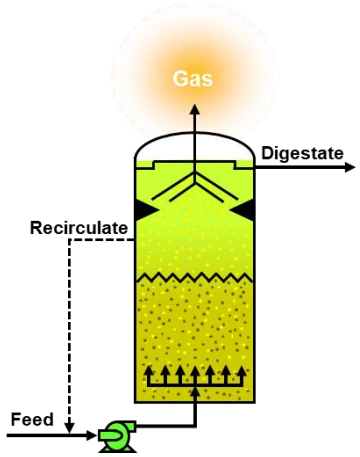

Fig. 1. Diagram of an Expanded Granular Sludge Bed (EGSB) reactor by Dölle et. al. [8]

The process generating biogas is complex and a form of biocenosis in which many different bacteria live together in a habitat. Together they are capable of breaking down organic material into products like biogas, water and new bacterial biomass. Figure 1. By Dölle et. al. [5] describes the anaerobic degradation pathway in more detail. The processes could be roughly classified into four groups, acetogenic, acetogenic and methanogenic bacteria. Enzymes and fermentative bacteria break down the substances in the influent into more complex sugars and acids (hydrolyses). Acetogenic bacteria degrade those components further into smaller organic building blocks like alcohols, organic acids and sugars, thereafter acetogenic bacteria into acidic acid. Methanogenic bacteria use then acidic acid as typical building block for forming biogas [8].

The degradation of the influent materials throughout the degradation route as described above and the production of biogas might change with the composition of the influent, the temperature and the pH-value. It is usually assumed that the produced biogas consists roughly out of two thirds methane and one third Carbon Dioxide (CO_2) with traces of other gases like hydrogen sulfide (H_2S) and hydrogen (H_2) [1, 16-18].

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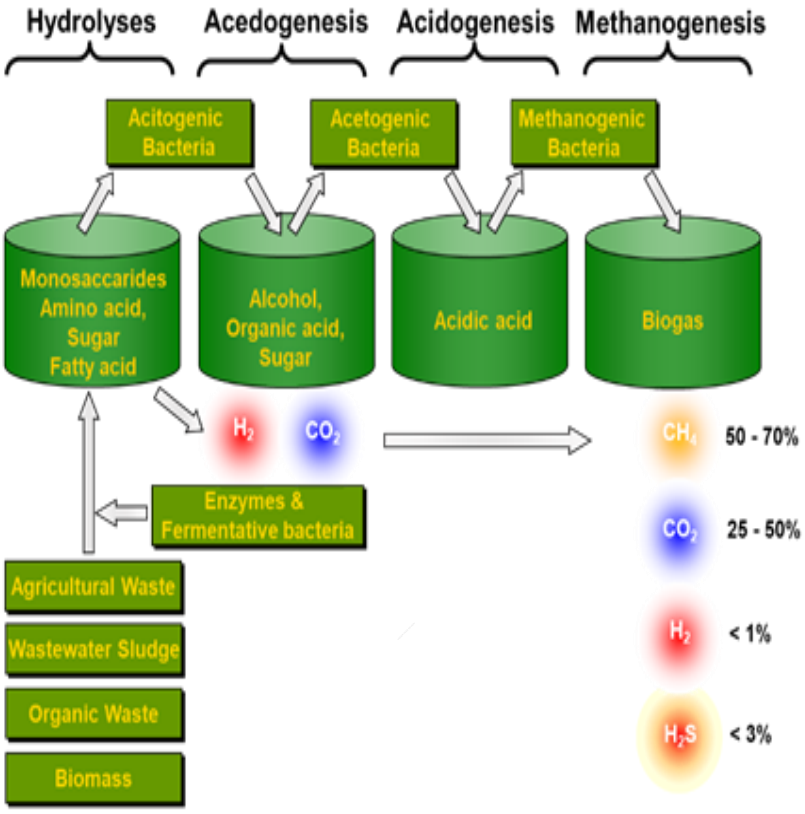

Figure 1: Pathway of anaerobic digestion by Dölle et. al. [8].

The objective for this research work is to treat on a laboratory scale municipal wastewater (MWW), manure effluent (ME) and milk waste (MW) with an up flow activated sludge blanket reactor, recirculating bio-tower to degrade organic components in the effluent.
The reported research could help to improve the described complex problematics on one side substituting fossil fuels and on the other side to decrease releasing nutrients in excess to the environment.

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2. MATERIAL AND METHODS

The material and methods section describes the effluent materials, laboratory type systems and procedures that were used for this research study.

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2.1. Materials

s2.1.1. Fermentation Materials

Cow Manure was obtained from The State University of NEW York Dairy Farm operation in Morrisville, NY. Wastewater was obtained from the Cleanwater Educational Research Facility (CERF) located at the Village of Minoa Wastewater Treatment plant in Minoa, NY.
Bacteria for the experiments were obtained from a nearby sludge blanket reactor at a nearby commercial wastewater treatment facility.
PVC pipe and fitting material from Charlotte Pipe and Foundry Company was obtained from a hardware store. Purple PVC primer and clear cement from Oatey® were used fuse the PVC pipe parts together.

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2.1.2. Barrier Fluid

The Preparation of the barrier fluid solution is initially described by Dölle and Hughes [1] following DIN 38414 [19]. To prepare the solution a 1500 ml glass beaker is filled with 1,000 ml deionized water and placed on a Themo Scientific brand-stirring hotplate. A magnetic stir bar was inserted into the beaker and the deionized water was heated under stirring until a temperature of 40°C was reached. Under stirring 30 ml of sulfuric acid (H_2SO_4; ρ=1,84 g/ml) were added, followed by slowly adding 200 g of sodium sulfate dehydrate (Na_2SO_4) to the diluted sulfuric acid solution till all sodium sulfates dehydrate is dissolved in the solution.
At a temperature of 20°C, 0.1 Methyl orange sodium salt is dissolved under constant stirring in 100 ml of distilled water using a 150 ml glass beaker and a magnetic stirring hot plate.
A few drops of the Methyl orange solution are added to the barrier fluid to allow for easier visualization. The color is adjustable to either a lighter or a darker orange by adding drops to the barrier solution as desired by the researcher.
To avoid crystallization of the barrier solution was stored under room temperature. Should crystallization occur, the crystallization process can be easily reversed by heating and stirring the barrier solution to 40°C using a stirring hotplate suitable for the container where the barrier solution is stored.

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2.1.3. Absorbent Fluid

The Preparation of the absorbent fluid solution is initially described by Dölle and Hughes [1]. The preparation was done as follows: 500 ml of deionized water having a temperature of 20°C, was filled into a 1,000 ml glass beaker, which was then placed on A Thermo Scientific brand stirring hotplate. Under constant stirring, using a magnetic stirrer, Sodium Hydroxide (NaOH) pellets were added until a final NaOH solution of 10% was achieved. After preparation, the adsorbent solution was filled in a labeled glass bottle. The glass bottle was closed and stored until used.

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2.1.4. Laboratory Anaerobic Aerobic Effluent Treatment System

To treat the three effluent types and assess the biogas production a laboratory Anaerobic Aerobic Effluent Treatment (AAET) system, shown in Figure 3., comprised of an Anaerobic Sludge Blanket Reactor (ASBR), Aerobic Bio-tower (ABT), and Aerobic Effluent Treatment Tank (AETT) was designed and build. The ASBR had an integrated Methane Gas Measuring (MGM) system to measure the raw biogas production. The biogas content without CO_2 was then determined with a Laboratory Benchtop Methane Analyzer (LBMA) system by Dölle and Hughes [1].
The ASBR reactor, see publication by Dölle & Lex (2022) [2] or more details, used for the laboratory benchtop AAET system, shown in Figure 3., was designed from schedule 40 Polyvinyl chloride (PVC) pipe parts to hold a volume of 2850 ml and width to height ratio of 1:6 of the inner reactor pipe.
The fermentation temperature of ASBR can be adjusted with an integrated water jacket. All PVC connections of the reactor have been fused together using purple PVC primer and clear PVC cement.
A 10-liter Fisher Scientific heating bath filled with deionized water (28) heated circulation water (4) into the heating jacket, based on the required fermentation temperature. A

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submersible small 25-Watt Pond pump (5) circulates the circulation of water. The pond pump has a maximal flow rate of 4.40 gal/min (16.66 l/min) at a head of 5.5 ft. (1.67 m). The water is pumped at a rate of 0.5 l/min through a PVC hose (29) into the heating jacked. The cooled down water flows back through hose (30) into heating bath (4).
A PVC funnel (6) with 60 mm in diameter is used for the collection of biogases produced from the substrate (15) in the ASBR sludge blanket reactor (1). A 1/8-inch clear PVC pipe (31) connects the funnel with the MGM system (7), built and installed according to the publication of Doelle [2], that collects the produced biogas.
Attached to the ASBR (1) is a settling vessel (8), manufactured from a 2-inch pipe, which collects the discharged reactor effluent (17). Settled waste can be removed by pipe 33 and discharged into the effluent container (35) with valve (34).
Influent container (2) serves as the reservoir for the influent substrate (14) used for anaerobic fermentation in the ASBR (1). The substrate (14) is pumped with a Jecod DP-2 peristaltic auto dosing pump (5) using ½" clear PVC hose (22) and (23) from the substrate reservoir (2) to the distributer (24) located in the reactor (1). The distributer (16) is located 1-inch (25.4 mm) above the bottom of reactor 1 and is manufactured from a 3/8 PVC caped pipe, containing there 1/8-inch holes.
Accumulated sludge of the SASBR can be discharged, if needed, through discharge pipe (25) and discharge valve 26 into the ASBR sludge container (27).
The settled effluent from the
The settled effluent from the effluent vessel (8) is discharged into the AETT as described in detail by Doelle et.al. [2,20] and a Laboratory Benchtop Bioreactor System (LBB) system as described by Dölle & Lex et. al. [2]. The AETT receives the influent liquid through the influent line (36) and is a holding vessel for recirculating the effluent of the ABT system (11). The covered AETT consists of a 5-gallon (18.9 l) recirculation tank (9), with a liquid capacity of 15 liters (3.97 gal.), and a divider that separates the LBS recirculation tank (1) in two equal sized chambers, a settling chamber (18) for solids, and the effluent chamber (19) with a volume of 7.5-liter (1.99 gal.).
A fish tank air pump (11) provides airflow at 0.14 gal/min (0.5 l/min) into the bottom of the glass tank (8) A using a fish tank air stone (12).
A small 25-Watt Pond pump (10) with a maximal flow rate of 4.40 gal/min (16.66 l/min) at a head of 5.5 ft. (1.67 m) recirculates the suspension from the recirculation tank (9) to the distributor (39). A valve (38) allows adjustment of the liquid flow through a Polyvinyl Chloride (PVC) hose with a 10 mm inside diameter (37) to the distributer (39).
The suspension trickles then onto the growth media (10), cut randomly from 0.276 ft^3 (0.008 m^3) recycled Bentwood CF-1900 cross flow media with 48 ft^2/ft^3 157 m^2/m^3 [21] to a maximum size of 1.0 x 1.0 x 1.0 in (25 x 25 x 25 mm).
After the suspension made its way through the growth media (40). The suspension is collected then by the collection chamber (20) in the lower part of the glass ABT and is transferred into the AETT influent line (36).
A fish tank air pump (11) provides airflow at 0.14 gal/min (0.5 l/min) into the bottom of the glass tank (8) A using a fish tank air stone.
Effluent (21) from the AAE is discharged into the collection vessel (13) by discharge line (41).

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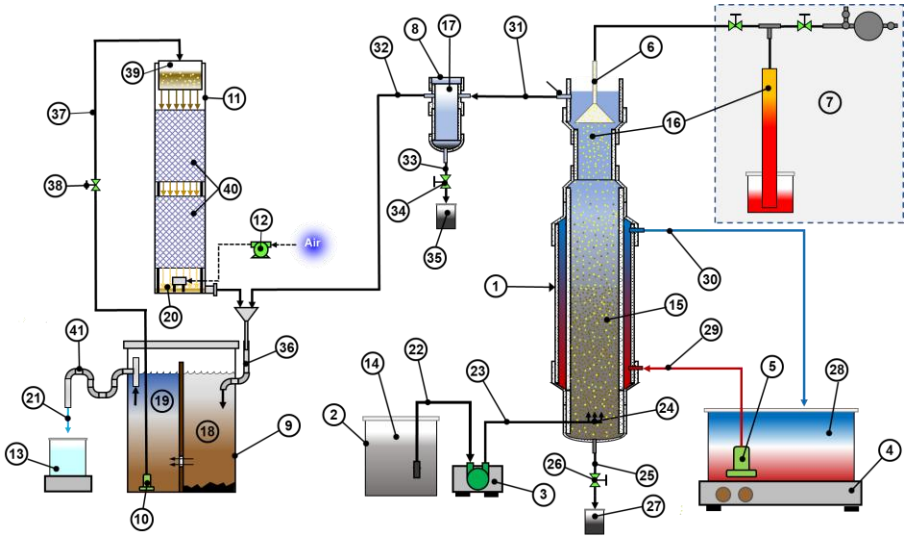

Fig. 3. Laboratory Anaerobic Aerobic Effluent Treatment (AAET) System [22]

2.1.5. Laboratory Benchtop Methane Analyzer System

Figure 4. shows a Laboratory Benchtop Methane Analyzer (LBMA) system as described by Dölle and Hughes [16]. The same system was used for this research and consisted of a 500 ml clear PVC beaker (1) containing the solvent. A 120 ml inverted PVC cylinder was used as the displacement vessel (2) for the absorbed solvent (10) and was located approximately 5 mm above the bottom of the PVC beaker. The displacement vessel was also fitted with a self-sealing pipe fitting. Both ends of the tee (4) were connected to a PVC hose (3). This was provided with valves (5) and (6) on both the left and right side. A 3-way rubber suction cup (7) was attached to the right of the tee-connector. In the last step, a 50 ml syringe (8) containing biogas (9) was attached to the left side.

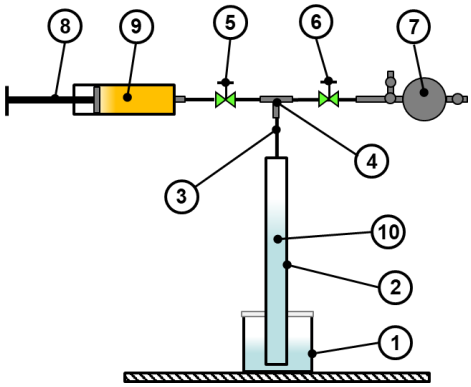

Fig. 4. Laboratory Benchtop Methane Analyses (LBMA) System by Dölle et. al. [1]

2.1.6. Laboratory Testing Procedures

For determining the Chemical Oxygen Demand (COD), Hach HACH COD TNTplus® Spectrophotometer Vial Test (3-150.0 mg/L) were used following HACH Method 8000 [23]. A HACH DRB200 Reactor was used to treat TNTplus® test vials according to the HACH 8000 Method, followed by analyzing the COD using a HACH DR900 Spectrophotometer.
The degradation of the substrate by bacteria to mainly biogas, carbon dioxide, water and new biomass has also an influence on the Total Solids (TS) and Total Suspended Solids (TSS). It can be assumed that the TS and TSS decrease through the degradation of substances into gases, water and biomass flocs with better settling properties. However, biomass with lower settling capabilities like bulking sludge could also increase the TS and TSS.
The TS of a given test sample was measured using 300 ml aluminum sample containers, which were marked and weighted accordingly. Then approximately 200 ml to 220 ml of the prepared substrate was added to each of the corresponding aluminum sample containers prepared for the given test sample. Weighting of the sample containers followed, before they were placed in a ~105°C oven to dry for 48 hours to evaporate the moisture. After drying, the samples were weight again to determine their dry weight measurement. The remaining solids were the TS content of the substrate.
For measuring, the TSS the Cole Parmer Total Suspended Solids Method and Procedure was used [24]. A sample of maximal 1000 ml was used. The sample was filtered using a 45 µm pore size glass fiber fabric filter (HACH, Be Right, grade: MGA, 47 mm). The solids which were retained on the filter and dried at 105 °C gave then the measurement for the TSS [24].
Temperature and pH measurements were conducted using a portable Milwaukee MW102 pH/temperature meter.
Measuring the biogas production in the laboratory BASBF reactor was done volumetrically.

2.1.7. Preparation of Selected Influent Substrates

To determine the working capacity of the designed Laboratory BASBF System three different influent substrates were used. First, Milk Waste (MW), a waste product from processing dairy products, which can contain but not limited to unusable milk product residues, wash water of milk processing equipment, The (MW) was manufactured by diluting a 2% milk product 10 times with tap water. Measurements showed that the influent TS of the MW had on average COD of 14360 mg/l ±30 mg/l, an TS of 793 mg/l ±6.0 mg/l, and a TSS of around 42 mg/l ±2 mg/l.
Second, Wastewater (WW), which is known to have low degradable and with water highly diluted substances, and second, separated liquid cow manure with more easily degradable and less diluted substances. The WW influent that was collected from the influent flow to a primary clarifier of the Minoa wastewater treatment plant was filtered prior to usage to avoid clogging the peristaltic feed pump (5) and the ½" clear PVC feed hoses (14) and (15) with larger suspended solids. However, the influent content and consistency of a WW is highly varying through the year, day and hour [14]. The reason of this lies in the nature of to the wastewater system connected homes and industries and the design of wastewater system itself. In addition, the WW also changes while storage and in the influent system until it enters the AAET system. Measurements showed that the TS of the influent WW into the AAET System had on average TS of 67 mg/l ± 5 mg/l, an TSS of around 2.4 mg/l ± 0.1 mg/l, and a COD of 335 mg/l ± 5 mg/l.
The cow manure obtained from the SUNY Morrisville dairy operation had an original consistency of 13.2 ±0.2 %. To obtain the targeted influent quality at an approximately COD level of 300mg/l, the manure was diluted to a consistency of 5 % using tap water. A hand operated screw press, shown in Figure 5., was used for separating large solids from the diluted manure. The screw press liquid effluent was afterwards diluted 1:50 with tap water to reach a final COD of 841 ± 42 mg/l and a final TS of 540 mg/l ± 20mg/l, and a TSS of 50 mg/l ± 5 mg/l.

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All three influent substrates were stored in a cold room at 5.0°C (41.0°F) until they were transferred to the room tempered 23.0°C (73.4°F) influent container (4).

Figure 5. Hand Operated Screw Press [25]

2.1.6. Start-Up and Operation of the Laboratory Anaerobic Aerobic Effluent Fermentation System

The Laboratory AAEF system was installed and tested followed by a 2-week start-up phase using prepared WW. First, WW prepared according to Section 2.1.7. was filled in reactor (1) till the WW did enter settling vessel (8) and from there entered the AETT (8) through the ¼-inch clear PVC hose (32) and influent line (36) respectively.

Second, 100 ml Bacteria, with a solids content of 6.5%, from a sludge blanket reactor from a nearby commercial wastewater treatment facility were added to reactor (1).

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Third, distilled water at 20°C (26) in the heating water bath (4) was slowly heated and pumped with pond pump (5) at a flow of 0.5 l/min through ¼-inch clear PVC hose (29) into the heating jacket. Recirculation water flowed back from the heating jacket through ¼-inch clear PVC hose (30) into the water bath (4). The final temperature in the water bath (3) was 45°C in order to maintain a reactor liquid temperature of 38°C.

Forth, prepared WW was filled into Influent container (2) which serves as the reservoir for the WW substrate (14) used for anaerobic fermentation in the ASBR (1). The WW substrate (14) is pumped with a peristaltic pump (3) at a flow rate of 20 ml/min, which equals a Hydraulic Retention Time of 6 days in the laboratory BASBF system using ¼-inch clear PVC hose (22) and (23) into the distributer (24). Effluent discharged by the BASBF settled in settling vessel (8) and flows by gravity into the AETT where it is recirculated through the ABT with a recirculation rate of 30 ml/h. Based on the HRT feed rate treated effluent (21) is discharged int the collection vessel (13) by discharge line (41).

The laboratory BASBF system continued to operate in this way for 2 weeks by adding daily prepared WW into influent container (2).

After the start-up phase, the laboratory BASBF system was operated for each of the three influent substrates under two feeding operation modes shown in Table 1., having a HRT of 1 day, 3 days, and 4 days and an influent feeding rate of 119 ml/d, 40ml/d, and 20 ml/d respectively.

Table 1. Feeding operation modes for the Laboratory Anaerobic Sludge Blanket Fermentation System

Operation Mode	HRT [d]	Influent [ml/h]
Test 1	3	40
Test 2	6	20

The produced biogas by the laboratory BASBF system was measured with the attached biogas collecting device.
The biogas collection during the operational modes was done as described in publication by Dölle & Lex (2022) [2], by adding barrier liquid barrier fluid reservoir. The produced biogas (16) by the laboratory ABTS and collected with collection funnel (6) flows into the displacement vessel where it measured as the volume of displaced barrier fluid.
It is known for systems with living organisms, bacteria in the bio-towers must adapt to new nutrient levels. It was assumed that a stationary operation was reached after at least 5 days adaptation time to a new substrate. Measurements were carried out after 5 days of running the laboratory AAFT system in the chosen operation mode.
The COD, TS, and TSS contents were measured from the different influents and resulting effluents.
Another parameter to characterize biological processes and to follow the reactor stability is the pH-value. It can show changes of organic acids and hydrate formation in the degradation process of organic material via bacteria, therefore the pH of the ASBR reactor was targeted between 7.5 and 8.2.
Temperature also could highly influence biological processes. For this reason, measurements of the temperature in the bio-tower systems were done to control the steady state, therefore the temperature of the ASBR reactor was targeted at 38°C.

3. RESULTS AND DISCUSSION

For this research work, the substrates MW, WW and separated LCM were used as influent media to characterize the degradation capability of a Laboratory AAET System. The following chapter compares and summarizes the degradation processes and effluent qualities of the AAET systems.
After the start-up of the laboratory AAET system with wastewater and the adaption time, the reactor was operated like described in Section **Error! Reference source not found.**.6. with MW, LCM and WW at an hydraulic retention times of 3 and 6 days after an adoption time of 7 days for the MW. The operational results of the laboratory AAET system are being discussed in the following subsections.

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3.1. Reduction of chemical oxygen demand

Figure 6., shows the degradation of the COD of the laboratory AAET system based on influent liquid COD level of MW, LCM and WW into the ASBR system. The influent liquid COD for the 6-day and 3-day HRT was 14360 mg/l for MW, 841 mg/l for LCM and 341 mg/l for the WW. The COD, as seen in Figure 6., differs between and within the operation modes of the two HRT of 6 and 3 days. The operation of the laboratory ASBR reduced the influent COD of the MW by 95.05% to an effluent level of 710 mg/l for the 3-day HRT, and by 96.89% to 446 mg/l for the 6-day HRT. The effluent liquids from the ASBR were transferred into the ABT combined with a AETT, which reduced the COD further to an effluent level of the AAET system of 320 mg/l or 97.77% for the 3-day HRT and 257 mg/l or 98.21% for the 6-day HRT for the 14360 mg/l influent level of the MW.

The laboratory ASBR operation reduced the influent COD of the LCM by 81.93% to an effluent level of 152 mg/l for the 3-day HRT, and by 95.84% to 35 mg/l for the 6-day HRT. The effluent liquids from the ASBR were transferred into the ABT combined with a AETT, which reduced the COD further to an effluent level of the AAET system of 124 mg/l or 85.25% for the 3-day HRT and 23 mg/l or 97.27% for the 6-day HRT for the 841 mg/l influent COD level of the LCM.

For the WW influent COD level of 335 mg/l the laboratory ASBR operation reduced the influent COD of the WW by 76.12% to an effluent level of 80 mg/l for the 3-day HRT, and by 95.84% to 35 mg/l for the 6-day HRT. The effluent liquids from the ASBR were transferred to the ABT combined with a AETT, which reduced the COD further to an effluent level of the AAET system of 20 mg/l or 94.03% for the 3-day HRT and 12 mg/l or 96.42% for the 6-day HRT based on the influent level of the WW.

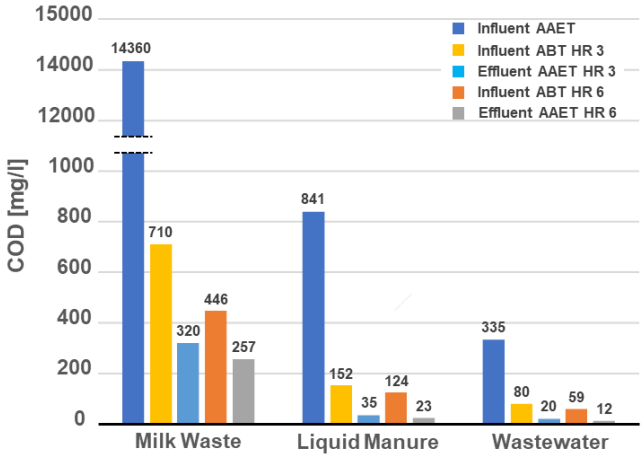

Fig. 6. Chemical Oxygen demand (COD) of Influent Liquid Waste in a Anaerobic Aerobic Reactor System with a Hydraulic Retention Times of 3 and 6 Days.

3.2. Reduction of Total Solids

Figure 7., shows the degradation of the TS of the laboratory AAET system based on the influent liquid TS level of MW, LCM and WW. The influent liquid TS for the 6-day and 3-day HRT was 793 mg/l for MW, 540 mg/l for LCM and 67 mg/l for the WW. The TS, as seen in Figure 7., differs between and within the operation modes of the two HRT of 6 and 3 days.

The operation of the laboratory ASBR reduced the influent TS of the MW by 87.89% to an effluent level of 96 mg/l for the 3-day HRT, and by 92.43% to 60 mg/l for the 6-day HRT. The effluent liquids from the ASBR were transferred into the ABT combined with a AETT, which reduced the TS further to an effluent level of the AAET system of 2.5 mg/l or 99.68% for the 3-day HRT and 0.5 mg/l or 99.96% for the 6-day HRT for the 793 mg/l influent level of the MW.

The laboratory ASBR operation reduced the influent TS of the LCM by 86.11% to an effluent level of 75 mg/l for the 3-day HRT, and by 87.96% to 65 mg/l for the 6-day HRT. The effluent liquids from the ASBR were transferred into the ABT combined with a AETT, which reduced the TS further to an effluent level of the AAET system of 65 mg/l or 87.96% for the 3-day HRT and 31 mg/l or 94.26% for the 6-day HRT for the 540 mg/l influent TS level of the LCM.

For the WW influent TS level of 67 mg/l the laboratory ASBR operation reduced the influent TS of the WW by 40.30% to an effluent level of 40 mg/l for the 3-day HRT, and by 53.85% to

30 mg/l for the 6-day HRT. The effluent liquids from the ASBR were transferred to the ABT combined with a AETT, which kept the TS level at 30 mg/l for both the 3-day and 6-day HRT.

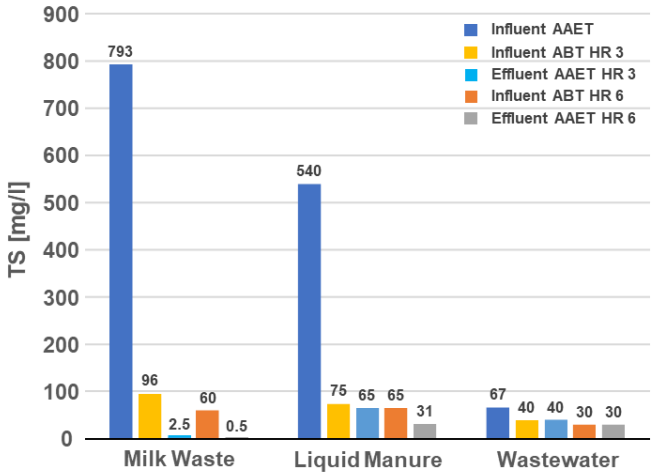

Fig. 7. Total Solids (TS) of Influent Liquid Waste in a Anaerobic Aerobic Reactor System with a Hydraulic Retention Times of 3 and 6 Days.

3.3. Reduction of Total Suspended Solids

Figure 8., shows the degradation of the TSS of the laboratory AAET system based on influent TSS level in the liquid of the MW, LCM and WW. The influent liquid TSS for the 6-day and 3-day HRT was 41 mg/l for MW, 50 mg/l for LCM and 2.4 mg/l for the WW. The TSS, as seen in Figure 6., differs between and within the operation modes of the two HRT of 6 and 3 days. The operation of the laboratory ASBR reduced the influent TSS of the MW by 17.07% to an effluent level of 34 mg/l for the 3-day HRT, and by 46.34% to 22 mg/l for the 6-day HRT. The effluent liquids from the ASBR were transferred into the ABT combined with a AETT, which reduced the TSS further to an effluent level of the AAET system of 0.05 mg/l or 99.87% for the 3-day HRT and 0.03 mg/l or 99.93% for the 6-day HRT for the 14360 mg/l influent level of the MW.

The laboratory ASBR operation reduced the influent TSS of the LCM by 52.00% to an effluent level of 24 mg/l for the 3-day HRT, and by 68.00% to 16 mg/l for the 6-day HRT. The effluent liquids from the ASBR were transferred into the ABT combined with an AETT, which reduced the TSS further to an effluent level of the AAET system of 10 mg/l or 80.00% for the 3-day HRT and 6.8 mg/l or 86.92% for the 6-day HRT for the 50 mg/l influent COD level of the LCM.

For the WW influent TSS level of 2.4 mg/l the laboratory ASBR operation reduced the influent TSS of the WW by 98.33% to an effluent level of 0.04 mg/l for the 3-day HRT, and by 99.16% to 0.02 mg/l for the 6-day HRT. The effluent liquids from the ASBR were transferred to the ABT combined with an AETT, which reduced the TSS effluent level of the AAET system by 50% further to 0.02 mg/l and 0.01 mg/l for the 3-day HRT and 6-day HRT respectively.

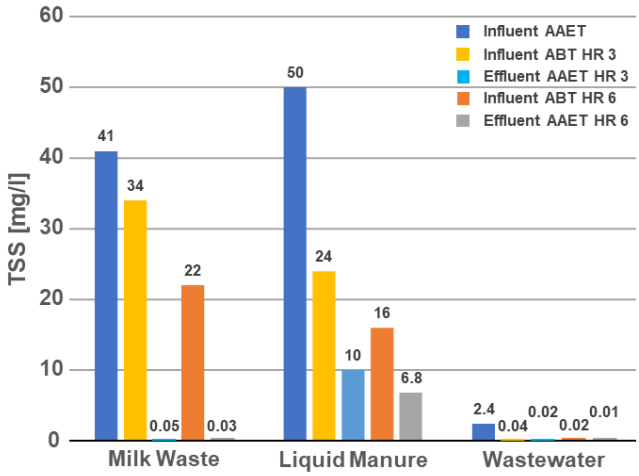

Fig. 8. Total Suspended Solids (TSS) of Influent Liquid Waste in a Anaerobic Aerobic Reactor System with a Hydraulic Retention Times of 3 and 6 Days.

3.4. Biogas production

The ability to break down organic matter contained in the influent and convert it into biogas by the laboratory AAET system was assessed by measuring the produced biogas volumetrically as described in Section 2.1.4. in ml/d after the reactor has been run for 7 days start up period with the MW, LCM and WW.

It can be seen in Figure 9., that for the MW feed liquid, the biogas production per day decreased with increasing HRT from 3 to 6 days from 2.23 ml/h to 1.92 ml/h.

For the LCM feed liquid, the biogas production per day decreased with increasing HRT from 3 to 6 days from 1.80 ml/h to 1.56 ml/h, and for the WW feed liquid, the biogas production per day decreased with increasing HRT from 3 to 6 days from 1.68 ml/h to 1.36 ml/h.

The measured CH_4 content of the biogas was 65% ± 5% for the collected biogas.

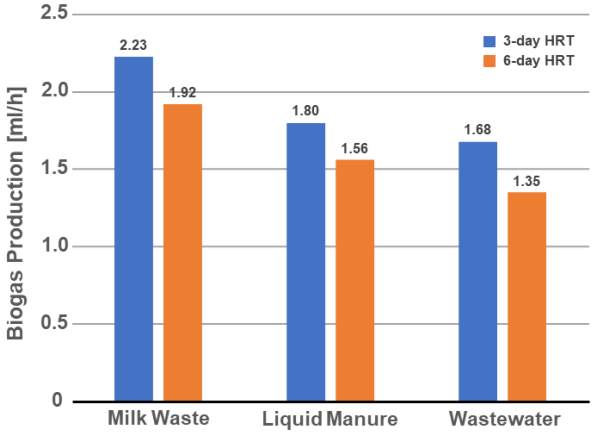

Fig. 9. Biogas Production of the Anaerobic Aerobic Reactor System with a Hydraulic Retention Times of 3 and 6 Days.

3.5. Discussion

The used MW had around 17 times higher COD compared to the LCM and the LCM had about a 2.5 times higher COD content compared to the LCM. The COD and subsequent the TS and TSS reduction for the 3-day HRT was lower compared to the 6-day retention time and therefore the AEET system has still potential in regard to COD, TS, TSS disintegration and Biogas production based on an operation temperature of 38°C and a pH between 7.5 and 8.0. One explanation could be that not enough bacteria are contained in the laboratory BASBF system able to convert the nutrition contained in the MW and LCM, which suggests that the laboratory AAET system can produce a higher biogas amount per liter reactor volume if a higher number of bacteria is present in the ASBR as well as an overall improved AAET system effluent in regard to COD, TS and TSS. Therefore, operating the ASBR with different amounts of bacteria in the ASBR should be investigated in a further research approach to determine the ASBR and the AEET system operation can be improved.

CONCLUSION

A laboratory AAET system comprised of an up flow ASBR, ABT with an integrated an AETT was designed, build, and started up with WW during a 240-hour inoculation and adjustment time. After start-up the AAET system was operated using prepared MW, LCM and municipal WW at an HRT of 3 days and 6 days.

The laboratory AEET system was able to degrade all three influent liquids MW, LCM, and WW for the 3-day retention time, showing that the designed laboratory AEET system is capable of reducing a variety of waste streams as well as produced biogas from the waste streams.

The influent COD of the MW was 14360 mg/l, 841 mg/l for LCM and 335 mg/l for the WW and was reduced respectively by 95.05%, 81.93%, and 76.12% by the ASBR. A 6-day HRT for the ASBR increased the COD removal to 96.89%, 95.84%, and 95.84% respectively before it entered the ABT with integrated AETT which decreased the MW COD removal further to 97.77% and 98.21% for the 3-day and 6-day retention time. The LCM could be decreased further to 85.25% for the 3-day HRT and 97.27% for the 6-day HRT. The COD of the WW was reduced by 94.03% for the 3-day HRT and 96.42% for the 6-day HRT.

The TS influent removal for a TS of 793 mg/l for MW, 540 mg/l for LCM, and 67 mg/l for WW was 87.89%, 86.11%, and 40.30% by the ASBR for the 3-day HRT. A 6-day HRT increased the TS removal to 92.43%, 87.96% and 53.85% respectively for the ASBR before the liquid entered the ABT with integrated AETT, decreasing the MW and LCM TS removal further to 99.68% and 87.96% for the 3-day HRT and 99.96% and 94.26% for the 6-day HRT. For WW the TS level did not decrease further for both the 3-day and 6-day HRT.

TSS removal for the MW, LCM, and WW with an influent liquid TSS of 41 mg/l, 50 mg/l, and 2.4 mg/l respectively for the 3-day and 6-day HRT achieved a reduction respectively of 17.07%, 52.00%, and 98.33% for the 3-day HRT. The 6-day HRT increased the TSS removal to 46.34%, 68.00%, and 99.16% for the MW, LCM, and WW respectively. The ABT combined with a AETT reduced the TSS further to 99.87%, 80.00%, and 50% for the 3-day HRT and 99.93%, 86.92%, and 50% for the 6-day HRT for the MW, LCM and WW respectively.

The ASBR of the AAET system operated at a temperature of 38°C and a pH between 7.5 and 8.2 achieved a biogas CH_4 content of 65% ± 5% of the produced biogas. The ASBR produced from MW 2.23 ml/h and 1.92 ml/h for the 3-day and 6-day HRT. LCM feed liquid achieved 1.80 ml/h and 1.56 ml/h, and WW feed liquid resulted in 1.68 ml/h to 1.36 ml/h for the 3-day and 6-day HRT respectively.

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