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Application of a Sludge Blanket Reactor for Effluent Treatment: A Laboratory Study

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Energy is required in all societies worldwide. This led to a dependency of fossil fuel. During uncertain times fossil fuel supply become highly politically and used as an influencing source. This requires establishing a more environmentally friendly processes to decrease dependency. To produce biogas from municipal, agricultural and industrial waste a laboratory benchtop up-flow sludge blanket reactor with a operating volume of 2850 ml was designed build, started up, and operated using prepared municipal wastewater and separated liquid cow manure at a hydraulic retention time of 1 day, 3 days and 6 days after an 120 h adjustment time prior to testing.

While using wastewater as influent, the laboratory benchtop up-flow sludge blanket reactor system was not able to reduce the chemical oxygen demand content significantly. Especially at a high volumetric flow rate for the 1-day hydraulic retention time. The produced gas amount decreased from 0.59 ±0.07 (ml/h)/L at a hydraulic retention rate of 6 days to 0.042 ±0.04 (ml/h)/L. The fluctuating influent chemical oxygen demand of 25 ±1 mg/L to 74 ±15 mg/L resulted in a stable effluent concentration of 39 ml/L and 45 ±11 mg/L respectively.

The laboratory benchtop up-flow sludge blanket reactor system with separated liquid cow manure showed a higher chemical oxygen demand degradation capability but resulted in higher chemical oxygen demand in the effluent. The influent chemical oxygen demand of 308 ±42 mg/L was broken downs to 59 ±1 mg/L at a hydraulic retention time of 6 days and to 114 ±5 mg/L for 1 day retention

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time. The biogas production result in a stable gas production rate of 0.27 ±0.02 (ml/h)/L through all three hydraulic retention times. For both the wastewater and separated liquid cow manure operation the biogas without carbon dioxide was between 55 and 65%.
The results show that the laboratory benchtop up-flow sludge blanket reactor system can reduce high chemical oxygen demand in wastewater and separated liquid cow manure. However, a minimum feed level having a minimal chemical oxygen demand above 36 mg/L is needed, otherwise, the active bacterial mass contributes to the effluent level as seen for the influent level below 36 mg/L and 25 mg/L which resulted in a minimum effluent level of 39 mg/L for a hydraulic retention time of 3-days and 6-days.

Keywords: Anaerobic digestion; biogas; co-digestion; effluent; energy production; fermentation; manure; sludge blanket reactor; wastewater

1. INTRODUCTION

In recent years, the problematic of increasing demand for substituting fossil fuels with renewable energy sources was discussed highly. This includes the possibility of reducing the dependency on fossil fuels. Fossil fuels show since years the tendency of being a highly politically and used influencing source. 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 [1].

Today, energy is required in all societies over the world to run productive processes and provide basic human needs [2]. According to the International Energy Agency (IEA) [3], between 1971 and 2019 the energy supply worldwide rose 2.6 times from 230 Exajoule (EJ) to 606 EJ. Oil accounts for 44% in 1971 and fell to 31% in 2010 but did not change significant since then. Oil is still the most important fuel worldwide followed by coal and its structure changed markedly. Oil fell from 44.3% to 30.9% of TES between 1971 and 2010; its share has held steady since then and it remains the most important fuel in 2019. Coal has consistently remained in second place with over a quarter (26.1% in 1971 and 26.8% in 2019) in the global energy mix. Nuclear energy increased from 0.5% to 5%. Renewables such as hydropower and other renewables (solar, wind, geothermal, ocean power) increased from 1.6% to 2.5% and 0.2% to 2.2% respectively [3].

The advantage of fossil fuel sources is their ease of storage and 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 [4].

Biofuels such as biogas can be stored, converted into liquid fuel or electricity when needed as well as produced from either energy crops or bio-based waste products. Waste products might include municipal wastewater residues and 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 B and have been practiced in ancient China over 3000 years ago [5].

Today, biogas produced by AD has become and an alternative, carbon-neutral, renewable fuel that can be easily generated from local, low-cost organic materials [6-8].

AD reactor technology is designed to treat a specific range of biomaterials [2]. For treating liquid waste flows, reactor designs have to maximize substrate-to-biomass contact and biomass retention simultaneously by maximizing the contact between substrate and biomass [9].

In recent years, manure has 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 [10]. This leads to the investigation of new techniques, which could reduce the weight of liquid cow manure to improve the economical transportation circumstances. Separating cow manure leads to better transportable organic fertilizer and liquid supernatant. The liquid supernatant is still high in nutrients and has to be further processed until it could be released directly to the environment [11].

Liquid waste flows from municipal Wastewater Treatment Plants (WWTP) have low

concentration of biodegradable materials e.g., Chemical Oxygen Demand of 50 mg/L to 200 mg/L [12].

Processing both, agricultural supernatant as well as WW could be done by using an aerobic up flow sludge blanket reactor.

The following Fig. 1. By Doelle, et. al. [13] shows a typical layout of a up flow sludge blanket reactor. A basic layout includes a vertical cylindrical formed tank. The influent of anaerobic digestible material enters the system via a pump from the bottom and products exit the tank at the top (up flow). The influent gets distributed across the whole reactor diameter and mixed up with the biocenosis of anaerobic bacteria and higher cellular creatures. Bacteria in biocenosis cooperate with each other to improve their different nutrition 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 [2,14].

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 to break down organic material into products like biogas, water and new bacterial biomass Fig. 2. By Dölle et al. [13] describes the anaerobic degradation pathway in more detail. The processes could be roughly classified into four groups, acitogenic, 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 uses then the acidic acid as typical building block for forming biogas [13].

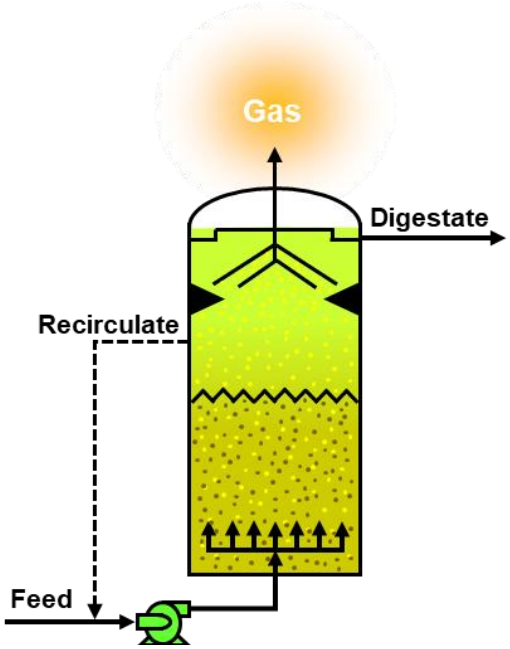

Fig. 1. Diagram of an Expanded Granular Sludge Bed (EGSB) reactor by Dölle et. al. [13]

However, this summarizes just roughly the whole degradation routes and pool of intermediate and products. Until today, it is still not completely clear how the whole processes in a biocenosis work to degrade biological degradable material into biogas. Additionally, products and pathways also change with changing 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) [2,14-16].

The objective for this research work is to design, build, install and start up a laboratory up flow activated sludge blanket reactor, followed testing its ability to degrade organic components in wastewater and agricultural 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.

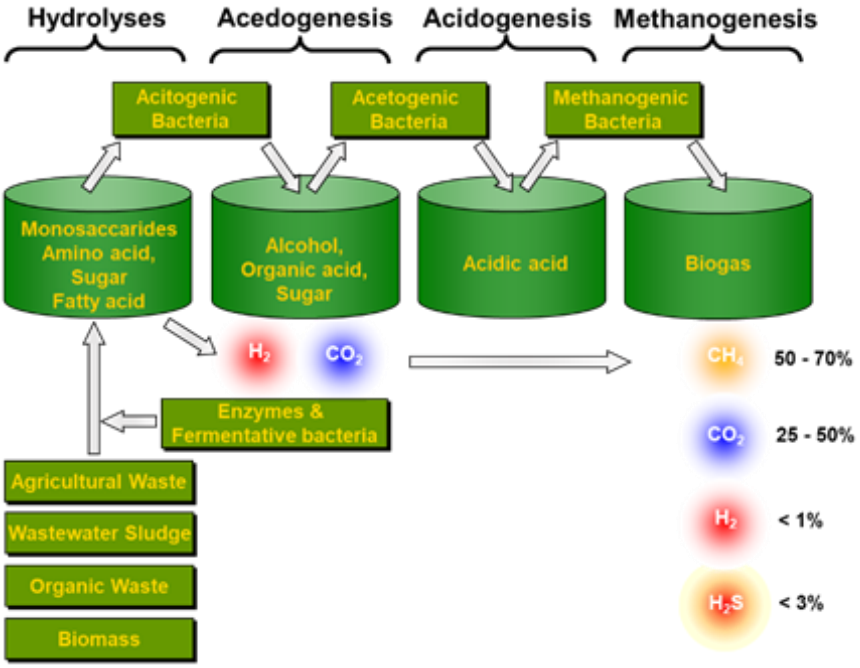

Fig. 2. Pathway of anaerobic digestion by Dölle et al. [13]

2. MATERIALS AND METHODS

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

2.1 Materials

2.1.1 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 waste water 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.

2.1.2 Barrier fluid

The Preparation of the barrier fluid solution is initially described by Dölle and Hughes [2] following DIN 38414 [17]. 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 sulfate 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 more or less 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 the barrier solution is stored.

2.1.3 Absorbent fluid

The Preparation of the absorbent fluid solution is initially described by Dölle and Hughes [2]. The preparation was done as follows: 500 ml of deionized water having a temperature 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.

2.1.4 Laboratory benchtop anaerobic sludge blanket fermentation systems

To treat the effluent and measure the biogas production a laboratory Benchtop Anaerobic Sludge Blanket Fermentation (BASBF) system with an integrated Methane Gas Measuring (MGM) system, as shown in Fig. 1., was designed to treat the effluents and 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 [2].

The reactor (1) of the laboratory benchtop BASBF system shown in Fig. 3. was designed from schedule 40 Polyvinyl chloride (PVC) pipe parts to hold a volume of 2850 ml in the inner reactor pipe (1.1), and width to height ratio of 1:6. All PVC connections of the reactor have been fused together using purple PVC primer and clear PVC cement.

The 3-inch inner reactor pipe (1.1) with an inside diameter of 3.042" (77.269 mm) was closed on the bottom with a 3-inch round cap (1.2).

The reactor (1) has a water jacket attached (1.6) to maintain and adjust the desired fermentation temperature. The water jacket was made from a 4-inch PVC pipe (1.7) with an inside diameter of 3.998" (101.549 mm) and a length of 11.000" (279.400 mm). The 4-inch pipe (1.7) was attached to the reactor pipe (1.1) with two 4-inch to 3"-inch pipe reducers (1.8). A 10-liter Fisher Scientific heating bath filled with deionized water provides heated circulation water (13) into the heating jacket, based on the required fermentation temperature. A submersible small 25-Watt pond pump (2) circulates the circulation 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 (12) into the heating jacked. The cooled down water flows back through hose (11) into heating bath (3).

The inner reactor pipe (1.1) was reduced on top to a 2-inch pipe (1.4) with and inside diameter of 2.047" (55.994 mm) and a length of 4.000" (101.600 mm) using a 3-inch to 2-inch PVE reducer (1.3). The 2-inch pipe section (1.4) was extended to 3-inch pipe section (1.5) with inside diameter of 3.042" (77.269 mm) and a length of 4.000" (101.600 mm) using a 3-inch to 2-inch PVC reducer (1.3). A PVC funnel (6) with 60 mm in diameter was located 10 mm above the 2-inch pipe section for collection of biogases produced from the sludge blanket reactor. A 1/8-inch clear PVC pipe (6.1) connects the funnel with the biogas collection device.

The biogas collection device consisting of a ¼-inch clear PVC tee (28), a 120 ml clear PVC graduated cylinder (29), which serves as the displacement vessel for the barrier fluid (30), which is stored in 300 ml clear PVC barrier fluid reservoir (31). All connections to and from the biogas collection device are made from a ¼-inch clear PVC hose (6.1). Valves (27) left and right of tee (28) allow biogas (26) either to displace the barrier fluid (30) in the graduated cylinder (29), or to allow barrier fluid to flow back into the displacement vessel (31) using the connected 3-way rubber suction cup (32).

Attached to the reactor (1) is a settling vessel (7), which collects the reactor effluent (25). The reactor effluent is then discharged into a collection vessel (8). The settling vessel (7) is manufactured from a 2-inch pipe (7.1) with and inside diameter of 2.047" (55.994 mm) and a length of 4.000" (101.600 mm). The 2-inch pipe is covered on the bottom with a 2-inch round cap (7.2), and extended with a slip on 2-inch x 2-inch x 1/2–Female Iron Pipe Thread (FIPT) reducing tee (7.3). All connections from and to the reactor and settling vessel were made using a ¼-inch x ½-inch Barbed Barb x Male Iron Pipe (MIP) PVC Fitting (1.9). All connecting hoses (15), (17), (18) & (21) were made using a ¼-inch clear PVC hose.

Influent container (4) serves as the reservoir for the substrate (23) used for anaerobic fermentation in the sludge blanket reactor (1). The substrate (23) is pumped with a Jecod DP-2 peristaltic auto dosing pump (5) using ½" clear PVC hose (14) and (15) from the substrate

reservoir (4) to the distributer (16) located in the reactor (1). The distributer (16) is located 1-inch (25.4 mm) above the bottom of the reactor 1 and is manufactured from a 3/8 PVC caped pipe, containing there 1/8-inch holes.

2.1.5 Laboratory benchtop methane analyzer system

Fig. 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. In the last step, a 50 ml syringe (8) containing the biogas (9) was attached to the left side.

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 [19]. 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.

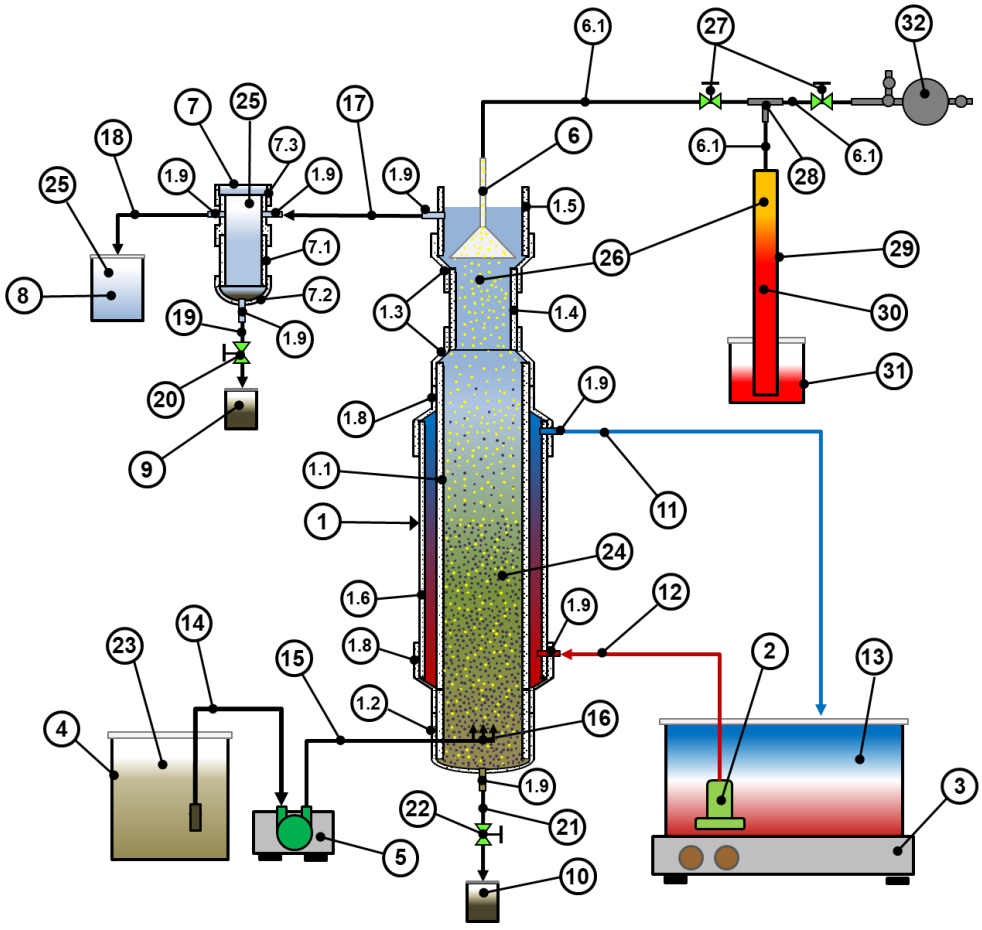

Fig. 3. Laboratory Benchtop Anaerobic Sludge Blanket Fermentation (BASBF) system [18]

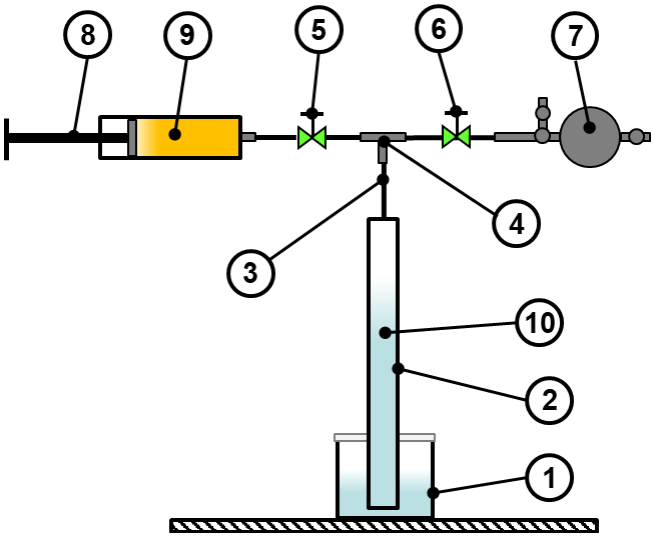

Fig. 4. Laboratory Benchtop Methane Analyses (LBMA) System by Dölle et al. [2]

The TS of a given test sample was measured using a 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 [20]. 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 [20].

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 two different influent substrates were used. First, 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 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.

The influent content and consistency of a WW is highly varying through the year, day and hour [10]. 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 BASBF. Measurements showed that the TSC of the WW had on average 0.053 ±0.018 % and an TSS of around 0.002 %. After filtration the TSS were reduced to < 0.001 % and the WW had a final influent COD of 42 ± 23 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 300 mg/L, the manure was diluted to a consistency of 5 % using tap water. A hand operated screw press, shown in Fig. 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 308 ± 42 mg/L and a final TS of

0.041 ±0.002 %, and TSS of 0.0187 % compared to the wastewater.

Both 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).

2.1.8 Start-Up and operation of the laboratory benchtop anaerobic sludge blanket fermentation system

The Laboratory BASBF system was installed, and a 3-week start-up phase was initiated using prepared WW. First, WW prepared according to Section 2.1.7. was filled in reactor (1) till the WW did enter settling vessel (7) and from there entered collection vessel (8) through the ¼-inch clear PVC hose (17) and (18) 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).

Third, distilled water at 20°C (13) in the heating bath (3) was slowly heated and pumped with pond pump (2) at a flow of 0.5 l/min through ¼-inch clear PVC hose (12) into the heating jacket. Recirculation water flowed back from the heating jacket through ¼-inch clear PVC hose (11) into the water bath (3). 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 (4) which serves as the reservoir for the WW substrate (23) used for anaerobic fermentation in the sludge blanket reactor (1). The WW substrate (23) is pumped with a peristaltic pump (5) 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 (14) and (15) through to the distributer (16).

The laboratory BASBF system continued to operate in this way for 3 weeks by adding daily prepared WW into influent container (4).

After the start-up phase, the laboratory BASBF system was operated under three 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, 40 ml/d, and 20 ml/d respectively.

Fig. 5. Hand operated screw press [21]

Table 1. Feeding operation modes for the laboratory anaerobic sludge blanket fermentation system

Operation Mode	HRT [d]	Influent [ml/h]
Test 1	1	119
Test 2	3	40
Test 3	6	20

The produced biogas by the laboratory BASBF system was measured with the attached biogas collecting device.

To initiate the biogas collection during the operational modes, barrier liquid (30) was filled into the barrier fluid reservoir (31). Valve (27) left of the tee (28) was closed and valve (27) right of tee (28) was opened. Barrier fluid (30) was sucked into the displacement vessel (31) to the top, using the 3-way rubber suction cup (32). Valve (27) right of the tee (28) was closed, and valve (27) left of the tee was opened. The produced biogas (26) by the laboratory BASBF system, to be collected with collection funnel (6), and flows through PVC hose (6.1) to the displacement vessel (31) where it displaces the barrier fluid (31).

Like 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 adaption time. Measurements were carried after 5 days of running the laboratory BASBF system in 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.

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, a reactor at stable state would show a stable pH-value and temperature. Inhibitions in degradation routs could lead to a drift of the pH-value. For this the pH-meter/temperature Milwaukee MW102 meter was used was used.

Finally, the temperature also could highly influence biological processes. For this reason, measurements of the temperature in the bio-tower systems and septic tank were done to control the steady state.

3. RESULTS AND DISCUSSION

For this research work, the substrates wastewater and separated liquid cow manure were used as influent media to characterize the degradation capability of a Laboratory BASBF System. The following chapter summarize and compare the degradation processes and effluent qualities of the systems.

After the start-up of the laboratory BASBF system with wastewater and the adaption time, the reactor was operated like described in Section 2.1.6. with WW and LCM at an hydraulic retention times of 1, 3 and 6 days. The operational results of the laboratory BASBF are being discussed in the following subsections.

3.1 Reduction of Chemical Oxygen Demand

The laboratory BASBF system was at first operated with WW as influent. Like described in Section 2.7.7. the constituents in the WW and their dilution are highly varying with the time [10,12]. The chemical oxygen demand (COD), as seen in Fig. 3, differs between and within the operation modes of the three hydraulic retention times. The lowest WW influent COD was 25 ±1 mg/L at a HRT of 6-days, and 74 ±15 mg/L at a HRT of 1-day. However, with including the standard deviation the COD of the effluent kept stable at 45 ±11 mg/L. This means an increase of the COD for the lowest influent level and a decrease for the highest influent level. A rising COD of the effluent could occur if bacteria are washed out of the reactor through a too low influent level. Based on this result, the laboratory BASBF systems degradation capacity of the influent is 45 ±11 mg/L. However, to achieve this a minimum feed level of COD above the 45 mg/L is needed, otherwise, the active bacterial mass contributes to the effluent level as seen for the influent level of 36 mg/L and 25 mg/L with an effluent level of 39 mg/L for a HRT of 3-days and 6-days respectively.

Compared to WW, the according to Section 2.7.7. separated and prepared liquid cow manure (LCM) has a much higher COD concentration. The influent COD variance of 1:50 diluted LCM shows a much more stable level (308 ± 42 mg/L) across the tested 1-day, 3-day and 6-day HRT. In Fig. 7 it can be seen that a higher influent COD results in changing effluent COD levels. Higher HRT decrease the resulting COD effluent level to a minimum of 59 mg/L for the 6-day HRT, 20 mg/L above the minimum effluent level possible using WW as feed liquid. The longest hydraulic retention time (HRT) of 6-days lead to the lowest effluent COD concentration of

59 ±1 mg/L at a n COD influent level of 298 mg/L, and the shortest HRT of 1-day to the highest level of 114 ±5 mg/L at a n influent COD level of 293 mg/L. A HRT of 3-days resulted at a COD concentration of 80 mg/L at an influent COD level of 335 mg/L.

3.2 Biogas Production

The ability to break down organic matter contained in the influent and convert it into biogas by the laboratory BASBF system was assessed by measuring the produced biogas volumetrically as described in Section 2.1.6. In ml/d and ml/h based on liter reactor volume (L) after the reactor has been run for 5-days (120 h) under the selected operational mode.

It can be seen in Fig. 8., that for the WW feed liquid, the gas production decreased with decreasing retention time, less significant from 6 to 3 days (0.59 ±0.07 (ml/h)/L to 0.48 ±0.05 (ml/h)/L, at a feed COD content of 36 mg/L and 29 mg/L respectively. It dropped very noticeably at 1-day retention time to 0.042 ±0.04 (ml/h)/L at a fed COD of 74 ml/d for the prepared WW feed liquid. This could be related to the inconsistency of the original WW composition at the day of sampling the WW [10].

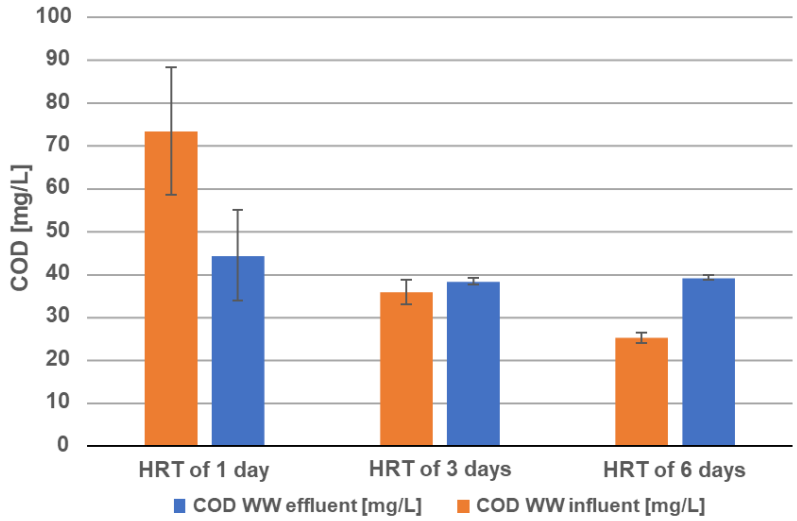

Fig. 6. Chemical Oxygen demand (COD) of Wastewater (WW) stabilization in a sludge blanket reactor over hydraulic retention times (HRT) of 1, 3 and 6 days

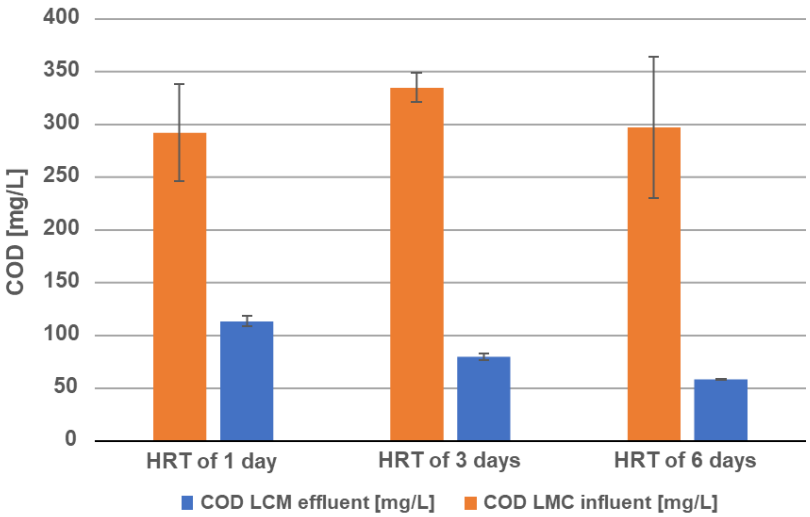

Fig. 7. Chemical Oxygen demand (COD) of separated Liquid Cow Manure (LCM) stabilization in a sludge blanket reactor over hydraulic retention times (HRT) of 1, 3 and 6 days

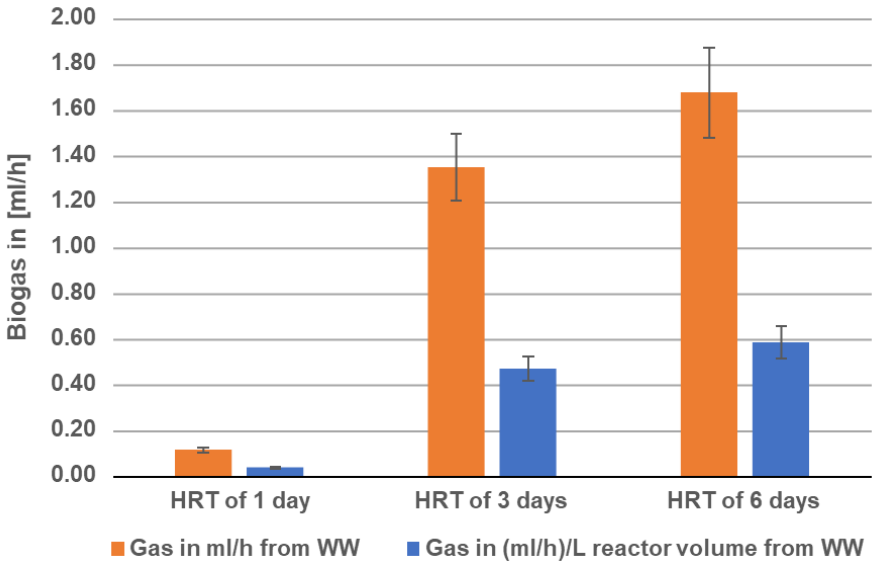

Fig. 8. Biogas production during wastewater (WW) stabilization in a sludge blanket reactor over hydraulic retention times (HRT) of 1, 3 and 6 days in ml/h and in (ml/h)/L reactor volume

Municipal WW is generally known to be a more complex substrate for biological degradation processes and the used wastewater influent had a very low COD content. With increasing the flow rate (reducing HRT) more difficult degradable components in the wastewater could not be broken down completely to needed compounds for the methanogenic bacteria. This might have resulted; that substrate contained in WW feed liquid could have left the reactor partially untreated or in a intermediate product state, and therefore, biomass could not be converted into biogas, CO_2 and water.

When operating the anaerobic sludge blanket reactor with separated LCM, the reactor showed as seen in Fig. 9, a completely different characteristic.

Fig. 9 shows, the measured biogas production during the operation of the sludge blanket reactor with LCM. It can be seen after the laboratory BASBF system has been run for five days (120 h) of the selected operation mode. The reactor showed stable operation characteristics and the steady state was always reached in the tests.

While decreasing the hydraulic retention time (HRT), the produced biogas flow per Liter reactor volume kept nearly stable at 0.30 ± 0.02 (ml/h)/L at a LCM COD feed rate of 293 mg/L, 0.25 ± 0.03 (ml/h)/L at a LCM COD feed rate of 335 mg/L, and 0.27 ± 0.02 (ml/h)/L at a LCM COD feed rate of 298 mg/L, having a HRT of 6-days, 3-days, and 1-day respectively. This could be related to easier degradable components in the LCM compared to municipal wastewater. However, this doesn't explain the overall lower biogas production when using separated liquid cow manure. The used LCM had an around six times higher COD content and should exhibit therefore a higher biogas production. One explanation could be that not enough bacteria are contained in the laboratory BASBF system able to convert the nutrition contained in the LCM, which suggests that the laboratory BASBF system can produce a higher biogas amount per liter reactor volume if a higher number of bacteria is present.

3.3 Change of pH-Value, Total Suspended Solids and Total Solids

As described in 2.1.6., the pH- value and the total solids with including total suspended solids could be used as measurements to control the stability of the reactor and quality of effluent. While operating the laboratory BASBF system with municipal wastewater, the pH kept stable at 7.5 ±0.1. The slight decrease from the influent pH of 8.0 could be related to the activity of acidifying bacteria in the reactor. TS was determined at 0.079 ±0.004 %, while the TSS content was under the detection limit and usage of a 45 µm pore size glass fiber fabric filter resulted in a clear effluent.

Compared to the operation with municipal WW, the laboratory BASBF system effluent of had a

similar stable pH- value (7.3 ±0.1) using separated LCM cow manure as influent. The influent pH was slightly lower at 7.5 ±0.1. As shown in Fig. 10, the total solids content (TS) in the effluent showed an increasing trend from 1 to 6 days hydraulic retention time 0.022 ± 0.001 %, 0.030 ± 0.001 %, and 0.040 ± 0.001 % for the 1, 3, and 6-day HRT respectively. Contrary to expectations of decreasing TS with decreasing flow rate. This result could be related to a change in the bacterial sludge over time. Depending on the environment and condition, the bacteria in the biogenesis of the sludge blanket could change their shape of flocs. New circumstances of available nutrients with decreasing flow rate could lead to less settle able properties of the sludge flocs and result in a higher TS and TSS in the effluent.

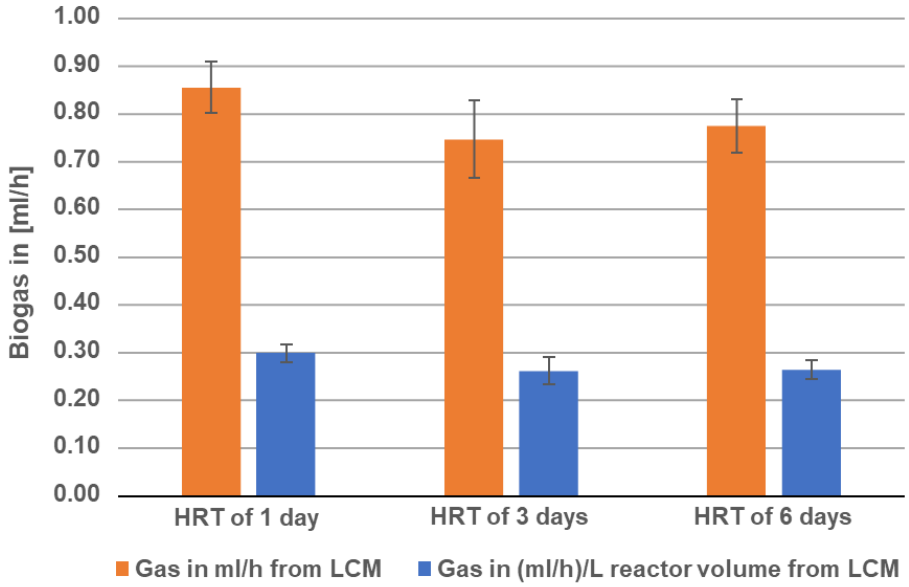

Fig. 9. Biogas production during separated liquid manure (LCM) stabilization in a sludge blanket reactor over hydraulic retention times (HRT) of 1, 3 and 6 days in ml/h and in (ml/h)/L reactor volume

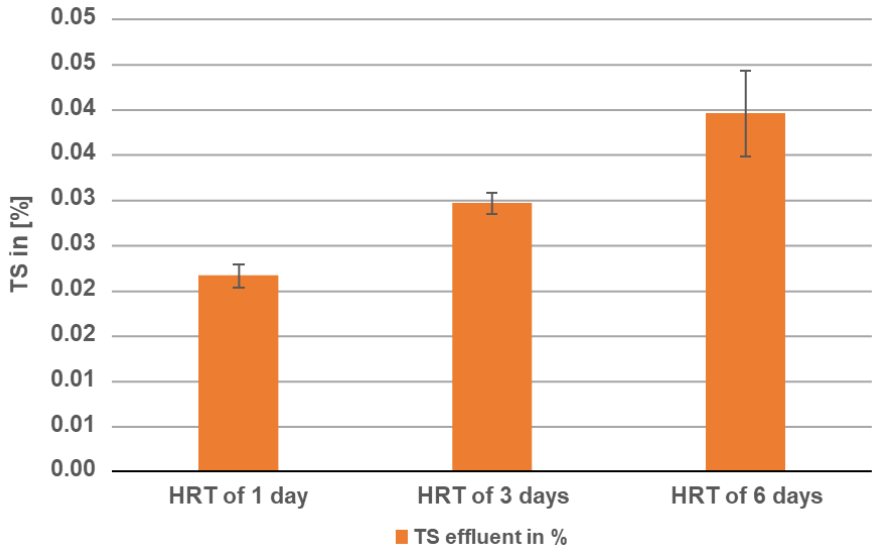

Fig. 10. Total solids (TS) during separated liquid cow manure (LCM) stabilization in a sludge blanket reactor over hydraulic retention times (HRT) of 1, 3 and 6 days

4. CONCLUSION

With looking at today's highly problematic fossil fuel availability and on the other side increasing environmental concerns in regards to excess nutrient release of municipal, agricultural and industrial waste treatment operations a laboratory up flow sludge blanket reactor with a operating volume of 2850 ml was designed build, started up and operated using prepared municipal wastewater and separated liquid cow manure at a HRT of 1 day, 3 days and 6 days after an 120 h adjustment time prior to testing.

While using wastewater as influent, the laboratory BASBF system anaerobic sludge blanket reactor was not able to reduce the COD content significantly. Especially at a high throughput level at a 1-day retention time. The produced gas amount decreased from 0.59 ±0.07 (ml/h)/L (HRT of 6 days) to 0.042 ±0.04 (ml/h)/L. The fluctuating influent COD content of 25 ±1 mg/L to 74 ±15 mg/L resulted in a stable effluent concentration of 39 ml/L and 45 ±11 mg/L respectively.

The laboratory BASBF system with separated LCM showed a higher COD degradation capability but resulted in higher COD effluent levels. The influent COD content of 308 ±42 mg/L was broken downs to 59 ±1 mg/L at a HRT of 6 days and to 114 ±5 mg/L for 1 day retention time. The biogas production result in a stable gas production rate of 0.27 ±0.02 (ml/h)/L through all three hydraulic retention times. For both the WW and LCM operation the biogas without CO_2 was between 55 and 65%.

The results show that the laboratory BASBF systems is able to reduce high a COD level in WW and LCM. However, a minimum feed level of COD above the 36 mg/L is needed, otherwise, the active bacterial mass contributes to the effluent level as seen for the influent level below 36 mg/L and 25 mg/L which resulted in an minimum effluent level of 39 mg/L for a HRT operation of 3-days and 6-days.

Future research on the laboratory BASBF system should include different amounts of activated sludge bacteria in the reactor to investigate the upper and lower process limitations, as well as other influent waste streams such as organic containing waste streams from milk converting plants and industry food processing plants.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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