Original Research Article

Benchtop Septic System for Effluent Treatment - A Laboratory Development

ABSTRACT

One in every five households in the United States of America operates a decentralized water treatment systems which is also know as septic system, which may contribute to pollutions in water bodies if not operated properly. For this research a 15.0-liter (3.97 gal.) laboratory benchtop septic system was designed, build, installed and operated at a temperature of 23.0°C (73.4°F) to investigate the remediation of municipal wastewater. A three-week start-up phase was used prior to operating the system with unfiltered wastewater collected from primary clarifier at a wastewater treatment. The operational test phase included an hydraulic retention rate of 5, 10 and 20 days which corresponds to 3000 ml/d, 1500 ml/d, and 750 ml/d respectively.

Based on the above results, the laboratory benchtop septic system minimum effluent values for the chemical oxygen demand are 18±1 mg/l, and 60±10 mg/l for the total solids content, and <5±1 mg/l for the total suspended solids. These values correspond to the published effluent concentration range of 30% to 80% of influent concentrations for septic tanks.

The results show, that the laboratory benchtop septic systems is able to reduce the chemical oxygen demand, total solids content, and total suspended solids content level of municipal wastewater and can be a valuable tool to access the performance of septic systems utilizing different wastewater influent types.

Keywords: contaminants, decentralized water treatment system, remediation, septic system, sewage, wastewater

1. INTRODUCTION

One of the most significant challenges facing our world in the future pertains to clean water. Without clean water life is not sustainable. Water pollution affects local wildlife and us humans equally and we all should work on minimizing and perhaps eliminating waste and water pollution [1].

Sustaining the natural beauty and quality of our water bodies is today's biggest challenge with ever growing urban and suburban developments. Many new urban and suburban developments are too far away from existing wastewater treatment fostering the use of decentralized wastewater treatment systems, also known as septic systems. Urban and suburban governments are faced with the burden decentralized water treatment systems and how to protect waterbodies in the affected areas [2]

According to the Environmental Protection Agency (EPA) one of every five households in the United States of America (USA) operates a decentralized wastewater treatment system, also known as septic system [3]. Human waste from underperforming decentralized wastewater treatment systems might contribute to the pollution of nearby water bodies and can cause

nitrification and increase in phosphorus components, which can increase algae growth mostly during warm summer month in the water body and can affect the environment, public health, and the economy [4].
Decentralized wastewater systems are well known in the field of wastewater treatment. They consist of a tank with an influent and effluent pipe. Liquid containing the organic degradable contaminants enter the system through an influent pipe and settle in the tank based on the high Hydraulic Retention Time (HRT). The process of biocenosis starts as soon as the liquid enters the system. The organic degradable constituents that are solubilized in the influent and organic degradable particles that settle on the bottom of the tank are broken down by an anaerobic bacteria regime in the tank. Because septic systems contain no mixing, the degradation of organic compounds is a very slow process [5].
The processed liquid discharges as effluent and percolates through a drain field downwards and might reach the ground water table in some cases. Contaminants that are small enough can potentially reach aquifers as they make its way through the drain field soil layers [6,7].
Wastewater in a domestic setting can contain many different potential pollutants which cause a risk to aquifers. These pollutants can be chemicals, household detergents from laundry and dishwashing, Phosphorous (P), Nitrogen (N), Ammonia (NH_4-N), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Suspended Solids (SS), and pharmaceutical compounds due to medicine use of residents [8,9,10,11,12].
The objective for this research work is to design, build, install and start up a laboratory Benchtop Septic (LBS) system which allows to test the degradation of organic components of various Wastewater (WW) effluent types.
The reported research may help to improve the operation and processes of current septic systems and can help to improve the described complex problematics current septic systems cause in regard to release excess nutrients into the environment.

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.

2.1. Materials

Wastewater was obtained from the Cleanwater Educational Research Facility (CERF) located at the Village of Minoa Wastewater Treatment plant in Minoa, NY.
5-gallon pail, Chlorinated Polyvinyl chloride (CPVC) pipe and fitting material from Charlotte Pipe and Foundry Company, purple PVC primer and clear cement from Oatey®, used to fuse the CPVC pipe parts together, and 3/8-inch (mm) plywood board for tank divider, and silicone sealant, was obtained from a nearby hardware store.

2.2. Laboratory Benchtop Septic Systems

For effluent treatment, a Laboratory Benchtop Septic (LBS) system, as shown in Figure1., was designed.

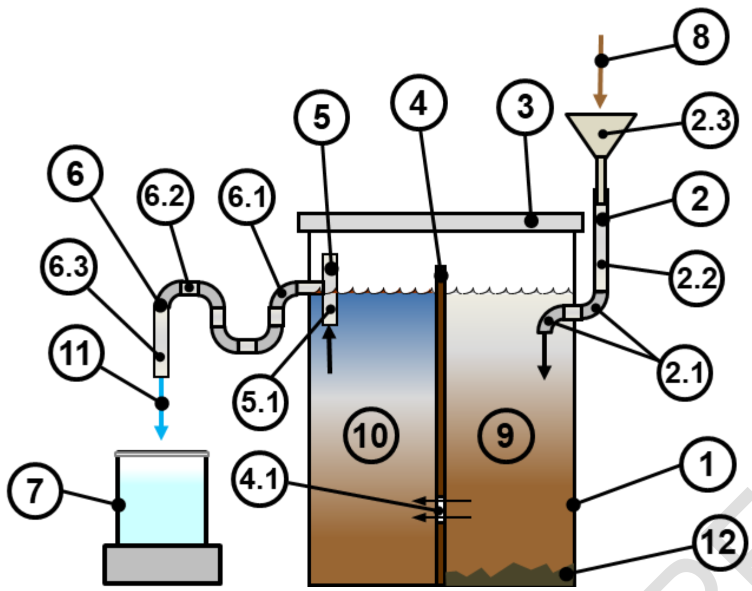

Fig. 1. Design of the Laboratory Benchtop Septic (LBS) System [xx]

The LBS design was kept simple, to allow other researchers to duplicate the system. All components should be available in local hardware stores. However, some deviation may be made based on local available materials and parts.

For the LBS main tank (1) a 5-gallon (19.9 l) High Density Polyethylene (HDPE) pail with cover (3) was used. The LBS liquid capacity is 15.0 liters (3.96 gal.) with a freeboard of 4.9 liters (1.29 gal.) to mimic a septic tank void volume as well as prevent overflow. A 3/8-inch (9.53 mm) plywood divider (4) with two 1.0-inch (25.4 mm) holes (4.1), spaced 4.0 inch (101.6 mm) apart, and 3-inch (76.2 mm) above the bottom of the LBS separates the LBS in two equal 7.50 liters (1.98 gal.) sized chambers (9), the settling chamber for solids (12), and the effluent chamber (10). Each chamber has a volume of 7.5-liter (1.99 gal.).

The inlet pipe assembly (2), the effluent Assembly (5), and outlet pig tail pipe assembly (6), as shown in Figure 1., was manufactured from a CPVC 0.5-inch (12.4 mm) pipe and fitting material fused together with purple PVC primer and clear cement and sealed to the LBS main tank (1) with silicon caulking material.

The inlet assembly (2), located 1.0-inch (25.4 mm) below the liquid level to prevent odor to escape the LBS, was manufactured from one 90° elbow (2.1) on the inside which is connected with a 1.0-inch (25.4 mm) long pipe to a 90° elbow (2.1) on the outside through the LBS main tank (1) wall. The outside elbow is connected to a 4.0-inch (101.6 mm) long pipe in which a PVC funnel (2.3) is inserted for easy filling in the influent liquid (8).

The effluent assembly (5), located at the 15-liter liquid level, is manufactured from a 0.5-inch (12.4 mm) tee that has a 1.0-inch pipe 0.5-inch (12.4 mm) pipe (5.1) attached to the end that faces to the bottom of the LBS).

The outlet pig tail pipe assembly (6) for sealing the LBS from odor to the outside, as shown in Figure 1., was manufactured from five 90° elbows (6.1), which are connected with four 1.0-inch (25.4 mm) long pipes (6.3). The elbow facing the 300 ml glass collection beaker (7), has a 4.0-inch (101.6 mm) long pipe attached, through which the effluent is dispersed into the collection beaker (7).

Effluent Assembly (5), and outlet pipe assembly (6) are connected with a 1.0-inch pipe CPVC 0.5-inch (12.4 mm) pipe through the LBS main tank (1) wall.

2.3. 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 [13]. 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 Total Solids (TS) was measured in triplicate. For the measurement of the TS, 300 ml aluminum sample containers were used. The containers 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 [14]. Measurements were done in triplicate. 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 [14].

Temperature and pH measurements were conducted using a portable Milwaukee MW102 pH/temperature meter.

2.4. Preparation of Selected Influent Substrates

To determine the working capacity of the designed LBS system WW was used as influent substrate.

The WW substrate was obtained from a primary clarifier at the Minoa wastewater treatment plant, and was used unfiltered for the start-up and operational phase. The WW was stored in a cold room at 5.0°C (41.0°F) until it was transferred to the laboratory for use in the LBS system.

3. RESULTS AND DISCUSSION

For this research work, wastewater was used as influent substrate to characterize the degradation capability of the LBS system. The following section summarize and compare the degradation processes and effluent qualities of the systems during start up.

After the start-up of the LBS system with wastewater and the adaption time, the LBS system was operated, like described below in Section 3.1., with WW at an HRT of 5, 10 and 20 days. The start-up and operational results of the LBS system are being discussed in the following subsections.

Measurements showed that the TS of the unfiltered WW used for the 3-week start-up phase had on average 340±26 mg/l. and an TSS of around 0.002 %. After the initial start-up phase

However, it is known that WW is changing its composition daily and is highly varying through the year, day and hour [15,16]. 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 might change its composition while in storage until it is used in the it LBS system.

3.1. Start-Up and Operation of the Laboratory Benchtop Septic System

The LBS system was installed in the laboratory and a 3-week start-up phase was initiated, based on previous experience, as well as to establish a microbial environment in the LBS system. Unfiltered WW collected from a primary clarifier at the Minoan NY wastewater treatment plant was used. The laboratory room temperature of the start-up phase was

23.0°C (73.4°F). The LBS system tank (1) with its two chambers was filled till the WW was moving through effluent assembly (5), and outlet pig tail pipe assembly (6) into the 300 ml glass collection beaker (7). The LBS contained a total 15.0 liter (3.97 gal.) of WW, that was conditioned under laboratory room temperature conditioned WW at 23.0°C (73.4°F). The cover (2) was attached and the continuous operated LBS was fed daily through inlet assembly (2) with 750 ml of WW with a temperature of 23.0°C (73.4°F). The daily feed rate correlates to a Hydraulic Retention Time (HRT) of 20 days based on the LBS system design. Larger particles contained in the unfiltered WW stored at the cold room at 5.0°C (41.0°F) settled during the storage time. It was decided to not mix the WW prior to usage in the LBS system due to the caused inconsistency of the influent. The settled WW's TS, TSS and COD for the start-up and operational test was measured before applied in the LBS system and showed an average TS of 212±4 mg/l, a TSS of 24.1±0.5 mg/l and a COD of 74 and 80 mg/l. After the start-up phase, the laboratory LBS system was operated manually under a feed rate of 3,000 ml/d, 1,500 ml/d, and 750 ml/d which corresponds to an HRT rate of 5, 10, and 20 days accordingly.

3.2. Operation of the Laboratory Benchtop Septic System

During the test period of the LBS system at a HRT of 5, 10 and 20 days the pH kept stable at 8.0 ±0.2 and the temperature was between 23.0±0.5°C (73.4±0.9°F).

Figure 2. shows the performance data of the LBS system at a HRT of 5 days, 10 days, and 20-day HRT. The system was operated continuously for the respective HRT for 5 days, plus the respective HRT, with samples taken at the end of the respective HRT. COD Influent (COD-I) for the 5-day HRT was 75 mg/l and for the 10-day and 20-day HRT the COD-I was 36 mg/l and 25 mg/l respectively. The TS Influent (TS-I) was for the 5-day HRT 208 mg/l and for the 10-day and 20-day HRT the TS Influent (TS-I) was 127 mg/l and 25 mg/l respectively. The TSS Influent (TSS-I) was 14.5 mg/l for the 5-day, 10-day, and 20-day HRT.

The COD Effluent (COD-E) for the 5-day HRT was 18 mg/l, for the 10-day HRT 19 mg/l, and for the 20-day HRT 17 mg/l. This correlates to a reduction of 74.6%, 47.2%, and 32.0% respectively.

The TS Effluent (TS-E) was for the 5-day HRT 50 mg/l, for the 10-day 60 mg/l, and for 20-day HRT 71 mg/l. This correlates to a reduction of 75.9%, 52.8%, and 44.1% respectively.

The TSS Effluent (TSS-e) was <4 mg/l for the 5-day, <6 mf/l for the 10-day, and < 4 mg/l for the 20-day HRT, having a reduction of >72.4% for the HRT of 5 days and 20 days and a reduction of >58.6% for the HRT of 10 days.

The difference in COD, TS influent values might have been caused by the storage of the entire WW in a cold room at 5.0°C (41.0°F) until it was transferred to the laboratory for use in the LBS. The long storage time allowed particles to settle and mycobacterial degradation of the WW. However, the TSS-I was not influenced by the storage time.

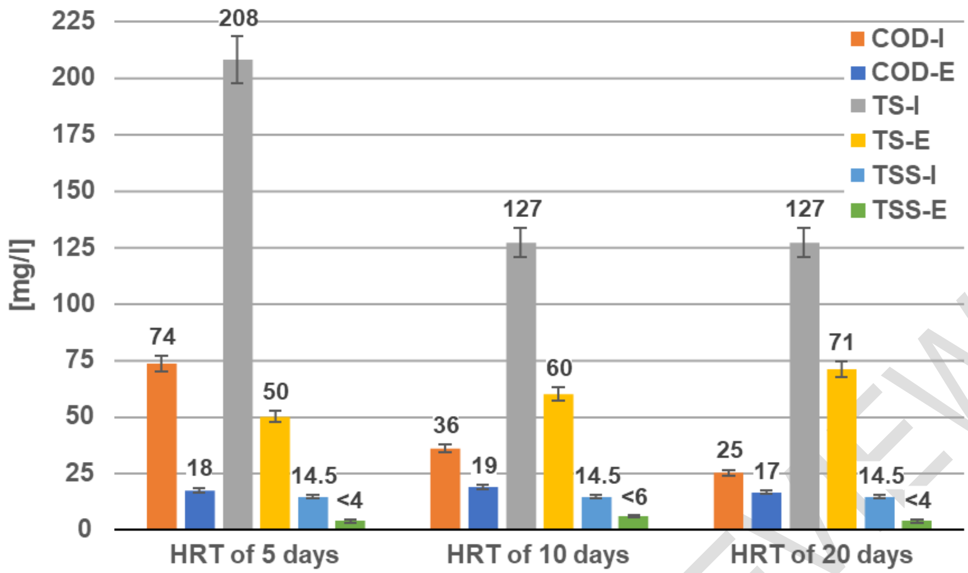

Fig. 2. Influent and Effluent Values of Laboratory Benchtop Septic (LBS) System

Based on the above results, the LBS system minimum effluent values for the COD-E are 18±1 mg/l, 60±10 mg/l for the TS-E, and <5±1 mg/l for the TSS-E values.

The LBS remediation range are in the published effluent concentration range of 30% to 80% of influent concentrations of septic tanks [16-21], and therefore the developed LBS system is usable for further investigations on septic tank system performances. However, effluent values can vary greatly and are influent specific based on the type of WW used as well as if prefiltering and removal processes such as grease traps, garbage disposals, and or biowaste composting are used prior to disposing the WW [20,21].

Further research should be conducted on different influent materials from municipals and agricultural operations. In addition, the plywood divider may be de replaced by an PVC divider to eliminate influence of the wooden material. In addition, future research trials should be designed to allow the use of original WW as close as possible to its original content. It is suggested to modify the system for the capture of odor and or gas/biogas produced by the system for basic evaluation.

CONCLUSION

Minimizing pollution from decentralized water treatment systems is a necessity to minimize environmental impacts on waterbodies. For this research a 15.0-liter (3.97 gal.) LBS system was designed, build, installed and operated to investigate the remediation of municipal WW. The LBS system was start-up with unfiltered WW collected from a primary clarifier. The feed rate during a 3-week start-up phase was 750 ml which corresponds to a HRT of 20 days. The TS of the unfiltered WW had on average 340±26 mg/l. and an TSS of around 0.002 %. The room temperature of the laboratory was start-up phase was 23.0°C (73.4°F) for the start-up and operational phase. The operational test phase included an HRT of 5, 10 and 20 days which corresponds to 3000ml/d, 1500 ml/d, and 750 ml/d respectively. The unfiltered WW was stored at the cold room at 5.0°C (41.0°F), which allowed larger particles to settle prior to its usage during the different HRT. The settled WW's TS, TSS and COD for the start-up and operational test was measured before applied in the LBS system and showed an average TS of 212±4 mg/l, a TSS of 24.1±0.5 mg/l and a COD of 74 and 80 mg/l.

The COD-E for the 5-day HRT was 18 mg/l, for the 10-day HRT 19 mg/l, and for the 20-day HRT 17 mg/l. This correlates to a reduction of 74.6%, 47.2%, and 32.0% respectively.

The TS-E was for the 5-day HRT 50 mg/l, for the 10-day 60 mg/l, and for 20-day HRT 71 mg/l. This correlates to a reduction of 75.9%, 52.8%, and 44.1% respectively.

The TSS-E was <4 mg/l for the 5-day, <6 mf/l for the 10-day, and < 4 mg/l for the 20-day HRT, having a reduction of >72.4% for the HRT of 5 days and 20 days and a reduction of >58.6% for the HRT of 10 days.

Based on the above results, the LBS system minimum effluent values for the COD-E are 18±1 mg/l, 60±10 mg/l for the TS-E, and <5±1 mg/l for the TSS-E values which correspond to the published effluent concentration range of 30% to 80% of influent concentrations of septic tanks [17-21].

The results show that the LBS systems is able to reduce the COD, TS, and TSS level of municipal WW and can be a valuable too to access the performance of septic systems utilizing different WW influent types, such as agricultural, municipal, and industrial effluents, including performance enhancer such as enzymatical products that foster degradation of biological contaminants in the effluent used.

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