Chapter

Acetogenic Pretreatment as an Energy Efficient Method for Treatment of Textile Processing Wastewater

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Abstract

This chapter will introduce the concept of a novel application of acetogenic pretreatment of textile processing wastewater. Acetogenic pretreatment is traditionally limited to high solids, easy to degrade wastewater to enhance degradation for methane generation. The application of the acetogenic process to a complex wastewater from textile processing facilities is novel and has the potential to remove color, chemical oxygen demand, biological oxygen demand in an energy efficient manner compared to the existing extended aeration processes applied in the industry. The application of the acetogenic process can be achieved to existing treatment facilities with minimum retrofit. The acetogenic operation will ensure the treatment process becoming greener with a small carbon footprint to achieve the goal of efficient wastewater treatment.

Keywords: Acetogenic, Pretreatment, Textile Processing Wastewater

1. Introduction

Anaerobic treatment of industrial wastewater was from its inception limited to wastewater that has a high concentration of biodegradable solids. The anaerobic biodegradation process is a multistep process where the first step in hydrolysis where extracellular enzymes secreted by microorganisms under anaerobic conditions solubilize the biodegradable solids, the subsequent steps being the conversion of the soluble organics in multiple steps to methane and carbon dioxide gas more commonly known as biogas [1]. The sequential transformation of solids to biogas is simply summarized in **Figure 1** below. It is important to note that the transformation process is sequential and complex, and more often than not, the rate limiting step determines the kinetics of the reaction and in most cases, this being the hydrolysis step where complex organics are broken down to soluble products such as organic acids alcohols, that are then converted to the common intermediator of acetic acid, which is then further transformed by methanogenic bacteria to methane and carbon dioxide [1–3].

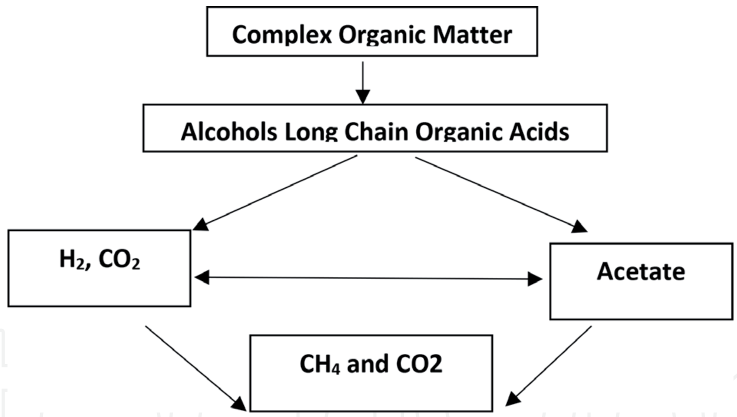

Figure 1.
Simplified schematic diagram of sequential transformation of organic compounds under the anaerobic condition to methane and carbon dioxide.

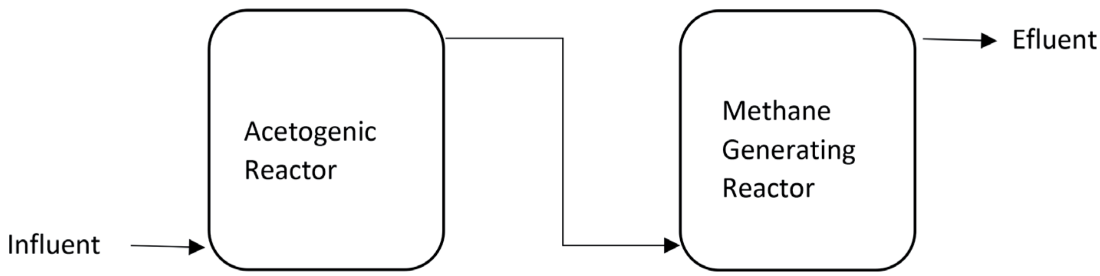

Figure 2.
Schematic of split transformation of acetogenic methanogenic reactor application.

In the era of sustainable development, the recent trends have been to optimize the process to enhance the production of biogas from biodegradable solids or high solids wastewater as a source of sustainable renewable energy, meaning biogas. Researchers have demonstrated that splitting the anaerobic process and its application as a two-step process and operating reactors as two-stage reactors (**Figure 2**). In the two-stage operation, the first stage reactor is followed by the methanogenic reactor to produce methane. The advantage of this split mode of operation is that more solids solubilized in the first step will increase the production of biogas in the second step. This split mode of application has been applied successfully to high solids wastewater, where the first reactor, referred to as acetogenic reactor, operates at a low hydraulic detention time in hours, generally between two to four days, followed by the methanogenic reactor with a hydraulic detention time of twenty days [4–6].

Acetogenic pretreatment has been limited in its application to high solids waste or wastewater in two-stage anaerobic reactors to enhance the hydrolysis of solids [7–9]. With a greener operation in mind, researchers have further progressed the acetogenic operation to optimized for hydrogen generation not just as a byproduct of gas of hydrolysis/acetogenesis but to produce hydrogen gas from organic waste solids. Hydrogen being a green fuel that can directly be used to generate electricity by using fuel cells [reference]. The thrust of the research has been to negate any methanogens in the acetogenic reactor, thereby increasing hydrogen yield. This chapter introduces the further progression of application of acetogenic operation of anaerobic reactors dedicated to the treatment of textile processing wastewater. At the laboratory level, progressive researchers have been applying the concept of the acetogenic process to pretreat textile processing wastewater in the hypothesis that anaerobic acetogenic operation of a reactor dedicated to textile wastewater will produce in the reduction of color, chemical oxygen demand, and total dissolved solids in an energy efficient manner [10].

2. Justification for application to textile wastewater

Textile wastewater is deleterious, containing complex organics, chroma, and also high in dissolved solids. If allowed to be realized to water bodies can be destructive to the aquatic environments. In recent decades the textile industries have been moving to developing economies to take advantage of the cheaper cost of production and deficiencies in regulatory requirements. Case in point Bangladesh, which is a developing industry and the second largest producer of readymade garments in the world. A forty-billion-dollar industry the largest employer of women and a progressive force that had bought the country from a least developed country to a middle income country in a few decades [11]. The flip side to all this is the negative impact on the environment of Bangladesh. Unabated discharge of untreated wastewater from the textile industries has severely affected the water bodies in the areas where the industries are located. The situation is so acute that in sections, the once ecologically sound rivers are highly polluted, and all aquatic life is dead. The picture below shows the unabated release of textile dye in a river in Bangladesh (**Figure 3**) [12, 13].

The reason more often than not for noncompliance by the industries is the cost of treatment [13, 14]. The convention wastewater treatment that is currently7 applied as the industry norm is chemically mediated settling to remove solids, the addition of decoloring agents to remove chroma, and extended biological activated sludge treatment (extended aeration with hydraulic detention times of greater than 13 hrs). The schematic flow diagram of the extended aeration chemically aided process currently used in Bangladesh and other countries is to treat textile processing wastewater shown in **Figure 4** below [11].

The extended aeration process is dependent on chemicals for the settling of solids and also chroma removal; the secondary biological treatment is energy intensive, requiring 7.0 kWh of energy per Kg of BOD_5 stabilized due to the aeration required by the aerobic microorganisms in the extended aeration process for operation of the blowers required for aeration. If we can negate the requirement of chemicals for chroma removal and solids removal and also reduce the BOD_5 loading to the secondary extended aeration system, this would call for a cheaper and energy efficient process and not to mention the reduction of greenhouse gas emission due to reduced energy requirements of the operation. Acetogenic pretreatment would provide an option of pretreatment that would remove color and solubilize solids and also reduce BOD_5 in the wastewater and thereby reduce the BOD_5 loading to the secondary aerobic treatment and reducing aeration requirement and thus savings in energy. The schematic of the proposed process retrofit using acetogenic pretreatment is shown in **Figure 5** below.

In the subsequent sections, the efficacy of the acetogenic pretreatment when applied to textile wastewater will be elucidated, along with the potential

Figure 3.
The picture shows the unabated release of textile dye in a river in Bangladesh.

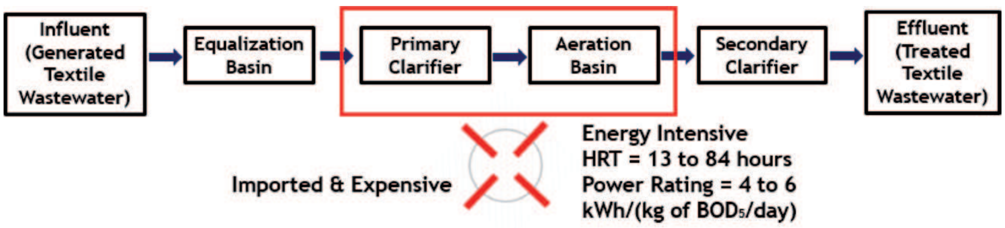

Figure 4.
The schematic flow diagram of the extended aeration chemically aided process currently used to treat textile processing wastewater.

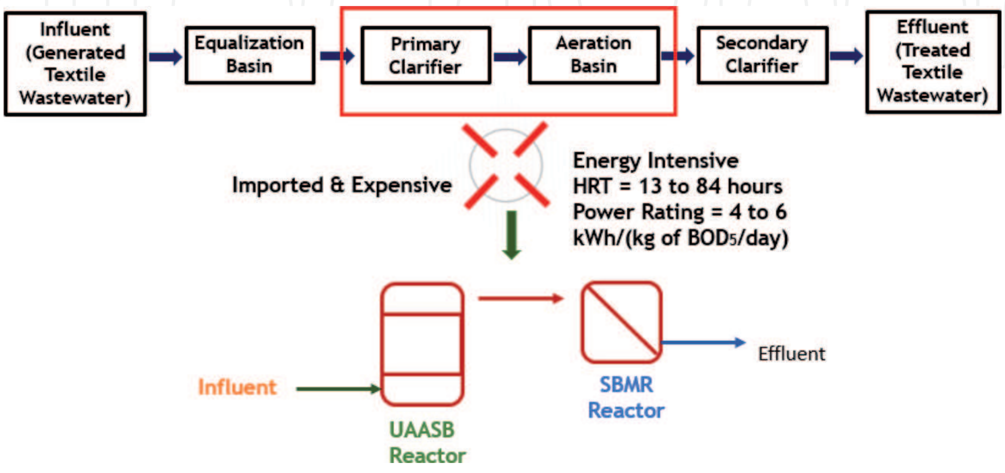

Figure 5.
The schematic of the proposed process retrofit using acetogenic pretreatment.

reduction in energy consumption in treatment will be highlighted. The discussion will be based on actual wastewaters from two textile processing industries.

3. Understanding acetogenesis as applied to textile processing wastewater pretreatment

The process of maintaining an acetogenic reactor is to curtail the growth of methanogenic microorganisms in a reactor and thereby stopping the conversion of fatty acid generated in the reactor to methane and carbon dioxide. Researchers reported controlling methanogenic microorganisms in an acetogenic reactor by shortening the hydraulic retention time greatly, usually at 2 to 4 days or even lower, in essence maintaining the reactor in a washout mode, thus limiting the growth of methanogens [15, 16]. Another method of controlling methanogenic microorganisms in an acetogenic reactor is oxygen shocked [17, 18]. Of the methods tried by prior researchers, the one that would be easier to apply in existing plants with minimum retrofitting. This method would be converting the existing basins such as equalization basins or parts of the extended aeration to the acetogenic reactor with retention time between 2-4 days and periodic shock aeration using existing in plant aeration capacities and equipment by nominal retrofitting [10]. To investigate this concept in the bench scale, acetogenic reactors were operated as proof of concept using actual textile processing wastewater. Two candidate wastewaters were used, one from a denim processing wastewater and another from com composite fabric processing wastewater. The findings of the bench scale study are summarized in the sub-headings below [10, 19].

3.1 Acetogenic reactor operation

The acetogenic reactors operated with the textile wastewaters were operated in a semi continuous batch mode with dally waste feeding; at a hydraulic retention time of 4.0 days, the reactor food to microorganism ratio (F/M) was constantly changing through the substrate loading was kept constant, thereby operating in a washout mode with a constant decrease of MLSS over the period of operation. This washout mode of operation ensures acetogenic conditions in the reactor operated under non forced aeration conditions. However, the periodic burst of shock aeration (dissolved oxygen raised to 2.0 mg/L once a day) to kill any growth of methanogenic microorganisms. The reactors used in this experimental program were flat bottomed class vessels in volume between 500 ml to 2000 ml. The test reactors were continually steered by means of a magnetic stirrer. The test reactors were plumed for sample withdrawal and feeding, along with plumbing and air diffuser systems for aeration. The aeration was provided using simple fish tank aerators through a fine air diffuser. The reactor vessel is insulated with temperature control. There is provision for temperature, dissolved oxygen, and pH monitoring in the reactor. The reactors were operated under the following conditions:

1. Maintained at mesophilic temperature (20-40°C),

2. A fixed hydraulic retention time,

3. A draw-and-fill waste feed schedule,

4. Waste feeding conducted once per day

5. No reactor pH adjustment, and

6. No augmentation of nutrients or buffer.

The raw textile wastewaters used in both the case studies reported in the following sections were obtained from textile processing facilities from the equalization basin. Time proportioned composite sampling procedure was used for the collection of the sample over a twenty-four-hour period of operation of the wastewater treatment plant [10, 19].

3.2 Acetogenic reactor seed source

The culture for the laboratory acetogenic cultures for both the case studies were from the sludge thickening tank that unaerated with a solids content of around 2%. The thickening tank contained waste activated sludge from the secondary clarifier of the extended aeration wastewater treating the complex wastewater in case study two discussed below.

3.3 Process operation parameters

The reactor per process operation parameters that were monitored were dissolved oxygen level during purging, reactor mixed liquor suspended solids, reactor pH, reactor temperature, reactor effluent color, total dissolved solids (for test case run 2), and reactor effluent chemical oxygen demand. Day two and day twenty reactor effluent sample for the second test case was sent for Furrier Transformation Inferred Spectroscopy.

3.4 Analysis procedures

The biological Oxygen Demand was measured using the serial dilution method HACH Method 8043, Chemical Oxygen Demand was measured by HACH method 8000 Digestion Method using preset vials 0-1500 mg/L rang, and the color was measured by HACH Method Platinum-Cobalt adapted from. Standard Method 8025 for the Examination of Water and Wastewater [20].

Total Dissolved Solids was measured using EC/TDS/NaCl probe and meter by HANNA Instruments HI 2300 system, and pH was measured HANNA HI 2211 pH/ORP probe and meter.

Total Suspended solids were determined by Standard Method 2540D, where a well-mixed volume of a sample was filtered through a pre-weighed glass fiber filter (pore size 0.45 micro meter). The filter was dried at 104°C and then weighed. The mass increase divided by the water volume filtered is equal to the Total Suspended solids (TSS) in mg/L [21].

The Fourier Transform Infrared (FTIR) spectrum of the reactor effluent was recorded using Bruker Vortex 70 FTIR. The spectra were taken in the range 400 to 4,000 cm^{-1}.

3.5 Case study acetogenic application to denim processing wastewater

The denim processing wastewater was characterized to have high total Chemical Oxygen Demand and high pH. The subject wastewater had a Chemical Oxygen Demand (COD) of 371 ± 37. mg/L, the color of 660 ± 66 ptco pH = 8.6 ± 0.6, and a five-day biological oxygen demand divided by the Chemical Oxygen Demand (BOD_5/COD) ratio of 0.62, indicating wastewater with a substantial organic fraction that should be biologically degradable. The wastewater was directly fed into the acetogenic reactor (Liquid volume 500 ml) without any adjustment, and the reactor operated as mentioned earlier in a waste feed more of semi-batch operation for a period of nine days. The results experimental program showed that after a period of acclimation, the acetogenic culture was able to completely remove the color and also produced substernal removal of chemical oxygen demand shown by respective parameters effluent concentrations decreasing with reactor operation (Refer to **Figures 5–8**). This clearly proved the efficacy of the process with ninety percent removal of color and greater than eighty percent removal of chemical oxygen demand for application for pretreatment of textile processing wastewater as an alternated to the chemical intensive decoloring and solids removal processes currently being employed. Reactor operating parameters also showed that beyond food to microorganism (F/M) operating ratio of 0.1, the system performance starts to decrease; this implies that for long term sustainable operation of acetogenic reactors, periodic reseeding with acclimated culture would be necessary [10]. Also, first order

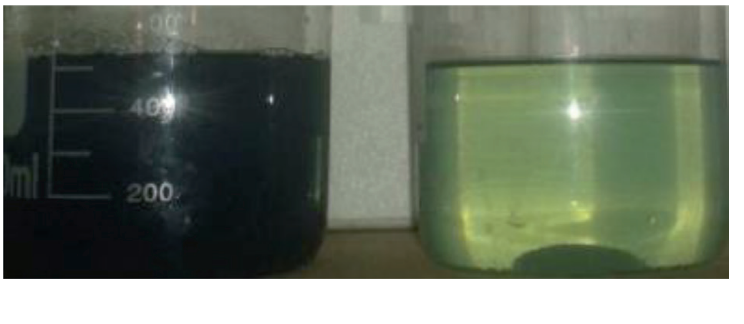

Figure 6.
Picture of raw and treated wastewater showing clearly the efficacy of the process.

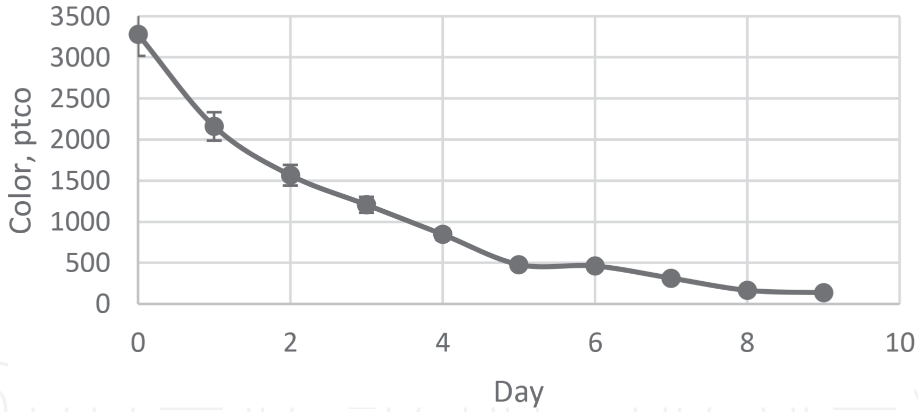

Figure 7.
Treated effluent color profile denim processing wastewater from the acetogenic pretreatment process for the denim processing wastewater.

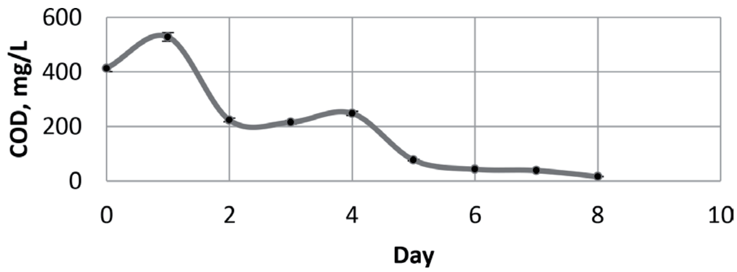

Figure 8.
Treated effluent Chemical oxygen demand profile denim processing wastewater from the acetogenic pretreatment process for the denim processing wastewater.

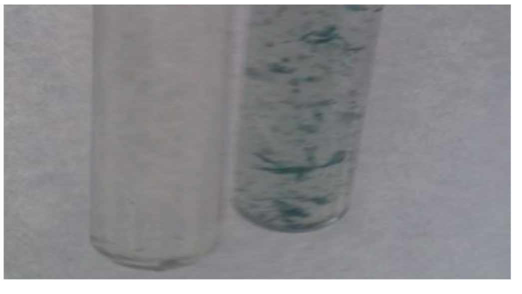

Figure 9.
Picture of raw and treated wastewater showing clearly the efficacy of the process for the complex wastewater.

rate kinetics defined both the color and chemical oxygen demand reduction and increased with days of operation and can be attributed to culture acclimation [10].

3.6 Case study acetogenic application to complex textile processing wastewater

The complex wastewater was from a composite factory where different fabrics are woven, dyed, textured, and finished stitched readymade garment products are produced. The facility that produces wastewater is varied and complex and was thought would be more of a challenging substrate to test the efficacy of the acetogenic process. Characteristics of the composite textile wastewater were color of 3540 ± 353 ptco, the chemical oxygen demand of 5186 ± 138 mg/L, BOD_5/COD ratio of 0.4, and pH of 9.6 ± 0.3 [19]. The proof of the efficacy of the acetogenic process in the treatment of textile processing wastewater is further illustrated in **Figure 9**, where the colloidal suspension is completely removed, indicating the extent of visual color removal. Furrier The acetogenic process was able to achieve for the complex textile processing wastewater with the color, and chemical oxygen removal was greater than 90 percent, along with a

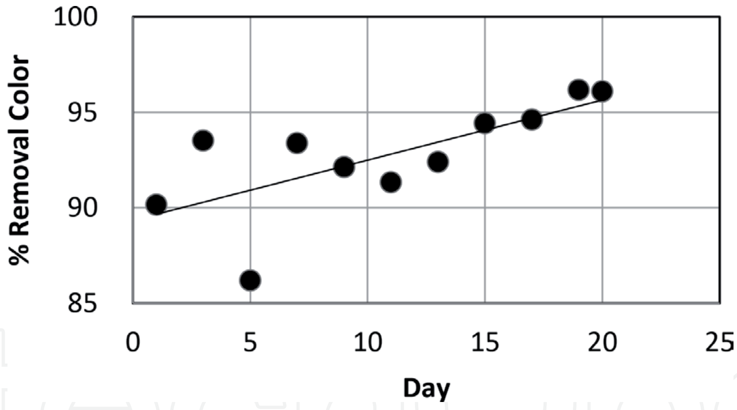

Figure 10.
Color removal efficiency for complex textile processing wastewater from the acetogenic pretreatment process.

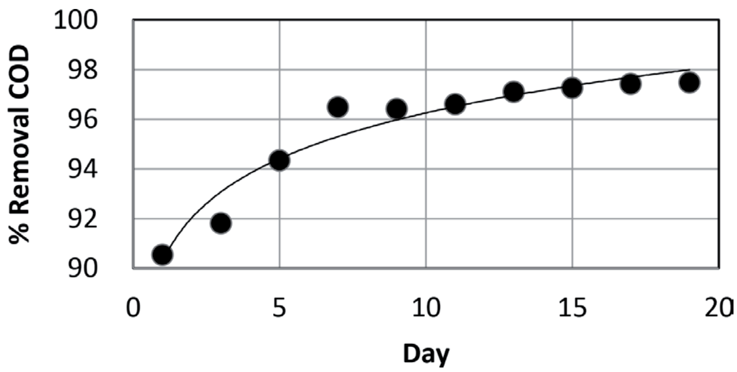

Figure 11.
Chemical oxygen demand removal efficiency for complex textile processing wastewater from the acetogenic pretreatment process.

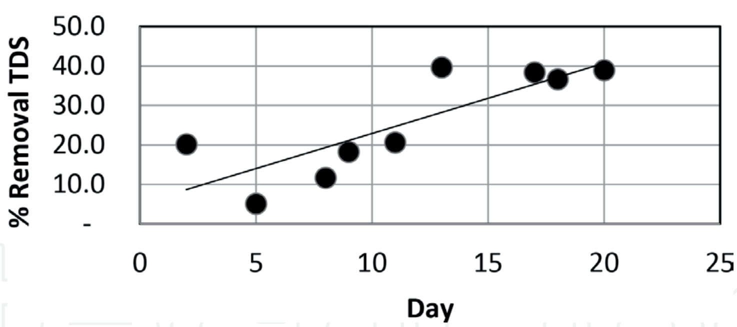

Figure 12.
Total dissolved solids removal efficiency for complex textile processing wastewater from the acetogenic pretreatment process.

reduction in total dissolved solids. The removal of total dissolved solids by the acetogenic process is an additional benefit as most textile processing wastewaters treated effluents have a hard time meeting the regulatory standers for total dissolved solids without employing expensive membrane systems [19]. **Figures 10–12** clearly illustrate the efficacy of the process with its high levels of color, Chemical Oxygen Demand, removal along with the removal of Total Dissolved Solids. Transformation Inferred spectroscopy further illustrates the efficacy of treatment where an effluent sample from day one (**Figure 13**) of the acetogenic reactor is compared to effluent from the acetogenic reactor on day 20 (**Figure 14**). The acetogenic reactor was operated for 20 days and the reactor operating liquid volume was 1000 m operated in a semi batch mode with daily waste feeding. The comparison clearly shows that with the reactor operating at a steady state prolonged operation, the complex organic peaks seen in the

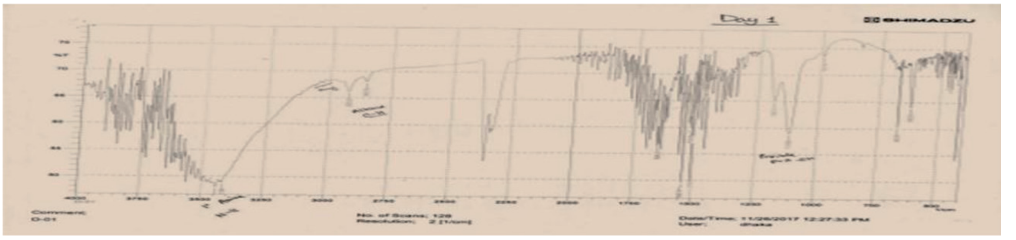

Figure 13.
Inferred spectroscopy effluent acetogenic reactor day 2.

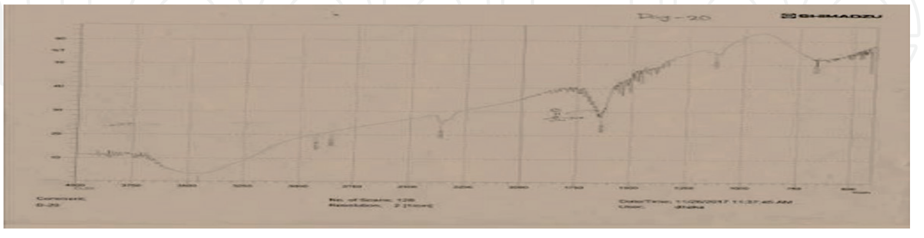

Figure 14.
Inferred spectroscopy effluent acetogenic reactor day 20.

effluent water were completely degraded by the acclimated acetogenic culture. They are again illustrating that the acclimated acetogenic culture can break down complex organics that are found in textile processing wastewater [19].

4. Energy savings potential and sustainable operation

Application of acetogenic pretreatment by reducing the biochemical oxygen demand/degradable chemical oxygen demand loading to the aerobic treatment system, which in return reduce the aeration volume, thus and reduce the electric energy requirement for running the aeration blowers. Aerator's energy consumption can range from 4.0 – 6.0 kWh/day-(kg of BOD_5/day) based on the type of blowers and aerators used [22]. Based on the database of the existing treatment plant wastewater characterization and laboratory study outlined for the case study one for the denim processing wastewater, the estimated energy requirement at a daily average flow of 722 m^3/day and the BOD_5 value of 228 mg/L the calculated BOD_5 loading to the existing aerobic basin at present is 164 kg of BOD_5/day. The plant uses fine bubble air diffusers with an energy rating of 4.0 kWh/day-(kg of BOD_5/ day energy requirement of 656 kWh/day. Based on the 85% BOD_5/COD removal efficacy of the acetogenic process, this would lead to loading of only 41 kg of BOD_5/ day and a blower energy requirement of 164 kWh/day, a net savings in energy of 495 kWh/day, a substantial saving of energy for any developing economy, case in point the energy requirement of an emerging economy like Bangladesh has a per capita annual energy requirement of 320 kWh [23].

5. Potential for industrial application

The acetogenic operation works when applied to pretreatment of textile processing wastewater for removal of color, reduction of COD, BOD5, and TDS. The process only requires periodic purging with air in contrast to the aerobic extended aeration process requiring constant aeration with substantial energy to operate the blowers. The proposed process can be applied to existing extended aeration wastewater treatment systems already existing in textile wastewater treatment facilities with nominal retrofitting. The existing aeration basin aerators could be modulated for just shock aeration, cutting aeration time from 24 hours a day to few minutes producing huge savings in electrical by limiting blower operation. The existing infrastructures also have built in secondary clarifiers and sludge storage and recycling systems; thus, added capital investment would be limited. It is anticipated that acetogenic pretreatment could be introduced with just process operational changes. Besides savings in energy, there would be a huge windfall in chemicals cost saving, for there would be no need for pH adjustment, activated carbon for color removal. All in all, acetogenic operation, with its reduced energy requirements and negating the needs of operating chemicals, makes it a greener viable option for textile wastewater treatment.

6. Conclusions

In an overall prospective the following conclusions can be drawn with regards to the application of acetogenic process to textile processing wastewater:

1. The acetogenic process can be applied to textile processing wastewater as a pre-treatment option to successfully remove color, chemical oxygen demand, total dissolved solids with a high degree of efficiency.

2. An added future of the process is that it requires periodic purge aeration rather than continuous aeration thus producing savings in energy for continuous functioning of aerators. Also the biological acetogenic process negates the requirement of chemicals for decoloring used in the conventional processes currently employed for textile wastewater treatment.

3. The seed culture requires a period of acclimation towards the treatment of textile wastewater and is operated in a washout mode with periodic seeding of recycled acclimated acetogenic culture.

4. The existing infrastructures can easily be retrofitted by modulating the aerators for shock aeration, and use the existing built in secondary clarifiers and sludge storage and recycling systems to reinject periodic acclimated culture to the acetogenic reactor for sustained operation.

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