

Acetogenic Pretreatment of Textile Wastewater for Energy Conservation

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Abstract: Bangladesh has come a long way in transforming its prehistoric cottage industry into post-industrial textile mills. International retail houses, instilling sustainable practices in the textile mills has become the norm. Most commonly the textile wastewater undergoes chemical pretreatment before extended aerobic treatment, which is both resource and energy intensive. The paper proposes to replace the chemical pretreatment with anaerobic acetogenic pretreatment which would reduce the biological oxygen demand loading to the aeration basin and hence, the amount of required energy for aeration. A bench scale study using an existing wastewater treatment plant influent with anaerobic acetogenic pretreatment was effective in reducing biodegradable organic matter with an efficiency of 95%. This meant a reduction of 143 kg BOD₅/day loading prior to aerobic treatment would generate an energy savings of 572 kWh/day. This amount of energy savings is deemed significant in the context of Bangladesh with a per-capita power consumption of 7kWh/day.

Keywords: textile wastewater, acetogenic pretreatment, energy conservation, first order model.

1. Introduction

Bangladesh has come a long way in transforming its artisan based cottage industry into a vibrant textile industry during the short transition within the past three decades from the prehistoric era to the modern industrial era. Keeping up with the never-ending global demand for clothing has led to the current establishment of about five thousand textile dyeing industries around greater Dhaka city [1]. The textile industry in Bangladesh bears utmost importance in terms of earning massive revenue thus sustaining the local economy through exports. A foresight of Bangladesh, that is soon to become the world's largest ready-made-garments producer, knocks on our conscience to ensure that the expanding garments sector of our economy does not further degrade the environment.

The international and local outcry for safeguarding the optimal quality of the limited available water resources for environmental conservation is demanding for improved wastewater treatment in the textile mills of Bangladesh. International retail houses are asking for sustainable management practices to be incorporated into the daily operations of the local textile mills, a part of which is to meet the wastewater discharge criteria set by the Government of Bangladesh as per international guidelines and minimize energy consumption [2]-[3].

The nature of the generated textile wastewater is complex due to its high alkalinity, high Biochemical Oxygen Demand (BOD), high Chemical Oxygen Demand (COD),

chroma/color, suspended solids, sulfide, and complex organic compounds. The presence of complex organic compounds is attributed to the use of dyes and texturing additives.

The existing textile wastewater treatment facilities usually consist of the process units shown in Figure 1. They commonly employ chemical pretreatment followed by extended aerobic treatments which are resource intensive and energy intensive respectively. The extended aerobic treatment has a Hydraulic Retention Time (HRT) three times the norm ranging from 13 hours to 84 hours, requiring aerators/blowers to supply air constantly to sustain the microorganisms. The aerators with a power rating of 4.0 to 6.0 kWh/(kg of BOD₅/day) is responsible for making the process of treatment energy intensive.



Figure 1: Process units of existing textile wastewater treatment facilities.

The aim of the paper is to show the significant power savings potential by acetogenic pretreatment of textile wastewater. The specific objectives are to assess the viability of acetogenic pretreatment of textile wastewater, to model the kinetics of the acetogenic microbial degradation of the textile processing wastewater, and to estimate the power savings due to the reduction of biological oxygen demand loading by acetogenic pretreatment of the textile wastewater.

2. Background

Acetogenic pretreatment makes use of a biological reactor that maintains a microbial medium under non-aerated conditions with a short hydraulic and solids retention time of 2 to 4 days. The operational conditions are ensured for optimal acetogenic breakdown of complex organic compounds to hydrogen, carbon dioxide and acetate. The process stabilizes the waste by reducing the BOD. Short bursts of periodic aeration may be necessary to ensure methanogenic microorganisms do not grow to convert the metabolic products of acetogenesis to methane and carbon dioxide.

Acetogenic reactors have been used only to treat wastes with high and readily biodegradable content such as food wastes [4]-[6]. Stretching the use of these reactors to treat complex textile wastewater is novel as it would simplify the treatment process by minimizing the use of chemicals and electricity. The acetogenic pretreatment would lower the BOD loading prior to aerobic treatment thereby, reducing the energy required for aeration.

The textile industry is also a major consumer of power and water. To supply the need for energy the Government of Bangladesh is welcoming initiatives to harness energy from renewable sources.

3. Methodology

The wastewater was sourced from a textile dyeing facility in Gazipur, where fabrics are dyed using blue reactive dye to produce blue denim, with an in house wastewater treatment facility that treats the generated wastewater using the conventional process of primary clarification followed by the energy intensive extended aerobic treatment. The wastewater samples were collected over a twenty-four hour period from the equalization basin. The collected samples were immediately preserved as per standard method before sending them for laboratory analysis for wastewater characterization.

An experimental program was conducted under controlled conditions using bench scale continuously stirred tank reactors for the optimization of hydrogen generation by limiting the process of hydrogenotrophic methanogenesis. Central to the protocol was the operation of a master culture reactor, which was maintained under waste feed mode (semi continuous batch mode operation) with a hydraulic retention time/ solid retention time of four days. A multilevel protocol for assessing the fate and effect of organic chemicals in anaerobic reactions, based on US Environmental Protection Agency (EPA) Project R814488, was adopted to assess the kinetics of microbial degradation as the substrate was optimized for hydrogen generation thereby limiting the emission of greenhouse gases and yet produce waste stabilization [7]-[13]. The master culture reactor, with a volume of 1.0 L and a temperature of 35°C, was operated in a semi-continuous batch with a regime of daily waste and feeding. The reactor's pH and temperature, monitored real time by using data acquisition systems, alongside the

reactor's Total Suspended Solids (TSS) and soluble COD (sCOD) were monitored on a daily basis using standard methods [12]-[13]. The cultures were transferred from the master culture reactor to small reactors for conducting batch kinetic studies. The batch reactors were serum bottle reactors continuously stirred and maintained at constant temperature. The reactor content composition with respect to COD, TSS, color, and Total Fatty Acid (TFA) was monitored at preset timed intervals.

The batch kinetics data were utilized to model the kinetics of sCOD transformation. The generalized rate Equation for first order transformation was used to model substrate transformation using MATLAB.

4. Results and Discussion

The diurnal flow pattern of the textile wastewater in focus is shown in Figure 2. The total daily flow is estimated at 30 m³/day.

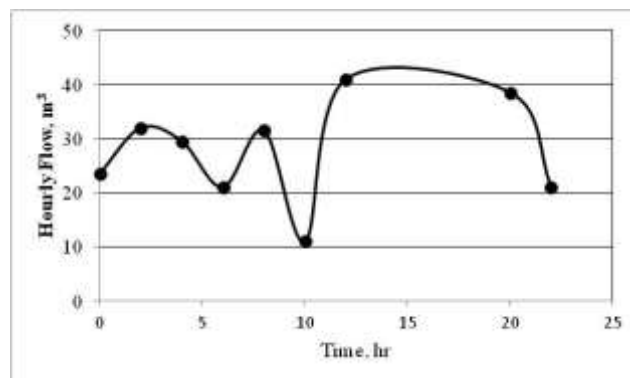


Figure 2: Observed pattern of diurnal flow of the textile wastewater treatment system.

The characteristics of the wastewater for a twenty four hour composite sample obtained from the textile wastewater treatment facility is summarized in Table 1.

Table 1: Wastewater characterization

Sample Location	TSS (mg/L)	pH	Colour (ptco)	TDS (mg/L)	COD (mg/L)	BOD ₅ (mg/L)
Equalization Basin	144	8.6	660	2470	371	228

The salient feature of the characterized wastewater is the ratio of BOD₅ to COD of 0.6, which indicates that the biological fraction is high enough to warrant biological treatment. The existing treatment system consists of an equalization basin with a HRT of 48 hours, a chemically aided primary clarifier with a HRT of 2.5 hours for removal of solids and color, an extended aeration basin with a HRT of 24 hours for removal of BOD, and lastly, a secondary clarifier. The soluble BOD₅ loading to the existing aerobic basin is 164 kg of BOD₅/day and the power rating of the fine bubble air diffusers is 4.0 kWh/day-(kg of BOD₅/day), which calls for an energy requirement of 656 kWh/day. The energy requirement in Bangladesh is less than 10 kWh per capita. Thus, 656 kWh per day is a substantial amount of power consumption by a single process unit in the context of the country's economic conditions. The energy required by the

blowers in extended aeration is an operational constraint in a developing country such as Bangladesh.

Acetogenic pretreatment makes use of a biological reactor that maintains a microbial medium under non-aerated conditions. The operational conditions are ensured for optimal acetogenic waste stabilization by operating at short solids retention times with periodic aeration bursts of air to ensure that in the bioreactor only acetogenic microorganisms predominate. Acetogenic pretreatment has been applied to easily degradable wastes such as food processing wastes with high readily biodegradable content [5]-[6]. In this paper we for the first time have applied the concept to complex textile denim dyeing wastewater purposefully to look at reduction of organic biodegradable fraction as a potential for substantially reducing loading to an aeration basin. To this end we operated an acetogenic reactor to pre-treat the textile dyeing wastewater characterized in Table 1. We further looked at the possible energy savings in reduced aeration by the reduction of BOD₅ loading per day to the aeration basin.

Operation of acetogenic reactor showed that the cultures required a period of operation to acclimate to the wastewater. Once steady state operation was achieved, the reactor attained a high degree of waste stabilization with sCOD removal efficiency of 95%, as indicated in Figure 3.

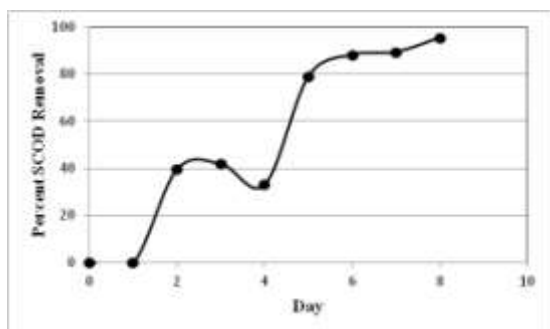


Figure 3: sCOD removal efficiency of the acetogenic reactor

The acetogenic reactor was also able to operate without the need of pH adjustment, which is attractive in a resource challenged environment as Bangladesh, compared to the existing system which required pH adjustment prior to aerobic treatment. The acetic acid generated in the acetogenic process neutralized the high pH of the influent wastewater as shown by the operating pH of the acetogenic reactor in Figure 4.

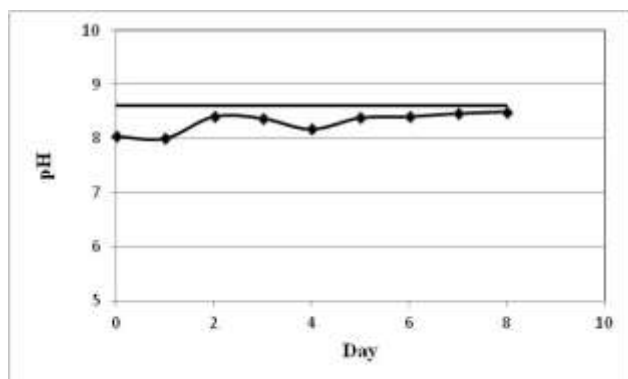


Figure 4: pH profile of the acetogenic reactor

Batch kinetics of the substrate/(textile dyeing wastewater) removal, expressed as sCOD removal, was defined by a first order model as depicted in Figure 5. There was a high degree of model fit between the observed and modeled data ($r^2 = 0.84$). The value of the first order rate constant, k , for the degradation of the textile dyeing wastewater was 0.047 hr^{-1} (95% confidence bound; 0.030, 0.064). This indicates that the first order kinetics predicts the acetogenic microbial degradation of textile dyeing wastewater which signifies that such first order models can be used to design acetogenic reactors for textile dyeing wastewater treatment facilities.

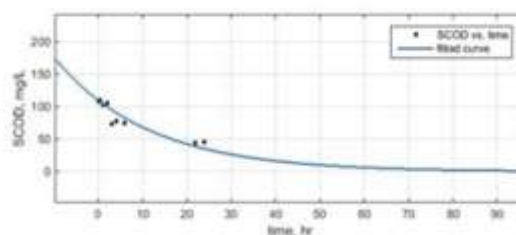


Figure 5: sCOD removal of the acetogenic reactor

The soluble BOD₅ loading to the aerobic basin after acetogenic pretreatment is 21 kg of BOD₅/day. The reduction in BOD₅ loading of 143 kg BOD₅/day is based on the reduction efficiency of the biodegradable fraction of the textile wastewater. This would conserve energy by an amount of 572 kWh/day as reduced BOD₅ loading to the aerobic basin implies reduced aeration needs.

Acetogenic pretreatment would conserve a significant amount of electrical energy when applied to not only one textile mill but to all the rest across the country. In terms of energy economics, the textile wastewater treatment facilities should be retrofitted to introduce acetogenic pretreatment for substantially reducing the BOD₅ loading to the aeration basin. Since we are reducing the BOD loading to the aeration basin, the size of the aeration basin would be reduced, hence, requiring nominal re-plumbing of the existing pipelines and switching from continuous aeration to periodic shock aeration using the existing aerators in place. This would require nominal expenditure in capital.

5. Conclusion

The paper has successfully demonstrated the compelling reduction in biodegradable matter by the use of acetogenic reactors. First order kinetics was successful in defining the kinetics of biodegradable organic matter transformation in the acetogenic reactor. The power savings from reduced loading to the aeration basin in wastewater treatment facilities by acetogenic pretreatment was established.

6. Future Scope

The paper is limited to energy reduction evaluation based on bench scale study to ascertain the exact potential in energy savings a large scale study needs to be done. This research needs to be expanded to a full scale plant application

References

- [1] M. M. Islam, K. Mahmud, O. Faruk, M.S. Billah, "Textile Dyeing Industries in Bangladesh for Sustainable Development," International journal of Environmental Science and Development, pp. 428-436, 2011.
- [2] K. R. Haque, "Guide for Assessment of Effluent Treatment Plants," Department of Environment, Ministry of Environment and Forest, Government of Bangladesh, pp. 3-10, 2008.
- [3] World Bank, The Bangladesh Responsible Sourcing Initiative. A New Model for Green Growth. World Bank. 1818 H Street, N.W. Washington DC 20433, USA, 2014.
- [4] E. FASETTI, E. DADDARIO, O. TODINI, A. ROBERTIELLO, (1998). "A photosynthetic Hydrogen Evolution with Volatile Organic Acids Derived from the Fermentation of Source Selected Municipal Solid Wastes." International Journal of Hydrogen Energy, 13(9), pp. 753-60, 1998.
- [5] H.H.P. Fang, H. Liu, "Effect of pH on Hydrogen Production from Glucose by a Mixed Culture," Bioresour Technol, 82(2), pp. 87-93, 2002.
- [6] M. Ferchichi, E. Crabbe, G. Gil, W. Hintz, A. Almadidy, "Influence of Initial pH on Hydrogen Production from Cheese Whey," Journal of Biotechnology, 120, pp. 402-409, 2005.
- [7] "Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act: Technical Amendments and Notice of Availability of Information," U.S. Environmental Protection Agency, Federal Register, 40 CFR Part 136, 1986.
- [8] J. F. Andrews, "Modeling of Biological Treatment Processes," in Biotechnology and Bioengineering, 10, pp. 707-723, 1968.
- [9] H. H. Tabak, S. Desai, R. Govind, "The Determination of Biodegradability and Biodegradation Kinetics of Organic Pollutant Compounds with the Use of Electrolytic Respirometry," Environmental Toxicology And Chemistry, 9(4), pp. 473-477, 1989. Proc. 1989. Research Symp.: Remedial Action, Treatment, and Disposal of Hazardous Wastes, Cincinnati, OH.
- [10] J. C. Young, H. H. Tabak, "Multi-Level Protocol for Assessing the Fate and Effect of Toxic organic Chemicals in Anaerobic Reactions," Final Report EPA Project R814488, Civil Engineering Department, University of Arkansas, Fayetteville, AR, 1991.
- [11] J. C. Young, M. L. Kuss, M. A. Nelson, "Use of Anaerobic Respirometers for Measuring Gas Production in Toxicity and Treatability Tests," In Proceedings of the 84th Annual Meeting of the Air and Waste Management Association, Vancouver, B.C., Canada, 1991.
- [12] Standard Methods for the Examination of Water and Wastewater, Supplement to the 16th Edition, American Public Health Association, Washington, D.C., 1988.
- [13] Standard Methods for the Examination of Water and Wastewater, 17th Edition, American Public Health Association, Washington, D. C., 1989.

Author Profile



Nadim Khandaker received the B.S. in Chemical Engineering from University of Massachusetts in 1986. M.S. degrees in Environmental Engineering from University of Arkansas, at Fayetteville in 1991 and PhD. in Environmental Engineering in 1995 from Pennsylvania State University, University Park. He is a Licensed Professional Engineer in the province of Ontario and New Brunswick, Canada. He is an associate Professor at the Department of Civil and Environmental Engineering at North South University Bangladesh.



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