

Treatment of Dairy & Distillery Wastewater by Anaerobic Digestion Process

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Abstract — Industrial wastewater generated from dairy and distillery industries contains high concentrations of biodegradable organic matter, suspended solids, dissolved solids, and nutrients, which may cause severe environmental pollution if discharged without proper treatment. In the present study, anaerobic digestion was investigated as an effective biological treatment method for dairy wastewater, distillery wastewater, and blended wastewater under different organic loading conditions. Laboratory-scale anaerobic reactors were operated to evaluate treatment efficiency based on parameters such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), pH, solids reduction, and biogas generation. The experimental results indicated significant reduction in organic pollutants along with stable methane-rich biogas production. The study demonstrates that anaerobic digestion is an economical and environmentally sustainable method for treating high-strength industrial wastewater while simultaneously recovering renewable energy. The treatment system also showed improved reactor stability under controlled loading conditions, making it suitable for industrial wastewater management applications.

Keywords: Anaerobic Digestion, Dairy Wastewater, Distillery Wastewater, COD Removal, Biogas Production, Industrial Wastewater Treatment, Methane Generation

I. INTRODUCTION

Rapid industrialization has significantly increased the generation of industrial wastewater, creating serious environmental and public health concerns. Dairy and distillery industries are among the major contributors of high-strength wastewater containing large amounts of biodegradable organic matter, suspended solids, dissolved solids, fats, proteins, sugars, and nutrients. Improper disposal of such wastewater leads to depletion of dissolved oxygen in water bodies, unpleasant odour generation, soil contamination, and adverse effects on aquatic ecosystems.

Dairy wastewater is mainly generated during milk processing, equipment cleaning, washing operations, and packaging activities. The effluent generally contains high concentrations of lactose, proteins, fats, and detergents, resulting in elevated Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Similarly, distillery industries generate highly polluted spent wash during alcohol and ethanol production processes. Distillery wastewater is characterized by dark brown colour, acidic pH, high organic load, and high dissolved solids concentration.

Conventional physical and chemical treatment methods for industrial wastewater are often associated with high operational cost and secondary sludge generation. Biological treatment methods, particularly anaerobic digestion, have gained considerable attention due to their ability to treat high-strength wastewater efficiently while producing methane-rich biogas as a renewable energy source.

Anaerobic digestion is a microbial process carried out in the absence of oxygen, where complex organic matter

is converted into methane, carbon dioxide, and stabilized sludge through hydrolysis, acidogenesis, acetogenesis, and methanogenesis stages. The process offers several advantages including low energy requirement, reduced sludge production, high organic matter removal efficiency, and renewable energy recovery.

The present study focuses on the treatment of dairy wastewater, distillery wastewater, and blended wastewater using anaerobic digestion process under different organic loading rates. The reactor performance was evaluated based on COD reduction, BOD removal, solids reduction, pH variation, and biogas production to determine the suitability of anaerobic digestion for sustainable industrial wastewater management.

II. LITERATURE REVIEW

Several researchers have investigated biological treatment methods for high-strength industrial wastewater generated from dairy and distillery industries. Among various treatment technologies, anaerobic digestion has been widely adopted because of its high organic matter removal efficiency and renewable biogas recovery potential.

Demirel et al. reported that anaerobic treatment of dairy wastewater using UASB reactors achieved high COD reduction efficiency under controlled operating conditions. The study concluded that anaerobic digestion is economical and effective for wastewater containing proteins, fats, and lactose [1].

Tawfik et al. investigated combined anaerobic and aerobic treatment systems for dairy wastewater and observed significant reductions in BOD, COD, and suspended solids. The authors emphasized the importance of maintaining stable pH conditions for efficient microbial activity and methane generation [2].

Karadag et al. studied anaerobic digestion of dairy wastewater under mesophilic conditions and reported stable reactor performance with COD removal efficiencies above 80%. The study highlighted the importance of optimum temperature and organic loading rate in maintaining methane production [3].

Several studies have also focused on the treatment of distillery wastewater, which possesses extremely high organic load and dark brown colour due to melanoidin compounds. Moletta reported that anaerobic digesters effectively reduced COD concentration in distillery spent wash while simultaneously producing methane-rich biogas [4].

Pant and Adholeya reviewed biological treatment methods for distillery wastewater and concluded that anaerobic digestion is one of the most suitable techniques for reducing pollution load in high-strength industrial effluents [5].

Driessen and Vereijken studied high-rate anaerobic reactors for distillery wastewater treatment and observed

efficient methane recovery with lower sludge generation compared to conventional treatment systems [6].

Lettinga et al. introduced the Upflow Anaerobic Sludge Blanket (UASB) reactor and demonstrated its effectiveness in treating industrial wastewater with high organic loading rates [7]. Speece also reported that anaerobic digestion systems are highly suitable for industrial wastewater due to low energy consumption and high treatment efficiency [8].

Previous research mainly focused on individual treatment of dairy wastewater or distillery wastewater. Limited studies are available on the combined treatment of dairy and distillery wastewater under varying organic loading conditions. Therefore, the present study aims to evaluate the treatment efficiency of anaerobic digestion for dairy wastewater, distillery wastewater, and blended wastewater with emphasis on COD reduction, solids removal, reactor stability, and biogas production.

III. MATERIALS AND METHODOLOGY

A. Collection of Wastewater Samples

The wastewater samples used in the present study were collected from nearby dairy processing industries and distillery units. Dairy wastewater mainly consisted of milk residues, fats, proteins, detergents, and cleaning chemicals generated during washing and processing operations. Distillery wastewater, commonly referred to as spent wash, contained high concentrations of organic matter, dissolved solids, and dark-coloured compounds generated during alcohol production.

The collected samples were stored in clean plastic containers and transported to the laboratory for further analysis and experimental investigation. Refrigerated storage conditions were maintained to avoid changes in wastewater characteristics before treatment.

B. Characteristics of Raw Wastewater

The collected wastewater samples were analyzed for important physicochemical parameters before treatment. Dairy wastewater showed moderate organic strength with high biodegradable content, whereas distillery wastewater exhibited extremely high COD, acidic pH, and strong odour. Typical characteristics of dairy wastewater included:

- pH: 6.8–7.5
- BOD: 1200–1800 mg/L
- COD: 1800–3200 mg/L

Typical characteristics of distillery wastewater included:

- pH: 4.0–5.5
- BOD: 25000–40000 mg/L
- COD: 40000–70000 mg/L

Parameter	Dairy Wastewater	Distillery Wastewater
pH	6.8–7.5	4.0–5.5
BOD (mg/L)	1200–1800	25000–40000
COD (mg/L)	1800–3200	40000–70000
Organic Strength	Moderate	Very High
Colour	Light White	Dark Brown

Table I: Characteristics Of Raw Wastewater

C. Experimental Setup

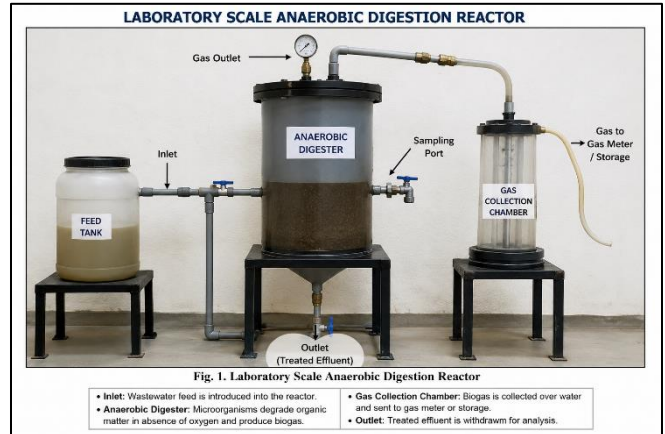


Fig. 1: Laboratory Scale Anaerobic Digestion Reactor
A laboratory-scale anaerobic digestion reactor was fabricated using a cylindrical airtight container to maintain oxygen-free conditions during the experiment. The setup consisted of an inlet chamber, outlet arrangement, gas collection chamber, sampling ports, and connecting pipes.

Anaerobic sludge collected from an existing treatment plant was used as inoculum for initiating microbial activity. The reactor was operated under controlled conditions to study the treatment efficiency for dairy wastewater, distillery wastewater, and blended wastewater.

D. Experimental Procedure

The reactor was initially seeded with anaerobic sludge, followed by gradual feeding of wastewater samples. Diluted wastewater was supplied during the start-up phase to avoid shock loading and to stabilize microbial growth. The organic loading rate was gradually increased after achieving stable reactor performance.

The reactor performance was evaluated under different operating conditions by monitoring:

- pH variation
- COD reduction
- BOD removal
- Solids reduction
- Biogas generation

The experimental study was conducted continuously for several days to analyze reactor stability and methane production efficiency.

E. Analytical Methods

Standard laboratory procedures were adopted for wastewater analysis before and after treatment. Important parameters analyzed during the study included pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), total solids, suspended solids, dissolved solids, and biogas production.

The pH was measured using a digital pH meter, while COD and BOD analyses were carried out according to standard wastewater testing procedures. Biogas generation was monitored periodically to evaluate methane production during anaerobic digestion.

IV. RESULTS & DISCUSSION

The performance of the anaerobic digestion reactor was evaluated based on important parameters such as pH variation, Chemical Oxygen Demand (COD) reduction, Biological Oxygen Demand (BOD) removal, solids reduction, and biogas generation. The reactor was operated under different organic loading conditions using dairy wastewater, distillery wastewater, and blended wastewater samples.

A. pH Variation

The pH of the reactor was monitored regularly throughout the experimental period because methanogenic microorganisms require stable pH conditions for efficient digestion. During the initial stages, slight acidic conditions were observed due to the formation of volatile fatty acids. However, stable reactor performance was achieved after acclimatization of microorganisms.

The pH values were maintained within the optimum range of 6.8–7.5 during most of the operational period, which supported effective methane generation and organic matter degradation.

B. COD Removal Efficiency

Significant reduction in COD concentration was observed during anaerobic digestion of wastewater samples. Dairy wastewater showed effective COD reduction because of the high biodegradable organic content present in milk residues and proteins.

Distillery wastewater also exhibited considerable COD removal, although the treatment efficiency was comparatively lower due to the presence of dark coloured compounds and high dissolved solids concentration.

The blended wastewater demonstrated improved reactor stability and balanced nutrient availability, resulting in better overall digestion performance. COD removal efficiencies ranging between 70% and 90% were observed under controlled loading conditions.

C. BOD Reduction

The Biological Oxygen Demand (BOD) values decreased considerably after anaerobic treatment, indicating effective degradation of biodegradable organic matter by anaerobic microorganisms.

Higher BOD removal efficiency was achieved at moderate organic loading rates, whereas excessive loading conditions reduced reactor stability and methane production. The experimental results confirmed that anaerobic digestion is highly suitable for treating high-strength industrial wastewater containing biodegradable pollutants.

D. Biogas Generation

Reduction in suspended solids and total solids was observed during reactor operation due to microbial degradation and stabilization of organic matter. Dairy wastewater showed better solids reduction because of the easily biodegradable nature of organic compounds.

Distillery wastewater exhibited comparatively lower solids removal due to the presence of complex organic compounds and coloured substances.

E. Solids Reduction

Biogas production was observed throughout the anaerobic digestion process as a result of microbial decomposition of organic matter. Methane-rich biogas was generated after stabilization of reactor conditions.

The quantity of biogas produced increased with increase in organic loading rate up to an optimum level. Excessive loading conditions resulted in reduced methane production because of acid accumulation and process instability.

The experimental study demonstrated that anaerobic digestion not only reduces pollution load but also provides renewable energy recovery through biogas generation. The methane-rich biogas produced during the process can be utilized for heating and energy applications.

F. Overall Reactor Performance

The experimental investigation confirmed that anaerobic digestion is an efficient and environmentally sustainable treatment method for dairy wastewater, distillery wastewater, and blended industrial wastewater. The reactor achieved effective organic pollutant removal with stable methane production under controlled operating conditions.

Among the wastewater samples studied, blended wastewater exhibited improved reactor stability and balanced digestion performance compared to individual wastewater treatment. The study also indicated that proper control of pH, organic loading rate, and retention time is essential for maintaining stable anaerobic digestion efficiency.

V. CONCLUSION

The present study investigated the treatment of dairy wastewater, distillery wastewater, and blended industrial wastewater using anaerobic digestion process. The experimental results demonstrated that anaerobic digestion is an effective biological treatment method for reducing organic pollutants present in high-strength industrial effluents.

Significant reduction in Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), suspended solids, and total solids was achieved during reactor operation. Stable reactor performance was observed under controlled pH and organic loading conditions. The anaerobic digestion process also produced methane-rich biogas, indicating the potential for renewable energy recovery during wastewater treatment.

Among the different wastewater samples studied, blended wastewater showed improved reactor stability and balanced treatment performance compared to individual wastewater treatment. Proper control of organic loading rate, retention time, and pH was found to be essential for maintaining efficient microbial activity and methane generation.

The study concludes that anaerobic digestion is an economical, environmentally sustainable, and energy-efficient technology for treating dairy and distillery wastewater. The process not only minimizes environmental pollution but also supports sustainable industrial wastewater management through resource recovery and biogas production.

REFERENCES

- [1] J. Demirel, P. Scherer, and M. Yenigun, "Production of methane and hydrogen from biomass through conventional and high-rate anaerobic digestion processes," *Critical Reviews in Environmental Science and Technology*, vol. 35, no. 2, pp. 97–135, 2005.
- [2] R. Tawfik, G. El-Gohary, and U. Mahmoud, "Treatment of dairy wastewater using an integrated anaerobic baffled reactor and activated sludge system," *Desalination*, vol. 227, no. 1–3, pp. 167–177, 2008.
- [3] M. Karadag, E. Koroglu, and B. Ozkaya, "Anaerobic digestion of dairy wastewater under mesophilic conditions," *Environmental Progress and Sustainable Energy*, vol. 34, no. 4, pp. 1108–1115, 2015.
- [4] N. Moletta, "Treatment of distillery wastewater by anaerobic digestion," *Water Science and Technology*, vol. 52, no. 1–2, pp. 199–206, 2005.
- [5] S. Pant and A. Adholeya, "Biological approaches for treatment of distillery wastewater: A review," *Bioresource Technology*, vol. 98, no. 12, pp. 2321–2334, 2007.
- [6] R. Driessen and T. Vereijken, "Recent developments in biological treatment of distillery effluent," *Water Science and Technology*, vol. 48, no. 11–12, pp. 199–206, 2003.
- [7] G. Lettinga, A. F. M. Van Velsen, S. W. Hobma, W. De Zeeuw, and A. Klapwijk, "Use of the upflow sludge blanket reactor concept for biological wastewater treatment," *Biotechnology and Bioengineering*, vol. 22, no. 4, pp. 699–734, 1980.
- [8] R. E. Speece, *Anaerobic Biotechnology for Industrial Wastewaters*, Nashville, TN, USA: Archae Press, 1996.
- [9] G. Lettinga and L. Hulshoff Pol, "UASB-process design for various types of wastewaters," *Water Science and Technology*, vol. 24, no. 8, pp. 87–107, 1991.
- [10] Metcalf and Eddy, *Wastewater Engineering: Treatment and Reuse*, 4th ed. New York, NY, USA: McGraw-Hill, 2003.
- [11] P. L. McCarty, "Anaerobic waste treatment fundamentals," *Public Works*, vol. 95, no. 9, pp. 107–112, 1964.
- [12] D. Deublein and A. Steinhauser, *Biogas from Waste and Renewable Resources*. Weinheim, Germany: Wiley-VCH, 2008.
- [13] Y. Chen, J. J. Cheng, and K. S. Creamer, "Inhibition of anaerobic digestion process: A review," *Bioresource Technology*, vol. 99, no. 10, pp. 4044–4064, 2008.
- [14] L. Appels, J. Baeyens, J. Degreè, and R. Dewil, "Principles and potential of anaerobic digestion of waste-activated sludge," *Progress in Energy and Combustion Science*, vol. 34, no. 6, pp. 755–781, 2008.
- [15] M. H. Gerardi, *The Microbiology of Anaerobic Digesters*. Hoboken, NJ, USA: Wiley-Interscience, 2003.