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Sustainable Textile Wastewater Treatment: Anaerobic Digestion with Starch for Enhanced Dye Removal

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ABSTRACT :

In this study, the treatability of dye wastewater using starch-based wastewater as a co-substrate by the anaerobic process was demonstrated. The objective of this work was to study the application of anaerobic reactors inoculated with flocculent biomass for the degradation of textile dye wastewater with sago effluent as a co-substrate. An anaerobic digestion technique was applied to textile dye wastewater, aiming at colour and COD removal. Five pet bottles of 5liter capacity each were used as reactors, which contained methanogenic sludge of half a liter, which was used for the treatment of combined synthetic textile dye and starch wastewater at different ratios of 20:80, 30:70, 40:60, 50:50, and 60:40 with initial COD concentrations of 3520, 3440, 3360, 3264, and 3144 mg/l, respectively. The pH of the reactor and the room temperature were maintained at 7 (neutral) and 30±10°C, respectively. The maximum COD and colour removal were 81.0% and 87.3 % at an optimum mixing ratio of 30:70 of textile dye and starch wastewaters.

Keywords: Anaerobic batch process, Bio-mass, Dye removal, Textile Wastewater, Bioremediation

INTRODUCTION

The safe use of water has long been a critical issue for dyeing companies that damage natural water bodies as a result of industrial development, especially the effects of global warming, which is a major concern for environmental pollution reduction. The textile sector is the primary source of dye pollution and has garnered increasing attention as a wastewater mitigation strategy. The textile industry employs a number of synthetic pigments for easily available dyed fabrics, with an estimated yearly manufacturing capacity of 7 × 10^5 tons. The majority of textile-colored substances produced and utilized for dyeing textiles are azo dyes, which account for more than 70% of the total dye output (*Bogale et al.,2024*). The textile industry is the leading cause of water contamination among industries. Textile effluents contain dyes, coloring agents, surfactants, grease, oil, metals, sulfate, chloride, and starch, all of which affect water quality. Dyes in water obstruct the passage of light, eventually reducing photosynthetic activity and oxygen levels (*Laizer et al.,2022*). Wastewater from the textile sector is a global issue that requires adequate treatment before it is released into the environment. Numerous solutions are available to treat wastewater from the textile industry. The choice of an appropriate technology is determined by several factors, including the manufacturing process, chemicals used, effluent constituents, release regulations, location, investment, operating costs, land availability, options for reusing/cycling-treated wastewater, and available skills and expertise (*Jegatheesan et al.,2016).*

1.1 Starch

Starch is an important co-substrate in the process of anaerobic dye removal because it promotes the decomposition of complex organic contaminants, such as dyes. Starch promotes the proliferation and activity of bacteria responsible for color breakdown by providing an easily accessible carbon source. This method increases the effectiveness of dye removal and biogas generation. Starch can be derived from a variety of sources, including plant materials, agricultural waste, and industrial byproducts. When starch is introduced into the anaerobic digestion process, it can promote the proliferation of bacteria, enhancing their capacity to break down dyes. Starch molecules can be broken down into simpler chemicals that provide energy and nutrition to microbes (*Gomes, R. F.,et al.,2015*). This procedure may effectively remove color from wastewater, thereby minimizing environmental contamination. Furthermore, using starch as a co-substrate can improve the stability and robustness of the anaerobic digestion process, allowing it to survive variations in operating conditions and dye concentrations. Overall, including starch during anaerobic digestion is a potential strategy for increasing the dye removal efficiency and supporting sustainable wastewater treatment techniques. Using starch as a co-substrate in wastewater treatment systems improves performance, reduces environmental impacts, and increases biogas generation (O' Neill et al.,,2000).

1.2 Biomass (Cow Dung)

Cow dung, a form of biomass, serves as a significant fuel in anaerobic digestion for color removal. Owing to its high organic content, cow dung provides an optimal environment for the proliferation of microorganisms, facilitating the effective breakdown of complex colored compounds. The anaerobic decomposition of cow dung not only generates biogas, which is a renewable energy source, but also aids in the decolorization of wastewater.

Microorganisms present in cow dung, such as methanogens and acidogens, collaborate to degrade organic pollutants including dyes. The utilization of cow dung for anaerobic decomposition offers several benefits, including low-cost feedstock, green energy production, and reduced pollution (Ahmad, Khan, et al., 2020). Given its abundance in many agricultural areas, cow dung is an accessible and environmentally sustainable alternative for wastewater treatment. By incorporating cow dung into the anaerobic digestion process, wastewater treatment facilities can achieve efficient color removal, lower operational costs, and improved energy self-sufficiency. Additionally, digestate, a nutrient-rich byproduct of anaerobic digestion, can be employed as a fertilizer to enhance the sustainability of the process. Overall, the integration of cow dung in anaerobic digestion represents a promising approach for color removal, alternative energy production, and eco-friendly wastewater treatment (Iwuozor et al., 2022).

1.3 Biodegradation of textile dyes

Various microorganisms, including bacteria, algae, fungi, and yeast have been shown to degrade textile dyes. Notably, bacteria play a pivotal role in the biological degradation of synthetic dyes because of their dynamic metabolic processes, which enable them to utilize the complex xenobiotic compounds present in dyestuffs as substrates. Moreover, bacterial communities exhibit superior adaptability and diversity compared with fungi and yeast, rendering them suitable for wastewater treatment across diverse geographical and seasonal contexts. In addition, sourcing microorganisms from wastewater treatment facilities enhances the likelihood of obtaining active enzymes that facilitate dye degradation. Dye biodegradation can occur through whole-cell microbial activities or enzymatic processes. During microbial biodegradation, various chemical groups present in dyes can serve as carbon and nitrogen sources, and these compounds can be removed through multiple mechanisms including biosorption, bioaccumulation, and biodegradation.

Removal of dyes from wastewater is imperative because of their potential adverse effects on aquatic environments. Traditionally, the treatment of textile wastewater has predominantly employed aerobic biological processes such as conventional and extended activated sludge methods. These processes are characterized by high oxygen demand and substantial sludge production, leading to considerable operational costs. Moreover, aerobic processes are ineffective in degrading azo dyes, which constitute the majority (60-70%) of the synthetic colorants. Recent research has indicated that synthetic and simulated wastewater containing hazardous dyes and other additives can be effectively treated using batch anaerobic systems. However, there is a lack of published studies on wastewater treatment using anaerobic batch reactor systems (Sponza et al., 2006). This study presents laboratory findings on the use of anaerobic batch reactors for decolorization of textile effluents. These reactors were employed to treat textile effluent with starch as a co-substrate (Rajeshwari, K. V., V., et al., 2000).

MATERIALS AND METHODOLOGY

Raw Materials

The process begins with the collection of textile wastewater containing complex dye molecules, which requires thorough characterization to determine its composition, pH, and nutrient levels. To enhance microbial activity and facilitate dye degradation, starch is introduced as a co-substrate. Make a starch solution for the degradation process, providing a readily available carbon source that supports the growth of microorganisms. Cow dung, which contains many different types of microbes, is also added to the system, where it works together with starch to break down organic pollutants, like dyes, into simpler and less harmful substances.

Experimental Setup

Batch studies were carried out in the laboratory using pet bottles of 5 L capacity each. To achieve and maintain anaerobic conditions in the bottles, the mouth of the bottles were closed tightly with rubber cork provided with two openings. One opening acts as sampling port to draw the samples and another one for gas collection connected with water displacement principle. In this experiment, the combined wastewater was prepared to fed into the batch reactor by mixing the synthetic reactive dye wastewater and tapioca starch effluent in various ratios such as 20:80, 30:70, 40:60, 50:50 and 60:40 respectively. The reactor contains half liter of seed sludge and 3.5 liters of synthetic dye-starch wastewater (various mixing proportions). The free space at the top of the liquid level acts as gas holder. The headspaces of the bottles were flushed with nitrogen to obtain anaerobic conditions. The total experiments were carried at room temperature (30±1 ^{0}C) and at neutral pH (7) for 20-23 days. The alkalinity and neutral pH were adjusted by $NaHCO_3$. The values of pH, COD, colour, biomass and biogas were monitored for every 24 hrs.

Fig 1: laboratory setup for the anaerobic digestion.

Gas displacement measurement is a technique used to quantify the volume of gas produced or consumed in a reaction or process. In the context of anaerobic digestion for dye removal, gas displacement measurement can be employed to monitor the production of biogas, which is a mixture of methane and carbon dioxide. By measuring the volume of biogas produced, researchers can assess the efficiency of the anaerobic digestion process and the effectiveness of dye degradation. This measurement can be achieved through various methods, including water displacement or using a gas flow meter, providing valuable insights into the microbial activity and process performance.

Fig 2: setup for gas displacement measurement

Fig 3: laboratory setup for the anaerobic digestion (different ratio)

RESULTS

pH level analysis

pH analysis determines the acidity or alkalinity of a solution, providing critical information about its chemical characteristics. The pH scale runs from 0 to 14, with values less than 7 indicating acidity and more than 7 suggesting alkalinity. pH analysis is useful in a variety of sectors, including water quality evaluation, industrial operations, medicines, and food production. Accurate pH readings contribute to product quality, process efficiency, and safety while also preserving equipment from corrosion. In environmental monitoring, pH analysis is used to measure the impact of contaminants on ecosystems. Identifying the pH level allows experts to make educated judgments and take remedial steps for ideal circumstances.

The Figure 3 shows pH of different mixing ratio through the process time. Initial pH of all the mixing ratios were maintained at 7, as the time increases the pH was decreased. In 20:80 mixing ratio the initial pH was 7 and at the end of the process pH was reduced to 6.1. For 30:70, 40:60, 50:50, 60:40 of textile dye and starch wastewater mixing ratio the pH reduced from 7 to 6.36, 7.01 to 6.4, 7 to 6.5, 7 to 6.6 respectively as the time increases. The initial pH must be maintained at 7 for better growth of the anaerobic organisms in batch process of textile dye wastewater decolourization (Beydilli and Pavlostathis 2005).

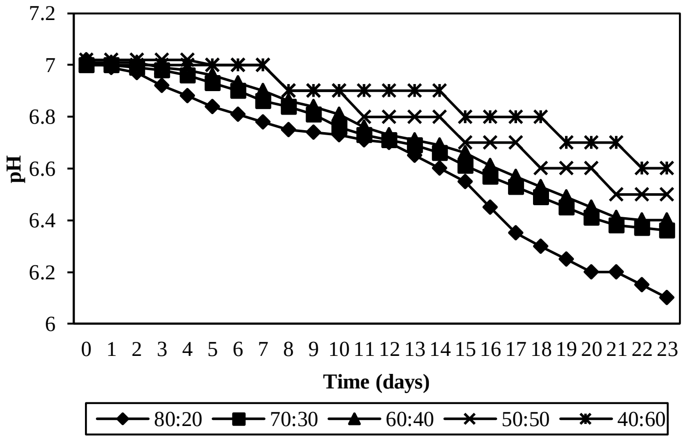

Fig. 4: pH at various mixing ratio

COD removal analysis

The Chemical Oxygen Demand (COD) analysis determines the quantity of atmospheric oxygen needed to chemically oxidize organic materials in water or wastewater. It is an important metric for evaluating water quality and estimating the extent of organic contamination. COD analysis assists in identifying possible environmental consequences, guiding treatment operations, and ensuring regulatory compliance. COD tests, which assess oxygen demand, give information on the efficacy of wastewater treatment systems as well as the potential for damage to aquatic ecosystems. This study is commonly used in industrial and municipal wastewater management to track and reduce the environmental impact of effluent discharges. COD removal efficiency at various mixing proportions of synthetic textile dye and starch effluent using anaerobic batch reactor was studied.

Fig. 4 show the percentage removal of COD at different mixing ratios was gradually increased from 6th to 16th day, after that it attains almost an equilibrium stage. From the graph it was clear that the COD reduction had started with lag phase of 24 h to get acclimatize to the new environment of having higher percentage of inorganic dyes mixed with starch effluent as feed. The maximum COD removal efficiency achieved at 30:70 (synthetic dye and starch wastewater) mixing ratio were about 81.05 % on 21st day. Huang et al. (2007) showed 96-97 % of COD removal by anaerobic process. The maximum COD reduction of 95% was achieved by Arutchelvan et al. (2003a) using *Sporotrichum pulverulentum.* Manu and Chaudhari (2002) had reported that the COD removal on 14th day was about 80% using pure culture and single dye whereas, in this study the COD removal on the same 14th day was about 74.7% may be due to usage of mixture of dyes in anaerobic mixed culture batch reactor.

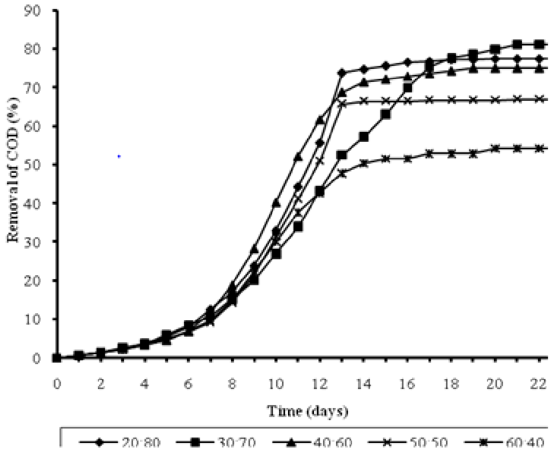

Fig. 5 Removal of COD at different mixing ratio

Colour Removal analysis

Color removal analysis is an important assessment in the treatment of wastewater, especially in businesses like textiles, dyes, and paper manufacture. This research assesses the efficacy of treatment techniques in lowering or removing color from effluents, which is critical for fulfilling environmental standards and avoiding aesthetic pollution. By assessing color removal efficiency, companies may estimate the efficacy of their treatment processes and make required changes to reduce environmental impact. Effective color removal not only improves water quality, but it also promotes sustainable industrial practices, which preserve aquatic ecosystems and save water resources. Figure 5 represents the removal efficiency of color at various mixing ratio.

From Fig. 5 it was clear that the color removal was very low during the initial period for the entire ratio, whereas, the COD removal starts much earlier than decolorization. The lag phase increases as there was increase in dye concentration. Maximum color removal efficiency of 87.3 % was achieved at 30:70 of synthetic dye and starch wastewater (Fig. 4). Bakshi et al. (1999) stated that the maximum decolourization was better under stationary condition (71.3 %) than agitated (57.2 %) cultures. Color removal occurred for the whole range of dye concentrations reaching levels after 96 h of reaction time, higher than 87 % (Bras et al. 2001). In this study maximum removal of colour achieved was 87.3 %, whereas almost complete decolourization of dye solution were achieved in 4-5 days of experimental run (Georgiou et al. 2004) this may due to addition of starch.

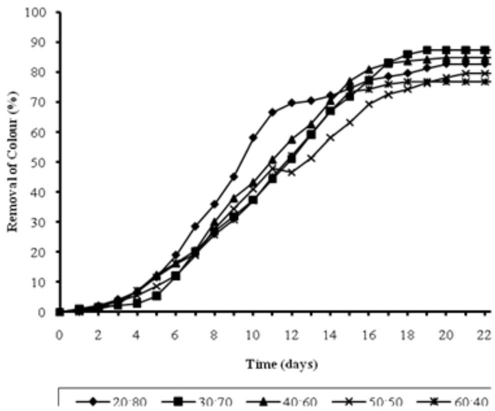

Fig. 6 Removal of Color at different mixing ratio

Biomass production analysis

Biomass concentration analysis determines the quantity of biological material in a sample, which is often used in biotechnological operations, wastewater treatment, or biofuel generation. This study is critical for monitoring microbial development, improving process conditions, and guaranteeing resource efficiency. By measuring biomass concentration, operators may analyze the health and productivity of biological systems, make educated decisions, and alter process parameters to optimize yields while minimizing costs. Accurate biomass concentration measurement is critical for optimizing performance in a variety of bioprocesses, including bioreactors and environmental monitoring.

Biomass was measured as mixed liquid volatile suspended solids (MLVSS) for various mixing proportions and the results were plotted in Fig. 6. It shows that the growth of biomass was gradually increased by utilization of the substrate. The growth rate was low at initial period and there was a gradual increase after two days, finally the growth has been steady. Optimum biomass growth was found at 30 % and 70 % of dye and starch mixing (34.2 – 51.5 g/l) respectively. At high starch biomass concentration was high and at low starch it gets decreased, this effect is due the carbon source available in the reactor (O'Neill et al. 2000).

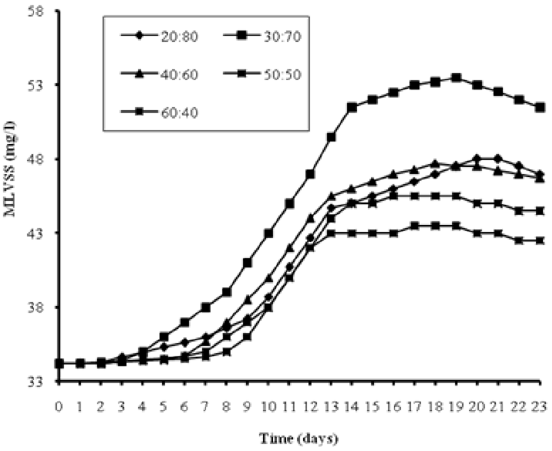

Fig. 7 Biomass concentration at different mixing ratio

Biogas production analysis

Biogas product analysis entails determining the volume and quality of biogas produced from organic waste during anaerobic digestion. This study evaluates pivotal factors similar as methane attention, carbon dioxide situations, and total gas product to give sapience into the digestion process's effectiveness. By assessing biogas affair, drivers may enhance process conditions, increase energy recovery, and lower hothouse gas emigrations. This exploration is critical for assuring biogas systems' profitable feasibility and environmental sustainability, making it an inestimable resource for renewable energy development and waste operation plans.

The Fig. 7 shows the quantum of gas produced at colorful mixing rates of substrate andco-substrate. The maximum gas product was about 7.2 l/ d at 30 of synthetic color and 70 of synthetic bounce wastewater mixing when compared to other mixing rates. The biogas product for other mixing rates 2080, 4060, 5050 and 6040 was 6.5, 5.5, 3.5 and 3 l/ d independently. Carliell et al.(1996) and Razo- Flores et al.(1997) reported the decolorization took place with the methane product step in anaerobic processes. The batch study easily showed the inhibition of color attention on biogas product was fulfilled with the inhibition of glucose declination(Isik and Sponza 2004) the same results were achieved in this study.

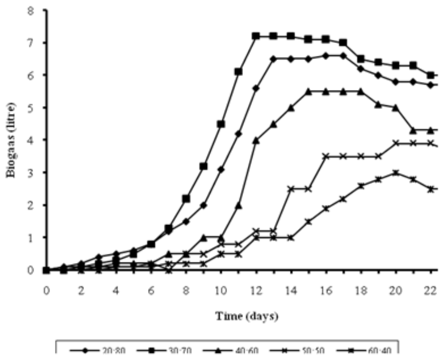

Fig. 8 Biogas production at different mixing ratio

CONCLUSION

This study successfully demonstrated the treatability of color wastewater using bounce- grounded wastewater as aco-substrate through anaerobic digestion. The anaerobic reactors invested with flocculent biomass effectively degraded textile color wastewater, achieving significant color and COD junking. The optimal mixing rates of 2080, 3070, 4060, 5050, and 6040 of textile color and bounce wastewaters redounded in the loftiest junking edge of 81.0 COD and 87.3 color, independently. These findings suggest that the anaerobicco-digestion of textile color wastewater with bounce wastewater can be a feasible and sustainable approach for the treatment of textile color wastewater. The use of bounce as aco-substrate not only enhances the biodegradability of the textile color wastewater but also provides a cost-effective and environmentally friendly result for the operation of bounce wastewater. This study contributes to the development of innovative and effective natural treatment styles for the cloth assiduity, eventually reducing the environmental impact of color wastewater and promoting sustainable artificial practices.

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