EVALUATION OF A UASB REACTOR PERFOMANCE FOR REMOVING COD, TRUE COLOR, AMMONIACAL NITROGEN, AND ORTHOPHOSPHATE FROM SYNTHETIC TEXTILE EFFLUENT CONTAINING AZO DYE

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ABSTRACT

The textile industry is a vital sector in global economies but poses environmental challenges due to the discharge of effluents containing complex chemical compounds, particularly dyes. Effluents, rich in color, organic matter, and inorganic salts, often contain unfixed dyes, exacerbating environmental pollution. This study investigates a pilot-scale Upflow Anaerobic Sludge Blanket (UASB) reactor's efficacy in treating synthetic textile effluent containing Remazol Brilliant Violet – 5R (RBV-5R) dye. Over 60 days, the UASB reactor achieved significant color removal (88.4%) via anaerobic dye reduction. However, COD removal was moderate (47.8%), potentially impacted by aromatic amine release during dye degradation. Minimal ammonia nitrogen removal (negative values) and modest phosphorus removal (15.2% average) underscore challenges in macronutrient treatment using UASB alone. Integrated treatment strategies are essential for comprehensive effluent remediation. Combining anaerobic/anoxic and aerobic processes enhances nitrogen and phosphorus removal. Incorporating biological methods with physicochemical approaches shows promise for addressing diverse effluent parameters. This research emphasizes tailored treatment strategies to mitigate textile effluent's environmental impact.

Keywords: Effluent treatment. Remazol Violet Brilliant – 5R. Anaerobic consumption.

1 INTRODUCTION

The textile industry, a vital sector in many global economies, produces substantial effluents containing persistent and complex chemical compounds such as wetting agents, dispersants, and dyes, which pose a significant environmental threat without proper treatment[1]. The dyeing and finishing stages are identified as major contributors to water consumption and pollutant generation. The effluents from these stages are distinguished by their high levels of color, dyes, organic matter, and inorganic salts. Approximately 20% of these effluents contain unfixed dyes, which exacerbate environmental pollution[2 3].

Dyes are a significant concern in textile effluents due to their complex chemical structure and resistance to biological degradation. Despite their often-lower concentration compared to other effluent chemicals, dyes can impart a noticeable color to water bodies even at low levels. The release of dyes, particularly azo dyes, into aquatic environments is a cause for concern due to their carcinogenic and mutagenic properties[4]. It is of paramount importance to remove dyes before discharge, not only for the preservation of the environment but also for the protection of public health. In anaerobic reactors, azo dyes are biologically degraded by microorganisms into less toxic and more degradable products through complex biochemical processes, utilizing the dyes as a carbon and energy source for their growth and metabolic activities. The efficiency of this degradation process is influenced by a number of factors, including the concentration and complexity of the dye, the organic load in the effluent, the hydraulic retention time, and microbial adaptation to the substrate. Recent studies have highlighted the effectiveness of anaerobic treatment in removing textile dyes, with a two-stage biodegradation process: initial reduction of azo dye in anaerobic/anoxic environments, followed by oxidation of aromatic amines in aerobic conditions[1 2].

Given the characteristics of textile effluent and the necessity for effective dye degradation, the UASB (Upflow Anaerobic Sludge Blanket) reactor stands out for its high-rate performance and formation of resistant granular sludge, making it suitable for treating wastewater with persistent and challenging compounds[5]. Therefore, the study examined the use of a UASB reactor to treat synthetic textile effluent, focusing on evaluating its performance in addressing challenges related to textile industry effluents. Specifically, the research assessed the effectiveness of the UASB in removing organic matter, nitrogen, phosphorus, and color from synthetic textile effluent containing 40 mgL^{-1} of the azo dye Remazol Brilliant Violet – 5R (RBV-5R).

2 MATERIAL & METHODS

The current study was conducted at the facilities of the Integrated Environmental Laboratory (LIMA) and the Water Reuse Laboratory (LaRA), both of which are affiliated with the Department of Sanitary and Environmental Engineering at the Federal University of Santa Catarina (UFSC). Throughout the research, a pilot-scale treatment system with a UASB reactor was employed. The system was operated continuously and consisted of a 50.0 L feed tank, a UASB reactor made of PVC, with a cylindrical design having a diameter of 0.3 m and height of 2.0 m, providing a useful volume of 96.0 liters. The anaerobic reactor was equipped with a three-phase separator designed to separate the liquid, solid, and gas phases. The UASB reactor operated continuously for a total of 60 days. Throughout the research period, the reactor was maintained at specified conditions, including no sludge disposal, an organic loading rate (OLR) of 1.5 kg $COD.m^{-3}day^{-1}$, and a hydraulic retention time (HRT) of 16 hours.

The reactor was continuously fed with synthetic textile effluent, prepared daily by combining chemical compounds containing organic carbon sources, inorganic nutrients, and an azo dye, in order to simulate the typical characteristics of industrial textile effluents containing azo dyes. The synthetic effluent solution included macronutrients such as sodium acetate (1.30 gL^{-1}), azo dye (0.40 gL^{-1}), ammonium chloride (0.115 gL^{-1}), dipotassium phosphate (0.124 gL^{-1}), and monopotassium phosphate (0.053 gL^{-1}). In addition, the solution contained micronutrients, including iron chloride (III) (1.291 mgL^{-1}), zinc chloride (0.013 mgL^{-1}), copper chloride (0.010 mgL^{-1}), manganese chloride (0.129 mgL^{-1}), and cobalt chloride (0.259 mgL^{-1}). The analytical methodologies employed for obtaining each parameter discussed in this work include a colorimetric method with closed reflux and spectrophotometer readings for Chemical Oxygen Demand (COD), membrane filtration (0.45 µm) followed by spectrophotometer readings for true color, the Nessler method with spectrophotometer readings for ammoniacal nitrogen, and a colorimetric method also with spectrophotometer readings for orthophosphate analysis.

3 RESULTS & DISCUSSION

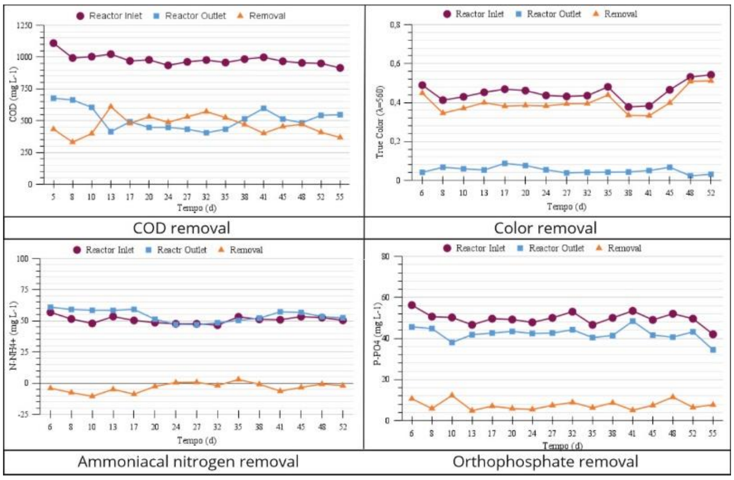

Figure 1 Removal results of the parameters analyzeds.

The Figure 1 presents the results obtained. During the observed period, the color removal efficiency remained consistently high, ranging from 85.0% to 95.0% over time. The observed color removal rates of above 90% align with previous studies[6,7,8]. This successful removal is primarily attributable to the anaerobic reduction of azo dyes, which involves the cleavage of azo bonds through the transfer of reducing equivalents. This process results in the formation of colorless aromatic amines, a phenomenon commonly referred to as discoloration[9].

The COD removal efficiency exhibited a range of values between 30.0% and 60.0%. These results are consistent with those presented in the aforementioned study[8]. Moreover, these findings are consistent with prior research that demonstrated a COD removal efficiency of 55.0% with a HRT of 16 hours. It was further observed that extending the HRT to 24 hours, while maintaining an OLR between 1.5 to 2.0 $kgCOD.m^{-3}day^{-1}$, resulted in a COD removal efficiency of approximately 70.0%[10]. This supports the notion that longer hydraulic retention times may enhance the efficiency of UASB reactors in COD removal, as evidenced by previous studies showing a decrease in removal efficiencies with reduced HRT[11]. Additionally, the release of toxic by-products during the degradation of azo dyes (aromatic amines) may have impacted the reactor biomass, affecting its ability to degrade organic matter and resulting in anaerobic consumption instability. This dynamic, influenced by the slower metabolic and reproductive rates of anaerobic bacteria compared to aerobic or anoxic bacteria, could explain the stabilization of removal efficiencies over time[12].

Regarding ammonia nitrogen, the removal was practically non-existent. This outcome aligns with the expectations and resembles findings that UASB anaerobic reactors are generally unable to remove large percentages of $N\text{-}NH_4^+$ [2]. However, the small amount that was removed is likely to have occurred through assimilation during the biomass cell reproduction process in the reactor. In the context of nitrogen removal, the conventional process involves nitrification, with refers to the oxidation of ammonia to produce nitrate, followed by denitrification, which is the reduction of nitrate to molecular nitrogen using organic material as a reducer. The absence of an electron donor presents a challenge to denitrification UASB systems.[13]. During the degradation of azo dyes such as RVB-5R, there is a reduction in azo bonds, resulting in the generation of aromatic amines with NH_2 radicals. These increase nitrogen concentrations, rendering the UASB reactor inefficient and potentially exacerbating nitrogen levels.

In terms of phosphorus removal efficiency, the average was 15.0% with a peak of 24.0%, which is consistent with expectations[14]. It is evident that UASB anaerobic reactors are constrained in their capacity to remove macronutrients such as nitrogen and phosphorus[15]. This limitation is exacerbated by the lack of sludge recirculation, which inhibits the growth of phosphorus-accumulating organisms, that are crucial for enhanced biological phosphorus removal [16]. However, in contrast to nitrogen, some level of phosphorus removal was observed, albeit at a relatively low level. This is because microorganisms utilize phosphorus during cellular synthesis and ATP production. Another reason for the decrease in concentration is luxury phosphorus uptake, whereby microorganisms absorb more phosphorus than is required, storing the excess as inorganic polyphosphate. This results in a decrease of 10 to 30% in concentration[16,17,18].

To achieve optimal treatment efficiency for both nitrogen and phosphorus, operational conditions need to be adjusted accordingly., A recommended approach for nitrogen removal involves a sequential anaerobic/aerobic reactor process, that promotes the degradation of aromatic amines in oxygen-rich environments[1,2]. It is also observed that increased COD removal efficiency is accompanied by nitrogen removal in an anoxic bioreactor, suggesting organic substrates were directed towards denitrification and phosphorus removal.[1] Furthermore, UASB reactor results support the necessity of combining anaerobic/anoxic and aerobic conditions for effective nitrogen removal. Similarly, effective phosphorus removal necessitates alterations in operational conditions. Under specific anaerobic/aerobic or anaerobic/anoxic conditions, phosphate-accumulating organisms (PAOs) are capable of storing polyphosphates[19].

There are still other approaches for removing phosphorus from effluents, such as physicochemical methods using aluminum sulfate, ferric chloride, and lime, which have demonstrated effectiveness in precipitating phosphorus by forming insoluble salts[20]. Electrocoagulation has also been shown capable of achieving total phosphorus removal from effluents, with removal rates of up to 100.0% when combined with a UASB reactor, although efficiency decreased considerably over time due to electrode corrosion[21]. Consequently, integrating biological and physicochemical methods can significantly increase macronutrients removal efficiency.

4 CONCLUSION

Through the analysis of data obtained during the 60 days of operation of the proposed anaerobic reactor, it is possible to conclude that in terms of color removal, the system demonstrated satisfactory performance with average removal rates of 88.4. Additionally, the reactor exhibited an average COD removal efficiency of 47.8%. Although the system's performance was satisfactory, when compared to other studies the results were just moderate, likely due the relatively low HRT of 16 hours and the release of aromatic amines during azo dye degradation that may have impacted the reactor biomass and consequently its efficiency. Moreover, phosphorus removal was minimal, with efficiency values of 15.2%, while the removal values for ammonia nitrogen were negative, indicating the production of N-NH_4^+ during the textile dye degradation process. In general, it is inferred that the anaerobic UASB system, when used alone, proves to be insufficient technology for the complete treatment of textile effluents containing the RVB-5R dye. This necessitates the implementation of a subsequent process for more efficient removal of nitrogen, phosphorus, and COD parameters.

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