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Araştırma Makalesi – Research Article

EFFLUENT DECOLORIZATION FOR SUSTAINABLE TEXTILE: WASTEWATER TREATMENT, ENVIRONMENTAL RISK AND HUMAN HEALTH

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ABSTRACT

Merely 0.4% of the world's water is accessible for human and animal consumption, a stark reminder of our planet's limited freshwater resources. With the escalating demands driven by population growth and industrial pollution, wastewater generation rates have surged. Of particular concern is the textile industry's heavy reliance on water in production processes, coupled with the challenge of treating wastewater laden with significant concentrations of dyestuffs, underscoring the urgent need for ecologically sound solutions.

In this study, we explore the efficacy of various parameters, including mechanical agitation and ozone dosage, in the decolorization using Fuzzy Logic estimation techniques. Our findings reveal that higher mechanical agitation enhances ozonation rates, albeit at the expense of decreased efficiency in degrading dyeing auxiliary chemicals.

Keywords: Textile effluent, Dyes, Textile wastewater treatment, Sustainability, Decolorization.

SÜRDÜRÜLEBİLİR TEKSTİL İÇİN ATIK SU RENK GİDERME: ATIK SU ARITIMI, ÇEVRESEL RİSK VE İNSAN SAĞLIĞI

ÖZ

Dünyadaki suyun ancak %0,4'ü insanlar ve hayvanlar için kullanılabilir. Nüfus artışından, sanayiden kaynaklanan kirlilik nedeniyle atık su oranı yükselmiştir. Tekstilde üretim sırasında büyük miktarda su kullanması ve yüksek miktarda boyar madde içeren atık suların arıtılması ekolojik açıdan önem kazanmaktadır. Bu sebeple atık suların arıtılmasında mekanik karıştırma yönteminin kullanılmasının önemini artırmaktadır.

Bu çalışmada mekanik hareket, ozon dozu gibi parametrelerin renk gidermedeki etkinliği bulanık mantık tahminleme yöntemi ile araştırması şeklinde incelenmiştir. Araştırma sonucunda yüksek mekanik hareket altında ozonlama hızının arttığı, boyama yardımcı kimyasallarının ozonlama verimini düşürdüğü görülmüştür.

Anahtar kelimeler: Tekstil atık su, Boyalar, Tekstil atık su arıtımı, Sürdürülebilirlik, Renk giderme.

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1. Introduction

The textile industry stands out as one of the largest consumers of water among industrial sectors. What sets textile wastewater apart from others is its characteristic coloring, stemming from the diverse array of dyestuffs and chemicals employed during production [1]. Primarily emanating from dyeing processes, textile wastewater carries unfixed dyestuffs and a plethora of auxiliary chemicals, many falling within the surfactant category. Consequently, textile wastewater exhibits elevated levels of color and organic matter, underscoring its environmental significance. Failure to adequately treat such wastewater leads to the discharge of dyes and toxins into receiving environments, posing aesthetic and ecological hazards. Elevated color levels not only impede photosynthesis by reducing light penetration in natural waters but also contribute to the accumulation of dyestuffs in aquatic organisms, potentially generating toxic byproducts [2].

Given the textile industry's preeminence in water consumption, it has become a focal point for wastewater recycling initiatives, particularly amid escalating concerns over dwindling water resources. Optimization of color removal processes is paramount, aiming for both economic efficiency and minimal environmental and human health impacts. Water pollution emerges as a critical environmental challenge, posing significant threats to the sustenance of life on Earth.

Hassaan et al., extensive research has delved into the sustainability challenges and wastewater management within the textile sector [1]. Hasanbeigi et al., and Kopperi et al., investigations have assessed current sustainability practices and explored avenues for widespread adoption of new methodologies [3,4]. Efforts to bolster environmental sustainability through the enforcement of legislation targeting unsustainable textile wastewater discharges have also been undertaken. Cantoni et al., textile facilities serve as pivotal testing grounds for methodologies geared towards minimizing environmental risks, showcasing their applicability across various domains [5]. Gomes et al., collaboration has emerged as a key strategy to surmount challenges hindering the sustainability of textile wastewater treatment [6]. Periyasamy et al., furthermore, studies have scrutinized the potential impacts of textile industry wastewater, laden with dyes and chemicals, on both human health and the environment [7]. Samsami et al., different treatment methods for color removal from textile wastewater were examined in detail and their mechanisms were discussed in relation to the factors affecting its performance [8]. As a result of the literature research, research on color removal processes attracts attention. When the literature is examined, the effect of parameters such as mechanical action and ozone dose on color removal draws attention as a deficiency. For this reason, in this study, unlike the literature, the effectiveness of parameters such as mechanical movement and ozone dose in color removal was examined using the fuzzy logic estimation method.

2. Sustainable Wastewater Treatment from The Textile Industry: Human Health and Environmental Risk

Methods employed in wastewater treatment can be classified into three main categories: biological, chemical, and physical. Annually, a staggering 700,000 tons of dye are produced, with 12-18% of these dyes discharged into the environment through wastewater resulting from dyeing processes [8]. Furthermore, the global demand for and usage of dyestuffs continue to rise steadily, exacerbating the adverse ecological impact of textile dyes [1].

Textile industries are notorious for their extensive water and chemical consumption, with the diversity of these compounds utilized in dyeing and other processes contributing to the varied properties of resultant wastewater [9]. The residual dyestuffs, both from production and usage, underscore the environmental significance of colored wastewater. Direct discharge of colored wastewater into receiving mediums precipitates primary environmental effects, such as the formation of toxic aromatic amines under uncontrolled anaerobic conditions, as well as secondary effects detrimental to aesthetic and environmental integrity [10].

Although colored organic compounds may constitute a small fraction of wastewater's organic load, their environmental coloring renders them aesthetically unacceptable. Colored wastewater disrupts light transmittance in aquatic environments, impeding photosynthesis, while the accumulation of dyestuffs in aquatic organisms poses risks of generating toxic and carcinogenic byproducts. Consequently, processes

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for removing colors from textile wastewater, given the complexity of their chemical structures and synthetic origins, are of paramount ecological importance [11].

Textile industries discharge wastewater laden with myriad components, posing significant challenges for purification. The daily and hourly fluctuations in dye compositions, coupled with their complex chemical structures, render the decolorization process exceedingly difficult. Efforts to reclaim wastewater are integral, as recycling significant volumes of hot water used in textile processes promises substantial water and energy savings [12].

Untreated wastewater discharged by textile industries contains colors, acids, alkalis, and a plethora of organic pollutants, posing significant toxic risks. Azo dyes, prevalent in industrial wastewater, pose human health risks via oral consumption and direct skin contact, with toxic amino compounds implicated in various ailments, including allergies, dermatitis, and cancers [13].

The detrimental effects of untreated textile industry wastewater extend to diverse aquatic ecosystems, manifesting in reduced photosynthetic activity and disruptions to aquatic vegetation [14]. Aquatic organisms, crucial protein sources for human consumption, face mortality risks from dye-induced gill obstruction, further exacerbating the ecological impact. Textile dyes, laden with highly lethal aromatic chemicals, heighten the risk of carcinogenicity, posing significant health threats to humans [15].

3. Material and Method

In this study, fuzzy logic tables were constructed using the MATLAB program, and the resultant data were meticulously analyzed. The Mamdani model, featuring two inputs and one output, was meticulously crafted utilizing the MATLAB fuzzy logic module. The utilization of the center of gravity method for result acquisition served as the cornerstone of this model [16-20].

The membership functions employed in the input sets were of the Generalized Bell Membership Function (GBellMF) variety, yielding trapezoidal shapes—geometrically robust and easily interpretable [21-23]. These membership functions facilitated the derivation of approximate values, guided by fuzzy logic rules. The selection of the GBellMF method was driven by the distinctive shape of trapezoidal fuzzy numbers, offering enhanced clarity over verbal variables. A comprehensive set of two hundred and fifty fuzzy rules was meticulously devised, aiding in the creation of output graphs. The input membership functions, pertaining to rotor speed, spanned a range of twelve, while those for liquid flow rate encompassed sixteen ranges. Meanwhile, the decolorization efficiency, our output function, was delineated across eighteen ranges. A robust rule base consisting of two hundred and twenty rules was assembled to discern the intricate relationship between the designated membership functions and the resultant outcomes. Decision making often requires a flexible approach, multi-criteria significantly affect the complexity of the calculation. There is fuzzy logic, which is a computational structure for information processing and decision making, with the fuzzifier, knowledge base (including rule bases or databases), fuzzy inference engine and defuzzifier.

4. Research Findings

Ozonation stands out as an environmentally sustainable approach in wastewater treatment, effectively targeting color, odor, and bacterial content [24-26]. This process facilitates the decomposition of organic compounds while converting detergents and phenols into smaller molecular components. Consequently, ozonation emerges as a promising alternative for wastewater treatment. However, the efficacy of ozonation is contingent upon the mass transfer of ozone from the gas phase to the liquid phase. Figure 1 vividly illustrates the influence of rotor speed and liquid flow rate on decolorization efficiency.

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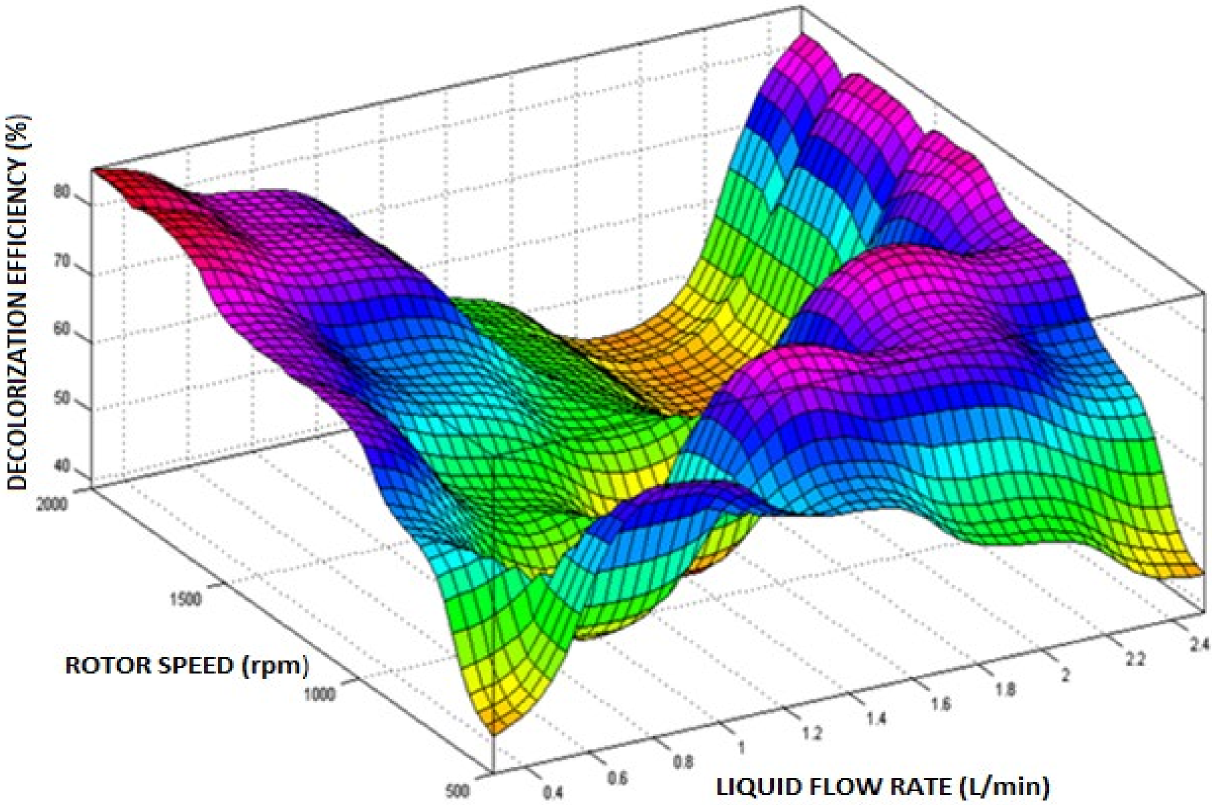

Figure 1. Effect of rotor speed and liquid flow rate on decolorization efficiency

Our study revealed a notable enhancement in color removal efficiency through ozonation with increasing rotor speed. This observed improvement can be attributed to the swift reaction kinetics of dye oxidation, where mass transfer limitations impact all processes. Please refer to Figure 2 for a graphical depiction illustrating the impact of rotor speed on decolorization efficiency.

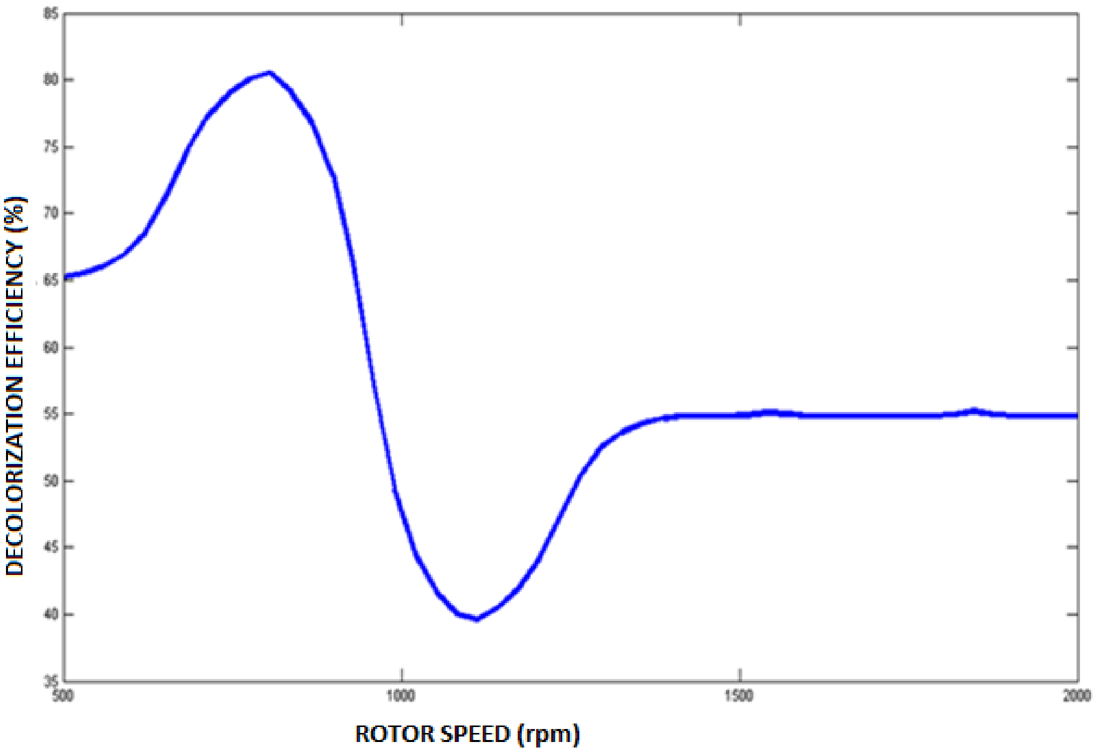

Figure 2. The effect of rotor speed on decolorization efficiency

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At a rotor speed of 750 rpm, decolorization reaches its peak at 80%. Subsequently, as the rotor speed escalates to 1150 rpm, decolorization diminishes to its nadir, registering at 40%. Surprisingly, despite further increases in rotor speed beyond 1350 rpm, decolorization remains stagnant, plateauing at 53%. This observation suggests that mechanical agitation facilitated by the rotor, coupled with resultant centrifugal forces, hampers the transfer of ozone from the gas phase to the liquid phase. Please refer to Figure 3 for a graphical representation illustrating the impact of liquid flow rate on decolorization efficiency.

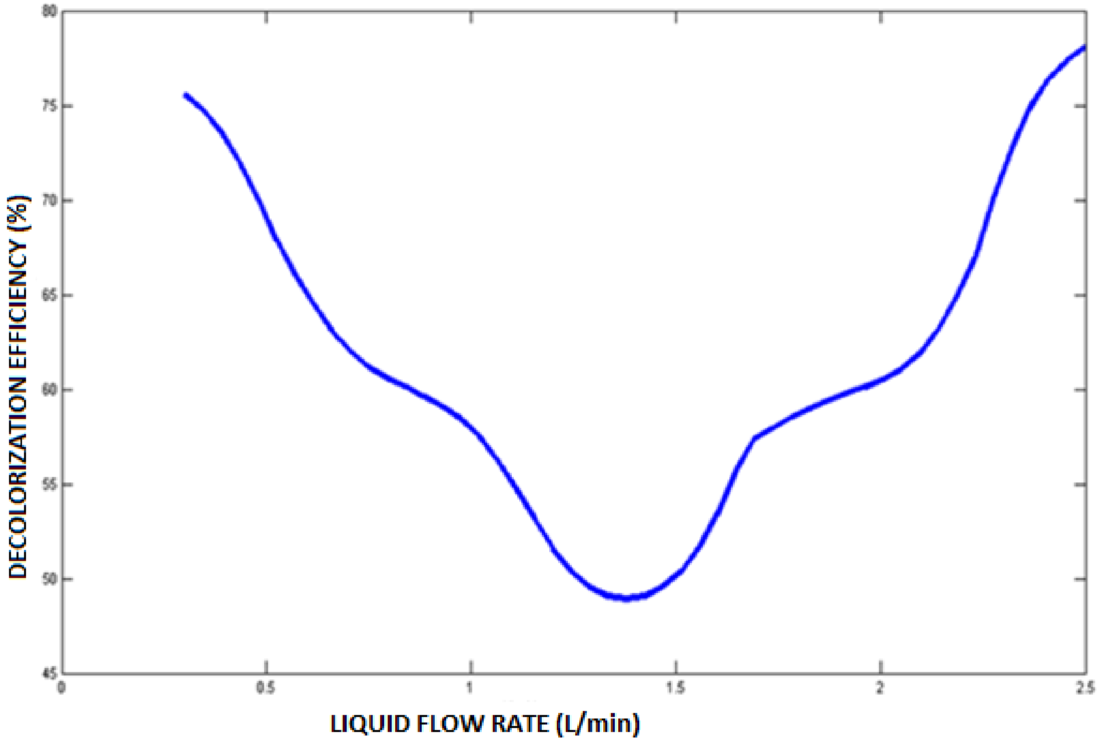

Figure 3. Effect of liquid flow rate on decolorization efficiency

At liquid flow rates of 0.389 (L/min) and 2.5 (L/min), decolorization peaks at 76%. Conversely, at a flow rate of 1.345 (L/min), decolorization dips to its lowest level, reaching 49%. This observed trend suggests that heightened solution circulation, driven by increased liquid flow rates, diminishes ozonation efficiency. One potential explanation for this phenomenon could be the shortened interaction time between ozone and the solution. Please refer to the provided literature for further insight.

5. Results and Discussion

In conclusion, the textile industry generates wastewater containing a plethora of hazardous compounds, such as dyes, chemicals, and aromatic substances, posing significant risks to aquatic life, the environment, and human health. To address this challenge, wastewater treatment plays a pivotal role, necessitating the implementation of life cycle management strategies and the expansion of wastewater treatment infrastructure for efficient reuse. In the pursuit of sustainable textile wastewater treatment, mechanical agitation for color removal has emerged as a crucial technique for water recovery. It has been observed that mechanical mixing enhances efficiency by facilitating mass transfer, while increased ozone dosage further augments efficiency. Moreover, despite the decrease in ozone solubility with rising temperatures, the reaction rate remains relatively unaffected, highlighting the resilience of the process. Given the complex nature of wastewater resulting from the amalgamation of various industrial effluents, the impact of coexisting substances on treatment efficacy cannot be overstated. Particularly, the influence of chemicals present in dyeing solutions on ozonation efficiency warrants careful consideration. This study underscores the significance of mechanical treatment methods in mitigating color imparted by dyestuffs in textile wastewater, paving the way for more sustainable industrial practices. In conclusion, this research contributes to efforts to reduce the environmental impact of the textile industry while harnessing the power of artificial intelligence to increase decolorization efficiency and precision. Using fuzzy logic in the treatment of textile wastewater reduced the need for humans by

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estimating the parameters. The combination of sustainable practices and advanced technology holds promise for a more sustainable and responsible future in textile production.

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