



TREATMENT OF WASTEWATER OF THE TEXTILE INDUSTRY IN SERBIA AS A PRECONDITION FOR SUSTAINABLE MANAGEMENT OF WATER RESOURCES

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ABSTRACT: The textile industry is one of the main sources of environmental pollution, primarily due to the types and amounts of waste water it generates. Estimates indicate that around 20% of global water pollution comes from textile manufacturing plants. These wastewaters generally contain a high level of microfibers and textile dust aerosols, various types of organic and inorganic hard-to-degrade chemical substances, pesticides, and heavy metals. The frequent occurrence of uncontrolled discharge of wastewater from textile industry facilities, which seriously disrupt water ecosystems, has conditioned the textile industry sector to establish more efficient systems for wastewater treatment and more responsible behavior towards the preservation of water quality and the environment. In this regard, this paper provides an overview of environmentally acceptable methods of processing wastewater from the textile industry, which can represent solutions for mitigating the negative effects of these waters on the environment.

Keywords: textile industry, sustainability, water resources, wastewater.

PREČIŠĆAVANJE OTPADNIH VODA TEKSTILNE INDUSTRIJE U SRBIJI KAO PREDUSLOV ODRŽIVOG UPRAVLJANJA VODNIM RESURSIMA

APSTRAKT: Tekstilna industrija predstavlja jedan od glavnih izvora zagađenja životne sredine, pre svega zbog tipova i količina otpadnih voda koje generiše. Procene ukazuju da oko 20% globalnog zagađenja voda dolazi iz proizvodnih tekstilnih pogona. Ove otpadne vode uglavnom sadrže visok nivo mikrovlakna i aerosola tekstilne prašine, različitih vrsta



organskih i neorganskih teško razgradivih hemijskih supstanci, pesticida, i teških metala. Učestala pojava nekontrolisanog ispuštanja otpadnih voda iz postrojenja tekstilne industrije, koji ozbiljno narušavaju vodne ekosisteme uslovlja je sektor tekstilne industrije na uspostavljanje efikasnijih sistema za tretman otpadnih voda i odgovornije ponašanje prema očuvanju kvaliteta voda i životne sredine. S tim u vezi u ovom radu dat je pregled ekološki prihvatljivih metoda prerade otpadnih voda tekstilne industrije koje mogu predstavljati rešenja za ublažavanje negativnih uticaja ovih voda na životnu sredinu.

Ključne reči: tekstilna industrija, održivost, vodni resursi, otpadne vode.

1. INTRODUCTION

The interaction between anthropogenic activities and natural ecosystems during the historical development of mankind has resulted in intense changes in the structure and functionality of the environment. Demographic growth, urbanization and accelerated industrial-technological modernization are the key drivers of these processes, where the continuous exploitation of natural resources and increased consumption of energy and raw materials additionally intensify the anthropogenic pressure on ecological systems [1].

Within the industrial sources of pollution of water resources, the textile industry occupies a particularly important place as one of the largest generators of pollutants. This sector is characterized by the intensive application of synthetic and organic chemical compounds throughout the entire life cycle of textile products, including the stages of production, chemical modification, use and post-consumer waste management [1, 2].

Technological processes in the textile industry, such as sumercenterization, bleaching, dyeing, refining and finishing of textile fibers, are characterized by a particularly high level of process water consumption. According to some data, the total amount of water used during the processing of a kilogram of textile material is approximately equal to the koikin of 100-200 liters of water. At the same time, complex streams of industrial wastewater are generated, whose chemical composition and physical-chemical characteristics depend on the type of fibers, applied technology and used chemical reagents. As much as 60 to 90% of the total water used is used when rinsing and washing textiles, which indicates a great potential for the implementation of water recirculation, regeneration and reuse systems within closed production processes [3].

Wastewater often shows high concentrations of dyes, heavy metals, surfactants, organic pollutants and other toxic substances, which is why they require the application of advanced purification technologies. In this sense, various physical-chemical, biological and integrated hybrid processes are used with the aim of decontamination of wastewater and potential valorization of the chemical components present [4,5].

The traditional approach to the management of textile wastewater was based primarily on its controlled release into natural recipients. However, the limited efficiency of conventional treatment systems and the continuous discharge of highly loaded industrial effluents have led to the degradation of aquatic ecosystems, the reduction of biodiversity, the disruption of the ecological balance and increased risks to public health. The modern



development of environmental engineering and waste water treatment technologies has directed the focus towards the principles of circular economy and sustainable management of water resources. Such a transformation is encouraged by increasingly strict international environmental standards, regulatory frameworks and environmental protection policies that promote water recycling, waste minimization and the reduction of the environmental impact of industrial plants.

Consequently, improving the efficiency of textile wastewater treatment systems has become one of the central research and engineering issues in the fields of environmental engineering, hydraulics, and environmental management. The main goal of these activities is to reduce the anthropogenic burden on natural resources and develop ecologically sustainable industrial processes.

2. INDUSTRIAL WASTEWATER

As one of the most important branches of the processing industry, the textile industry also belongs to the group of the most risky in terms of environmental and health safety. Excessive use of natural resources, primarily water and energy, as well as the use of chemicals in the dyeing and processing processes, place this sector of the processing industry at the very top of the list of the biggest polluters. According to United Nations reports, this sector generates more carbon dioxide emissions than international aircraft and maritime transport [6].

Based on the data of the Republic Institute of Statistics, shown in Table 1, the total amount of wastewater generated from industrial production processes in 2024 was 112 million m³. Of this, a significant share originates from the processing industry sector (36.6%), [7] with a large share of wastewater originating from the textile industry.

Table 1: Wastewater in the industrial sector, 2024

Republic of Serbia		mil.m ³		
Sector	Total	Unpurified	Purified	
Total ¹⁾	112	82	30	
C - Manufacturing	41	15	26	

¹⁾The field of collection, treatment and disposal of waste is included

Based on the aforementioned data, it is evident that there is a significant amount of untreated water that is directly or indirectly discharged into the recipients, thereby questioning the quality of water resources and the general environment. In order to prevent further deterioration of water quality and environmental degradation, legal and by-law frameworks were adopted that define emission limit values for different categories of pollutants. These regulations refer to technological wastewater that must be purified before discharge into the sewage system, as well as to technological and other wastewater that is directly discharged into natural and artificial waterways. These measures are necessary to preserve ecological standards and integral aquatic ecosystems [8].

According to the report of the Environmental Protection Agency, the textile industry's production plants mostly emit wastewater containing high concentrations of oil and fat, as well as increased pH values due to the presence of alkali and azo dyes. The concentration



of chemical substances in wastewater depends on the processing method and the specifics of production processes, which can be complex and demanding, especially in the stages of dyeing and fine processing of textiles. These processing steps often involve the use of additives such as phosphonates, polyacrylates and maleic acid copolymers. Table 2 shows the measured values of wastewater emissions from various production processes of the textile industry at the discharge point. This information is crucial for understanding the environmental impact and implementing adequate wastewater management measures. The tests were carried out during 2024, and the data refer to waste water from the production process of the textile industry, which is discharged into recipients on the territory of the Jablanica administrative district.

Table 2: Measured values of wastewater emissions from production processes of the textile industry at the point of discharge into surface waters [9]

Sample name:		Waste water - Textile industry		
Field test data				
Test parameters	Unit of measurement	Determined value	Permissible value	Test method
Air temperature	°C	20,2	ND	US EPA 170.1:1974
Water temperature	°C	26,4	40,0	SRPS H.Z1.106:1970
pH value	-	11,65	6,50-9,00	SRPS EN ISO 10523:2016
Oil and fat content	mg/l	56.80	40	EPA 1664 revision A, 1999
Ammonia (NH ₃) content	mgN/l	<5	10	SMEWW 4500 NH ₃ C 24th edition, 2022
Content of anionic detergents	mg/l	0.17	10	SMEWW 5540 C 24th edition, 2022

Due to the high content of various toxic and dangerous components, industrial wastewater especially requires specialized treatment procedures and wastewater treatments, including physical-chemical, biological and membrane processes, in order to ensure their safe disposal or deployment in the environment, in accordance with current legal regulations and standards for environmental protection.

3. WASTEWATER PURIFICATION IN THE TEXTILE INDUSTRY

Based on data from the Republic Institute of Statistics, a total of 30 million m³ of waste water was treated in 2024. The degree of purification was organized in several stages, where the first stage included 56.2% of the treated quantity, the second stage 22.5%, while the third stage covered 21.3%. The sectoral analysis shows that production processes in metallurgy (16.8%) have the largest share of purified water, followed by the food industry (16.2%), the chemical industry (15.0%) and the paper and paper products industry (11.0%). Other industrial branches, including the textile industry, make up the remaining 41.0% [6].



Wastewater treatment in the textile industry includes three key stages: primary, secondary and tertiary treatment. Each of these stages is aimed at removing specific types of pollutants, resulting in better quality water. Primary treatment focuses on the elimination of suspended solids, floating debris and coarse particles. Secondary treatment reduces the concentration of oxygen-demanding chemicals as well as dyes. Tertiary treatment aims to eliminate residual contaminants that are still present after the previous stages of treatment. Given that synthetic dyes are resistant and non-biodegradable, their removal represents a significant challenge for physical, chemical and biological treatments. Significant efforts have been made to develop advanced treatment methods that are effective, economical, flexible and easy to apply; however, many of these technologies can be expensive, especially when dealing with large amounts of waste. Some of those methods used in recent production processes are: adsorption, membrane filtration, electrochemical processes and oxidation processes.

Adsorption methods are key physico-chemical processes in the treatment of textile waste water, because they enable the selective elimination of organic and inorganic pollutants through their binding to highly porous adsorbents with developed surface active centers. Adsorption is realized through physisorption (Van der Waals forces, hydrogen bonds) and chemisorption (covalent, coordination bonds, complex formation) [10]. Biosorption uses microbial biomass to immobilize contaminants within cellular matrices.

Primary adsorbents include activated carbon, biochar, chitosan, phyllo-silicates, ion exchange resins and zeolites. Modern directions of development are focused on low-budget, agro-industrial derivative sorbents and multifunctional hybrid materials for simultaneous adsorption of dyes and heavy metals. Nanoscale adsorbents with high specific surface area and heterogeneous porous structure (micro-, meso-, macropores) allow increased sorptive efficiency and kinetics. Metal-oxide composites (Fe_3O_4 , TiO_2 , MnO_2) contribute to synergistic effects and improved performance. Adsorption efficiency depends on granulometry, adsorbent morphology, contaminant concentration, temperature, ionic strength, pH value and process hydrodynamics [11].

Activated carbon with microporous architecture and specific surface area up to $500 \text{ m}^2/\text{g}$ is synthesized by thermal/chemical activation from coal and biomass. In the textile industry, it is used in powder form (PAC) and granulated (GAC), with the possibility of regeneration through chemical, thermal or steam treatment, which optimizes the economy of the treatment.

Membrane technologies, including microfiltration, ultrafiltration, nano-filtration and reverse osmosis, operate on the principle of pore size and selective separation based on the diffusive and electrochemical properties of the membranes. Polymeric and ceramic membranes allow efficient removal of dispersed colors, suspended substances and ionized substances [12].

Electrochemical processes, especially electrocoagulation, are based on the in situ formation of metal hydroxides from the electrode that adsorb and precipitate pollutants, including heavy metals and organic pollutants. This method has high efficiency (>95%), reduces generated waste and enables continuous operation with parameter control, although it requires regular replacement of electrodes and control of oxide layers [13].



Advanced oxidation processes (AOP) use hydroxyl radicals to mineralize difficult-to-degrade organic compounds. These include ozonation, UV/H₂O₂ treatments and photo-Fenton processes. Ozone oxidation is environmentally friendly and effective in decolorization and disinfection, with pH-dependent mechanisms of direct and indirect free radical oxidation [14, 15]. The use of photocatalysts based on nano-TiO₂ enables the generation of reactive radicals under UV or solar light, which promotes the decomposition of organic load and reduces BOD and COD [16].

In summary, the integration of adsorption systems, membrane processes, electrochemical treatments and AOP represents a modern holistic approach to the treatment of complex textile wastewater, with an emphasis on economically viable and ecologically optimized technologies.

4. CONCLUSION

Modern systems for purification of industrial effluents include different levels of treatment: primary, secondary and tertiary. First of all, they are based on mechanical processes aimed at removing suspended particles, sediments and coarse dispersed substances, followed by the application of biological and chemical procedures for reducing organic load, reducing biochemical oxygen consumption (BOD) and chemical oxygen consumption (COP), as well as the elimination of dissolved organic substances and color pollutants.

Advanced treatment technologies, which are particularly highlighted in current research, are aimed at eliminating residual micropollutants and refractory organic compounds that remain after conventional treatment.

By integrating these high-performance technological solutions, a significant improvement in the degree of contaminant removal is achieved, which leads to an improvement in the quality of treated effluents and compliance with modern environmental regulations. This approach not only contributes to sustainable development, but also to the rational use of water resources, which encourages the transition towards resource-efficient and environmentally responsible industrial systems.

This paper presents an integrated overview of sustainable methods and techniques of wastewater treatment from the textile industry. These innovative approaches aim to optimize the treatment process, ensuring that the treatment of wastewater from the textile industry meets the strict standards required for environmental sustainability. By adopting these advanced methods, the textile industry can significantly reduce its environmental impact, contributing to the broader goal of sustainable water management. The joint efforts of all stakeholders – industry, researchers and policy makers – can continue to drive the transformation towards a more sustainable and environmentally friendly textile industry.

REFERENCES

- [1] Đorđević, M. (2019). Vode u Srbiji i njihovo zagađenje. Beograd:Univerzitet u beogradu, Filološki fakultet, 380-388.



9. Međunarodna naučna konferencija
„Savremeni trendovi i inovacije u tekstilnoj industriji“
17-18. septembar 2026. Beograd, Srbija

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- [2] Dorđević, N., & Mihajlović, S. (2022). Osvrt na svetske patente i domaća rešenja održivog razvoja i bezbednosti vode. *Šesta naučno-stručna konferencija sa međunarodnim učešćem: „održivi razvoj i zaštita voda (pravo, ekonomija i menadžment)“ Zbornik radova*, Vol. (p. 93).
- [3] Yaseen, D.A., Scholz, M. (2018). Treatment of synthetic textile wastewater containing dye mixtures with microcosms, *Environmental Science and Pollution Research*, Vol. 25, 1980–1997.
- [4] Lin, J., Ye, W., Huang, J., Ricard, B., Baltaru, M.-C., Greydanus, B., Balta, S., Shen, J., Vlad, M., Sotto, A., et al. (2015). Toward Resource Recovery from Textile Wastewater: Dye Extraction, Water and Base/Acid Regeneration Using a Hybrid NF-BMED Process, *ACS Sustainable Chemistry and Engineering*, Vol. 3, 1993–2001.
- [5] Kesari, K.K., Soni, R., Jamal, Q.M.S., Tripathi, P., Lal, J.A., Jha, N.K., Siddiqui, M.H., Kumar, P., Tripathi, V., Ruokolainen, J. (2021). Wastewater Treatment and Reuse: A Review of its Applications and Health Implications. *Water, Air and Soil Pollution*, Vol. 232, 208.
- [6] <https://www.unep.org/>
- [7] Republički zavod za statistiku. (2024). *Еко-билтен, 2024*. (ISSN 0354-3641). Beograd.
- [8] Malinauskaite, J., Delpech, B., Montorsi, L., Venturelli, M., Gernjak, W., Abily, M., ... & Jouhara, H. (2024). Wastewater reuse in the EU and Southern European countries: Policies, barriers and good practices. *Sustainability*, 16(24), 11277.
- [9] <https://www.nriz.sepa.gov.rs/TeamsPublic/teamssr.aspx?FormName=WaterEmissionperYearForm>
- [10] Ali, H. (2010). Biodegradation of Synthetic Dyes- A Review, *Water, Air, and Soil Pollution*, Vol. 213, 251–273.
- [11] Periyasamy A.P. et al. (2018). *Sustainable Innovations in Apparel Production*, S.S.Muthu (ed.), *Textile Science and Cloting Technology*, Springer Nature Singapore Pte Ltd.
- [12] Obotey Ezugbe, E., Rathilal, S. (2020). Membrane Technologies in Wastewater Treatment: A Review, *Membranes*, Vol. 10, 89.
- [13] Barrera-Díaz, C.E., Balderas-Hernández, P., Bilyeu, B. (2018). *Electrocoagulation: Fundamentals and Prospectives*. In *Electrochemical Water and Wastewater Treatment*, Martínez-Huitle, C.A., Rodrigo, M.A., Scialdone, O., Eds.; Butterworth-Heinemann: Oxford, UK; pp. 61–76.
- [14] Sevimli, M.F., Sarikaya, H.Z. (2002). Ozone treatment of textile effluents and dyes: Effect of applied ozone dose, pH and dye concentration, *Journal of Chemical Technology and Biotechnology*, Vol. 77, 842–850.
- [15] Shriram, B., Kanmani, S. (2014). Ozonation of textile dyeing wastewater- A review. *Journal of Institue of Public Health Engineers*, 2014-15 (3), 46–50.
- [16] Chen, Y.-d., Duan, X., Zhou, X., Wang, R., Wang, S., Ren, N., Ho, S.-H. (2021). Advanced oxidation processes for water disinfection: Features, mechanisms and prospects, *Chemical Engineering Journal*, Vol. 409, 128–207.