UNION OF ENGINEERS AND TEXTILE TECHNICIANS OF SERBIA

VI INTERNATIONAL SCIENTIFIC CONFERENCE

CONTEMPORARY TRENDS AND INNOVATIONS IN THE TEXTILE INDUSTRY

VI MEĐUNARODNA NAUČNA KONFERENCIJA

SAVREMENI TRENDOVI I INOVACIJE U TEKSTILNOJ INDUSTRIJI

PROCEEDINGS

EDITOR:
Prof. dr SNEŽANA UROŠEVIĆ

Belgrade, 14-15th September, 2023
Union of Engineers and Technicians of Serbia
Dom inženjera „Nikola Tesla"

UNION OF ENGINEERS AND TEXTILE TECHNICIANS OF SERBIA

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UNION OF ENGINEERS AND TECHNICIANS OF SERBIA
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CONTRIBUTION TO THE CIRCULAR ECONOMY THROUGH THE UTILIZATION OF FIBROUS TEXTILE WASTE AS BIOSORBENTS FOR WATER PURIFICATION

Marija Vukčević[1*], Biljana Pejić[1,2], Marina Maletić[3], Katarina Trivunac[1], Mirjana Kostić[1]

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ABSTRACT: *Frequent changes in clothing fashion trends and the furniture industry have led to the excessive consumption of textiles to meet human needs. This leads to an increase in the production and finishing of textile materials, and the generation of large amounts of waste, making the textile industry one of the main polluters of the environment nowadays. Therefore, there are concerns about the reckless disposal of chemical and solid textile waste (natural or synthetic yarns, fibers, pieces of clothing, etc.) which can cause serious soil, water, and air pollution. To reduce the amount of waste generated in the industry, and preserve the environment and human health, it is necessary to apply modern trends of sustainable development. These trends imply the simultaneous satisfaction of the principles of ecological efficiency, social responsibility, and economic profitability. In this way, waste from the textile industry becomes a resource of the circular economy system with the aim of realizing sustainable development. In this work, waste materials of lignocellulosic, cellulosic, and synthetic origin were used as biosorbents for the purification of water polluted by organic and inorganic pollutants. This kind of waste utilization represents a special way of recycling, which is one of the most important links in the chain of sustainable development.*

Keywords: *biosorbent, circular economy, recycling, textile waste, sustainability.*

DOPRINOS CIRKULARNOJ EKONOMIJI KROZ KORIŠĆENJE VLAKNASTOG TEKSTILNOG OTPADA KAO BIOSORBENATA ZA PREČIŠĆAVANJE VODE

APSTRAKT: *Česte promene modnih trendova u odevnoj industriji, kao i industriji nameštaja, dovode do prekomerne potrošnje tekstila. Ovo direktno utiče na povećanje proizvodnje i dorade tekstilnih materijala, kao i stvaranja velike količine otpada, što tekstilnu industriju čini jednim od najvećih zagađivača životne sredine. Poseban problem predstavlja odlaganje hemijskog i čvrstog tekstilnog otpada (prirodna i* *sintetička prediva, vlakna, komadi odeće itd.) koji mogu izazvati ozbiljno zagađenje zemljišta, vode i vazduha. U cilju smanjenja količine otpada koji se generiše u industriji, a samim tim i očuvanja životne sredine i zdravlja ljudi, primenjuju se moderni trendovi održivog razvoja, koji podrazumeva istovremeno zadovoljenje principa ekološke efikasnosti, društvene odgovornosti i ekonomske isplativosti. Na taj način otpad iz tekstilne industrije postaje resurs sistema cirkularne ekonomije sa ciljem realizacije održivog razvoja. U ovom radu, otpadni materijali lignoceluloznog, celuloznog i sintetičkog porekla korišćeni su kao biosorbenti za prečišćavanje vode zagađene organskim i neorganskim polutantima. Ovakvo korišćenje otpada predstavlja specijalni vid reciklaže koja je jedna od najvažnijih karika u lancu održivog razvoja.*

Ključne reči: *biosorbent, cirkularna ekonomija, reciklaža, tekstilni otpad, održivost.*

1. INTRODUCTION

The growth of the world population, improved living standards, and frequent changes in clothing fashion trends („fast fashion" trends) have led to excessive consumption of textiles to meet human needs. Due to the tendency of using readily available and inexpensively-made clothing, textile production is highly increased in the past two decades. The increased textile production significantly influences the environment, since the textile industry is known for generating high amounts of waste through the processes of fiber, yarn, and fabric production, dyeing and finishing, confection, and distribution. Mostly, solid textile wastes (natural or synthetic yarns, fibers, pieces of clothing, etc.) are discarded in landfill sites or incinerating plants, causing serious soil, water, and air pollution. The additional impact that textile production has on the environment is reflected in the cultivation of crops, necessary for the production of natural fibers. For example, cotton is the most important material used in textile production, and the cultivation of the plant from which the fiber is obtained requires a large consumption of water, pesticides, and energy. On the other hand, grow of flax and hemp does not require the usage of pesticides, actually, these plants have the potential of cleaning the soil of different organic and inorganic pollutants. Various chemical agents used during textile production for finishing, dying, increasing fineness, or improving the properties of natural fibers can also harm the quality of the environment. Although textile wastes of natural origin (wool, cotton, hemp, flax, etc.) are biodegradable, there is a particular concern about non-degradable synthetic fibers that are usually mixed with natural fibers during textile production. These synthetic fibers can be the source of plastic microfibers, which represent a significant and unique group of microplastics that have a dramatic environmental impact since it is estimated that 22 million tons of plastic microfibers will be poured into the oceans between 2015 and 2050. The way to decrease the negative impact of textile waste on the environment is the transition of textile production from the linear to the circular economy [1] by implementing different mechanisms, such as reuse, redesign, recycling, and soil composting (in the case of natural origin waste). In that manner, the value of waste materials can be recovered and the textiles' End-of-Life management can become more sustainable. At this point, it can be estimated that 73% of textile waste is incinerated or landfilled, 12% is recycled (downcycled), and only 1% is collected to make new clothing [2]. Current recycling practice mostly implies the downcycling processes for obtaining a lower quality product than the initial one. These processes are used for the production of stuff mattresses, insulations, or cleaning cloths, as well as construction materials, where the addition of recycled fibers to the asphalt, polymers, cement, etc. improve their mechanical performances, durability, and sustainability [3-5].

One of the promising applications is the use of textile waste for ecological applications such as purification of water and air, and pollution remediation. Utilization of textile waste as adsorbents for the purification of water will decrease the amount of disposed, or incinerated waste, leading to the overall positive environmental effect.

2. UTILIZATION OF TEXTILE WASTE FOR WATER PURIFICATION

The presence of pollutants in the environment becomes a serious concern due to the increase in the world population, agricultural and industrial activities, and effluent discharge into the environment. These effluents mostly contain different organic and inorganic toxic substances (dyes, pesticides, pharmaceuticals, heavy metals, etc.), which presence in the environment is of major concern. Heavy metals are permanent environmental pollutants due to their bio-accumulating tendency, while pesticides and pharmaceuticals continuously enter the environment and represent persistent pollutants. Therefore, one of the major ongoing topics is to find the optimal method for the purification of polluted water. Among many methods developed for water purification (photocatalytic degradation, aerobic degradation, ozonation, chemical precipitation, chemical oxidation or reduction, electrochemical treatment, evaporative recovery, filtration, reverse osmosis, ion exchange, and membrane technologies) adsorption is considered a simple and fast method with low energy and operating costs, without the creation of toxic by-products that would cause secondary pollution. Also, utilization of the inexpensive and renewable materials as alternatives for conventional activated carbon makes the adsorption process even more cost-effective. The past three decades have shown an expansion in the development of new waste-based adsorbents for the removal of inorganic and organic pollutants in adsorption-oriented processes. The application of adsorbents derived from different kinds of waste, for water purification, is the equivalent of using one waste for cleaning up another [6]. In the textile industry, the different textile processes create various waste materials in different stages such as fiber, sliver, yarn, and woven. The waste materials obtained during textile production are also classified as ecologically and economically acceptable materials and good candidates for the substitution of commercial adsorbents in wastewater treatment.

Considering that due to the increase in the production and consumption of cotton materials, huge amounts of waste are generated, special attention is focused on the use of waste cotton fibers and yarn as adsorbents. Cotton fibers are natural, biodegradable, and cheap, and can be used as biosorbents in their natural form or modified (chemically and/or thermally). Other natural fibers, such as lignocellulosic (flax, hemp, sisal, coir,

jute, kenaf, ramie, etc.), are also utilized as a biosorbent, especially for heavy metals removal from water. These natural fibers are characterized by complex structures and heterogeneous chemical compositions especially pronounced for lignocellulosic fibers. The main structural component of natural fibers is cellulose, while secondary components are hemicelluloses, lignin, pectin, fats, and waxes. The content of these chemical components varies depending on the type of fiber, as well as geographical location, cultivation methods, and primary processing [7]. The quantity of these constituents and their location within the fiber structure has an influence on fibers' physico-chemical, mechanical, and especially sorption properties, due to the ability of carboxylic (primarily present in hemicelluloses, pectin, and lignin), phenolic (lignin and extractives) and to certain extent hydroxylic (cellulose, hemicelluloses, lignin, extractives, and pectin) and carbonyl groups (lignin) to act as active sites for adsorption. Numerous studies have been conducted on the use of natural fibers as adsorbents for the removal of different pollutants from water. Table 1 gives an overview of unmodified and modified waste materials obtained from textile production and used as adsorbents for the removal of different pollutants from water. Along with cotton as a natural fiber, polyester fibers are the most commonly used synthetic fibers for the production of textile materials, both individually and in a mixture with cotton. Considering their mass production and subsequent application, large amounts of polyester-based waste are generated. Therefore, several studies examined the possibility of using mostly modified polyester fibers as adsorbents for heavy metals removal from water (Table 1).
Different modification methods were applied to improve the adsorption characteristics of both, natural and polyester fibers. Physical treatments alter the structural and surface properties of the fibers without the use of chemical agents. In that way, treatments like stretching, calendaring, steam explosion, thermomechanical and ultrasound treatments promote the separation of fiber bundles into more homogenous structures, while treatments such as corona, dielectric barrier and plasma discharges, and laser and UV irradiation are used for modification of fiber surface [8]. Also, waste fibers' surface can be easily functionalized by a chemical modification that involves different reactions such as esterification and etherifications, oxidation, acetylation, chemical coupling, alkalization, de-waxing, de-lignifications, fiber impregnation, etc. As special ways of waste fiber modification, processes of classical and hydrothermal carbonization can be applied to convert the lignocellulosic precursors into efficient carbon adsorbents.

Table 1: Waste fibers modification and environmental application

Material	Modification	Pollutant	Ref.
Hemp fibers	graphite oxide	Methylene blue	[9]
Waste cotton fabrics	carboxylate-functionalized cellulose	Methylene blue, Rhodamine 6G	[10]
Hemp fibers	H_2SO_4	C.I. Reactive Blue 109	[11]
Hemp fibers	-	Turquoise Blue H5G, Red ME4BL, Green HE4B	[12]
Hemp fibers	0.7% $NaClO_2$ 17.5% NaOH	Cu^{2+}, Pb^{2+}, Zn^{2+}	[13]

Flax fibers	-	Cu^{2+}, Pb^{2+}, Zn^{2+}	[14]
Flax fibers	0.7% $NaClO_2$ 17.5% NaOH Impregnation with Ag^+	*E. coli, S. Aureus, C. Albicans*	[15]
Jute and sisal fibers	5, 7 and 10% NaOH	Cd^{2+}, Cu^{2+}, Ni^{2+}, Pb^{2+}	[16]
Jute fibers	carboxylate-functionalized jute fibers impregnated with iron	As(III)	[17]
Cotton fibers	10% and 18% NaOH	Pb^{2+}, Cd^{2+}, Cr^{3+}, As (V)	[18]
Cotton and cotton/polyester yarns	-	Pb^{2+}, Cr^{3+}	[19]
Denim fabric residues 100% cellulose, cellulose/polyester 75%/25%	H_3PO_4, and carbonization 500°C	Pb^{2+}	[20]
Cotton textile waste	$FeCl_3$, $FeCl_2$, $FeC_6H_5O_7$ pyrolysis 300 °C	Pb^{2+}	[21]
Hemp fibers	Carbonization 900°C, KOH activation 900°C	Pesticides: acetamiprid, dimethoate, nicosulfuron, carbofuran, and atrazine	[22]
Hemp fibers	0.7% $NaClO_2$, 17,5% NaOH and carbonization 900°C	Cu^{2+}, Pb^{2+}, Zn^{2+}	[23]

In our previous works [7,8,13,15,18,19] and ongoing experiments, waste hemp (H) and flax (F) fibers, along with cotton (Cott) and cotton/polyester (Cott/PES) yarn were used for the removal of different pollutants from water (Figure 1). The adsorption properties of examined lignocellulosic fibers and cotton-based yarns depend on chemical composition and the location of the structural constituents within the fiber structure. Lower adsorption efficiency of Cott and Cott/PES toward the cationic dye methylene blue (Figure 1a) can be the consequence of the higher content of α-cellulose than in lignocellulosic fibers, as well as the presence of polyester component. All samples showed high adsorption efficiency for lead ions adsorption (Figure 1b), and the adsorption of pharmaceutical molecules of different polarities (Figure 1c). Cott and Cott/PES show slightly better adsorption efficiency due to the more exposed external fiber surface to the adsorbate solution than more porous lignocellulosic fibers.

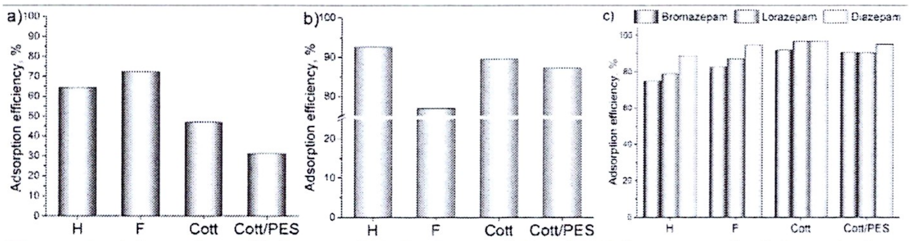

Figure 1: Adsorption efficiency of H, F, Cott and Cott/PES for removal of a) methylene blue, b) lead ions and c) pharmaceuticals

The morphology of H, F, Cott and Cott/PES samples is given in Figure 2, along with morphologies of these materials after modification with 18 % NaOH. Alkali modification was performed in order to improve adsorption properties through changes in fiber structure, morphology, and surface chemistry.

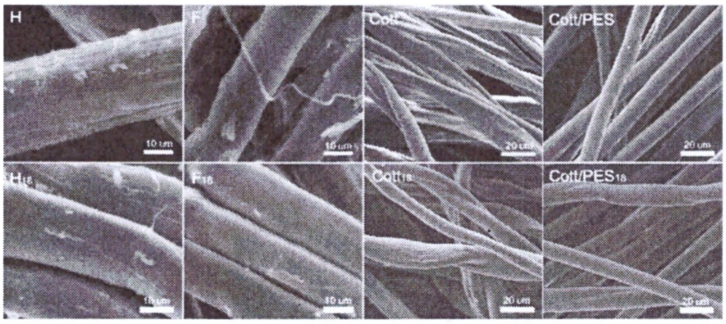

Figure 2: SEM photographs of unmodified and alkali modified H, F, Cott and Cott/PES samples.

The surface of lignocellulosic flax and hemp fibers is rough and uneven, characterized by partially separated elementary fibers, embedded in resinous substances (matrix of hemicelluloses, lignin, and some pectin). This liberation of elementary fibers becomes more pronounced after alkali modification as a consequence of the removal of hemicelluloses from the interfibrillar region in the structure of hemp and flax fibers. The cotton fibers within the structure of Cott and Cott/PES are spirally twisted, with the structure looking like a twisted ribbon [7]. The polyester component from the Cott/PES is characterized by a straight filament, with a noticeable smooth surface. Applied alkali treatment has more influence on surface chemistry, than on the morphology of cotton-based yarns. The influence of alkali modification is visible from the differences in FTIR spectra of unmodified and modified fibers and yarns (Figure 3). The spectra of the modified samples (two shoulders at 3478 cm^{-1} and 3436 cm^{-1}) confirmed the polymorphic transformation of Cell I to Cell II and the presence of a specific hydroxyl group of cellulose II [15]. Differences observed between the intensity of bands in the range 1000-1370 cm^{-1} that originate from cellulose and hemicelluloses indicate that modification affected the number of hemicelluloses in the fiber structure.

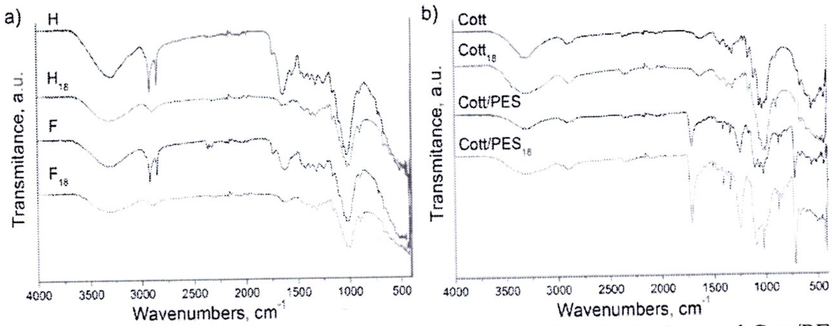

Figure 3: FTIR spectra of unmodified and alkali modified H, F, Cott and Cott/PES samples.

These surface and structural changes led to the better adsorption efficiency of lignocellulosic and cotton fibers, while in the case of Cott/PES NaOH modification did not significantly influence adsorption properties, which is the consequence of the presence of polyester component (Figure 4).

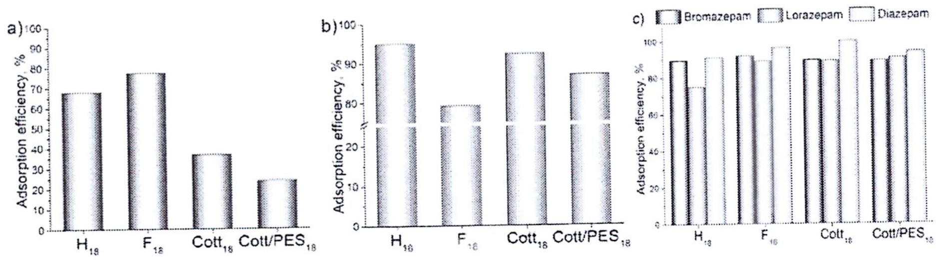

Figure 4: Adsorption efficiency of modified H, F, Cott and Cott/PES for removal of a) methylene blue, b) lead ions and c) pharmaceuticals

Another type of modification, used on textile waste materials for obtaining efficient adsorbents is carbonization, followed by activation. After carbonization, hemp fibers and cotton and cotton/polyester yarns retain the structure of the precursor (Figure 5) with pronounced longitudinal cracks along the fiber which is probably the consequence of activation.

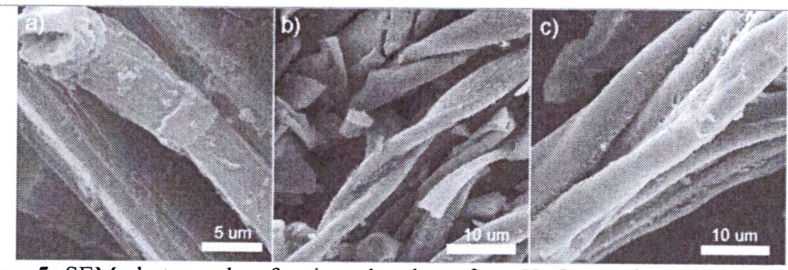

Figure 5: SEM photographs of activated carbons from H, Cott and Cott/PES, and their porous properties.

Depending on the type of precursor and parameters of carbonization and activation, waste textile materials could be converted into carbon materials with a highly developed specific surface area. It was found [24] that chemical modification of hemp fibers, prior to carbonization, affects the specific surface area, amount of surface oxygen groups, and morphology of carbonized hemp fibers. Furthermore, activation of carbonized materials with potassium hydroxide improves the sorption properties of carbonized hemp fibers by increasing the specific surface area (up to 2192 m^2/g) and amount of surface oxygen groups. It was noted that the adsorption characteristics are primarily influenced by porous properties and the amount of surface oxygen groups, while the morphology of examined samples does not show a direct influence on the adsorption efficiency.

3. CONCLUSION

Recycling and converting textile-related waste to produce advanced materials for ecological applications can be a sustainable way to give such waste a new life in the value chain. The present work highlights the use of textile waste as biosorbents for the removal of inorganic and organic pollutants from water. More heterogeneous chemical composition and the presence of non-cellulosic components in the fiber structure, along with the presence of fibrillation, cavities, and cracks on the surface of the fibers are key factors that affect the efficiency of waste fibers as biosorbents. Adsorption efficiency of fibrous textile waste can be increased by applying different modification methods, or carbonization to convert it to efficient carbon adsorbents. These kinds of re-employment of textile waste fits into the concept of circular economy and increase the sustainability of textile production processes.

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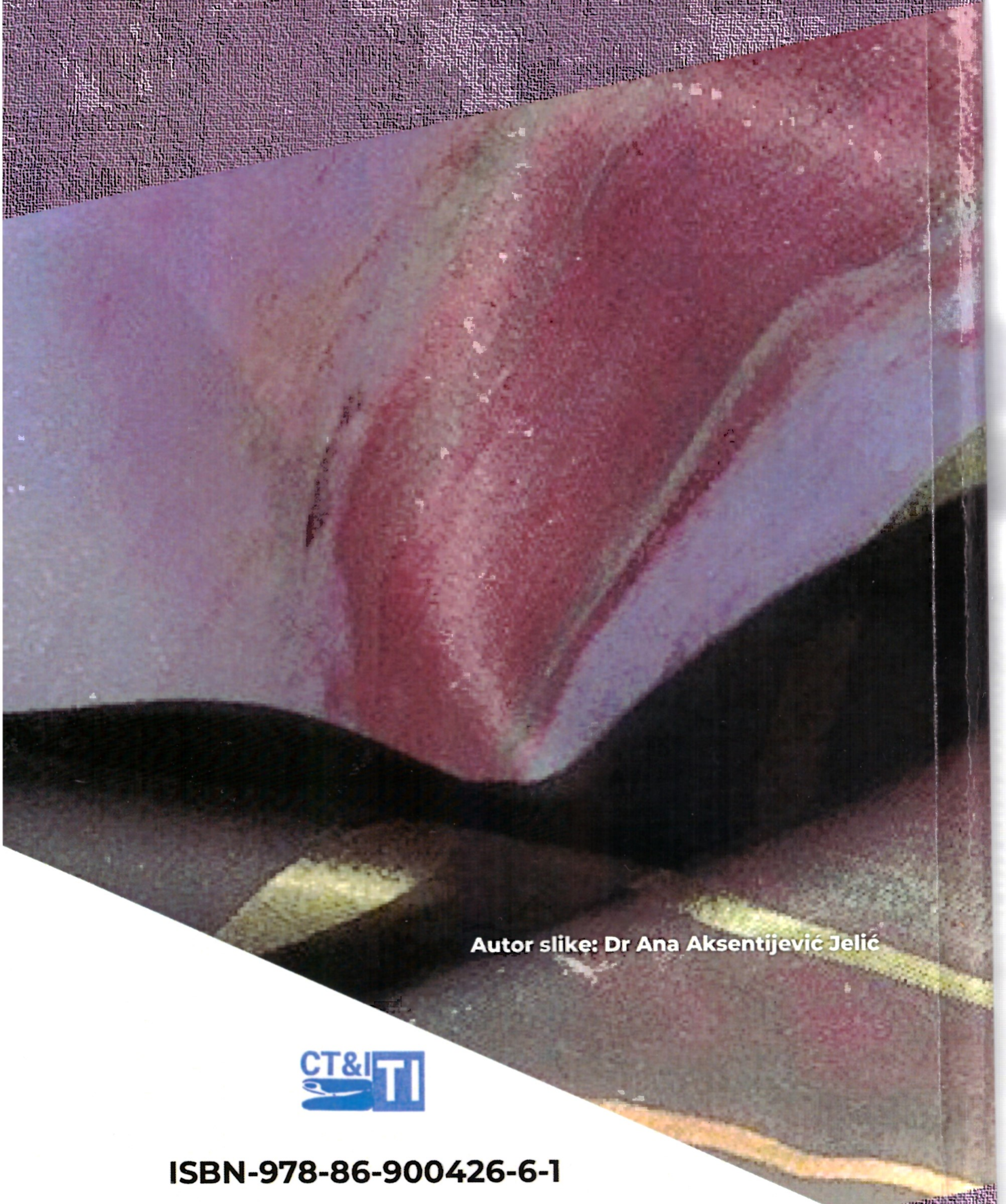

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