Chapter

The Waste Problem of Antimicrobial Finishing

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Abstract

Growing awareness of health and hygiene has increased the demand for bioactive or antimicrobial textiles. As a result the global market of antimicrobial textile products has been growing day by day. Antimicrobial finishing protects the wearer from microorganisms for aesthetic, hygiene, or medical reasons and protects the textile from biodeterioration caused by mold, mildew, and fungi. Antimicrobial textile products have crucial functions such as ensuring hygienic conditions and preventing spread of diseases especially crowded places like hospitals, baby nurseries, and barracks. However the antimicrobial agents used in antimicrobial finishing have adverse effects (toxic, allergic, and carcinogenic) on wearer and all the living organisms during the antimicrobial textile product's production and serving life. The effects of finish content released in waste water bath and the release of finish content to surrounding skin of user and its contact/inhalation/consumption by other living species require studies. The contamination substances in the sludge may be consumed by the cultivated plants, eventually becoming component in feed and food. Contamination is also possible in water and soil organisms. The chapter is about the waste problem of the antimicrobial finishing (especially metal-based antimicrobial finishing and triclosan-based antimicrobial finishing).

Keywords: antimicrobial finishing, heavy metal, silver, triclosan, waste, environment, pollution, toxicology

1. Introduction

The foundations of the textile industry were laid in Britain; spinning and weaving technologies developed here. However, in the aftermath of this development, in the nineteenth century, textile production shifted to Europe and North America following pace with the industrial modernization in these regions. In the preceding years, almost all countries have realized industrialization and development processes via the textile industry. Countries undergoing the development process continue to produce more traditional textile products, whereas countries that have already completed their development processes and have achieved an advanced level of technology continue to produce high-tech technical textiles [1].

While the textile industry was initially in a traditional position that met basic requirements, such as yarn and fabric production, clothing, and home textiles, the development of technology over time and the increase in human needs have resulted in the industry being much more technological and functional today as a result of diversification [1].

Looking at the global textile market volume in 2015 and beyond, it is observed that it reached \$667.5 billion in 2015. Europe accounted for 54.6% of this volume and the Asia-Pacific region 20.6%. When the 2018 data is examined, the global textile market volume is estimated to be \$858 billion, up to 5% from 2019, and estimated to reach \$1.207 billion by 2025 [1, 2]. It is also estimated that interest in high-tech textile products will continue to increase in the coming years and that the market in this field will continue to grow in Europe (especially Germany, France, and Italy) [2].

In recent years, consumers' desire to feel comfort, be hygienic, feel good and control odor, and be protected from microorganisms has led to the rapid growth of the market of antimicrobial textiles [1, 3, 4]. The current uses of antimicrobial textiles range from outdoor applications such as tents, tarpaulins, awnings, blinds, parasols, sails, and waterproof clothing to indoor applications such as shower curtains and mattress ticking. They are also used in some consumer textiles such as sportswear, T-shirts, and socks and also in medical purpose such as masks, surgical clothing, wound dresses, and bandages [5]. Global antimicrobial textile market volume in 2019 reached \$9468 million. And it is estimated to reach \$12,313 million in 2024 [6]. According to the 2015 data, the market volume of global finishing chemicals is 1.14 million tons, and there is an increase of 6.1% each year by 2025. A significant portion of this amount consists of antimicrobial finishing agents [7]. The volume of the global wet wipe and wet napkin market is thought to have the potential to increase by \$5.75 billion between 2020 and 2024 [8]. And by 2016, the volume of diapers will be \$46.50 billion and is estimated to reach \$67.46 billion by the end of 2022 [9].

By 2025, the world's population is estimated to be 8.2 billion. Growing world populations, rising living standards, and fast fashion trends are causing the global textile industry to grow day-by-day. This also means large amounts of raw materials and resource usage, ultimately producing pollution and a high rate of waste [1, 10].

In this section, the issue of antimicrobial textile production (especially metal-based antimicrobial textile production, triclosan-based antimicrobial textile production) and subsequent product life spans are investigated.

2. Textile and waste

The word waste is defined as things that people do not need and want to get rid of. Waste according to their physical form can be classified as solid, liquid, and gas. It is also possible to classify waste according to its original uses (packaging waste, textile waste, etc.), according to its materials (glass, metal, fiber, etc.), according to its physical characteristics (recyclable, composite, fuel, fertilization, etc.), according to its origin (domestic, commercial, industrial, agricultural, etc.), and according to its safety level (dangerous or hazardous) [9]. Household waste and commercial waste are classified together as solid municipal wastes. Excessive and unnecessary consumption in all areas of daily life increases the burden of a clogged-up world [10].

European Union member states have targeted a 50% reduction of municipal waste by 2020 through reuse and recycling [10].

In the textile industry, during the production of textile products, high amounts of solid, liquid, and gas in the form of wastes are produced as well as during the lifetime of textile products by the consumer and after the end of its lifespan [1, 10, 11].

Aged textile processes, which include pre-finishing, dyeing, printing, and finishing processes, usually consist of chemical applications, fixation, washing, and drying steps. In particular dyeing and finishing processes are processes where the highest amount of water is used [1, 11]. In textile production, a very large amount of water, chemicals, dyeing, and auxiliary chemicals are used. Therefore, textile wastewater is contaminated with these substances, has alkaline at high concentrations, is sharply scented, has the need for high biological oxygen (BOD) and for chemical oxygen (COD), and contains highly dissolved solids if it is not properly removed, which can cause environmental complications [1, 11].

Textile products other than disposable products are repeatedly exposed to washing, drying, ironing, and dry cleaning during their lifetime [12]. Wastewater contaminated with detergent, stain remover, and softener in washing baths are toxic to marine creatures [13]. With each washing, the active finishing chemicals applied on the textile product also leave the textile surface and pass on to the washing water subsequently increasing the waste load. Active finishing chemicals can leave the textile surface not only with bathing but also when faced with bodily fluids during use. This condition can cause itching, skin sensitivity, and allergies in people with sensitive skin [14].

The average life expectancy of textile products is 2 years, and then they continue to be waste loads by being stored in landfills. The amount of textile waste that has completed its life span is 10.5 million tons per year in the United States, 350,000 tons in the UK, and 287,000 tons in Turkey [10]. In particular, some studies and trends have been initiated to evaluate textile products that have completed their life spans in the United States and Europe. These studies can be summarized as recycling, reuse, energy production, second-hand clothing trends, vintage clothing trends, and slow fashion trends [10, 15]. According to 2009 data, only 15% of the textile products that have completed their life in the United States are utilized through recycling or donation, and the remaining 85% are left to solid waste landfills. However, it is thought that it is possible to utilize up to 95% with successful waste management [10].

The textile industry also produces waste in gas form, causing air pollution. Especially in spinning and weaving processes, a large amount of dust and sublimates are emitted into the operating environment. This condition can cause respiratory diseases and chronic lung diseases in workers [10].

From an environmental point of view of the textile industry, energy consumption, gas emissions, solid waste, and odor problems are also important issues, but the main problem is the chemical waste load produced in large quantities of wastewater and the chemicals in the wastewater [10].

2.1 Toxic or hazardous waste in the textile industry

Toxic or hazardous waste is waste that is dangerous for the environment and human health or has the potential to create harmful effects. Toxic and hazardous waste can occur in the form of solid, liquid, gas, and sludge as a result of various industrial production activities [16].

There are many toxic and dangerous chemicals in textile wastewater caused by different production processes [10]. Some of these are as follows [10]:

- Chlorinated solvents: chlorinated solvents are used in many processes such as bleaching, scouring, and dyeing in the textile industry. They are known to have allergic, carcinogenic, and toxic properties for human and environmental health.

- Hydrocarbon solvents-aliphatic hydrocarbons: hydrocarbons of organically structured compounds consisting of aliphatic compounds and carbon and hydrogen elements are aliphatic. They can be straight-chained, branched, or ringed and are divided into two: saturated and unsaturated. They are flammable and have sultry properties. They are known to cause nervous system diseases and cancer.

- Hydrocarbon solvents-aromatic hydrocarbons: it is very difficult to purify textile wastewater from aromatic hydrocarbons. Aromatic hydrocarbons are not easily dissolved in water. Most aromatic hydrocarbons stick to solid particles, settling in lake and riverbeds and blending into groundwater. These compounds are known to cause cancer in the long term.

- Oxygenated solvents (alcohols/glycollics/ethers/esters/ketones/aldehydes): oxygenated solvents are solvents with a high solvent feature containing an oxygen molecule. These solvents (methanol, ethanol, propane, ethylene glycol, etc.) are widely used in textile processes. They are harmful to both human health and all flora and fauna. Exposure to high amounts of these compounds can lead to sudden deaths. Prolonged exposure can cause blindness, irregular heartbeat, and damage to the kidney and lungs. Some of these compounds are in the carcinogenic category for humans. Glycol ethers can cause developmental impairment in the fetus and infertility in men. Regular exposure to these solvents can cause memory and hearing loss, depression, headache, coordination disorders, and skin disorders. Exposure to the vapors of these solvents can cause ailments such as asthma or shortness of breath.

- Grease and oil contaminated waste: grease can be animal-based, oil-based, and synthetic-based. Wastewater contaminated with grease is toxic to marine life in the long run.

- Used oils: some of the oils used in textile processes are carcinogenic to human health if they are in physical contact with humans or digested.

- Dye materials and pigments containing harmful substances: the presence of dye substances and treatment of textile wastewater are serious problems because most dye materials are stable and are not easy to parse with traditional treatment methods. The chemical structures and contents of the dyes have an effect on toxicity sites:

- Organohalogens: pigments can contain fluorocarbon, chlorocarbon, bromocarbon, or iodo-carbon bond and contains toxic elements such as lead, cadmium, mercury, valve, chromium, cobalt, nickel, arsenic, etymon, and selenium and are toxic and dangerous.

- Organic compounds (such as benzyte, methane, paraffin) are made up of carbon and hydrogen elements; they are found in coal, crude oil, natural gas, and vegetables. Hydrocarbons, pesticides, dyes, and plastics are the cornerstone of numerous product groups.

3. Textile antimicrobial treatments

Antimicrobial finishing applied to textile material should be effective against microorganisms as well as meet a number of requirements including the fact that antimicrobial finishing is suitable for the textile process; is resistant to washing, dry cleaning, and hot press; and is not harmful to the environment [17].

Different antimicrobial methods of finishing may be preferred depending on the genus, structure, surface characteristics, and usage area of textile material. Antimicrobial finishing can be carried out during the phase of finishing procedures, as well as the application of antimicrobial agents into the polymeric matrix during the production phase of synthetic fiber. The activity against microorganisms occurs through contact and/or diffusion. There are no antimicrobial agent disperses in activity through contact and show impact on the microorganism at the time of contact. In the event of diffusion, the antimicrobial agent reaches the outer environment away from the fiber surface, or polymer matrix, and shows activity on the microorganism [17–21].

A living germ, bacteria, or fungal has a cell wall of polysaccharides on the outermost surfaces. This structure ensures their integrity and protects them against the external environment. There is a semipermeable cell membrane on the cell wall. The cell wall and membrane stores, protects, and performs the cell's vital organelles, enzymes, genetic information, and transport. The type of activity of the antimicrobial agent against the microorganism is the main factor in its classification. If the antimicrobial agent only prevents the growth of the microorganism, it is called a biostatic effect; if it kills microorganisms, it is called biocidal effect [22–24].

Antimicrobial finishing processes have three different mechanisms [25]:

3.1 Controlled release

Most antimicrobial substances operate with a controlled oscillation mechanism. In this mechanism, the antimicrobial substance, which has already been applied to the textile material, is released at a certain speed in a controlled manner during use. This type of antimicrobial substance, which is removed when the textile material is washed, is very effective against microbes on or around the fiber surface. However, since it is constantly released during use, the amount of the textile material is gradually depleted at the end of the antimicrobial substance, and therefore the exhaustion process is depleted. On the other hand, the environmentally released antimicrobial substances are toxic to beneficial microorganisms and other creatures [24–26].

In recent years, studies have increased the use of silica carriers such as zeolite and microencapsulation technology for controlled oscillation in order to increase the strength of antimicrobial process or effect and cause less damage to the environment [25–27].

3.2 The regeneration principle

The renewal model was formulated by Gagliardi in 1962. This model, described in Gagliardi's article, is based on the application of a chemical finishing process product to fabrics that produce active germ killer (antiseptic) substances that are constantly renewed by adding bleaching substances during washing or exposure to ultraviolet light. This regeneration occurs when the covalent bonds in the chemically modified fiber are severed as a result of washing or photochemical effects, so that the model has an unlimited antimicrobial repository [27]. Although the regeneration technique has not yet been implemented, the microencapsulation technique is close to performing the function of this model. However, although the surface is suitable for a long period of time, microencapsulated antimicrobial substance storage is not unlimited [25, 27, 28].

3.3 Blocking or the blocking effect

The blocking or blocking mechanism for the protection of fabrics from microorganisms can be divided into two: (a) inert (ineffective) physical obstacle layers or coatings that are simply resistant to the passage of microorganisms into fabric or (b) layers or coatings with direct surface contact effect against microbial proliferation [27].

Fire, water, weather, and mildew resistant (FWWMR) end process is an example of obstacle coating. In this process, fabrics are coated with a mixture of organic and anorganic compounds containing fungicide. The blocking or blocking mechanism has been used to protect fabrics from mold yeast and decaying fungi with resin applications or chemical modification of cellulose with cyanoetylation or acetylation. When the finishing process containing flame-retardent agents and resins forms of finishing agent with covalent bonds, they are the most effective products against mold [27].

The product of the only antibacterial finishing process based directly on the concept of surface contact attachment obstruction is an organosilicon polymer containing hanging quaternary ammonium groups that form a biobarrier in the fabric [27].

Most of the antimicrobial agents used to manufacture commercial textiles have biocidal effects, but they show activity on microorganism in different ways [17]:

- They damage or inhibit the synthesis of the cell wall, which is critical for life and survival.
- They damage intracellular and non-cell matter transport by inhibiting cell membrane function.
- They cause the death of the microorganism by inhibiting the synthesis of the proteins that make up the building rocks of the cell and enzymes.
- By inhibiting nucleic acid (DNA and RNA) synthesis, they prevent the survival and proliferation of the cell.
- By inhibiting metabolic processes, they cause the death of the microorganism.

4. Antibacterial agents used in the textile industry

The most common antimicrobial substances used to give textile materials antimicrobial properties are quaternary ammonium compounds (QAC), polyhexamethylene biguanide (PHMB), chitosan, regenerated N-halamine compounds, peroxy acids, metal/metal salts, and triclosan. In addition, there are antimicrobial-enabled paints (e.g., metallic paints) that allow simultaneous dyeing and antimicrobial finishing processes [25]. The chapter is about metal-based antimicrobial finishing and triclosan-based antimicrobial finishing.

4.1 Metal-based antimicrobial finishing

Many heavy metals are toxic to microorganisms, both freely and in compounds, even at very low concentrations. Other heavy metals such as copper, zinc, and cobalt are also used in the production of antimicrobial textiles, but the most preferred are silver and silver compounds for this purpose [17, 29, 30]. In recent years, the nano-forms of metal and metal compounds have attracted attention as new generation biocides [30]. According to 2018 data, the most commonly used antimicrobial substances in the production of antimicrobial medical textiles are metal/metal salts (39.6%) [31]. The most commonly used metallic salts are silver, copper, zinc, and cobalt [31–33]. The global nano-silver market volume is estimated to exceed $3.3 billion in 2024 [34].

Metal and metal compounds cause oxidative stress in the microorganism, causing damage to microorganism lipid, protein, and DNA, resulting death [30]. The mechanism of action of the nano-forms of metal/metal compounds is similar. Silica such as zeolite, polymer matrixes, and various cross linking agents are used to stabilize nanoparticles in the structure, to provide controlled oscillation, and to ensure washing durability [30].

In synthetic fibers, metal and metal compounds can be added to the environment before fiber extraction or in the polymer stage before electrospinning and nano-fiber production. During its lifetime, metal ions are released causing biocidal effects in the presence of moisture. The amount of metal ion released varies depending on the chemical structure of the fiber, its surface feature, and the amount of metal/metal salt on the fiber [29].

The application of metals to natural fibers can only be done during the finishing process. Various strategies have been developed to improve binding and durability. Cotton was pre-treated with succinct acid anhydrites. Succinic acid anhydride acts as a ligand (atom, molecule, or ion attached to the central atom) for metal ions and provides very effective antibacterial activity by increasing the retention of metal salts (Ag^+ and Cu^{2+}) on the surface. In protein fibers (e.g., wool), aspartyl and glutamyl residues are thought to be binding groups for free carboxyl groups, most likely metal ions. Binding capacity can be further increased with EDTA with the ability to skip the tannin acid or metal ions that increase the serious restrictions due to technical and environmental problems; therefore, it is not accepted in commercial production [29].

4.1.1 Silver-based antimicrobial finishing

Silver has been used in many areas for centuries as a broad-spectrum antimicrobial substance with antibacterial, antifungal, and antiviral properties. Metallic silver, silver nitrate, and silver sulfadiazine forms have been used for many years to treat burns, wounds, and numerous bacterial infections [35]. Most metal ions are also known to have antimicrobial properties, but silver is best effective against bacteria, viruses, and other eukaryotic microorganisms [35]. Silver has very important advantages as an antibacterial substance. These benefits include the fact that silver is a very broad-spectrum antibiotic and has almost no bacterial resistance to silver, and there is no toxicity in low concentrations [35–37].

It is known that the use of silver in the treatment of burns and chronic ulcers in water disinfection dates back to the 1000 BC. In the literature, it is mentioned that silver was used as an eye drop in the 1800s, and then its used was reduced with the presence of penicillin, but 0.5% silver nitrate solution in the 1960s was widely used in burn treatment. In these years, silver's effectiveness against bacteria such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli* has been proven. In 1968, silver sulfadiazine cream was obtained by combining silver nitrate with sulfonamide. This cream has been widely used in the treatment of burns due to its effectiveness against many microorganisms. The literature states that silver sulfadiazine is active against bacteria such as *E. coli*, *S. aureus*, *Klossiella* sp., and *Pseudomonas* sp. and also has antifungal and antiviral activities [35]. 1% silver nitrate solution is still used as eye antiseptic for various purposes in newborn babies [38]. Today, wound dresses containing different amounts of silver against antibiotic-resistant bacteria are used [35].

Concentrations greater than 0.5% are not generally preferred in silver solutions used for medical purposes. In these concentrations, silver allergy is not reported.

However, when using wound dress containing a high amount of silver ion in large wounds, a disease called argyrism can be found in the form of bluish and brown lesions in the skin and mucous membrane. This disease causes the removal of silver ions from the open wound for a long time [35, 39].

Metallic silver is actually inert, but when it comes into contact with the skin, the moisture and fluid of the wound on the skin make it ionized. Iodine silver is highly reactive. It connects to tissue proteins, causing structural changes in the bacterial cell wall and then the nuclear membrane, causing the death of the microorganism [35].

4.1.2 Mechanism and toxicity of silver

The mechanism of killing microorganisms by silver is still not very clear. The mechanism was attempted to be clearer by examining morphological and structural changes caused by metallic silver, silver ions, and silver nanoparticles in the bacterial cell. In light of the studies, it is known that silver is connected to the bacterial cell wall and cell membrane, interacting with thiol groups to inhibit respiratory enzymes, thus leading to the death of the microorganism [35, 36].

Liau and his colleagues studied the effect of silver ions on amino acids containing thiol (–SH) groups in 1997 [40].

A 2000 study by Feng and colleagues examined the morphological changes that silver ions have on gram-positive *S. aureus* and gram-negative *E. coli* bacteria. AgNO3 was used as an ion source in the study. Gram-positive *S. aureus* has been shown to be able to better resist silver ions due to its thick cell wall, which is typical of positive bacteria. Again, the study reported that DNA, which can only be copied while free, has become a more intense form within the cell, which shows that DNA has lost its ability to copy itself [41].

In his 2005 study, Holt and colleagues reported that the increase in the amount of potassium in the environment was detoxicated by the toxicity of silver against microorganisms [42].

Li and colleagues studied the antibacterial effect mechanism of silver nanoparticles on *E. coli* in a 2010 study. In this study, silver nanoparticles first disrupted the structure of the cell membrane and entered the cell and then inhibited the respiratory enzymes by relocating the hydrogen atoms (–S–Ag–) in the cysteine thiol (–SH) groups. The development and proliferation of bacteria stop if cell member permeability and respiratory of cell deteriorate [43].

Many studies are being conducted on the antimicrobial mechanism of nano-silver particles, but there is not enough work on toxicity. A limited number of studies conducted in in vitro conditions show that nano-silver particles are much more toxic than conventional silver and other heavy metals [35, 44]. Shapes, particle sizes, crystalline, surface properties, ambient humidity, ambient pH, cations in the environment, and their concentrations are among the particles that affect the toxicity of silver nanoparticles [45]. In vitro studies reveal that nano-silver particles cause damage to the brain, liver, and reproductive cells in mammals. In 1999, the FDA warned that the use of colloidal silver solutions containing micro- or nanoparticles could lead to neurological problems, headaches, skin irritation, weakness, stomach ailments, and kidney ailments. It is also reported that silver nanoparticles will affect rivers, lakes, and all living things that make up the ecosystem by blending into the food chain by mixing into the water. Washing machines produced in recent years, using nano-silver technology, are also objectionable in this context. In order to further clarify this issue, a large number of independent animal and clinical trials that are not supported by producers must be performed [35, 43, 46].

4.1.3 Silver contaminated waste and silver accumulation

Silver and its different forms are wide spectrum antibiotics. They have low risk of bacterial resistance, and their low concentrations are not toxic, and they have ease of application and low cost. Because of these advantages, silver and other forms of it are widely used in most areas and surfaces, which are being antimicrobial desired. It is also widely used in the production of antimicrobial textiles in different forms of Ag and silver (colloidal silver, silver salts, and elemental silver in powder form) [35–37].

Ag particles are applied to the textile surface using binder or cross-binding substances; it is possible to increase washing resistance. However, as a result of washing both during antimicrobial textile production and throughout its life cycle, most of the Ag particles on the textile surface mix into rivers, lakes, and groundwater along with wastewater, causing the accumulation of silver in the ecosystem. Disposable hygiene products are a similar situation [36]. Most antimicrobial textile products are released into washing water for 50% of the amount of silver at the end of three washings. And the textile products release 10–98% content of the silver into washing water at the end of 10 washings [47]. According to a study, up to 75% of silver may be released from textiles impregnated with Ag NPs in one washing cycle [48]. It is clear that silver accumulated in the ecosystem, water or soil, will have a toxic effect on all living organisms and reach the food chain [14, 35].

According to a study conducted in 64 countries on the release of silver from different products into nature, the United States is the country that releases the most silver into the environment, globally. The Asian continent is the continent which has the most silver emissions directly into the aquatic environment and land [49]. According to a report, 68% of the global silver consumption is used for water treatment and 32% for other uses. And 3.4–40 metric tons of silver are used in textiles per year [5]. In the United States, 29% of the silver used in different industries is released into the aquatic environment, and 69% are known to be dumped in solid waste storage [50]. In recent years nano-silver consumption in textiles like other industries has been increasing rapidly also [51]. The regions where antimicrobial medical textiles containing metallic salts such as copper, zinc, cobalt, mainly silver most used are North America (39% of market volume), Europe (23% of market volume), the Asia Pacific regions (30% of market volume) and the rest of the world (7% of the market volume) respectively [31, 48]. The highest use rate belongs to North America because hospital infection and cardiovascular disease rates are high in this region [31].

4.2 Triclosan-based antimicrobial finishing

Triclosan has been widely used in commercial products for many years as an antimicrobial substance used in soaps, deodorants, cosmetics, cleaning lotions, plastics, toothpastes, and antibacterial textiles [52–56]. The European Union's consumption of triclosan in 2006 is reported to be approximately 450 tons. It is reported that 85% of this is used in personal care products, 5% in textile products, and 10% in plastics and products that come into contact with food [54, 57]. Triclosan is also frequently used in the textile industry. Triclosan is used to prevent the formation of bad odor in wool; to prevent the reproduction of bacteria and fungi in synthetic, mixtures, and non-woven textile materials; and to keep mites away from textile materials [57].

75–210 metric tons of triclosan are used in textiles per year globally [5]. According to a 2009 report by the Australian government, between 2001 and 2005, the amount of triclosan contained in textile products exported to Australia varied between 1 and 20%. The report stated that between 2001 and 2005, textile products containing approximately 1 ton of triclosan were used. In the same report, it is stated that triclosan in used in Australia in wool bed-duvet production, upholstery fabrics, towels, woolly textile products, preparatory fabric production, marine and sports clothes, socks, underwear, shoe linings, zippers, gloves, surgical masks, non-woven products, sleeping bags, and insulation textiles [57]. Triclosan can be added to the textile materials during the fiber production stage and can be applied as a finishing process or transferred in the form of coating [57].

4.2.1 Mechanism and toxicity of triclosan

Triclosan is known to have bacteriologic effects on gram-positive and gram-negative bacteria, as well as antifungal and antiviral properties [53, 56]. Triclosan inhibits lipid synthesis by blocking enoyl-acyl reductase (ENR) of the microorganism. Thus, it prevents the development of the microorganism and its proliferation of division [53].

In 1986 in accordance with the European Union Cosmetics Directive, triclosan has been confirmed that it can be used in materials in contact with foods of up to 0.3% concentration as protective material, 5 mg/kg textile materials (especially in sportswear), and 0.3% concentration of plastic (plastic packaging, brushes) materials [54]. The Japanese government has stated that in cosmetics, the maximum amount of triclosan that can be used is 0.1%. In oral care in Canada, the amount of triclosan allowed in their products is 0.03%, and in cosmetic products it is 0.3%. According to a 2009 report by the Australian government, with regard to triclosan, eyes, respiratory system, and skin have been described as being irritating and toxic to inhalation [57].

Studies on the effects of triclosan on human health are usually carried out with mice, rabbits, dogs, and monkeys [53, 54]. Triclosan is taken into the body through the skin, nose, and mouth during contact with products containing triclosan. In addition, triclosan has contaminated the sea, lake, and groundwater and has reached the food chain, especially from foods such as seafood; triclosan enters the human body [53]. A study of 36 breastfeeding mothers who stated that they used personal care products containing triclosan as a result of a series of studies in America found triclosan in the mothers' milks [53]. Studies have shown that triclosan affects androgens in the male body and estrogen in the female body. Triclosan was found to affect the transport between the fetus and the placenta in the bodies of pregnant sheep, which has been reported that this can cause abnormal development. It has also been reported that triclosan can trigger breast cancers, especially in females. A number of studies on rabbits have been reported to reduce the sperm count in male rabbits and cause tissue destruction in reproductive organs, disrupting masculinity hormones [53].

The thyroid is known to have vital effects on development and metabolism. The thyroid hormone is a highly effective hormone in the development of fetuses and young children. Studies have shown that triclosan lowers thyroid hormone levels in rabbits and changes metamorphosis time in frogs [53, 58].

4.2.2 Triclosan contaminated waste and triclosan accumulation

Water supplies all over the world have been contaminated with triclosan due to wide commercial use in commercial products. In a 1999–2000 study conducted in the United States, samples from different water sources were examined in terms of 95 different chemicals, and as a result, one of the chemicals with the highest concentration was triclosan. Again, the researchers found a very high amount of triclosan in the bodies of marine creatures in particular. The Environmental Protection Agency reported that some of the triclosan in the environment was disrupted by the effect of ultraviolet rays and turned into toxic dioxins. It is reported that the access of dioxins to the food chain will have bad consequences [52]. Because the demolition products of triclosan are also toxic [59]. Again, the formation of cancer is associated with triclosan exposure [59]. According to a study, antimicrobial textile products containing triclosan are sold in 64–84% of the triclosan wash water at the end of 10 washings [57].

5. Bioactive plant-based environment-friendly antimicrobial finishing

Bio-functionalization of textiles with natural bioactive agents with antimicrobial properties is becoming increasingly important because they are not toxic, skin, and environment-friendly. These antimicrobial compounds extracted from most plants are phenols, polyphenols (simple phenols, phenolic acids, quinines, flavonoids, tannin, coumarin, etc.), terpenoids, essential oils, alcoholicoids, lectins polypeptides, and polyacethylenes. Most of these substances obtained from plants are colorful and are natural antimicrobial dyes and pigments used for the dyeing of both natural and synthetic fibers [30, 60–65]. Eco-friendly pigments can be obtained with fermentation of bacteria and fungi [30, 66, 67]. Different methods are mentioned in the literature to increase washing habits of bioactive vegetable-based antimicrobial compounds uncinated on textile fiber: resin application with cross-binding agent, glyoxal, and glycol [30, 68]; sol-gel matrix of liquid bioactive compounds, such as essential oils [30, 69]; and application with microcaps or with the pad-dry-cure method [30, 70–72].

Hydrogen peroxide is a natural antimicrobial produced against invasive bacteria in human cells. It is also found in honey as a preservative. Antimicrobial activity of hydrogen peroxide against bacteria, mold, fungi, algae, and viruses is known. The finishing processes and substances with hydrogen peroxide have become popular and commercialized in recent years [14].

It is thought that the importance of antimicrobial-effective herbal (such as vegetable wastes etc.) and animal-derived natural materials will increase for reducing the waste load (production, during its lifetime, and at the end of its lifespan) and engaging in more environment-friendly manufacturing [14].

6. Conclusion

In today’s world, the role of the textile industry is very important. While the textile industry initially met traditional human needs such as dressing with yarn and fabric production and home textiles, today due to rising living standards, textiles have become much more technological and functional with diversified human requirements. It is also an important industry sector for both countries in the growth and development process (rather than traditional textile production) and countries that have completed their development (rather than high technological textile production). However, despite all these advantages, the textile industry causes a large amount of waste and environmental pollution.

At different stages of textile production, numerous chemicals and auxiliary substances are used, many of which are toxic and harmful to the environment and human beings. As a result of these production stages, a large amount of solid, liquid, gas, and sludge form waste is exposed and causes pollution. Noise pollution is also another negative result of the textile industry. Textile finishing operations are the processes where high amounts of water are used, so high amounts of wastewater (with high chemical load) occur. Therefore, the biggest problem of the textile industry is this wastewater burden. According to some studies, 20% of all fresh water pollution is made by textile treatment and dyeing [73]. Textile wastewater needs to be properly purified to reduce environmental damage. In this context, the selection of chemicals and dyes with less environmental damage or environment-friendly finishing operations is also important in this context.

Any textile product has been subjected to washing, dry cleaning, and ironing many times during its service life. With each wash, the active chemical finishing agent in its structure is mixed into washing water, which then threatens the entire ecosystem by mixing into the sea, lakes, and underground waters, and is consequently used by water and soil plants contaminated with antimicrobial lice chemicals to be included in the food chain. Again, the seas and rivers contaminated with antimicrobial substances threaten water creatures and the human health as a result of consuming these creatures.

Studies on antimicrobial textiles have focused mainly on the synthesis of antimicrobial matter and its performance against microorganisms and washing durability. However, the effects of waste/wastewater content on the user's skin and health and all other creatures through contact/respiratory/consumption are needed to be further studies during the production of antimicrobial textiles, during and at the end of its lifecycle [74]. Antimicrobial agents derived from natural sources are safe for human and the environment, but the spectrum of activity and efficiency is not as good as the synthetic ones. To achieve this, more research work is needed in the field. Hence, natural antimicrobial agents derived from plant sources would be of prime importance in the future [75]. It is so urgent to protect and conserve the natural ecosystem of the earth, thereby restoring the global sustainability.

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References

[1] Sivaram M, Gopal M, Barik D. Toxic waste from textile industries. In: Energy from Toxic Organic Waste for Heat and Power Generation. UK: Elsevier; 2019. pp. 43-54. DOI: 10.1016/B978-0-08-102528-4.00004-3

[2] Global Textile Market [Internet]. 2020. Available from: https://www.globenewswire.com/newsrelease/2019/05/02/1814045/0/en/Global-Textile-Market-Will-Reach-USD-1-207-Billion-By-2025-Zion-Market-Research.html [Accessed: 24 January 2020]

[3] Afraz N, Uddin F, Syed U, Mahmood A. Antimicrobial finishes for textiles. Current Trends in Fashion Technology and Textile Engineering. 2019;**4**(5):87-94. DOI: 10.19080/CTFTTE.2019.04.555646

[4] Gao Y, Cranston R. Recent advances in antimicrobial treatments of textiles. Textile Research Journal. 2008;**78**(1):60-72. DOI: 10.1177/0040517507082332

[5] Windler L, Height M, Nowack B. Comparative evaluation of antimicrobials for textile applications. Environment International. 2013;**53**(C):62-73. DOI: 10.1016/j.envint.2012.12.010

[6] Global Antimicrobial Textile Markets [Internet]. 2020. Available from: https://www.globenewswire.com/news-release/2019/11/08/1943912/0/en/Global-Antimicrobial-Textile-Markets-Forecast-to-2024-Synthetic-Organic-Compounds-Active-Agent-Expected-to-Drive-the-Market.html [Accessed: 24 January 2020]

[7] Global Functional Textile Finishing Agents Market [Internet]. 2020. Available from: https://www.grandviewresearch.com/industry-analysis/functional-textile-finishing-agents-market [Accessed: 24 January 2020]

[8] Wet Tissue and Wipe Market Industry Analysis [Internet]. 2020. Available from: https://www.technavio.com/report/wet-tissue-and-wipe-market-industry-analysis [Accessed: 24 January 2020]

[9] Global Baby Diaper Market Size [Internet]. 2020. Available from: https://www.globenewswire.com/news-release/2019/07/11/1881415/0/en/Global-Baby-Diapers-Market-Size-Will-Reach-USD-67-46-Billion-By-2022-Zion-Market-Research.html [Accessed: 24 January 2020]

[10] Yalçın İ, Küçükali M, Sezgin H. Risks and management of textile waste. In: Gothandam K, editor. Nanoscience and Biotechnology for Environmental Applications, Environmental Chemistry for a Sustainable World Book 22. Switzerland: Springer Nature; 2019. pp. 29-53. DOI: 10.1007/978-3-319-97922-9_2

[11] Körlü A. Use of Ozone in the Textile Industry. Rijeka: Intechopen; 2018. DOI: 10.5772/intechopen.81774

[12] Can Y, Akaydın Y. Effects of laundering process on pilling characteristics of the cotton plain fabric. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi. 2013;**19**(4):170-173. DOI: 10.5505/pajes.2013.63935

[13] Detergents Effects on Marine Life [Internet]. 2020. Available from:https://www.lenntech.com/aquatic/detergents.htm [Accessed: 24 January 2020]

[14] Uddin F. Environmental concerns in antimicrobial finishing of textiles. International Journal of Textile Sciences. 2014;**3**(1A):15-20. DOI: 10.5923/s.textile.201401.03

[15] Domina T, Koch K. The textile waste lifecycle. Clothing and Textiles Research Journal. 1997;**26**(3):505-515. DOI: 10.1177/0887302X9701500204

[16] Toxic and Hazardous waste [Internet]. 2020. Available from: https://www.epa.gov./environmental-topics/land-waste-and-cleanup-topics [Accessed: 24 January 2020]

[17] Morais DS, Guedes RM, Lopes MA. Antimicrobial approaches for textiles: From research to market. Materials. 2016;**9**(6):498. DOI: 10.3390/ma9060498

[18] Shahidi S, Wiener J. Antibacterial Agents in Textile Industry. Rijeka: Intechopen; 2012. pp. 387-406. DOI: 10.5772/46246

[19] Korkmaz BR. Günümüz Tekstillerinde Kumaşa Kazandırılan Teknik Özellikler [Yüksek Lisans Tezi]. Marmara Üniversitesi, Güzel Sanatlar Enstitüsü: Çiğdem Çini; 2015

[20] Bshena O, Heunis TD, Dicks LM, Klumperman B. Antimicrobial fibers: Therapeutic possibilities and recent advances. Future Medicinal Chemistry. 2011;**49**(10):691-707. DOI: 10.4155/fmc.11.131

[21] Shishoo R. Plasma Technologies for Textile. Cambridge, UK: Elsevier; 2007. ISBN-10: 1-84569-257-8

[22] Bacterial Resistance [Internet]. 2020. Available from: https://amrls.cvm.msu.edu/microbiology/bacterial-resistance-strategies/introduction/introduction [Accessed: 24 January 2020]

[23] Glazer AN, Nikaido H. Microbial Biotechnology: Fundamentals of Applied Microbiology. Cambridge, MA, USA: Cambridge University Press; 2007. ISBN-10: 0-511-34136-9

[24] Rahman MA, Ahsan T, Islam S. Antibacterial and antifungal properties of the methanol extract from the stem of *Argyreia argentea*. Bangladesh Journal of Pharmacology. 2010:41-44. DOI: 10.3329/bjp.v5i1.4700

[25] Arslan P, Tayyar AE. Tekstil Alanında Kullanılan Antimikrobiyal Maddeler, Çalışma Mekanizmaları, Uygulamaları ve Antimikrobiyal Etkinlik Değerlendirme Yöntemleri. Düzce Üniversitesi Bilim ve Teknoloji Dergisi. 2016;(4):935-966. ISSN: 2148-2446

[26] Schindler WD, Hauser PJ. Chemical Finishing of Textiles. UK: Woodhead Publishing: 2004. ISBN: 9781845690373

[27] Vigo TL. Textile Processing and Properties Preparation, Dyeing, Finishing, and Performance. ABD: Elsevier; 1983. ISBN: 0 444 88224 3

[28] Gagliardi DD. Antimicrobial Finishes. American Dyestuff Reporter. 1962;**51**(1):49

[29] Bulan J, Celikiz G. Use of heavy metals in textile wet processing. Textile Chemist and Colorist. 1990;**22**(1):23-27

[30] Simoncic B, Tomsic B. Structures of novel antimicrobial agents for textiles—A review. Textile Research Journal. 2010;**80**(16):1721-1737. DOI: 10.1177/0040517510363193

[31] Antimicrobial Medical Textiles Market [Internet]. 2020. Available from: https://www.reportsanddata.com/report-detail/antimicrobial-medical-textiles-market [Accessed: 24 January 2020]

[32] The market for antimicrobial additives/biocides in plastics and textiles worldwide 2011- 2025: Development, Strategies, Markets, Companies, Trends, Nanotechnology, Home page [Internet]. 2020. Available from: http://www.hkc22.com/antimicrobials.html [Accessed: 24 January 2020]

[33] Giannossa LC, Longano D, Ditaranto N. Metal nanoantimicrobials for textile applications. Nanotechnology Review. 2013;**2**(3):241. DOI: 10.1515/ntrev-2013-0004

[34] Nanosilver Market [Internet]. 2020. Available from: https://www.gminsights.com/pressrelease/nanosilver-market [Accessed: 24 January 2020]

[35] Rai M, Yadav A, Gade A. Silver nanoparticles as a new generation of antimicrobials. Biotechnology Advances. 2009;**27**(1):76-83. DOI: 10.1016/j.biotechadv.2008.09.002

[36] Bozoğlu A. Türkiye'de Çıkan Doğal Zeolitin Bebek Bezlerinde Antimikrobiyal Madde olarak Kullanılması [thesis]. İstanbul Teknik Üniversitesi; 2010

[37] Silver Properties [Internet]. 2020. Available from: http://www.beggandco.com/admin/downloads/IMSL%20White%20Paper-JIS%20Z%202801-1005.pdf [Accessed: 24 January 2020]

[38] Çetin ET. Dezenfeksiyon, Antisepsi, Sterilizasyon. Turkey: İstanbul Tıp Fakültesi Yayını; 1982

[39] Grönvall H. On argyrosis and concretion in the Lacrymal Sac. Acta Ophthalmologica. 2009;**21**(4):17

[40] Liau SY, Read DC, Pugh WJ, Furrn JR, Russell AD. Interaction of silver nitrate with readily identifiable groups: Relationship to the antibacterial action of silver ions. Letters in Applied Microbiology. 1997;**25**(4):279-283. DOI: 10.1046/j.1472-765x.1997.00219.x

[41] Feng QL, Wu J, Chen GQ, Cui FZ, Kim T, Kim JO. A Mechanistic Study of the Antibacterial Effect of Silver Ions on *Escherichia coli* and *Staphylococcus aureus*. ABD: John Wiley and Sons; 2010. pp. 662-668. DOI: 10.1002/1097-4636(20001215)52:4<662::aid-jbm10>3.0.co;2-3

[42] Holt K, Bard A. Interaction of silver (I) ions with the respiratory chain of *Esherichia coli*: An electrochemical and scanning electrochemical microscopy study of the antimicrobial mechanism of micromolar Ag. Biochemistry. 2005;**44**(39):13214-13223. DOI: 10.1021/bi0508542

[43] Li W, Xi X, Shi Q, Zeng H, Ou S, Chen Y. Antibacterial activity and mechanism of silver nanoparticles on *Escherichia coli*. Applied Microbial and Cell Physiology. 2010;**85**(4):1115-1122. DOI: 10.1007/s00253-009-2159-5

[44] Nano-silver Report [Internet]. 2020. Available from: http://www.foeeurope.org/activities/nanotechnology/Documents/FoE_Nanosilver_report.pdf [Accessed: 24 January 2020]

[45] Jones C, Hoek E. A review of the antibacterials effects of silver nanomaterials and potential implications for human health and the environment. Journal of Nanoparticules Research. 2010;**12**(5):1531-1551. DOI: 10.1007/s11051-010-9900-y

[46] ABG L. Silver I: It's antibacterial properties and mechanism of action. Journal of Wound Care. 2002;**11**(4):125-130. DOI: 10.12968/jowc.2002.11.4.26389

[47] Silver Accumulation [Internet]. 2020. Available from: https://www.kemi.se/global/pm/2012/pm-1-12-antibact-en.pdf [Accessed: 24 January 2020]

[48] Rosenberg M, Ilic K, Juganson K, Ivask A. Potential ecotoxicological effects of antimicrobial surface coatings: A literature survey backed up by analysis of market reports. PeerJ. 2019;(1):2-34. DOI: 10.7717/peerj.6315

[49] Eckelman MJ, Graedel TE. Silver emissions and their environmental impacts: A multilevel assessment. American Chemical Society. 2007;**41**(17):6283-6289. DOI: 10.1021/es062970d

[50] Silver Accumulation in ABD [Internet]. 2020. Available from:

https://www.who.int/ipcs/publications/cicad/en/cicad44.pdf [Accessed: 24 January 2020]

[51] Lombi E, Donner E, Scheckel K, Sekine R. Silver speciation and release in commercial antimicrobial textiles as influenced by washing. Chemosphere. 2014;(111):352-358. DOI: 10.1016/j.chemosphere.2014.03.116

[52] Triclosan [Internet]. 2020. Available from: www.minddisrupted.org [Accessed: 24 January 2020]

[53] McGinnis D. Toxicological Profile of Triclosan in the Aquatic Environment. Department of Marine and Environmental Systems Florida Institute of Technology Melbourne; 2008

[54] European Commission, Health and Consumer Protection Directorate-General, Scientific Committee on Consumer Products Opinion on Tirclosan [Internet]. 2009. Available from: https://ec.europa.eu/health/sites/health/files/scientific_committees/consumer_safety/docs/sccs_o_023_note.pdf [Accessed: 24 January 2020]

[55] Minnesota Department of Health, Drinking Water Contaminants of Emerging Concern Program, Triclosan Exposure and Toxicity Summary. 2010

[56] Orhan M, Kut D, Güneşoğlu C. Use of triclosan as antibacterial agent in textiles. Indian Journal of Fibre and Textile Research. 2007;**32**(1):114-118

[57] Australian Government Department of Health and Ageing NICNAS, Priority Existing Chemical Assessment Report Triclosan [Internet]. 2009. Available from: https://www.nicnas.gov.au/chemical-information/factsheets/chemical-name/triclosan [Accessed: 24 January 2020]

[58] Triclosan Toxicity [Internet]. 2020. Available from: http://www.beyondpesricides.org/pesticides/factsheets/Triclosan%20cited.pdf [Accessed: 24 January 2020]

[59] Weatherly LM, Gosse JA. Triclosan exposure, transformation, and human health effects. Journal of Toxicology and Environmental Health, Part B: Critical Reviews. 2017;**20**(8):447-469. DOI: 10.1080/10937404.2017.1399306

[60] Cowan MM. Plant products as antimicrobial agents. Clinical Microbiology Reviews. 1999;**12**(4):564-582. DOI: 10.1128/CMR.12.4.564

[61] Holme I. Finishes for Protective and Military Textiles [Internet]. 2005. Available from: https://www.tib.eu/en/search/id/tema%3ATEMA20050605954/Finishes-for-protective-and-military-textiles/ [Accessed: 24 January 2020]

[62] Son YA, Kim BS, Ravikumar K, Kim TK. Berberine finishing for developing antimicrobial nylon 66 fibers: Exhaustion, colorimetric analysis, antimicrobial study, and empirical modeling. Journal of Applied Polymer Science. 2007;(103):1175-1182. DOI: 10.1002/app.25364

[63] Gupta D, Khare SK, Laha A. Antimicrobial properties of natural dyes against gram-negative bacteria. Coloration Technology. 2004;**120**(4):167-171. DOI: 10.1111/j.1478-4408.2004.tb00224.x

[64] Han S, Yang Y. Antimicrobial activity of wool fabric treated with curcumin. Dyes and Pigments. 2005;**64**(2):157-161. DOI: 10.1016/j.dyepig.2004.05.008

[65] Giri Dev VR, Venugopal J, Sudha S, Deepika G, Ramakrishna S. Dyeing and antimicrobial characteristics of chitosan treated wool fabrics with henna dye. Carbohydrate Polymers. 2009;**53**(2):646-650. DOI: 10.1016/j.carbpol.2008.09.003

[66] Hobson DK, Wales DS. Green colorants. Journal of the Society of Dyers and Colourists. 1998;**114**(2):42-44. DOI: 10.1111/j.1478-4408.1998.tb01944.x

[67] Alihosseini F, Ju KS, Lango J, Hammock BD, Sun G. Antibacterial colorants: Characterization of prodiginines and their applications on textile materials. Biotechnology Progress. 2008;**24**(3):742-747. DOI: 10.1021/bp070481r

[68] Joshi M, Ali SW, Rajendran S. Antibacterial finishing of polyester/cotton blend fabrics using neem (*Azadirachta indica*): A natural bioactive agent. Journal of Applied Polymer Science. 2007;**24**(3):793-800. DOI: 10.1002/app.26323

[69] Haufe H, Muschter K, Siegert J, Böttcher H. Bioactive textiles by sol–gel immobilized natural active agents. Journal of Sol–Gel Science and Technology. 2008;**45**(1):97-101. DOI: 10.1007/s10971-007-1636-5

[70] Boh B, Knez E. Microencapsulation of essential oils and phase change materials for applications in textile products. Indian Journal of Fibre and Textile Research. 2006;**31**(1):72-82

[71] Thilagavathi G, Bala SK, Kannaian T. Microencapsulation of herbal extracts for microbial resistance in healthcare textiles. Indian Journal of Fibre and Textile Research. 2007;**32**(3):351-354

[72] Islam S. Butola BS. Nanomaterials in the Wet Processing of Textiles. ABD: Scrivener Publishing; 2018. ISBN: 978-1-119-45984-2

[73] Textile Industry and Environment [Internet]. 2020. Available from: https://www.greenofchange.com/textile-pollution [Accessed: 17 February 2020]

[74] Rovira J, Domingo J. Human health risks due to exposure to inorganic and organic chemicals from textiles: A review. Environmental Research. 2019;**168**(1):62-69. DOI: 10.106/j.envres.2018.09.027

[75] Reshma A, Priyadarisini B, Amutha K. Sustainabel antibacterial finishing of fabrics using natural bioactive agents—A review. International Journal of Life Science and Pharma Research. 2018;**8**(4):10-20. DOI: 10.22376/ijpbs/lpr.2018.8.4.L10-20