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Remedial Measures for Microfiber Mitigation in the Environment: A Review

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Abstract

The escalating usage of household laundry machines among city dwellers significantly contributes to the contamination of the environment due to fiber release. Microfibers and laundry discharge find their way into sewage systems adjacent to rivers and oceans, eventually resulting in marine pollution. Once emitted, these minuscule particles spread widely throughout the sea because of their low molecular mass. Raising public consciousness initiatives and enhanced training regarding nanofiber pollution during the laundering process will effectively raise social awareness about nanofiber release. This review delves into the mitigation strategies and techniques for the identification and characterization of microfibers.

Keywords: Microfibers; Pollution; Laundry; Techniques; Mitigation; Strategies; Artificial

Introduction

The clothing sector operates as a constantly shifting sector, given that the desires and demands of buyers frequently fluctuate. The rapidly evolving vogue and aesthetics requisites consistently seek innovative primary materials and recent items. This turns into a primary concern when contemplating eco-friendly material fabrication. Conversely, eco-friendliness revolves around the durability of a product and extending the material's lifespan to the utmost degree [1]. In the current era of speedy fashion prevailing in the textile industry, items are crafted for a briefer life span and limited utilization. The industry primarily prioritizes the quantity of products introduced in a season over the product's excellence. During utilization, the unleash of nanofibers transpires while wearing, primarily during the laundering method. These fragments possess minuscule structures and are impervious to traditional filtration units. These nanofibers floating in aquatic environments are frequently mistaken for sustenance by diminutive organisms. From these microorganisms, there exists the potential for these nanofibers to be ingested by humans *via* the food web. The initial investigation into the release of nanofibers from fabrics was carried out by Browne and co-authors [2]. While examining nanoplastic particles in coastal waters worldwide, they discovered that nanofibers were the primary cause of nanoplastic pollution. Polymeric and synthetic fibers emerged as the primary nanofiber varieties contributing to nanoplastic pollution. Man-made fabric nanofibers are unleashed from the fabric during the manufacturing, utilization, and discard phases (Figure 1) [3]. While employing laundry detergents, scientists assessed the release of nano fabrics and stated the release of fabric ranging from 124 to 308 milligrams per kilogram of laundered textile and the associated tally signifies a range extending from 640,000 to 1,500,000 nanofibrils [4]. The latest studies by marine researchers from Flinders university shed light on the elevated nanofiber concentration in Naifaru, situated in the mid-Indian ocean. This area, which boasts an estimated population count of 5,408 exhibited microplastic levels ranging from 55 to 1127.5 nanoplastic particles per kilogram of deposition. This notably surpassed previously documented levels in densely populated areas in Tamil Nadu, which ranged from 3 to 611 microplastic particles per kilogram. Furthermore, particulate matter from deserted islands also disclosed a heightened proportion of microplastic particles, varying from 197 to 822 microplastics per kilogram [5]. Among various nanofiber pollution sources, domestic washing has emerged as the primary contributor due to inadequate rules and inappropriate polluted water management. Presently, limited research exists on measures to control nanofiber pollution.

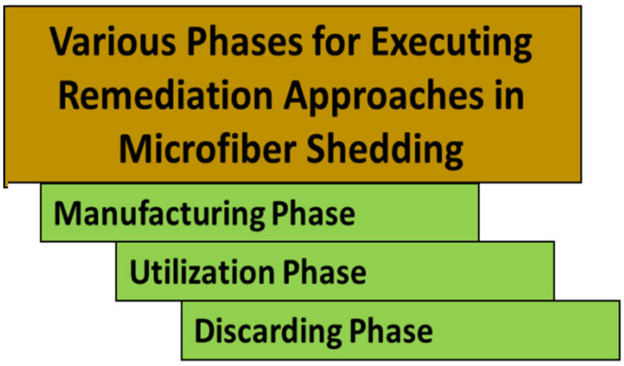

Figure 1: Various phases for executing remediation approaches in microfiber shedding.

Literature Review

Identification and remediation techniques for microfiber pollution

Understanding the channels through which these contaminants propagate is crucial for effective treatment and resolution. Given the challenges associated with the entry and circulation of these minuscule contaminants from aquatic environments to humans, as well as their impact on human health, these are primary research areas that warrant investigation in the years ahead. Employing sustainable methodologies allows for the assessment and exploration of the harmful consequences of these contaminants, particularly in regions marked by extraordinary irregularities. The recurring presence of large amounts of artificial nanofiber particles poses a considerable challenge to control, and their quick dissemination disrupts worldwide ecological trophic stages. Various methods for identifying and characterizing man-made nanofibers and other harmful contaminants infiltrating the ocean are of paramount importance. Researchers are exploring cutting-edge visual, spectral, and molecular-scale technologies to effectively detect nanofibers. Both Raman and Fourier Transform Infrared (FTIR) spectroscopy have been employed for the rapid identification of nanofiber. In the latest investigation, microfibers were identified using FTIR in the stomach and intestines of fish specimens from examination of subtropical gyres. Alternative methods for identifying nanofibers in specimens of water involve the use of a specially designed net known as the Manta net, which gathers fibrils from the surface layer of the seas and rivers *via* a 30-mesh sieve [6]. Thorough structural examination and inspection of the surface characteristics of separate nanofibers can be conducted with a stereoscopic microscope and electron beam microscope. Addressing artificial microfiber release necessitates a concentration on the following: Rigorous governmental mandates, public awareness initiatives, and advancements in technology for effective elimination and mitigation.

Scientists are persistently exploring new microbes obtained from bacteria strains capable of breaking down specific polymer materials. However, it is equally crucial to determine how these enzymes can be deployed without adverse side effects. The bioaugmentation of nanofibers with microorganisms can demonstrate effectiveness only when ecological factors are conducive to bacterial proliferation and their functions. Microfiber marine contamination has presently become incredibly widespread, making manual removal a formidable task. The latest research merges optical techniques with more advanced structural and physiochemical analysis methods like Raman and FTIR spectral techniques. Raman and FTIR analysis methods assist in mitigating issues related to the misrecognition and undervaluation of nanofibers linked with primary recognition and verification through optical microscopy. In the scientific study conducted by Ding and co-authors to identify plastic materials in indigenous ocean fauna, plastics were examined and classified using electron beam microscopy [7]. These microplastics displayed diverse forms, comprising pieces, strands, particles, and sheets with sizes spanning from 57 to 8639 micrometers. Notably, plastic fiber materials measuring below 1 mm in length were prevalent and constituted the majority, comprising approximately 70% of the overall plastics found in various marine organisms. In the latest research, man-made microfibers within planktonic animal specimens from Charleston Harbor coastal convergence areas were identified and analyzed using fluorescence and visible-light microscopy. The observed microfibers ranged in diameter from approximately 43 to 104 micrometers [8]. FTIR analysis is an economical method employed to scrutinize the source and constitution of man-made textiles within a specimen. It provides insight into the precise atomic linkages present in the specimen, making the identification of polymeric materials quite straightforward. In the pursuit of detecting and analyzing artificial nanofibers within the digestive tracts of six industrially significant fish species from Central Chile, high-magnified FT-IR analysis and light microscopy were utilized. The nanofibers ranged in diameters from approximately 176 to 2842 mm and were predominantly detected as polyethylene, polyester, and polyethylene terephthalate [9].

Mitigation strategies

Manufacturing phase: Coating of synthetic fibers: Fibrous materials are identified as the primary origin of fiber release. Addressing this issue anticipatively involves changing or transforming these materials. Surface modification of fibrousmethod in fiber production, plays a crucial role in imparting both fashion and utility to materials. The surface modification methods can be done either chemically or mechanically. Surface modification by chemical method, especially, has a notable impact on minimizing fiber pollution [10-11]. In surface modification by chemical method, textile modifiers are evenly applied on the material surface using water as a solvent. Successive drying and setting methods eliminate the water, leaving a layer of textile modifiers on the fabric surface. This coating is believed to affix the textiles and avoid their sliding and separation.

e Falco and co-authors undertook an initiative to minimize fiber release from the surface of polyamide by employing a biopolymer *i.e.*, pectin [12]. To facilitate the efficient use of pectin on polyamide, researchers altered the pectin structure with glycidyl methacrylate. Subsequently, the pectin-methacrylate composite was incorporated onto the polyamide surface. The primary objective behind the structure of pectin alteration was to minimize pectin's hydrophilicity which is a crucial aspect in fabric processing. These modifications efficiently contributed to minimizing the microfiber release from the fabric. To sum up, when opting for treatments to minimize fiber release, it's essential to consider the sustainability of the selected coating, the compatibility of the finishing agent with the fabric, the specific operating conditions (Table 1), and the preservation or enhancement of the textile's favorable characteristics. While many studies have focused on parameters such as the kind of washing machine employed and fabric deterioration on the microfiber release, more research is needed on different parameters such as textile kind, textile manufacturing, and coating methods to draw exact findings. Liu et al. recommended further investigation to gain insights into the characteristics, origins, and impacts of nanofibers in the ecosystem, and also underscored the significance of nanofibers on the long-term viability of the fabric and clothing industry as the primary domain necessitating additional comprehensive research [13]. The advancement and adoption of environmentally conscious bio textiles and renewable biomaterials, along with the utilization of naturally sourced and renewed textile resources, represent the primary avenues to address nanofiber release in the emerging trends of the apparel and clothing sectors. The structural characteristics of thread and textile including the ratio of various fibrous materials, the number of fibers per meter length, size of the fiber, thread rotation, fiber compactness, yarn thickness, weave pattern repetition, and mass of fiber/m^2 will impact the fiber's inhibition to balling and wear. The strategy for managing materials and effluents must integrate sustainable guidelines and provide initiatives for upcycling, dismantling, and the development of long-lasting patterns in certain emerging nations that serve as the primary hubs for fabric and apparel production and export.

Kind of laundry machine	Temperature	Time	Frequency of wash cycles	Washing liquid	Conditioner

Kind of laundry machine	Temperature	Time	Frequency of wash cycles	Washing liquid	Conditioner
-	With temperature rise, microfiber shedding rises	-	Minimization in fiber release in initial 4 wash cycles	Fiber release rises with the use of organic wash liquid	No influence of softener/conditioner
Upper-loading washing machines result in more fiber release than face-loading washers	-	-	-	-	-
Drying causes 3.5 times more fiber release than washing	-	-	Lowering in fiber shedding in following wash cycles	No influence	No influence
-	-	No influence	-	Rise in microfiber release with the use of washing liquid	-
Lab washing machine results in smaller fiber release than household washing machine	A rise in temperature increases fiber release	-	-	Increase microfiber release	-
-	-	-	Microfiber release lowers in 1 to 5 wash	-	-
-	-	-	Microfiber release lowers in the following wash cycles	-	-

Table 1: Influence of different washing conditions on fiber release.

Enhancing decomposability of textile materials: The decomposability of fabrics plays a crucial role in identifying the extent of their negative impact on the surroundings. Enhancing the biodegradable ability of fabrics can reduce their persistence in the surroundings. It has been observed that the virgin fabrics' rapid breakdown lessens their environmental influence, making fiber release less concerning in textiles crafted from organic fiber materials. This broadens the strategy for eliminating fiber release to changing the decomposability of fabrics [14]. It's important to note that the decomposability of natural fabrics can be modified during processing methods such as cloth dyeing and surface treatment. The research conducted by Lykaki and co-authors highlighted that the degradability of viscose fibers can be hindered by the application of industrial antibacterial coating (RUCO-BAC HAS CONC) in comparison to untreated samples. The bonding between antibacterial coating and viscose fiber hampers the interplay between microorganisms and viscose, leading to decreased biodegradation [15]. Other research endeavors have also noted alterations in the decomposability of cotton in the starting levels during various finishing agents like silicone conditioner, wrinkle-free treatment, hydrophobic, and a fiber-reactive colorant [16]. Therefore, when proposing fabric finishing to meet operational properties, it's essential to balance and consider decomposability. In situations involving man-made fabrics, which are inherently non-decomposable, there exists the opportunity to enhance biodegradability. Consequently, enhancing the decomposability of artificial fabrics stands as a promising method to mitigate the environmental effects of fibers. The degradability rate of artificial fabrics can be modified by altering the fabric during the extrusion process while preserving the fabric's favorable characteristics. However, these alterations should not have adverse effects, and caution must be exercised in this regard. Additionally, enhancing the degradability of fabrics only delays their persistence, without mitigating their overall environmental impact. Fabrics with enhanced decomposability can still act as carriers of pollutants over their lifespan. Similar to virgin and reprocessed fabrics that emit adhered contaminants into the surroundings, these fabrics also contribute to environmental pollution. This approach may minimize the duration of the effect from man-made fabrics, but it represents only a tiny effort in decreasing their overall ecological footprint [17].

Results and Discussion

Utilization phase

Employment of laundry aids: The employment of laundry agents, primarily detergents, adversely affects microfiber pollution as it expedites the release of fibers from the material surface [18]. Conversely, fabric softeners frequently employed laundry agents to maintain textile softness and reduce wrinkles have shown a favorable impact in regulating fiber release during laundering [19]. Researchers recommend incorporating conditioners at the time of the washing process instead of post-washing. Both the processes of conditioner application (during and post-laundering) contribute to fabric smoothness and desired texture. However, integrating softeners in the washing process notably enhances the minimization of fiber release. The critical factor to consider with the utilization of conditioners is their chemical constituents, which are non-decomposable and consequently, influence the surroundings. The promotion of eco-friendly softening agents should be encouraged, and their efficiency in reducing fiber release should be assessed when contemplating their use as a viable method. Specifically innovative products in this area constitute Microfiber-catching bags, Cora balls, LUV-R filter systems, eco-friendly filtration systems, and several others. These innovative products effectively capture fibers released from artificial fabrics, which can further be recovered from them. These innovative products can be categorized into two main groups: Internal tools and outer filtration systems. Internal tools are utilized inside the laundry machine, whereas outer filtration systems are affixed to the drain pipe of the laundry devices. Wash bags and Cora balls are examples of internal tools that have proven to be efficient in managing fiber release.

Research endeavors examined the effectiveness of Cora balls when laundering different man-made fabrics such as acrylic, polyester, and poly-cotton fabrics. The results demonstrated a 31 ± 8% decrease in fiber presence in the wastewater [20]. Another intriguing aspect of Cora balls is their ability to curtail fiber shedding from the surface of textiles when laundering, in addition to trapping released threads. However, some drawbacks are associated with these balls. Post-use, the threads entrapped in the balls need elimination, and the balls must be rinsed before the subsequent wash cycle, which can be cumbersome due to threads becoming entwined in the ball's elastic framework. Secondly, the washing bag, serving as an internal laundry product, operates differently from Cora balls in terms of usage. With Cora balls, they are just placed inside the washing machine drum, whereas when employing washing bags, fabrics are first placed within the bags and then placed inside the laundry drum. Consequently, fibers released from the artificial textiles are captured at the edge of the laundry bags, avoiding their release into the laundry discharge.

Washing bags and fourth element laundry bags are distinct washing carriers crafted from nylon fibers and equipped with zip locks. These bags feature small pores measuring 50 µm in size. The nylon fibers utilized in the laundry bags were kept natural and uncolored, ensuring their freedom from any additional supplements. Despite the micropore diameter being 50 µm, these washing bags effectively capture threads thinner than 10 µm. These washing bags are recommended for utilize till a temperature of 40°C and are thus not appropriate for washes with temperatures exceeding 40°C. Additionally, since these washing bags are crafted from artificial nylon fibers, they are prone to microfiber pollution. Moving on, another significant group of laundry additives comprises filter systems (Table 2). These washing filters are typically affixed to drain pipes, capable of sieving threads from the wastewater and discharging contaminants with some threads into drainage networks. Various washing filters designed to trap fibers have been commercialized, such as LUV-R filter systems, XFiltra™, Filtrol 160™, and PlanetCare filter systems. The fundamental idea behind these laundry filter systems are straightforward: The wastewater discharge is directed through these washing filters, which aim to trap and hold fibers, ultimately leading to some or no fibers being discharged into the surroundings. PlanetCare Filters represent a type of outer filtration system, demonstrating a notable efficiency of 25% of fibers in the wastewater, as documented in the study by Napper and co-authors [21]. These filter systems have been documented to trap threads spanning from 50 µm to 5 mm in length. Notably, these cartridges can be sent back to the producers after 20 wash cycles. The producers are responsible for washing the cartridges, and ensuring they are ready for subsequent use. This process guarantees the proper removal of microfibers accumulated in the filter systems. The girlfriend collective is another filtration system composed of a metal grid with a pore diameter of 200 µm. According to the producer, these filter systems can trap fibers as tiny as 0.072 mm. Studies suggest that a collective approach, utilizing both internal drum aids and outer filtration systems can enhance microfiber shedding efficacy.

Fabric type	Laundry device	Washing parameters	Filtration system	Quantification
Pure polyamide 6.6 Pure acrylic Poly polyester Polyester-cotton blend (65/35 %)	Linitest device	UNI EN ISO 105-C12 for commercial laundering and UNI EN ISO 105-C06 for household laundering	Fluoropolymer filtration of pore diameters 0.1 µm, 0.2 µm, 5 µm	Calculating
Pure polyacrylic Pure polyamide Pure polyester fur jacket	Whirlpool laundry machine	Time: 75 min, Rotation: 1400 rpm	Microporous nylon filter of pore diameter 25 µm	Measuring
Polyester fur jacket	Laundry machines (both load)	Upper load configuration: Temp-29.6°C, Time: 30 min, face load configuration: Temp: 29 to 41°C, Time: 24 min, Speed: 1200 rpm, No utilization of wash liquids	Nylon filament filtration system (333 µm and 20 µm)	Measuring
Puff blankets	Laundry machine (front-facing)	Time: 15 min, Temp: 30°C, Rotation: 600 rpm, wash liquids and conditioners employed	Steel filtration unit (200 µm × 200 µm)	Measuring

Table 2: Different filters employed in laundry devices.

Discard phase

Wastewater management facilities: Wastewater purification strategies serve as a broad-level method to eliminate the shedding of fibers from household washing discharge. The primary goal of these polluted water management facilities is to eliminate potential contaminants from water before it is discharged into the surroundings. Depending on their specific use, these polluted water treatment facilities can be categorized as wastewater treatment facilities, household discharge treatment facilities, and clean water purification facilities. Modifying household discharge treatment facilities can effectively lower the dispersion of fibers from household washing into the surroundings. Similarly, the adaptation of polluted water treatment facilities in the fabric manufacturing sector can help regulate the shedding of fibers occurring during the production of apparel. These management facilities are efficient in trapping tiny plastics, achieving a removal rate of up to 98%. However, due to the vast amount of polluted water processed, a substantial number of plastics still manage to enter the surroundings, especially through wastewater [22,23]. Scientists have meticulously examined various segments of sewage treatment facilities and interfered specifically in the part before the drainage pipe, precisely between the purification phase and the ultimate disposal. Comprehensive evaluations encompassing the component selection, production method, product evaluation, price considerations, and comprehensive examination within renewable and stable structures should be conducted. The sewage treatment facility holds promise in terms of trapping fibers. A primary challenge faced by these facilities revolves around the substantial amount of wastewater being processed, leading to a considerable release of fibers into the surroundings. Additionally, the subsequent impacts of these treatment facilities raise significant concerns. Zhang and co-authors have documented that treatment plant residue could introduce 4,010,000 kg per year of plastic particles into land habitats in the United States [24]. Additionally, Petroody and co-authors asserted the presence of 129 to 238 plastics per gm of residue from sewage treatment plant facilities [25]. Furthermore, these treatment plant residues are frequently employed as fertilizing agents, transporting these plastic particles to farmlands. Therefore, it is imperative to devise comprehensive strategies for wastewater effluent management to enhance the effectiveness of sewage treatment facilities (Figure 2).

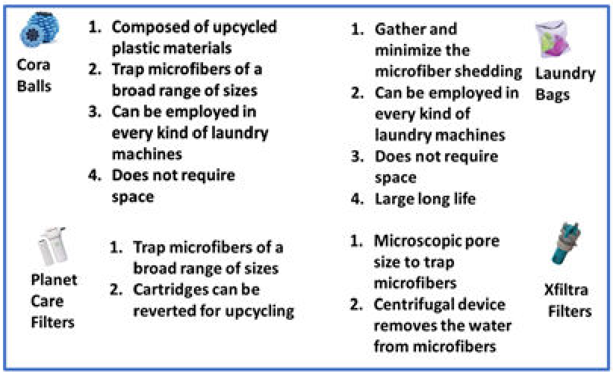

Figure 2: Advantages of different washing products.

Conclusion

This review provided valuable knowledge about potential methods for addressing fiber release. These solutions span different stages and levels of the process. In the manufacturing phase, alterations to fabrics have been proposed. These changes can either minimize microfiber release or enhance the degradability of man-made textiles. During the utilization stage, specifically during garment washing, the use of laundry aids has been observed to potentially minimize microfiber shedding. It emphasized the importance of public consciousness and government initiatives, as these are vital. Government entities should enhance the integration of sellers, wastewater purification facilities, and laundry machine producers to take a leading role in addressing the issue of fiber release. During the discard phase, wastewater purification strategies are explored. This comprehensive overview provides in-depth knowledge of the continuing research efforts aimed at tackling microfiber pollution.

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Conflict of Interest

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