ZERO WASTE FASHION

WHAT HAPPENS TO MY OLD CLOTHES?

REUSE

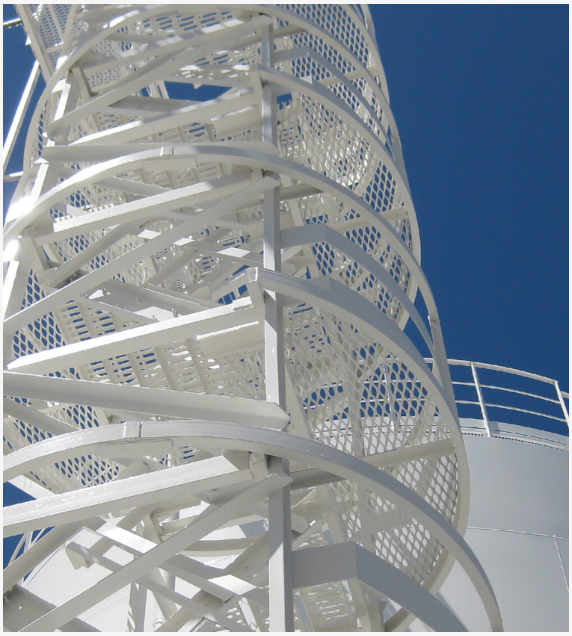
Garments are used in their entirety. The garments are not cut up or amended but sold on ‘as is’. They may be resold through vintage fairs or charity shops or they may be put into fashion ‘lending libraries’.

UPCYCLING

A garment may be amended, restyled, or made into a product completely unrelated to clothing. The energy and resources spent in making the garment is maintained intact.

RECYCLING

Garments are dismantled into their constituent parts or elements to form the raw materials for another industrial process. Garments and textiles made of woven fabric are either put through a mechanical process of cutting and shredding or put through chemical treatments to form fibres that may be put into the spinning process again or into a nonwovens process.



PYROLYSIS

Pyrolysis takes place between 350˚C-600˚C in the presence of a catalyst (such as nitrogen). The outputs of this thermal decomposition are: heat, a combustible liquid and combustible gas and char (carbon black). Pyrolysis is often followed by gasification.

GASIFICATION

Heat of over 700^{0}C – 1200^{0}C is applied to carbon rich materials with the presence of a small amount of oxygen and steam as a catalyst to produce carbon monoxide, hydrogen and carbon dioxide. Combustion of the gases results in power which is used as a source of energy, eg to power electricity generators.

REUSE

Recycling of vat and reactive dyed textile waste to new colored man-made cellulose fibers

Haslinger, S., Wang, Y., Rissanen, M., Lossa, M.B., Tanttu, M., Ilen, E., Määttänen, M., Harlin, A., Hummel, M. and Sixta, H. 2019. Recycling of vat and reactive dyed textile waste to new colored man-made cellulose fibers. *Green Chemistry, 21*(20), 5598-5610

The successful recycling of colored textile waste and reuse of respective dyes would represent a major milestone of global efforts to reduce the environmental impact of the textile industry. The chemical upcycling of dyed pre- and postconsumer cotton waste is promoted by studying the spinability and color fastness of seven vat and reactive dyes (i.e. Indanthren Blue BC 3%, Indanthren Red FBB coll, Indanthren Brilliant Green FBB coll, Levafix Brilliant Red E-4BA, Levafix Blue E-GRN gran, Remazol Brilliant Blue R spec, and Remazol Black B 133%) during dry-jet wet spinning. Apart from the fabrics dyed with Levafix Brilliant Red E-4BA, all samples dissolved in 1,5-diazabicyclo[4.3.0]non-5-ene actetate, a superbase based ionic liquid, and could be converted to new colored man-made cellulose fibers. It was found that there is a clear discrepancy between the recyclability of dyed pre- and postconsumer cotton waste, resulting in significantly higher fiber properties up to tenacities of 59.8 cN/tex and elongations of 13.1% in case of the latter. All recycled fibers displayed a noticeable color change in the CIELab space (Δ E = 8.8–25.6) throughout the spinning process. Despite these deviations, almost all fibers and demo fabrics produced thereof exhibited bright colors that can be reused in textile industry. Only Remazol Black B 133% did not sufficiently translate to the new textile product. The wash and rubbing fastness of the fabrics knitted from the regenerated fibers was superior to the dyed waste fabrics mainly because of the homogenous distribution of the dyes along the fiber cross-section.

Model of industrial textile waste management

Rapsikevičienė, J., Gurauskienė, I., Jučienė, A. 2019. Model of industrial textile waste management, Environmental Research, *Engineering and Management, 75*(1), 43-55

Manufacturing of textile and apparel contributes depletion of water resources, the use of natural resources, the release of water and air pollution and increasing the amount of waste entering landfills. Industrial textile waste represents nearly half of the whole flow of textile waste. Major part of the industrial textile waste is landfilled, because of the lack of technologies and infrastructure for recycling. The practice of mixing all the textile cuttings at

the apparel production companies, leads to the challenge for reuse or recycling of the leftovers.. Textile companies are obliged to look for alternative waste management options in order to meet the requirements and challenges of Circular Economy action plan published by the European Commission. This article represents the model created for the analysis of industrial textile waste flows and development of scenarios for reasonable waste management. The model and methodologies involved are oriented to preventive solutions –The evaluation of the efficiency of the model is based on sustainability indicators which represents the effect of the scenarios for environmental, economic and social aspects. The implementation of the model to the case study of Lithuanian apparel production company, have disclosed that improvements at the industrial textile waste management within the company, could lead to the increase of efficient use of resources (three times) and environmental impact (twice).

Recycling of vat and reactive dyed textile waste to new colored man-made cellulose fibers

Haslinger, S., Wang, Y., Rissanen, M., Lossa, M.B., Tanttu, M., Ilen, E., Määttänen, M., Harlin, A., Hummel, M., Sixta, H. 2019. Recycling of vat and reactive dyed textile waste to new colored man-made cellulose fibers, *Green Chemistry, 21*(20), 5598-5610

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Review of wool recycling and reuse

Russell, S., Ireland, A. 2016. Review of wool recycling and reuse, *RILEM Bookseries, 12*, 415-428

The clothing and textile industry forms a considerable part of the world's economy. Of the more than $1 trillion sales of clothing worldwide, roughly two thirds is consumed in Western Europe and North America (University of Cambridge 2007). In addition to high-street products purchased directly by consumers, clothing is also consumed in the form of workwear, uniforms and corporate apparel distributed by brand owners and employers. Once this clothing is discarded by its user the main End of Life (EoL) options are in descending order of resource efficiency: (a) Reuse—garments worn again after donation and/or re-sale; (b) Closed loop recycling—garments used as raw materials for the manufacture of new products of similar value; (c) Open loop recycling—garments used as raw materials to manufacture industrial products of lower value; (d) Incineration—thermal energy generation; (e) Landfill. This chapter focuses on the collection, recycling and reuse of wool garments with particular emphasis on mechanical recycling in open and closed loop systems.

Apparel disposal and reuse

Lewis, T. 2015. Apparel disposal and reuse, *Sustainable Apparel: Production, Processing and Recycling*, 233-250

The fate of clothing at the end of its life cycle has become increasingly burdensome and complicated with the growth of mass production and multinational retail firms enabling the rapid delivery of fashionable items on a global scale to a trend-driven industry. The imbalance of consumption and disposal often pushes the overconsumption of developed nations into the markets of lesser-developed countries. To understand the context of apparel reuse and disposal, an examination of the global supply chain for apparel production and consumption is necessary because apparel is discarded at different points along this chain. Charitable organizations such as Oxfam, Goodwill, and the Salvation Army may be the first point of collection for unwanted clothing, but other for-profit organizations have entered the market for clothing collection in an effort to meet the market demands of a global trade in used clothing. Once the used garments enter a new market with new consumers it cannot be assumed that this is a sustainable solution to end-of-life management. Consideration of the impact of the used garment once it passes on to a new market should be factored into part of its life cycle. Demand for used clothing is slowing in some developing nations due to low-cost imports of new clothing or import restrictions. Therefore, developed nations will have to generate more alternatives for reuse in their own countries in order to prevent direct disposal of used clothing into waste streams.

Sustainable waste management strategies in the fashion industry sector

Dissanayake, G., Sinha, P. 2013. Sustainable waste management strategies in the fashion industry sector, *International Journal of Environmental Sustainability, 8*(1), 77-90

Textile waste can be either pre-consumer or post-consumer. In recent years, postconsumer textile waste has gained increased attention, both within the industry and academia, due to environmental concerns. The emergence of fast fashion culture and the throwaway attitude of consumers build up mountains of unwanted fashion clothing disposed of in landfill sites. This paper analyses recycling, reusing and refashioning as three alternative strategies for waste management in the fashion industry sector. Based on empirical data collected by using a multiple case study approach, the paper discusses the concept of each strategy, and associated sustainability impacts of employing each strategy in practical terms. Suggestions are provided on the development of waste diversion programs and sustainable business models for the developing economies.

Reuse and recycling of textile solid wastes

Adivarekar, R.V., Pisal, S. 2009. Reuse and recycling of textile solid wastes, *Journal of the Textile Association, 70*(3), 118-126

Due to increased awareness and strict laws, disposal of waste is strictly avoided through the use of recycling technologies. The most practical way to reduce pollution is to reuse and recycle the waste several times before it is discarded. Though textiles are nearly 100% recyclable, in reality, the rate of recycling in textiles, both preconsumer and postconsumer is not very high. This paper sheds light on the recycling industry, on the scope of recycling the textile solid waste through various mechanical and chemical processes and also recycling from an energy saving perspective. The importance of the recycling behavior through the micro and macro approach is also emphasized.

Recycling of waste PET into useful textile auxiliaries

Shukla, S.R., Harad, A.M., Jawale, L.S. 2008. *Recycling of waste PET into useful textile auxiliaries, Waste Management, 28*(1), 51-56

Polyethylene terephthalate (PET) waste fibers were initially depolymerized using a glycolysis route in the presence of sodium sulfate as a catalyst, which is a commonly used chemical and ecofriendly as compared to heavy metal catalysts. Good yield of the pure monomer bis(2-hydroxyethylene terephthalate) (BHET) was obtained. Further, to attempt its reuse,

the purified BHET was converted to different fatty amide derivatives to obtain quaternary ammonium compounds that have a potential for use as softener in the textile finishing process. The products were characterized by infrared spectroscopy. Application of these synthesized compounds was carried out on cotton fabric; they were evaluated for performance and were found to give good results. The chemicals used during depolymerization and reuse of PET are inexpensive and comparatively less harmful to the environment, and thus offer advantages in the chemical recycling of polyester waste fibers.

Carpet recycling: Determining the reverse production system design

Realff, M.J., Ammons, J.C., Newton, D. 1999. Carpet recycling: Determining the reverse production system design, *Polymer-Plastics Technology and Engineering, 38*(3), 547-567

Roughly 4 billion pounds of carpet are disposed of in the United States each year. This carpet is composed of a significant fraction of nylon, polypropylene, and polyester fiber. A key limiting factor to recycling is effective design and development of the reverse production system to collect and reprocess this large volume of valuable material. A reverse production system is composed of material and chemical recycling functional elements interconnected by transportation steps. In this article, we develop a mixed-integer programming model to support decision-making in reverse production system design. To illustrate its use and applicability, we apply the model to a representative U.S. carpet recycling industrial case study. The overall economic feasibility of recycling is strongly dependent on the volumes that can be expected from investments in collection infrastructure. The geographic location of processing centers influences the network economics, and the subdivision of recycling tasks to avoid the shipment of low value material is proposed as an effective strategy for carpet recycling.

UPCYCLING

Eco-fabrication of antibacterial nanofibrous membrane with high moisture permeability from wasted wool fabrics

Zhong, X., Li, R., Wang, Z., Wang, W., Yu, D. 2020. Eco-fabrication of antibacterial nanofibrous membrane with high moisture permeability from wasted wool fabrics, *Waste Management, 102*, 404-411

Wasted wool fabrics are a kind of textile waste source and the upcycle of them can not only benefit the environmental protection, but also turn waste into treasure by developing other potential applications. In this work, ionic liquid (IL) 1-butyl-3-methylimidazolium chloride ([Bmim]Cl) was used as a green solvent to upcycle wasted wool fabrics into a wool keratin (WK)/IL/polyacrylonitrile (PAN) composite nanofibrous membrane with good antibacterial and high moisture permeability through electrospinning. The morphology and structure of the regenerated nanofibrous membrane were characterized by Scanning Electronic Microscopy (SEM), Energy Dispersive Spectrometer (EDS), Fourier Transfer Infrared Spectroscopy (FTIR). The antibacterial test demonstrates that it has 89.21% inhibition rate against E. coli, and 60.70% against S. aureus. Furthermore, the keratin containing in the membrane can effectively improve the hydrophilic property of it, as Moisture Management Test (MMT) indicates that it performs an excellent wetting performance and water transport property. In addition, IL is supposed to be recycled from the composite membrane through immersing in distilled water, which makes the fabrication process green and sustainable.

Development of new treatment methods for multi material textile waste,

Jenull-Halver, U., Holzer, C., Piribauer, B., Quartinello, F. 2020. Development of new treatment methods for multi material textile waste, *AIP Conference Proceedings, 2205*

The EU's new circular economy directive presents a substantial challenge for the polymer processing industry, in the course of which this study has been initialized. The aim is to upcycle textile waste from various sources and to produce textiles again or technical parts from the recycled material with a high demand on mechanical and thermodynamic properties. In this study several textile waste streams were examined. There were two waste streams from home textiles (towels, bed sheets, etc) and one waste stream from industrial textiles (sieves and felts for paper and cement industry). The home textiles are a

blend of ~50 wt.% polyethylene terephthalate (PET)-fibre and ~50 wt.% cotton fibre. One central task of this study was to develop an enzymatic process to break down the cotton fibres and to retrieve the pure PET-fibres. In the following steps the gained PET fibres will be spun again to fibres and woven into towels, as in the original application. Additionally, the textiles will be tested according to oecotex. The second waste stream, three different polyamide (PA) and PA blends were tested for their suitability for injection moulding and spinning. These materials will be tested for selected products which have to comply with very high standards and are partially used in safety-critical applications.

Consumer interest in upcycling techniques and purchasing upcycled clothing as an approach to reducing textile waste

Bhatt, D., Silverman, J., Dickson, M.A. 2019. Consumer interest in upcycling techniques and purchasing upcycled clothing as an approach to reducing textile waste, *International Journal of Fashion Design, Technology and Education, 12*(1), 118-128

This study investigates the constructs of environmental concern, consumer creativity, and fashion consciousness and examines the relationships between these variables and consumer interest in learning upcycling techniques and purchasing upcycled clothing. Students (n = 120) at a Mid-Atlantic university were surveyed with an instrument created for the study using multi-item scales to measure each variable. Simple linear regression and multiple regression tests were run to measure the strength, direction, and significance of the hypothesised relationships. Results show a positive and significant relationship between interest in learning upcycling techniques with environmental concern and with consumer creativity, as well as between interest in purchasing upcycled clothing with environmental concern and with fashion consciousness. The findings can be used by brands selling upcycled apparel to successfully target creative, as well as environmentally and fashion-conscious, consumers to limit post-consumer textile waste.

"No Need for Nudism": Children's Clothing in the United States, 1940 to 1945

Mower, J.M. 2019. "No Need for Nudism": Children's Clothing in the United States, 1940 to 1945, *Dress, 45*(2), 173-181

This study explores the influence of World War II on the United States infant and children's clothing industries. Relying on the federal records of the Office of Price Administration's Apparel Enforcement Division, periodicals, extant objects, and photographs, this study concludes that general military requirements of textiles and a spike in births, coupled with federal wartime policies, resulted in shortages of infant and children's wear throughout the United States. Even with these shortages, consumers, mostly mothers, were expected to

make do. This study also explores the influence of war on infant and children's dress and strategies recommended to and employed by wartime mothers to upcycle worn-out clothes. The research sheds light on wartime culture and social expectations of mothers with a nation at war.

A slow fashion lab in Indonesia: mapping landscape of urgencies in developing countries

Murwanti, A. 2019. A slow fashion lab in Indonesia: mapping landscape of urgencies in developing countries, Landscape Architecture Frontiers

This article highlights the urgencies and challenges in interpreting slow fashion in Indonesia to join the global movement. The term "slow fashion" as technical production was never familiar in Indonesian society despite a slow process is an integrated part of Indonesia cultural heritage - especially in producing the textile craft practice and repairing clothing to the tailor. The term "slow fashion" as a modern lifestyle philosophy is totally a new thing in Indonesia. When this term was brought to develop exhibition by IKAT/eCUT Project Goethe-Institut in 2017, the biggest challenge was to map the fast fashion landscape and to explore the practice of this philosophy in Indonesia. This list of urgencies will highlight the realistic way to adapt the concept of slow fashion in the country. Since western fast fashion products are not massively occupying major Indonesian market, the parameter of counter must be slightly shifted into a contextual one. The term slow fashion then should be interpreted in a broader way than what has been set in the West, including extending the principle pillars to fit with Indonesia situation and context.

Redesign and upcycling - a solution for the competitiveness of small and medium-sized enterprises in the clothing industry

Cuc, S. and Tripa, S. 2018. Redesign and upcycling-a solution for the competitiveness of small and medium-sized enterprises in the clothing industry. *Industria Textila, 69*(1), 31-36

The paper aims to open a new field of research applicable to small and medium enterprises in the clothing industry, namely, the focus on new product design by increasing the efficiency of fabric use and recycling and a value chain perspective that concentrates on downstream in the chain. The main objective of this paper is to present how small and medium-sized enterprises (SMEs) in the clothing industry can achieve a competitive advantage by using a sustainable approach. This study provides useful solutions for understanding the product development processes for fashion to rethink reuse or upcycle the waste in the production stage. We propose a better connection between different links of the value chain: design, production, marketing to create fashion items so when possible, this waste to be used to make new products and highlights the advantages of implementing

this solution. Sustainable production can be a way of gaining a competitive advantage. This strategy can be successful by integrating the vertical value chain by strengthening the creative department, fashion design, and involvement in marketing and sales. In the clothing industry, the strategy of integrating design and retail can lead to a more flexible design process and, therefore, to an increased product performance.

Redesigning Fashion: An Analysis and Categorization of Women's Clothing Upcycling Behavior

Janigo, K.A., Wu, J., DeLong, M. 2017. Redesigning Fashion: An Analysis and Categorization of Women's Clothing Upcycling Behavior, *Fashion Practice, 9*(2), 254-279

Upcycling used clothing could transform textile waste into raw materials for new fashion items. Our research goals were to add a longitudinal element to previous research which engaged female focus group participants in a collaborative upcycling project, to further understand motivations for upcycling used clothing, and to identify common characteristics of those who choose to upcycle. Upcycling behavior of 30 women (mean age 44, 87% Caucasian) was explored through questionnaires, in-depth interviews, and visual analysis. The study also aimed to determine the conditions under which upcycling used clothes might be most successful and to further study potential for a service or business. The findings will have practical implications for those interested in fostering sustainable best practices in clothing and for entrepreneurs to weigh the pros and cons of starting a new upcycling business.

RECYCLING

Solid-state NMR method for the quantification of cellulose and polyester in textile blends

Haslinger, S., Hietala, S., Hummel, M., Maunu, S.L. and Sixta, H. 2019. Solid-state NMR method for the quantification of cellulose and polyester in textile blends. C*arbohydrate polymers, 207*, 11-16

The valorization of cellulose rich textile waste is promoted by the development of a novel solid-state NMR method for the quantification of cellulose and polyester in textile blends. We applied C-13 CP-MAS NMR as a tool for the quantification and structural characterization of cellulose in cotton polyester blends. Gaussian functions were used to integrate the spectra obtained from a set of calibration standards in order to calculate a sigmoidal calibration curve. Acid hydrolysis was chosen as a reference method. The results demonstrated that solid-state NMR enables a reliable determination of cellulose and polyester in both preconsumer and postconsumer waste textiles and suggests a possible extension of the concept to blends of man-made cellulose fibers (MMCFs) and polyester.

Recycling of vat and reactive dyed textile waste to new colored man-made cellulose fibers

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process. Despite these deviations, almost all fibers and demo fabrics produced thereof exhibited bright colors that can be reused in textile industry. Only Remazol Black B 133% did not sufficiently translate to the new textile product. The wash and rubbing fastness of the fabrics knitted from the regenerated fibers was superior to the dyed waste fabrics mainly because of the homogenous distribution of the dyes along the fiber cross-section.

Separation of waste polyester/cotton blended fabrics by phosphotungstic acid and preparation of terephthalic acid

Ling, C., Shi, S., Hou, W., Yan, Z. 2019. Separation of waste polyester/cotton blended fabrics by phosphotungstic acid and preparation of terephthalic acid, *Polymer Degradation and Stability, 161*, 157-165

In order to recycle waste polyester/cotton blended fabrics (WBFs), an environmentally friendly process was designed for separating WBFs with phosphotungstic acid (H3PW12O40, HPW). Polyester and microcrystalline cellulose (MCC) were obtained after the process and the polyester was further degraded into terephthalic acid (TPA) by neutral hydrolysis. The effects of separation conditions were investigated, and the optimum conditions were determined as follows: HPW concentration of 3.47 mmol/L, a solid/liquid ratio of 1:20, reaction temperature of 140 °C, and reaction time of 6 h. Under the optimum conditions, the yields of polyester and MCC were 99.77% and 85.12%, respectively. HPW could be extracted and recycled easily with diethyl ether without affecting the yields of polyester and MCC. In addition, the separated polyester, MCC and prepared TPA were characterized. The results showed that the crystallinity of polyester decreased, and the cotton was hydrolyzed to MCC after the separation treatment. TPA was prepared with a high purity of 99.92%, and exhibited high crystallinity, favorable thermal stability, and small particle size.

Renewable High-Performance Fibers from the Chemical Recycling of Cotton Waste Utilizing an Ionic Liquid

Asaadi, S., Hummel, M., Hellsten, S., Härkäsalmi, T., Ma, Y., Michud, A. and Sixta, H. 2016. Renewable high-performance fibers from the chemical recycling of cotton waste utilizing an ionic liquid. *ChemSusChem, 9*(22), 3250-3258

A new chemical recycling method for waste cotton is presented that allows the production of virgin textile fibers of substantially higher quality than that from the mechanical recycling methods that are used currently. Cotton postconsumer textile wastes were solubilized fully in the cellulose-dissolving ionic liquid 1,5-diazabicyclo[4.3.0] non-5-enium acetate ([DBNH]OAc) to be processed into continuous filaments. As a result of the heterogeneous raw material that had a different molar mass distribution and degree of polymerization,

pre-treatment to adjust the cellulose degree of polymerization by acid hydrolysis, enzyme hydrolysis, or blending the waste cotton with birch prehydrolyzed kraft pulp was necessary to ensure spinnability. The physical properties of the spun fibers and the effect of the processing parameters on the ultrastructural changes of the fibers were measured. Fibers with a tenacity (tensile strength) of up to 58 cN tex(-1) (870 MPa) were prepared, which exceeds that of native cotton and commercial man-made cellulosic fibers.

Behavior in simulated soil of recycled expanded polystyrene/waste cotton composites

Borsoi, C., Berwig, K.H., Scienza, L.C., Zoppas, B.C., Brandalise, R.N. and Zattera, A.J. 2014. Behavior in simulated soil of recycled expanded polystyrene/waste cotton composites. *Materials Research, 17*(1), 275-283

Composites consisting of waste cotton yarn (CF) from the textile industry and postconsumer expanded polystyrene (EPS) was followed during 90 days of exposure in simulated soil. The mechanical properties, morphologies and chemical natures of the composites were determined before and after exposure in simulated soil. The composites were made using a single-screw extrusion, a twin-screw extrusion and injection molding. The composites showed an increase of the mechanical properties nearly 50% in relation to the recycled expanded polystyrene (rEPS). After exposure in simulated soil the composites presented losses of mechanical properties. Evidence of the oxidation of the samples was demonstrated by the increase in the values of the carbonyl index after 30 days of exposure in simulated soil. Changes in the color of the surface of the sample were observed after 90 days of exposure and are due to the fungi and bacteria colonization on the surface.

Poly (ethylene terephthalate) recycling for high value added textiles

Park, S.H., Kim, S.H. 2014. Poly (ethylene terephthalate) recycling for high value added textiles, *Fashion and Textiles, 1*(1)

This study reviews the problems in the use and disposal of poly (ethylene terephthalate) (PET) and includes the concise background of virgin and recycled PET as well as their possible applications. The current state of knowledge with respect to PET recycling method is presented. Recycling of PET is the most desirable method for waste management, providing an opportunity for reductions in oil usage, carbon dioxide emissions and PET waste requiring disposal because of its non-degradability. Advanced technologies and systems for reducing contamination, mechanical and chemical recycling, and their applications are discussed, and the possibility of diverting the majority of PET waste from landfills or incineration to recycling is suggested.

Sustainable waste management strategies in the fashion industry sector

Dissanayake, G., Sinha, P. 2013. Sustainable waste management strategies in the fashion industry sector, *International Journal of Environmental Sustainability, 8*(1), 77-90

The environmental impact of production and consumption has been addressed globally since the 1992 Rio Earth Summit; and in 2002 at the Johannesburg World Summit a 10-year framework was developed to promote sustainable production and consumption patterns (Ferrara and Serret, 2008). Agenda 21 from the Rio Earth Summit highlighted the fact that sustainable consumption is an issue that needs to be addressed in terms of waste reduction, resource conversion, and control of pollution. Section II of the framework focuses on waste management: minimising waste and maximising reuse and recycling of environmentally sound waste.

Fashion consumption and sustainability are often opposing ideas. Fashion consumption is a highly resource-intensive, wasteful practice; and sustainability frowns on wasteful consumption. Sustainability in the fashion business is still an emerging agenda, not yet established, and many authors have recognised the importance of investigating how sustainability could be achieved (Young et al 2004, Pears 2006, Fletcher 2008). Reuse or recycling of discarded fashion items reduces the environmental impact significantly compared to the purchase of new fashion products. It has been found that approximately 65kWh of energy is saved for every kilogram of cotton replaced by used clothing, and 90 kWh of energy is saved for every kilogram of polyester replaced (Woolridge et al, 2006). Additionally, closing the materials and product cycles is becoming an increasingly important aspect of any recovery option (Michaud and Llerena, 2006).

In order to understand how the clothing end-of-life management is practically handled in the UK, this study examined the current processes and strategies within the UK to utilizing textile wastes with the aim of reducing the volume of textiles and clothing sent to landfill. Based on the study, this paper presents an overview of three end-of-life waste management strategies: reusing, recycling and refashioning. We discuss the advantages and implications of each strategy and conclude by providing recommendations for the development of waste diversion programs and sustainable business models.

An introduction of structure, synthesis and safety concerning polypropylene applications

Sun, H., Xie, L. 2013. An introduction of structure, synthesis and safety concerning polypropylene applications, *Polypropylene: Synthesis, Applications and Environmental Concerns*, 1-10

Polypropylene, a thermoplastic polymer, can be made from the monomer propylene by Ziegler-Natta polymerization and by metallocene catalysis polymerization. According to three-dimensional structure or tacticity, polypropylene can be classified into three types: isotactic, syndiotactic, and atactic. All the methyl groups in isotactic propylene are on the same side of the chain, methyl groups in syndiotactic propylene are positioned alternately, and the methyl groups in atactic polypropylene are placed randomly on both sides of the chain. The relative orientation of methyl groups has a strong effect on the polymer's ability to form crystals, which affects the polymer's physical properties and its application. Isotactic polypropylene, which has high crystallinity, is rugged and unusually resistant to many chemical solvents, bases and acids. It is used in a wide variety of applications including packaging, textiles, furniture, stationery, reusable containers, appliances, automotive components, and construction materials. Syndiotactic polypropylene with low crystallinity has a promising application prospect in films, medical tubing, and medical adhesive. Atactic polypropylene is rubbery and widely used as hot melt adhesives, sealing materials, emulsifiers, paint and etc. Since polypropylene contains only carbon and hydrogen atoms, it does not poison the environment after its disposal, but deterioration time in the land field will be long. The best way to limit PP disposal is to recycle the PP wastes, or incinerate the wastes especially when they are seriously polluted. Thus, from the aspect of environmental protection and public health assurance, PP wastes should be recycled as much as possible. However, the recycled PP products should not be used as pharmaceutical packaging materials due to technical and hygienic reasons.

An air-based automated material recycling system for postconsumer footwear products

Lee, M.J. and Rahimifard, S. 2012. An air-based automated material recycling system for postconsumer footwear products. *Resources, Conservation and Recycling, 69*, 90-99

The worldwide consumption of footwear is estimated to be in excess of 20 billion pairs of shoes per year. To date very little work has been done to develop material recycling solutions for mixed footwear products. In fact less than 5% of end-of-life shoes are being recycled, with most being disposed of in landfill sites around the globe. One of the primary reasons is that most modern footwear products contain a complex mixture of leather, rubber, textile, polymers and metallic materials, that makes it difficult to perform complete separation and reclamation of material streams in an economically sustainable manner. This paper discusses the development of an economically feasible automated material recycling process for mixed postconsumer footwear waste. Central to this process are bespoke air-based separation technologies that separate granulated shoe particles based upon the difference in size and weight. Experimental studies with three different types of postconsumer footwear products show that it is possible to reclaim four usable material streams; leathers, textiles, foams and rubbers. For each of the reclaimed materials there are a variety of applications such as surfacing materials, insulation boards and underlay products.

Chemical recycling of PET flakes into yarn

Upasani, P.S., Jain, A.K., Save, N., Agarwal, U.S. and Kelkar, A.K. 2012. Chemical recycling of PET flakes into yarn. *Journal of Applied Polymer Science, 123*(1), 520-525

Polyesters such as polyethylene terephthalate are widely used in textile fibers, films, and packaging of food and beverages. Originally driven by environmental reasons, recycling of postconsumer polyester bottles into textile fibers is now becoming commercially attractive. We studied the chemical recycling wherein part of the virgin raw-materials during preparation of polyester was replaced by washed post consumer polyester. During the process, the postconsumer polyester undergoes partial depolymerization before repolymerization. Role of reactor-agitator configuration in achieving the solid-slurry and solid-melt mixing, and in depolymerization, was studied. Finally, suitability of the polymer for melt spinning and drawing of polymer into yarn was examined.

Reuse and recycling of textile solid wastes

Adivarekar, R.V., Pisal, S. 2009. Reuse and recycling of textile solid wastes, *Journal of the Textile Association, 70*(3), 118-126

Due to increased awareness and strict laws, disposal of waste is strictly avoided through the use of recycling technologies. The most practical way to reduce pollution is to reuse and recycle the waste several times before it is discarded. Though textiles are nearly 100% recyclable, in reality, the rate of recycling in textiles, both preconsumer and postconsumer is not very high. This paper sheds light on the recycling industry, on the scope of recycling the textile solid waste through various mechanical and chemical processes and also recycling from an energy saving perspective. The importance of the recycling behavior through the micro and macro approach is also emphasized.

Carpet Fiber Recycling Technologies

Wang, Y. 2007. Carpet Fiber Recycling Technologies, *Ecotextiles: The Way Forward for Sustainable Development in Textiles*, 26-32

Significant progress has been made in waste minimization and pollution prevention in textile manufacturing processes. Because most carpets and textiles are for replacement, recycling post-consumer fibrous waste should be an integral part of sustainability for textile products. Currently in the United States alone, over 2 million tons of postconsumer carpet waste is

discarded into landfills each year, and the amount is expected to increase to over 3 million tons by 2012. Very little post-consumer carpet at present is recycled. To establish a sustainable commercial network to recycle fibrous waste, operations based on different technologies must coexist such that different types of materials collected can be recycled to the greatest extent. This paper reviews technologies for carpet waste recycling.

Convenience and frequency of recycling - Implications for including textiles in curbside recycling programs

Domina, T. and Koch, K. 2002. Convenience and frequency of recycling: implications for including textiles in curbside recycling programs. *Environment and behavior, 34*(2), 216-238

This research investigated the effect of convenience on recycling frequency and variables that could be used as indicators in the prediction of recycling behavior as a basis for including textiles in curbside recycling programs. Results clearly indicated that access to curbside recycling significantly affected the amount and variety of materials recycled. Logistic regression results pointed to the variables of access, shopping behaviors, age, family size, and income as significant predictors of recycling activity, regardless of how recycling activity was defined. Despite reduced access to textile recycling opportunities, textile recycling overall was still high. The authors concluded that households with high recycling activity could be identified and targeted for extending curbside recycling programs to include textiles. To continue to reduce the amount of solid waste that is diverted to landfills, curbside recycling programs must be extended to include a greater diversity of postconsumer waste products such as textiles and apparel.

The introduction of postconsumer recycled material into TYVEK®: Production, marketing, and organizational challenges

Sharfman, M., Ellington, R.T., Meo, M. 2001. The introduction of postconsumer recycled material into TYVEK®: Production, marketing, and organizational challenges, *Journal of Industrial Ecology, 5*(1), 127-146

In the late 1980s, with the advent of increased consumer environmental awareness, DuPont faced a challenge with its TYVEK® family of nonwoven polyethylene textile products. TYVEK is used in a wide variety of applications ranging from house wrap to medical packaging. One of the most visible portions of the business is envelopes used by FedEx (previously known as Federal Express), the well-known courier and delivery service and by the U.S. Postal Service. As early as 1988, end users began asking questions about the environmental characteristics of TYVEK envelopes. As these questions increased, DuPont began to address the concerns directly, In response to the market's concern and because of the increased availability of

postconsumer-recycled (PCP) polyethylene, DuPont decided to put PCR polyethylene into TYVEK, beginning with the envelope business. Further, DuPont developed a recycling infrastructure for TYVEK because, although TYVEK consists entirely of high-density polyethylene, which is highly recyclable, no infrastructure was in place to recycle the material. These decisions produced a wide variety of technical and organizational challenges the firm had to overcome. This case study examines how DuPont made these choices and overcame the difficulties created by implementing needed changes. Whereas the envelope market for TYVEK embraced PCR polyethylene, other product markets resisted the innovation. The article closes with a discussion of the lessons learned from DuPont's experience.

PYROLYSIS

Investigation of the influence of supercritical carbon dioxide treatment on meta-aramid fiber: Thermal decomposition behavior and kinetics

Zhang, C., Jiang, Y.-X., Sun, J.-P., Xiao, H., Shi, M.-W., Long, J.-J. 2020. Investigation of the influence of supercritical carbon dioxide treatment on meta-aramid fiber: Thermal decomposition behavior and kinetics, *Journal of CO2 Utilization, 37*, 85-96

Influence of supercritical carbon dioxide (SCF-CO2) on the thermal decomposition behavior and kinetics of meta-aramid fiber was investigated at the first time, in order to develop some fundamental bases for sustainably and cleanly manufacturing some relative products from this fiber with the supercritical green medium. Particularly, the thermal decomposition behavior of treated samples was explored and characterized by thermogravimetric and differential thermogravimetric analysis (TGA-DTGA). The kinetics of the main steps of thermal decomposition was also investigated via different kinetics models. The results show that an influence of SCF-CO2 treatment on the thermal decomposition behavior of the fiber was observed by TGA-DTGA, accompanied with successive and partially overlapped predominant two-step degradation as sample temperature from 380.0 °C to 700.0 °C, as well as a small pyrolysis Step three at 650.0 °C to 800.0 °C. Decreases in thermal property and behavior were detected by TGA-DTGA for the samples as treatment temperature from 80.0 °C to 120.0 °C. The fitted results reveal that good linear regressions of the TGA-DTGA data were achieved from the kinetics models accompanied with high values of adjusted R-Square. The kinetics parameter of the apparent activation energy (E) decreased with the treatment temperature from 80.0 °C to 120.0 °C, as well as with the conversion degree (α) of the samples. Moreover, a second-order chemical reaction mechanism for the predominant thermal decomposition steps was successfully supposed by Coats-Redfern and Achar-Brindley-Sharp-Wendworth models combined with a solid mechanism function of C2.

Microwave Assisted Preparation of Self-Extinguishing Cotton Fabrics by Small Molecules Containing Phosphorous and Nitrogen.

Chang, S., Condon, B. and Smith, J. 2019. Microwave Assisted Preparation of Self-Extinguishing Cotton Fabrics by Small Molecules Containing Phosphorous and Nitrogen. *Current Microwave Chemistry, 6*(1), 3-12

Introduction: New methods for preparing surface modification of flame retardant cotton fabrics were employed by applying a microwave-assisted technique with a minimum amount of co-solvent. Efforts at flame retardant cotton fabrics treated with economic and environmentally friendly flame retardant compounds based on the small molecules piperazine, PN and PNN, were done successfully. Methods and Results: The evidence of flame retardant chemical penetrations or surface modification of cotton fabrics was confirmed by Scanning Electron Microscope (SEM), and the treated cotton fabrics were evaluated by flammability tests, such as 45°angle (clothing textiles test) and limiting Oxygen Index (LOI). Thermogravimetric analysis of all treated cotton fabrics in a nitrogen atmosphere showed high thermal stability, as decomposition occurred between 276.9~291.2°C with 30.5~35.7% residue weight char yield at 600°C. Limiting Oxygen Index (LOI) and the 45° angle flammability test were used to determine the efficiency of the flame-retardant treatments on the fabrics. LOI values for control twill fabric showed ~18 vol% oxygen in nitrogen, whereas the highest treatment level had 32 vol%. High add-on treatments with flame retardants also readily passed the 45° angle flammability test. Conclusion: In the Microscale Combustion Calorimeter (MCC) tests, a decline in heat of combustion was shown through the smaller values acquired for THR, HRC and Tmax for all PN and PNN samples.

One-pot fabrication of superhydrophobic and flame-retardant coatings on cotton fabrics via sol-gel reaction

Lin, D., Zeng, X., Li, H., Lai, X. and Wu, T. 2019. One-pot fabrication of superhydrophobic and flame-retardant coatings on cotton fabrics via sol-gel reaction. *Journal of colloid and interface science, 533*, 198-206

Waterproof and flame-retardant fabrics are widely utilized in many fields, such as automotive interiors, indoor decorations, outdoor clothing and tents. Herein, a facile one-pot sol-gel approach was developed to construct superhydrophobic and flame-retardant (SFR) coatings on cotton fabrics. The cotton fabric was activated by O2 plasma and then immersed into the ethanol suspension containing tetraethoxysilane (TEOS), hydroxyl-terminated polydimethylsiloxane (HPDMS) and ammonium polyphosphate (APP). The hydrogen bonding interaction between APP and cellulose motivated the APP to attach to the cotton fibers during the initial stirring process. After the addition of ammonia, the in situ sol-gel reaction of TEOS and HPDMS was initiated to generate polydimethylsiloxane-silica hybrid (PDMS-silica). The micro-nano structured composite coating on cotton fabric was successfully fabricated by the PDMS-silica and APP. The SFR cotton fabric showed outstanding durability and self-cleaning ability with a water contact angle (WCA) above 160°. When exposed to fire, the SFR cotton fabric quickly charred to extinguish the fire by generating a dense intumescent char layer under the physical barrier effect of PDMS-silica and the intumescent flame-retardant effect of APP. This one-pot approach for fabricating SFR cotton fabric is simple, cost-effective and timesaving, demonstrating significant advantages in practical production.

Flame retardant vinylon/poly(m-phenylene isophthalamide) blended fibers with synergistic flame retardancy for advanced fireproof textiles

Zhang, X., Shi, M. 2019. Flame retardant vinylon/poly(m-phenylene isophthalamide) blended fibers with synergistic flame retardancy for advanced fireproof textiles, *Journal of Hazardous Materials, 365*, 9-15

Superior flame retardant textiles are urgently needed to address high fire and heat risks. This study provides a simple and effective strategy to improve the flame retardancy of textiles through a synergistic effect between the blended fibers, and a system with synergistic in flame retardant vinylon (FRV)/poly(m-phenylene isophthalamide) (PMIA) blended fibers is discovered. The FRV/PMIA 50/50 exhibits a much higher time to ignition and a lower peak heat release rate than those of the neat components, indicating a synergistic flame retardancy between constituents. The corresponding mechanism is explored. The residual char layer formed by blended fibers connects together and keeps the original fiber shape, which acts as a barrier slowing heat transmission and gas diffusion. Concurrently, thermal degradation analysis of blended fibers implies that both components mutually interact with each other, resulting in a higher experimental amount of incombustible gases at an early degradation stage and lower experimental amount of combustible gases at a later degradation stage as compared to the theoretical one. Therefore, the synergistic flame retardancy in FRV/PMIA blended fibers is attributed to the actions in the condensed and gas phases during pyrolysis. This work provides an effective strategy to design fireproof textiles.

Condensed tannin from Dioscorea cirrhosa tuber as an eco-friendly and durable flame retardant for silk textile

Yang, T.-T., Guan, J.-P., Tang, R.-C., Chen, G. 2018. Condensed tannin from Dioscorea cirrhosa tuber as an eco-friendly and durable flame retardant for silk textile, *Industrial Crops and Products, 115*, 16-25

Condensed tannin derived from Dioscorea cirrhosa tuber was employed as a novel and eco-friendly flame retardant agent for enhancing the thermal shielding and flame retardant properties of silk textile. A facile adsorption technique of condensed tannin in the weakly acidic condition was able to impart good and durable flame retardancy to silk fabric. In the treatment process, the adsorption, diffusion and deposition of condensed tannin onto silk fiber took place. The flame retardancy was demonstrated by limiting oxygen index, vertical burning and pyrolysis combustion flow calorimetry tests. The treated fabric exhibited the limiting oxygen index above 27% and the char length below 12 cm even after 20 washing cycles. The thermogravimetric analyses of the treated fabric and the morphological studies of the burned fabric residue suggested that a significant condensed-phase mechanism contributed to the improvement in the flame retardancy of silk fabric. In addition to flame

retardancy, antibacterial and antioxidant activities were imparted to silk fabric. Such multifunctional properties provided by condensed tannin can expand the application of flame retardant silk. The present research indicates that condensed tannin is a promising alternative to traditional flame retardants for the finishing of silk textile.

Adsorbents made from textile scraps: preparation, characterization and application for removal of reactive dye

Correia, J., Vasques Mendonça, A.R., de Souza, S.M.A.G.U., Valle, J.A.B. 2018. Adsorbents made from textile scraps: preparation, characterization and application for removal of reactive dye, C*lean Technologies and Environmental Policy, 20*(4), 839-853

Textile scraps from the clothing industry were used to prepare a low-cost adsorbent to remove anionic dye from textile effluents. Adsorbents were prepared through pyrolysis and chemical activation with K2CO3. These samples were characterized through thermogravimetric analysis, scanning electron microscopy, N2 adsorption/desorption isotherms, Fourier transform infrared spectroscopy, point of zero charge, isoelectric point, elemental composition and proximate analysis. Batch kinetic experiments and adsorption isotherm modeling were conducted in different conditions. The surface properties of the adsorbents were significantly influenced by the activation process. The highest BET surface area (SBET = 358.55 m2 g−1) was attributed to the sample with chemical treatment. The results indicate that activation process raised 700% the adsorption capacity. The adsorption was strongly dependent on the pH. For the activated adsorbent, 6 g L−1 was sufficient for the complete removal of 40 mg L−1 Reactive Black 5 (RB5) solution. The monolayer capacity was up to 10.3 mg g−1 and was higher than a commercial activated carbon commonly used in textile sector, which was 9.7 mg g−1.

Waste management system in the clothing industry in Santa Catarina State Brazil: An initial overview

Correia, J., Dal Forno, A.J., Marangoni, C. and Valle, J.A.B. 2018. Waste management system in the clothing industry in Santa Catarina State Brazil. M*anagement of Environmental Quality: An International Journal*

Purpose - The purpose of this paper is to identify and diagnosis waste management practices used by clothing manufacturing companies in Santa Catarina state Brazil. Design/methodology/approach - The data for this multiple case study were obtained from interviews and by using a questionnaire to collect company data. After the analysis of the responses to questionnaires issued to 22 companies, a scoring system was developed to systematically classify these companies at either a basic, intermediate or advanced levels.

Findings - According to the classification used, eight companies were characterized at the basic level, eight at the intermediate level and six as advanced. Most of the companies have already implemented measures for reuse or recycling of textile scraps, probably because of the economic value added. Research limitations/implications - The classification system proposed proved to be an effective tool for identifying: if each company had a plan of action involving requirements of Brazil's National Solid Waste Policy; if the company had a management system in accordance with Law 12,305; the quality of solid waste treatment at the entire company and in its clothing sector; if the company adopted shared responsibility actions; and if it had knowledge of the negative environmental impacts. Originality/value - This paper presents a classification system for companies based on a questionnaire. The system allows determining the degree of compliance with Brazilian waste management legislation.

Investigating the composition and degradation of wool through EGA/MS and Py-GC/MS

Sabatini, F., Nacci, T., Degano, I. and Colombini, M.P., 2018. Investigating the composition and degradation of wool through EGA/MS and Py-GC/MS. *Journal of analytical and applied pyrolysis, 135*, 111-121

Wool has been the most widely used textile fiber in Europe since the Iron Age. It was largely employed to weave fabrics and clothes, and also for artistic purposes such as producing tapestries. This kind of artworks is among the most fragile of our heritage and is often in bad preservation conditions. Thus, the knowledge on the degradation processes of wool fibers is crucial for conservation issues. In the present study, we tested the potentialities of Pyrolysis coupled with Gas Chromatography and Mass Spectrometry (Py-GC/MS) and Evolved Gas Analysis coupled to Mass Spectrometry (EGA/MS) for the characterization of woolen reference samples, also subjected to artificial ageing, and of historical and archeological samples. The reference sheep wool yarns were prepared with different mordants and dyes, and have been analyzed both after storage in the dark for three years after preparation, and artificially aged for different time intervals and at different relative humidity values. We created a detailed pyrolysis database, evidencing the phenomena occurring with ageing and including camel wool for comparison. The ageing process undergone by the proteinaceous fraction of wool has also been investigated through monitoring specific fragment ions in the EGA profiles. The relevant parameters affecting the degradation process identified in this study match those assessed in previous investigations by different and complementary techniques, thus validating our approach. We proved that the novel approach based on EGA/MS is suitable for quickly assessing the conservation conditions of the woolen yarns and represents an advantage with respect to more time-consuming and complex methods, such as GC/MS or High Performance Liquid Chromatography (HPLC).

Flammability of natural plant and animal fibers: a heat release survey

Galaska, M.L., Horrocks, A.R. and Morgan, A.B., 2017. Flammability of natural plant and animal fibers: A heat release survey. *Fire and Materials, 41*(3), 275-288

With increased interest in sustainable materials for use in building materials and clothing, there is a renewal in the use of natural fibers (plant or animal-based) versus synthetic fibers in a variety of applications. However, there is not as much information available on the flammability of these natural fibers especially when they are used in products where purification techniques used in conventional textile processing are not required. The literature to date suggests that all of the fibers can be grouped into two categories: cellulosic and animal, with the assumption that regardless of original species, the flammability is similar for fibers within each category. In this report, we have conducted a survey via microcombustion calorimetry to determine if all cellulose-based and all protein-based fibers are the same from a heat release perspective. Our findings show that this is not the case, and there are notable differences in fiber types within each genus. Further, how the natural fiber has been treated prior to use can have some dramatic effects on heat release caused by residual impurity content. The results in this paper suggest that there is more to be learned about these natural fiber types in regards to their inherent flammability.

Cellulose/paraffin composite fibers for thermal energy storage and temperature regulation, Materials Science Forum

Xia, W., Xiang, H.X., Chen, W.P., Li, Y., Chen, W., Chen, L.J., Zhao, J., Zhu, M.F. 2017. Cellulose/paraffin composite fibers for thermal energy storage and temperature regulation, *Materials Science Forum, 898*, 2318-2328

Cellulose is a good bio-based material for rich resources and recyclability. Paraffin is widely used in the field of energy storage and temperature regulation due to its excellent heat storage properties and mature preparation technology. In this paper, the cellulose fibers with energy storage and temperature regulation were prepared by wet spinning process using paraffin as phase change material. Field Emission Scanning Electron Microscope (FE-SEM), X-Ray Diffraction (XRD), Differential Scanning Calorimetry (DSC) and Thermal Gravimetric Analysis (TGA) were utilized to characterize the morphology structure, crystalline properties, phase transition properties and heat resistance of fibers and so on. The results showed that the fiber surface without holes and paraffin was uniformly distributed in the cellulose matrix, and paraffin was not easily overflow during the process of phase change. Paraffin and cellulose substrate had good compatibility due to the interaction of hydrogen bonding, and 30% of paraffin did not cause a significant impact on the degree of crystallinity and thermal stability of cellulose fibers. Enthalpy of the resultant functional fibers could reach 27.44 J/g, and the thermal decomposition temperature was over 300 °C. The fibers possessed the phase change ability and certain mechanical

properties. Furthermore, it was found that the fibers still had good resistance to washing under extreme conditions.

An alternative for the end-of-life phase of flame retardant textile products: Degradation of flame retardant and preliminary settings of energy valorization by gasification

Yasin, S., Curti, M., Rovero, G., Behary, N., Perwuelz, A., Giraud, S., Migliavacca, G., Chen, G., Guan, J. 2017. An alternative for the end-of-life phase of flame retardant textile products: Degradation of flame retardant and preliminary settings of energy valorization by gasification, *BioResources, 12*(3), 5196-5211

It is well established that current flame retardant (FR) products at disposal generate various ecological hazards. Irrespective of their environmental impacts, the FR market is growing and is estimated to reach 2.8 million tons globally in 2018. In the textile domain, FRs are incorporated into baby clothing, pushchairs, car seats, etc. When disposed, these FR textile products end up in a landfill or are incinerated. These disposal processes are unsustainable. With landfilling, there is a huge chance of the FR product leaching into the environment. Similarly, FRs decrease energetic yields in the incineration process due to incomplete combustion. To cope with such issues, degradation and elimination of the FR product from the textile products before disposal could be a sustainable alternative. This study dealt with the preliminary degradation of flame retardant from the cotton textiles and its thermal characterization. Energy valorization by gasification is considered beneficial opposed to incineration with overall low energy recovery. The initial optimum gasification conditions including FR-treated cotton as a feeding material and potential outcomes of FR-treated cotton after degradation were characterized.

Silica precursor as synergist for cotton flame retardancy

Grancaric, A.M., Botteri, L., Alongi, J. and Tarbuk, A. 2016. Silica precursor as synergist for cotton flame retardancy

Purpose - The cotton and its blends is the most commonly used textile material in the design and production of protective clothing. However, as the cellulose textiles are the most flammable materials it is necessary to improve its flame retardancy. The government regulations have been the driving force for developing durable flame retardants finishes for textile, to improve its performance and to reduce the negative impact on the environment. The paper aims to discuss these issues. Design/methodology/approach - This paper investigates the effect of silica precursor (tetraethoxysilane – TEOS) added in bath with conventional flame retardant urea/ammonium polyphosphate in full and half concentration for achieving environmental-friendly cotton flame retardancy. Silica precursors have excellent thermal stability and high heat resistance with very limited release of toxic gases during the thermal decomposition. Synergistic effect between urea/ammonium polyphosphate and TEOS has been calculated. Thermal properties of treated cotton fabrics

were determined by limiting oxygen index (LOI), thermogravimetric analysis (TGA) and microscale combustion calorimeter (MCC). Findings - TEOS, significantly improves the flame retardancy of cotton when added in the bath with conventional flame retardants urea/ammonium polyphosphate by increasing the LOI values and other thermal properties as increasing char residue measured by TGA and higher heat release rate measured by MCC. Originality/value - This paper represent a good synergistic effect between urea/ammonium polyphosphate and TEOS. This phenomena is evident in better thermal properties when TEOS was added in the bath with conventional flame retardant especially for half concentration of urea/ammonium polyphosphate.

Flame retardants based on amino silanes and phenylphosphonic acid

Kappes, R.S., Urbainczyk, T., Artz, U., Textor, T. and Gutmann, J.S., 2016. Flame retardants based on amino silanes and phenylphosphonic acid. *Polymer Degradation and Stability, 129*, 168-179

The sol-gel approach offers a new class of flame retardants with a high potential for textile applications. Pure inorganic sol-gel systems do, however, typically not provide an effect sufficient for a self-extinguishing behavior on its own. We therefore employed compounds with nitrogen and phosphorous containing groups. Especially the combination of compounds with both elements, using the synergism, is promising for the aim to find well-applicable, environmental friendly, halogen-free flame retardants. In our approach, the sol-gel network ensured on the one hand the link to the textile as non-flammable binder. On the other hand, the sol-gel-based networks modified with functional groups containing nitrogen groups provided flame retardancy. In this way, a flame retardant finishing for textiles could be obtained by simple finishing techniques as, e.g., padding. Besides a characterization with various flame tests (e.g., according to EN ISO 15025 – protective clothing), we used a combination of cone calorimetry, thermogravimetry coupled with infrared spectroscopy analysis and scanning electron microscopy to analyze the mechanism of flame retardancy. Thus, we could show that the main mechanism is based on the formation of a protection layer. This work provides a model system for sol-gel-based flame retardants and has the potential to show the principle feasibility of the sol-gel approach in flame retardancy of textiles. It therefore lays the groundwork for tailoring sol-gel layers from newly synthesized sol-gel precursors containing nitrogen and phosphorous groups.

Parametric study of fabric characteristics' effect on vertical flame test performance using numerical modeling

Kim, E., Dembsey, N., Godfrey, T.A. 2016. Parametric study of fabric characteristics' effect on vertical flame test performance using numerical modeling, *ASTM Special Technical Publication, 1593*, 78-101

A parametric study of fabric characteristics' effect on performance in the standard vertical flame test (VFT; ASTM D6413) is conducted using computational fluid dynamics modeling. This bench-top test is used for characterizing fire performance of textiles during the fabric design stage to determine flame resistance. The advantage of utilizing modeling to study fire performance of textiles during VFT is the ability to conduct detailed studies of the effect of fabric characteristics on flame spread. First, two textile materials are chosen for modeling that exhibit two limit cases: either complete flame spread (nylon 6,6/cotton fiber fabric; NYCO) or self-extinguish (flame-retardant rayon/nylon 6,6/para-aramid fiber fabric; FR Army combat uniform) in the VFT. Parameter estimation for various model parameters - kinetic parameters and heat of reactions, heat of combustion, thermophysical parameters, and optical parameters-is performed for these samples by combination of independent measurements and numerical optimization using bench-scale experimental data. Second, parametric analysis is conducted for these two cases. The parameter values are varied one at a time, and their effect on the pyrolysis modeling (one-dimensional cone test simulation) and the flame spread modeling (threedimensional VFT simulation) are analyzed. Based on this work, the parameters that are significantly sensitive to modeling outputs (i.e., switch from complete flame spread to self-extinction or vice versa) are identified. Third, understanding the sensitive parameters in this VFT modeling with fabric samples, a new sample is modeled-flame-retardant cotton fiber fabric, FR cotton. The modeling results show that numerical modeling is capable of capturing the fire characteristics of a fabric sample when parameters are carefully estimated, especially the sensitive parameters. Understanding the effects of fabric characteristics on different fire behaviors observed in the standard VFT through numerical modeling will help designers more efficiently and effectively develop fire-safe fabrics.

A study on the thermal properties of polysulfonamide fiber

Lu, X.-P., Xu, Y.-Q., Ye, J.-Q. 2016. A study on the thermal properties of polysulfonamide fiber, Textile Bioengineering and Informatics Symposium Proceedings 2016 - 9th Textile Bioengineering and Informatics Symposium, TBIS 2016, in conjunction with the 6th Asian Protective Clothing Conference, APCC 2016, 791-799

Polysulfonamide (PSA) fiber belongs to polyamide aromatic polymer materials. In order to study the termal stability of PSA, thermo gravimetric analysis was used to obtain the thermogravimetric progress of the fiber. The pyrolysates of the fiber were identified by pyrolysis-gas chromatography/mass spectrometry, and the thermal behavior was analyzed using differential scanning calorimetry. The results obtained from thermal decomposition

process indicate that the existence of the conjugated aromatic rings and the additional sulfone group structure in its molecular main chain enable PSA fiber has high degradation temperature and can be applied to various fields in our daily life.

In situ degradation of organophosphorus flame retardant on cellulosic fabric using advanced oxidation process: A study on degradation and characterization

Yasin, S., Behary, N., Giraud, S., Perwuelz, A. 2016. In situ degradation of organophosphorus flame retardant on cellulosic fabric using advanced oxidation process: A study on degradation and characterization, *Polymer Degradation and Stability, 126*, 1-8

N-methylol dimethyl phosphonopropionamide (MDPA) is one of the most effective organophosphorus flame retardants for cellulosic fabrics, used in combination with Trimethylol melamine (TMM) to obtain durable and improved flame retardant properties. While their use is responsible for severe health problems, there is a need today to study methods to eliminate or degrade the durable flame retardant products which stay on discarded flame retardant textiles. The final aim is to improve the reusability of discarded textiles and to increase their energetic yield during the incineration phase. In this work, the degradation and mineralization of the flame retardant MDPA on cellulosic fabric, was studied using an advanced oxidation process (AOP) based on Fenton reaction. The effect of varying concentrations of Fenton's reagents (H2O2 and Fe2+ in aqueous medium) on the degradation of the MDPA was studied. The degradation of MDPA in aqueous media was monitored by measuring chemical oxygen demand (COD) of the reaction mixture over time. The mechanical properties of the cellulosic fabric after Fenton's reaction were unaltered in both warp and weft directions. The flammability test and thermogravimetric (TGA and DTG) results confirmed the degradation of MDPA flame retardant from the fabric. Pyrolysis combustion flow calorimeter (PCFC) confirms that there is a higher heat release after Fenton's reaction degradation which makes the degraded flame retardant cotton interesting for energy production by incineration.

Kinetics of pyrolysis of ramie fabric wastes from thermogravimetric data

Zhu, F., Feng, Q., Xu, Y., Liu, R., Li, K. 2015. Kinetics of pyrolysis of ramie fabric wastes from thermogravimetric data, *Journal of Thermal Analysis and Calorimetry, 119*(1), 651-657

The reutilization of the ramie-based textile waste or scraps from textile production through pyrolysis is a promising route for producing bio-fuels. In this work, the thermal behaviors and pyrolysis kinetic of used ramie fabric were investigated using thermogravimetric analysis at different heating rates of 5, 10, 20, and 40 °C min-1 under nitrogen conditions. Three model-free methods, the isoconversional Kissinger, Kissinger-Akahira-Sunose (KAS)

and Flynn-Wall-Ozawa (FWO) models and Coats-Redfern model-fitting method were employed to identify the kinetic triple including activation energy, pre-exponential factor, and reaction model. It was established that the Coats-Redfern model-fitting method was suspectable for determining the kinetic reaction mechanism but the most probable reaction R (R2 or R3) function can be evaluated on the basis of the activation energy value which is nearest to the value of E a obtained by the FWO and KAS methods. A kinetic compensation effect, represented by the equation lgA = -1.3515 + 0.0808E a can be observed

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Pyrolysis kinetics of recycled polyesters, International Journal of Clothing Science and Technology

Al-Juaidiyah, J. 2015. Pyrolysis kinetics of recycled polyesters, *International Journal of Clothing Science and Technology, 27*(4), 523-531

Purpose – The purpose of this paper is to study the non-isothermal degradation kinetics of recycled polybutylene terephthalate, polytrimethylene terephthalate and polyethylene terephthalate using thermogravimetric analysis (TGA) in a nitrogen atmosphere. Design/methodology/approach – To achieve this goal, the author utilized standard kinetic models, such as Coats-Redfern and Kissinger equations, for analysis of the TGA data. Findings – When applied to the TGA data, the Kissinger model resulted in a coefficient of determination (R2) value greater than 0.99. Originality/value – This study describes the maiden application of the Kissinger model to obtain the preexponential factor (A) and activation energy (E) for different polyester systems used in the textile industry.

Prospective environmental life cycle assessment of nanosilver T-shirts

Walser, T., Demou, E., Lang, D.J., Hellweg, S. 2011. Prospective environmental life cycle assessment of nanosilver T-shirts, *Environmental Science and Technology, 45*(10), 4570-4578

A cradle-to-grave life cycle assessment (LCA) is performed to compare nanosilver T-shirts with conventional T-shirts with and without biocidal treatment. For nanosilver production and textile incorporation, we investigate two processes: flame spray pyrolysis (FSP) and plasma polymerization with silver co-sputtering (PlaSpu). Prospective environmental impacts due to increased nanosilver T-shirt commercialization are estimated with six scenarios. Results show significant differences in environmental burdens between nanoparticle production technologies: The "cradle-to-gate" climate footprint of the production of a nanosilver T-shirt is 2.70 kg of CO2-equiv (FSP) and 7.67-166 kg of CO2-equiv (PlaSpu, varying maturity stages). Production of conventional T-shirts with and without the biocide triclosan has emissions of 2.55 kg of CO2-equiv (contribution from triclosan insignificant). Consumer behavior considerably affects the environmental impacts during the

use phase. Lower washing frequencies can compensate for the increased climate footprint of FSP nanosilver T-shirt production. The toxic releases from washing and disposal in the life cycle of T-shirts appear to be of minor relevance. By contrast, the production phase may be rather significant due to toxic silver emissions at the mining site if high silver quantities are required.

High surface area carbide-derived carbon fibers produced by electrospinning of polycarbosilane precursors

Rose, M., Kockrick, E., Senkovska, I., Kaskel, S. 2010. High surface area carbide-derived carbon fibers produced by electrospinning of polycarbosilane precursors, *Carbon, 48*(2), 403-407

Highly porous carbide-derived carbon fibers have been synthesized by electrospinning of polycarbosilane with subsequent pyrolysis and chlorination. The resulting ultrathin fibers show specific surface areas up to 3116 m2 g-1 and very high storage capacities for hydrogen up to 3.86 wt.% at 17 bar and 77 K. Due to the outstanding adsorption performance and other properties such as high temperature stability and the unique CDC fiber shape, this new kind of fiber material offers promising possibilities for several applications like air or liquid filters or textiles for protective clothing. Application as a flexible electrode material for supercapacitors is conceivable.

Mathematical Model of Heat and Mass Transfer within Fabric Used for Fire Protective Clothing under High Temperature Conditions

Zhu, FL., Gu, BH., , Li., SC, Wang., WY, An., Y. 2010. Mathematical Model of Heat and Mass Transfer within Fabric Used for Fire Protective Clothing under High Temperature Conditions, Progress in Safety Science and Technology, Vol. VIII, PTS A and B, Progress in Safety Science and Technology Series, 7th International Symposium on Safety Science and Technology (ISSST).

The paper reports an improved model of heat and mass transfer considering which considered the influence of pyrolysis was established to predict thermal performance of heat-resistant fabric under high heat flux conditions. The new model has been validated using data from modified Radiant Protective Performance (RPP) tests of flame-resistant cotton fabric. The simulated results were compared with experimental data and time to the 2nd degree burn can be predicted based on skin burn model. This work provided a foundation for further researching heat transfer characteristics of heat resistant fabric exposed to a simulated fire. This also provided the theoretical and technological basis for study on degradation for combustible textiles.

Resources recovery of waste rayon by pyrolysis: kinetics study

Huang, H.C., Chang, C.Y., Chen, Y.H., Shie, J.L., Lin, J.P. and Wu, C.H. 2004. Resources recovery of waste rayon by pyrolysis: kinetics study. *Journal of the Chinese Institute of Chemical Engineers, 35*(6), 623-632

Rayon derived from natural biomass fibers are extensively used in the production of a wide range of commercial industrial, and engineering products especially rayon clothes. The rayon discharged by textile industry, and consumers are becoming a large proportion of wastes. The conversion of rayon to various useful materials such as lower molecular weight organic compounds (liquid fuels and combustible gas) and carbonaceous fibers or activated carbons via pyrolysis not only solves the disposal problem but also matches the wastes minimization and resource utilization. Before considering the thermal treatment of utilization of rayon clothes, one should investigate the behavior of rayon alone during the thermal treatment. The pyrolysis of rayon is thus examined with a thermal gravimetric analyzer (TGA). The kinetics of the thermal pyrolysis of rayon is conducted using nitrogen as the carrier gas in 378-800K and at various constant heating rates (beta) of 5, 12 and 20K/min. The results indicate that the entire pyrolysis process of rayon under the experimental conditions of this investigation can be described by two competitive reactions forming volatiles and residues (including carbon). The corresponding activation energies (E), reaction orders (n) and frequency factors (A) of volatiles and char formed by the two competitive (parallel) reactions of pyrolysis of rayon are 171.6 and 191.8 kJ/mol of E, 1 and 1.5 of n, and 4.3 x 10(11) and 5.6 x 10(12) s(-1) of A, respectively. All this information is useful to the proper design of a pyrolysis system of rayon.

Durable Flame-Retardant Finished Cotton Fabrics Characterized by Thermal Degradation Behaviors

Nakanishi, S., Masuko, F., Hashimoto, T. 1999. Durable Flame-Retardant Finished Cotton Fabrics Characterized by Thermal Degradation Behaviors, *Journal of Applied Polymer Science, 71*(6), 975-987

After a series of investigations on the durable flame-retardant finishes, it was thought to be important to study these durable flame-retardant finished materials from the thermal analytical standpoint. Accordingly, cotton fabric was finished with N-methylol dialkyl phosphonopropionamide (Pyrovatex C) by thermofixation and tetrakis (hydroxymethyl) phosphonium sulfate (THPS) precondensate by ammonia cure (Proban), as well as with THPS monomer by heat cure under various conditions, and subjected to the thermogravimetry (TG) to observe thermal degradation behaviors and obtain apparent activation energy (Ea). TG curves of Proban-finished samples showed the largest shift to lower temperatures with a steep slope; thermofixed THPS-finished sample gave a smaller shift with similar steep slope,

whereas Pyrovatex-finished samples exhibited a similar shift but with a gradual slope. Ea versus residual ratio curves led us to conclude that C - N bond-rich Proban polymer requires the highest Ea and decomposes with considerable rapidity, whereas ethylene-bond-rich Pyrovatex-finished samples with melamine crosslinking decompose gradually with the lowest Ea. As for the relationship between flame retardance and Ea distribution in the process of thermal degradation, typical differences among the above three kinds of finished samples were found, which are compared and discussed.

Developments in flame retardants for heat and fire resistant textiles—the role of char formation and intumescence

Horrocks, A.R. 1996. Developments in flame retardants for heat and fire resistant textiles—the role of char formation and intumescence. *Polymer Degradation and Stability, 54*(2-3), 143-154

The currently available heat and flame resistant textiles are reviewed. These fall into two groups, each of which is based on the use of non-thermoplastic fibres as the major fibre component. The first group consists of flame retarded cellulosic, wool and certain man-made fibre-containing fabrics which are well established in various markets, have moderate to high heat and flame resistance and are available at reasonable cost. Performance limitations are determined by stability of the chars produced following interaction of the flame retardants and the fibre when heated. The second group relies on the exploitation of the inherent heat and flame resistance of aromatic and carbonized fibres which form chars with superior mechanical stabilities, and hence barrier properties, compared with the first group. However, fibres within this group are expensive, often difficult to process and, from an environmental point of view, difficult to recycle. Thermoplastic fibres such as polyester, polypropylene and polyamide, even when flame retarded using either comonomeric, modifications or additives introduced during polymerisation and/or fibre extrusion stages, melt drip and/or form holes when exposed to flame. They cannot, therefore, be used in applications, such as protective clothing and barrier textiles, where sustained thermal protection via char formation is an essential requirement. The mechanism and role of char formation are discussed and the incorporation of intumescents in textile materials explored. Recent developments have shown that combinations of flame retarded char-forming fibres and intumescents may give rise to a consolidated fibrous char-reinforced intumescent char which exhibits enhanced heat and flame resistance compared to individual chars. These interactive fibre-intumescent combinations offer opportunities for creating high performance barrier textiles based on more conventional, cost effective and environmentally acceptable raw materials.

GASIFICATION

Spouted-bed gasification of flame retardant textiles as a potential non-conventional biomass

Yasin, S., Curti, M., Rovero, G., Hussain, M., Sun, D. 2020. Spouted-bed gasification of flame retardant textiles as a potential non-conventional biomass, *Applied Sciences (Switzerland), 10*(3)

Renewable energy from thermal valorization plays a key part in today's energy from natural cellulosic textiles that are resourceful biomass and safe from toxicity at high temperature treatments. The situation is opposite, when technical textiles are treated with synthetic chemical finishes adding functionality as anti-bacterial, water repellent or flame retardant, etc. Incineration of flame retardant textile results in possible unfavorable gases, toxic fumes and contaminated ash. Other thermal valorization techniques like gasification would assist in avoiding the formation of additional toxic hazards. Herein, gasification of flame retardant textile is carried out the likelihood to get quality gas composition. For comparative analysis, flame retardant textiles, after their flame retardant ability being revoked, are also gasified. The output gas components suggested that gasification can be a useful thermal valorization approach for flame retardant textiles and relevantly improved gas composition was seen in textiles with their flame retardant substrate/species being removed.

Waste management system in the clothing industry in Santa Catarina State Brazil: An initial overview

Correia, J., Dal Forno, A.J., Marangoni, C. and Valle, J.A.B. 2018. Waste management system in the clothing industry in Santa Catarina State Brazil. *Management of Environmental Quality: An International Journal*

Purpose - The purpose of this paper is to identify and diagnosis waste management practices used by clothing manufacturing companies in Santa Catarina state Brazil. Design/methodology/approach - The data for this multiple case study were obtained from interviews and by using a questionnaire to collect company data. After the analysis of the responses to questionnaires issued to 22 companies, a scoring system was developed to systematically classify these companies at either a basic, intermediate or advanced levels. Findings - According to the classification used, eight companies were characterized at the

basic level, eight at the intermediate level and six as advanced. Most of the companies have already implemented measures for reuse or recycling of textile scraps, probably because of the economic value added. Research limitations/implications - The classification system proposed proved to be an effective tool for identifying: if each company had a plan of action involving requirements of Brazil's National Solid Waste Policy; if the company had a management system in accordance with Law 12,305; the quality of solid waste treatment at the entire company and in its clothing sector; if the company adopted shared responsibility actions; and if it had knowledge of the negative environmental impacts. Originality/value - This paper presents a classification system for companies based on a questionnaire. The system allows determining the degree of compliance with Brazilian waste management legislation.

An alternative for the end-of-life phase of flame retardant textile products: Degradation of flame retardant and preliminary settings of energy valorization by gasification

Yasin, S., Curti, M., Rovero, G., Behary, N., Perwuelz, A., Giraud, S., Migliavacca, G., Chen, G., Guan, J. 2017. An alternative for the end-of-life phase of flame retardant textile products: Degradation of flame retardant and preliminary settings of energy valorization by gasification, *BioResources, 12*(3), 5196-5211

It is well established that current flame retardant (FR) products at disposal generate various ecological hazards. Irrespective of their environmental impacts, the FR market is growing and is estimated to reach 2.8 million tons globally in 2018. In the textile domain, FRs are incorporated into baby clothing, pushchairs, car seats, etc. When disposed, these FR textile products end up in a landfill or are incinerated. These disposal processes are unsustainable. With landfilling, there is a huge chance of the FR product leaching into the environment. Similarly, FRs decrease energetic yields in the incineration process due to incomplete combustion. To cope with such issues, degradation and elimination of the FR product from the textile products before disposal could be a sustainable alternative. This study dealt with the preliminary degradation of flame retardant from the cotton textiles and its thermal characterization. Energy valorization by gasification is considered beneficial opposed to incineration with overall low energy recovery. The initial optimum gasification conditions including FR-treated cotton as a feeding material and potential outcomes of FR-treated cotton after degradation were characterized.

Effects of coal and ammonium polyphosphate on thermal degradation and flame retardancy of polyethylene terephthalate

Zhu, X., Pan, Q., Xu, H., Lu, J. 2010. Effects of coal and ammonium polyphosphate on thermal degradation and flame retardancy of polyethylene terephthalate, *Journal of Polymer Research, 17*(5), 621-629

Polyethylene terephthalate (PET) is of excellent mechanical properties and melt processability and is widely used as raw material for textile fibers and engineering plastics. However, its flame retardant properties are rather poor, and its melt-dripping behavior during burning hasn't been handled properly. In this work, coal powder and ammonium polyphosphate (APP) were blended with PET, and the thermal degradation, flame retardancy, char formation and mechanical properties of the modified PETs were investigated. All results show that the initial thermal degradation was accelerated remarkably with APP but to less extent with coal. The gasification of carbonaceous residues was suppressed by the two additives at higher addition levels. The oxygen indice of the modified PETs with APP were increased whereas unchanged with coal unexpectedly. APP/Coal synergistically improved the flame retardancy of PET. There existed some physical and chemical interactions among PET, APP and coal during combustion process. The mechanical properties of the modified PETs were worse than those of virgin PET.