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AN APPROACH OF RECYCLING TEXTILE WASTE WITH INDUSTRIAL APPLICATIONS

BY

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Abstract. The fashion industry output a great volume of waste caused by mass production. A great percentage of those garments are disposed in land fields after use, instead of being recycled. In order to prevent the generation of this enormous quantity of waste, the paper will explore methods or strategies to recycle natural and synthetic textile waste. Industrial methods used to recycle textile waste evaluated are: textile recycling to cellulose, separation and conversion of textile waste from wool-polyester and cotton-polyester blends. Associated Recyclability Potential Index (RPI) will be evaluated. Some methods to separate textile waste use selective digestion of wool fibers from wool-polyester mixtures. Some applications use the keratinize in two step process with addition of a reducing agent. The polyester fibers are recovered after the process. We can see that, after the process, the natural fibers are decomposed and the polyester fabric is in good conditions, then can be used for new garment production.

Keywords: Textile waste, environmental strategies, recycling, wool-polyester blends, cotton-polyester blends.

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1. Introduction

Reuse-repair-remanufacturing-recycle can help on the long run, the global economy. The pre-consumer waste is by far easier to recycle compared with the post-consumer waste, because these are constituted by a large variety of materials (Islam and Bhat., 2019; Kamyar *et al*., 2020; Muthu *et al*., 2012). The mixture of natural and synthetic fibres from the blended textiles waste are very difficult to separate in the recycling process. As an example, the separation of polyester fibres from wool polyester blends can be done by selective digestion of wool fibres or by keratinization in two stages in the presence of reducing agents. Following these processes, the natural fibres are decomposed, and the polyester fabric remains in good condition, and can be used for new garment production. The obtained keratin hydrolysate can be used as nutrient for microbial mediums or as fertilizer in agriculture, following the concepts of circular economy.

2. Textile recycle methods

A great variety of textile products needs to be recycled at their end-of-life. Some research proposed a concept called Recyclability Potential Index (RPI) of textile fibres tacking in consideration the impact of recycling those fibres of the environment and global economy. An important factor which taken in consideration was the land filling, because here the fibres are not recycled, will create negative effects on the environment.

Among the most common, polypropylene and polyester are the fibres with the highest degree of recyclability, while acrylics are medium situated and cotton ranked 5th in the table. Among the most common, polypropylene and polyester are the fibres with the highest degree of recyclability, while acrylics is medium situated as cotton ranked 5th (Table 1). As result of the above polyester and polypropylene are the fibres with higher RPI, followed by natural fibres at the middle of the ranking (Navone *et al*., 2020). As shown in the above study, the main recycled methods used are focused on the recovery of the fibres from natural-synthetic textile mixtures type wool-polyester and cotton-polyester blends. For a proper recycling it is necessary to separate the blended fabrics in their constituents. As an example, polyester must be separated from cotton or wool in order to be melted and spinning as yarn. The cotton-polyester separation methods are more versatile by comparison with versus the ones used for separate wool from polyester. Thus, some approaches which consist in dissolving the wool can affect the physical properties of the polyester from the blends. In the case of wool, the difficulties to separate the polyesters from the blends are generated by the main constituent of the wool (keratin). To avoid pollution, keratin is separated using enzymatic treatment methods in several stages. As result of the above polyester and polypropylene are the fibres with higher RPI, followed by natural fibres at the middle of the ranking (Navone *et al*., 2020). As shown in the above study, the main recycled methods used are focused on the recovery of the fibres from natural-synthetic textile mixtures type wool-polyester and cotton-polyester blends.

Table 1
Textile fibres recyclability ranking

Fibres	RPI	Ranking in terms of recyclability
Nylon 6	32	8
Nylon 66	37	9
Viscose	33	7
Acrylic	27	4
Polyester	21	1
Cotton	29	5
Wool	32	6
PP	21	1
LPDE	23	3
HDPE	22	2

For a proper recycling it is necessary to separate the blended fabrics in their constituents. As an example, polyester must be separated from cotton or wool in order to be melted and spinning as yarn. The cotton-polyester separation methods are more versatile by comparison with ones used for separate wool from polyester. Thus, some approaches which consist in dissolving the wool can affect the physical properties of the polyester from the blends. In the case of wool, the difficulties to separate the polyesters from the blends are generated by the main constituent of the wool (keratin). To avoid pollution, keratin is separated using enzymatic treatment methods in several stages.

2.1. Separation and conversion of textile waste from wool-polyester blends

Wool-polyester fabrics are treated in two-steps enzymatic process in the presence of sodium thioglycolate as catalyst with very good results in wool degradation. The process monitored by weight loss measurements and electron microscopy show that there isa complete elimination of the wool. The polyester obtained after treatment preserve the original properties of the virgin fibers and can be used in the process of obtaining new garments. The experiments performed on the samples of 100% wool knit, 100% wool woven, 70% wool-30% polyester knit, 45% wool-55% polyester woven, 100% polyester knit and 100% polyester woven in the presence of protease, showed the keratine degradation with the temperature.

The result of the experiments conducted at 37°C, (Table 1), 50°C, (Table 4) and 60°C show an intensification of the reaction at medium temperature as 50°C. The keratinase activity of the protease evaluated by the keratin azure assay in the presence of reducing agents. One keratinase unit (KU) is defined as an increase of 0.1 in absorption units at 595 nm after incubation with keratin azure for 1 h at 37°C, 50°C, or 60°C. Data are represented as mean values ± standard deviation (n = 3) (Navone *et al*., 2020). In some experiments a complete degradation was not possible to be obtained because of the inactivation of the enzyme after a few hours treatment at 50°C. The fact that was necessary of a second treatment, (Table 2), to a complete keratin degradation indicate that the inactivation of the enzyme during the fabric treatment and show that the enzyme cannot be reused.

Table 2

Two different temperatures, 37°C and 50°C, were tested for enzymatic degradation, with complete degradation of wool fibres achieved in one-step process at 50°C in the presence of the reducing agent sodium thioglycolate

Fabrics	Temperature	Reactants	Output
100% wool woven	37°C/One step reaction	Sodium sulfite 1%	70% for 100% woven
			70% for 45/55% woven
100% wool knit		Sodium thioglycolate 2%	50% for 100% knit
			50% for 45/55% knit
45/55%wool/polyester	50°C/One step reaction	Protease	70% for 100% woven
			70% for 45/55% woven
70/30%wool/polyester			50% for 100% knit
			50% for 45/55% knit

For the mixed fabrics which are an important problem in the recycling technology, those methods can provide a sustainable approach for wool-polyester blends. Closing the loop of the fashion waste is very important part for a circular Economy approach (Table 3) (Sanchis-Sebastiá *et al*., 2021).

Percentages correspond to weight loss percent for each fabric type. Results correspond to 5 _ 5 sample size and 2% sodium thioglycolate where not indicated otherwise.

Table 3

Two-step process at 50°C in the presence of the reducing agent sodium thioglycolate

Fabrics	Reactants/Time	Reactants/Time	Output
100% wool woven	Sodium thioglycolate 2% /6h	Sodium thioglycolate 2% /16h	95% for 100% woven
100% wool knit			90% for 45/55% woven
45/55% wool/polyester	Protease/6h	Protease/16h	100% for 100% knit
70/30% wool/polyester			90% for 70/30% knit

2.2. Separation and conversion of textiles from cotton-polyester blends

Another approach in recycling of the textile waste, except the fibre-to-fibre recycle techniques who is a down cycling process where the mechanical properties of the fibres are diminished, is the chemically recycling. One of the methods is the depolymerization of the cotton fibres to the glucose solutions, who can be used as prime material in the fabrication of chemicals or fuels. This process usually occurs in the presence of acid catalyst. Because one step chemical procedure with sulphuric acid was not able to produce a high concentration of glucose, a twostep procedure with high concentration in the first step and low concentration in the second step were used (Xin *et al*., 2021).

Glucose with 40 g/L concentration was achieved in this process, these values being enough to fermentation and be transformed in high value products. The experiments were conducted with 40 g of dry cotton was added to 760 g of sulphuric acid, at different concentration, temperature and reaction times (Table 4).

Table 4
Temperature, residence time and sulphuric acid concentration in the one-step acid hydrolysis experiments

Conditions/Sample	Temperature (°C)	Reaction time (h)	Concentration H_2SO_4 (g%)
1.	130	6	60
2.	130	6	5
3.	130	1	60
4.	130	1	5
5.	30	6	60
6.	30	6	5
7.	30	1	60
8.	30	1	5
9.	80	3.5	5
10.	80	3.5	60
11.	80	6	32.5
12.	80	1	32.5
13.	130	3.5	32.5
14.	30	3.5	32.5
15.	80	3.5	32.5
16.	80	3.5	32.5

During the experiments, the quantity of glucose obtained was calculated using the total content of the glucose in the waste (1.11 times the cellulose of the sample). The studied textile waste had 93% cellulose as dry basis and 4.6% residue content. During one step hydrolysis process, was observed that from textile waste that is not produce enough glucose. This show the fact that, the post-consumer textile waste is more reluctant to be processed than virgin cotton fibres, considering the fact that consuming cotton with 55% sulphuric acid at room temperature was proved possible. The results show that, one-step acid hydrolysis is not a proper method to recycle waste textiles with glucose generation, but can provide alternatives for chemical polyester fibres separation. Two-step acid hydrolysis is done by dissolution in the first step, using a 80% concentration sulphuric acid treatment at 30°C was able to dissolve the textile and improve the degree of hydrolysis, (Xin *et al*., 2021). The highest concentration of the acid in the first step (dissolution), lead to an improved degree of glucose production in the second step.

A maximum concentration of glucose obtained with the second method was 40 g/L who can be enough for fermentation into valuable products but not for low value products as bio-ethanol. The two steps process is necessary in order to achieve dissolving of the cotton waste with high concentration acid, and in the second step a sufficient glucose yield can be obtained with the treatment with low concentration sulphuric acid.

3. Conclusions

a) The textile waste can be converted in useful chemicals, fuels or recycled as new garments. There is a necessity in evaluate the proper method to asses recycling in order to get the maximum conversion of waste textile in energy or new garments. As an example, two step acid hydrolysis can be useful to transform cotton waste textiles into glucose and then these through the fermentation process to converted in chemicals or fuels.

b) The chemical methods for recycle natural or natural-synthetic textile mixtures are more pollutant comparing with textile methods to recycle synthetic fabrics with content of polyester or polypropylene

c) Polyester and polypropylene fibres have the highest RPI, followed by natural fibres situated at the middle of the ranking. Those facts suggest the necessity to find new ways to create synthetic materials clothes with greater degree of comfort, coupled with recycling methods for extracting useful materials from textile waste.

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RECICLAREA DEȘEURILOR TEXTILE CU APLICAȚII INDUSTRIALE

(Rezumat)

Industria modei produce o cantitate foarte mare de deșeuri textile. Un procent mare de confecții sunt aruncate la gropile de gunoi după folosire în loc să fie reciclate. Scopul cercetării este enumerarea și evaluarea de metode industriale de reciclare a deșeurilor textile naturale și sintetice. Metodele industriale de reciclat materiale textile luate în considerare se bazează pe reciclarea de celuloză, separarea și conversia deșeurilor textile provenite din amestecuri lâna-poliester și bumbac-poliester. Indicele potențial de reciclare pentru diverse materiale textile va fi evaluat și luat în considerare. Metodele prezentate se referă la dizolvarea selectivă a fibrelor de lână din amestecuri lână- poliester și keratinizarea în două etape cu adăugarea unui agent de reducere a amestecurilor bumbac-poliester. În urma acestor procese industriale se vor obține fire de poliester de calitate bună care pot fi refolosite în procesul de fabricare a unor confecții textile.