



Sustainable deinking processes to recover post-industrial printed plastic films

Mestrado em Engenharia para Fabricação Digital Direta

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Master's thesis conducted under the supervision of Prof. Dr. Marcelo Rudolfo Calvete Gaspar, Professor at the School of Technology and Management of the Polytechnic Institute of Leiria, and Prof. Dr. Nelson Simões Oliveira, Professor at the School of Technology and Management of the Polytechnic Institute of Leiria

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Abstract

The current commercial deinking technology uses non-bio-based surfactants and non-renewable surfactants, which are harmful to the environment. Therefore, the main objective of current research is to develop an environmentally sustainable process for ink removal on printed post-industrial flexible plastic films using bio-based surfactants. This process focuses on obtaining a deinked plastic that may be reprinted, thus avoiding for inappropriate disposal or reprocessing problems. The value increase of upcycling such post-industrial waste makes it possible to match the quality of the virgin plastic, which is key to carrying out an effective cost analysis of recycled plastic when compared to the new plastic films. In this research, the use of aqueous bio-based surfactant solutions for plastic film deinking was analyzed and discussed, since these surfactants are more environmentally friendly. Dedicated laboratory deinking procedures were undertaken with transparent polyethylene films printed by flexography with different conditions. In the end, a dedicated design proposal for a prototype to industrially deink plastic films printed was presented and discussed.

Keywords: Plastic film recycling, deinking, solvent-based ink removal, cationic surfactant, biobased surfactants

Resumo

A atual tecnologia comercial de remoção de tintas em filmes impressos por flexografia utiliza surfactantes de base não biológica e surfactantes não renováveis, que são prejudiciais ao meio ambiente. Neste contexto, o principal objetivo da pesquisa atual é desenvolver um processo ambientalmente sustentável para remoção de tinta em filmes plásticos flexíveis pós-industriais impressos utilizando surfactantes de base biológica. Este processo tem como foco a obtenção de um plástico com uma total e completa remoção de tintas nos filmes impressos por flexografia que poderá ser reimpresso, evitando problemas de descarte inadequado ou reprocessamento. O aumento de valor da reciclagem desses resíduos pós-industriais permite igualar a qualidade do plástico virgem, o que é fundamental para realizar uma análise eficaz dos custos do plástico reciclado quando comparado com os novos filmes plásticos. Nesta pesquisa foi analisado e discutido o uso de soluções aquosas de surfactantes de base biológica para remoção de tinta de filmes plásticos, uma vez que esses surfactantes são mais ecologicamente corretos. Assim, neste trabalho foram realizados procedimentos de processos de remoção de tinta laboratoriais dedicados com filmes de polietileno transparentes impressos por flexografia em diferentes condições. Os resultados preliminares mostraram que o procedimento experimental dedicado de remoção de tinta usando surfactantes de base biológica é eficaz e ambientalmente sustentável. O estudo realizou procedimentos laboratoriais utilizando filmes de polietileno impressos transparentes e constatou que a aplicação de surfactantes de base biológica removeu efetivamente a tinta, alinhando-se aos princípios de sustentabilidade de acordo com análise multicritério. Concluiu-se que o método experimental aplicado para remoção de tinta com suporte de surfactantes de origem biológica é eficaz, bem como oferece efeitos condizentes com os princípios da sustentabilidade. No final deste estudo, foi apresentada e discutida uma proposta de design dedicada a um protótipo para remoção de tintas em filmes impressos por flexografia.

Palavras-chave: Reciclagem de filmes de plástico, surfactantes de base biológica, remoção de tinta a partir de solventes, surfactantes catiónicos.

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1. Introduction

1.1. Background and Motivation

Plastic packaging accounts for approximately 40% of worldwide plastic use [1], with the corresponding waste posing a significant threat to nature and the environment, thus requiring the adoption of a greener, circular economy centered on waste avoidance and recycling [2]. As a result of such increased plastic usage, there is a corresponding exponential growth in plastic waste, which leads to greater demand for natural gas and oil as raw materials for plastic manufacturing [3]. Due to the general demand for raw materials, environmental concerns, and solid waste considerations, recycling plastic film from industrial and household waste streams is becoming ever more important [4].

Most of the plastics currently used are almost completely derived from petrochemicals produced from fossil oil and gas. Thus, to manufacture these plastics, significant amount of energy is required, which leads to a high consumption of corresponding volumes of fossil fuels [5]. To minimize the effect of raw material depletion the combined use of recycled and virgin plastics leads not only to minimize energy consumption and reduce environmental impacts, but also, in some cases, to improve their properties [6].

Plastic film waste has a variety of negative environmental consequences and is a high concern for the consumer goods industry, as large quantities of scrap plastic films are currently disposed of in landfills or incinerated [7]. Effective film deinking technology is a promising alternative to conventional recycling of plastic films as it allows for the reuse of scrap plastic films usually disposed of as industrial waste [8].

Waste from plastic packaging poses an imminent risk to global sustainability, and this situation requires the application of organizational measures focusing on environmental-related aspects, especially preventive measures, and protective actions, such as the recycling process of plastic waste [2]. The continuous increase in plastic used globally is responsible for the immense increase associated with plastic waste, generating greater consumption of natural gas and oil, whose supplies are essential for the plastic production process [3]. When considering consumption factors on supplies, attributes related to environmental

responsibility and relevant issues about solid-form waste, the process of recycling plastic film waste – plastic waste from the industrial environment, or plastic waste from household use by individuals in general – has presented a fundamental value for the economic environment, as well as for the social environment [4].

Much of the use of plastics in the contemporary economic context occurs through the petrochemical sector, whose production comes from oil and fossil gas. Therefore, in the production process of plastics, it is essential that there is a large quantity of energy, and this factor increases the consumption of fossil fuels [5]. To reduce the impact of depletion of supplies, the integrated application between recycled plastics and virgin plastics promotes: a) Reduction in energy use; b) Reduction of damage to the environment; (c) And especially in certain situations, the integrated application between recycled plastics and virgin plastics can promote improvement on the properties of plastic [6].

Historically, plastic film waste has been responsible for causing many negative impacts on the environment, and this is one of the main reasons for organizations operating in the industrial sector regarding consumer goods to show concern about this serious problem, mainly because a huge volume of scrap plastic films is sent to landfills or go through an incineration process [7]. The technological procedure of film deinking, developed with a high level of efficiency, becomes an important solution for the traditional recycling process of plastic films, mainly because it allows the reuse of scrap plastic films that, in general, are usually dispensed as waste from the industrial environment [8] and therefore it is noted that waste does indeed present an imminent risk to the ecosystem. [9] . Due to these risks generated by waste to the environment, it is essential to apply economic circulation strategies with emphasis on sustainability principles, through preventive measures and intelligent processes for the correct recycling of waste [10]. The large volume of plastic material generated in the world raises, alarmingly, the amount of waste from these plastics; this situation results in the increase in the use of natural gas and oil – essential subsidies in the production process of plastic materials [11]. Thus, because of the increase in demand for these raw materials, there is a greater concern about the issues associated with the ecosystem, and there is also a greater concern about the processing of solid-form waste, especially the recycling process related to plastic film materials from the industrial process that

continuously generates plastic waste, in addition to plastic waste generated in domestic activities [12].

Most plastic materials applied in the contemporary economic scenario derive from petrochemical processes based on fossil oil and gas. To produce these plastic materials, an important volume of electricity is required, and this demand greatly increases the use of fossil fuels [13]. In order to mitigate the impacts generated by the excessive use of these raw materials, the integrated application between recycled plastic materials and virgin plastic materials is able to reduce the demand for electricity, in addition to reducing the harmful consequences of the environment; in certain situations, the integrated application between recycled plastic materials and virgin plastic materials can improve the properties of the elements used [14].

Waste from plastic materials has a diversity of harmful impacts on the ecosystem and, consequently, is a cause for concern to stakeholders operating in the industrial market of products used by consumers in general, especially due to the elimination of a large volume of plastic particles through disposal in landfills, or incineration [15]. The technological innovation involved in the process of removing paint in plastic particles is a promising method compared to the procedures applied in traditional plastic particle recycling, considering that the removal of paint in plastic particles offers the possibility of reuse of plastic particles that are often discarded in the form of industrial waste [16].

The removal of paint in plastic particles developed by a flexographic method is an important challenge for the recycling context, especially because the available technological resources are dependent on non-biological surfactants, as well as non-renewable surfactants, whose elements cause imminent risks to the ecosystem [17]. This limitation associated with the recycling process of plastic films requires emergency measures, with the purpose of detecting strategies consistent and consistent with the principles of sustainability, so that the removal of paint in plastic particles occurs responsibly in relation to the environment. The general objective of this study is to generate a methodology based on sustainable principles in order to remove the ink in plastic films after printing through the flexographic method with the support of surfactants of biological origin. In this research, the importance of applying aqueous solutions of biological origin and surfactants in order to remove the ink in

plastic films we analyzed, as these elements, in turn, demonstrate greater compatibility with the principles of sustainability [18].

1.2. Research Objectives

Plastics are key engineering materials for our society and economy. Nonetheless, their main drawback is related to the fact that when these cannot be reprocessed, they do generate waste, which leads to several environmental impacts. Therefore, considering plastics' circularity, minimizing their waste, and the resulting impacts, stresses the need for these to be recyclable. One of the main challenges that concern their recyclability is the deinking of plastic films when printed by flexography. The current technology uses non-bio-based surfactants and non-renewable surfactants, which are harmful to the environment. This process focuses on obtaining a deinked plastic that may be reprinted, avoiding this way for inappropriate disposal or reprocessing problems. The value increase of upcycling such post-industrial waste makes it possible to match the quality of the virgin plastic, which is key to carrying out an effective cost analysis of recycled plastic when compared to the new plastic films.

The deinking of plastic films produced by flexography is one of the most significant barriers to their recyclability as the current technology relies on non-biodegradable and non-renewable surfactants, which are harmful to the environment [9]. This severe constraint in the recyclability of plastic films requires urgent action to identify sustainable alternatives to the current deinking processes.

However, their sustainability poses a significant challenge, as improper disposal can harm the environment. Plastic recycling plays a crucial role in mitigating this issue by collecting and reusing plastic materials. A specific challenge lies in deinking plastic films with flexographic printing, where the use of non-biobased surfactants can harm the environment. The aim is to create deinked plastic that can be reprinted, thus preventing environmental risks associated with incorrect disposal or unsustainable recycling. By aligning with contemporary sustainability principles, value can be created for this new production process.

In the field of engineering, plastics are essential instruments, with several relevant purposes in the social and economic environment, mainly due to two factors: versatility of use;

simplified treatment. On the other hand, there is a worrying disadvantage, because, in cases where these plastics are not treated correctly, there is the dissemination of waste, whose action generates harmful effects for nature. When considering the proliferation of waste from the plastics production process, and the harmful effects that such waste can cause on the environment, the importance of improving the processes associated with the recycling of these materials is verified. In the recycling process, there is an important barrier to be overcome: the removal of ink in plastic films after printing by means of the flexographic method. Contemporary technological resources apply non-biological surfactants, as well as non-renewable surfactants, whose materials cause damage to the ecosystem.

As mentioned above, the production process of deinking of plastic films through flexography is a major challenge for recyclability, considering that the contemporary technological structure has non-biodegradable and non-renewable surfactants, and are therefore responsible for causing environmental damage [9]. This perspective on plastic film recycling requires emergency measures, with the purpose of diagnosing sustainability-based options related to contemporary processes associated with deinking. In the present study, the evaluation and the discussion on the use of aqueous substances with bio-based surfactants for plastic film deinking was promoted, considering that the surfactants demonstrate greater compatibility with the principles of sustainability [10]. To such an end, multicriteria analysis is necessary to deal with the complexity and diversity of factors involved in decision-making processes. It helps to comprehensively consider relevant criteria, balance trade-offs, promote transparency and objectivity, deal with uncertainty and risk, and facilitate communication and understanding among decision makers.

In a nutshell, the general objective of this study is to generate a methodology based on sustainable principles in order to remove the ink in plastic films after printing through the flexographic method with the support of surfactants of biological origin. This procedure focuses on the extraction of inkless plastic, making possible the reprinting process, in order to prevent adversities associated with incorrect suppression, or even avoid reprocessing. The construction of value linked to the reuse of waste that arises after the industrial process enables the equalization of efficiency on virgin plastic material, an essential feature to more effectively ascertain the expenses with recycled plastic compared to newly industrialized plastic films. Processes associated with ink removal through laboratory techniques were

applied with the support of transparent films in polyethylene material, with flexographic printing under different parameters.

1.3. General Structure

The present study is structured in chapters that divide each stage of this work.

Firstly, in chapter 1 introduces this research work in the light of current technological challenges related to the deinking processes of plastic films. The following chapter presents a brief literature review on the state-of-the-art related to the deinking processes of plastic films.

Chapter 3 focuses on the materials and methods used to conduct the current research, whilst chapter 4 focuses on the presentation and discussion of the most relevant results.

Finally, in chapter 5, a brief summary of the study is presented, as well as a discussion of the most significant results. A conclusion is also made, where potential future work to be done is discussed, with the aim of deepening the development of this preliminary study.

2. Deinking of Plastic Films

The conventional methods for deinking plastic films are mostly based on non-biodegradable and non-renewable surfactants, which require complex procedures that result in hazardous waste with negative impacts on the environment [11]. Most of the surfactants on the market are synthesized from petrochemical products [12]. However, the desire to reduce the use of products that are harmful to human health and the environment has led to the development of green surfactants, which are surfactants that are formulated with natural, biodegradable surfactant components of biological (plant or microbiological) origin or chemically synthesized from natural raw materials [13].

Most of the surfactants offered in the market environment are concentrated by means of elements from the petrochemical area [12]. The need to reduce the use of elements that cause harm to people's health and harmful to natural resources has caused specialists to create green surfactants, developed based on natural surfactant substances, in addition to having their structure characterized by biodegradability, that is, biological source – plant or microbiological – as well as there are also surfactant substances concentrated through natural resources [13].

On the other hand, the need to reduce artifacts harmful to people's health and that generate imminent risks to the ecosystem encouraged the creation of green surfactants, that is, surfactants based on sustainability principles, with the presence of natural and biodegradable surfactants with biological nature (plant origin / microbiological origin), or condensed through chemical processes supported by natural raw materials [13].

2.1. Bio-based surfactants

In the case of printed packaging, the presence of printing ink during mechanical recycling is a major issue that has a significant negative influence on the process. Given this, research has often been conducted to develop more efficient ways to remove ink from plastics [8]. In this quest, it may be pointed out that aqueous surfactant solutions are considered suitable

choices for such work because of their biodegradability, non-toxicity, and non-volatility [14].

The use of natural compounds instead of chemical surfactants has been explored due to their environmental sustainability and low toxicity, as well as a range of additional advantages [13]. These bio-based surfactants, also often referred to as green surfactants, are acknowledged to be the next generation of industrial surfactants, as they meet most of the requirements for low environmental impact solutions [15]. Bio-based surfactants are key in the current research effort towards greening industrial processes, as these compounds may be considered environmentally friendly due to their low (or absent) toxicity and high biodegradability [16].

The term bio-based surfactant refers to a surfactant produced by a chemical or enzymatic process that uses renewable substrates as raw materials [17]. According to ISO/DIS 21680, a bio-based surfactant is defined as a surfactant wholly or partly derived from biomass (based on biogenic carbon) [18]. Because bio-based surfactants frequently require extra features to increase their functional qualities, combining bio and petroleum-based feedstocks has been one approach for overcoming some of the green surfactants' functional constraints [19]. To support analyzing the bio-based surfactants' sustainability standards, the European Commission of Standardization in its EN 17035:2021 standard has defined categories for biosurfactants, including >95% totally bio-based, 50–94% majority bio-based, 5–49% minority bio-based, and 5% non-bio-based [20].

When analyzing the context related to printed packaging, the existence of printed ink in the traditional recycling process is a worrisome factor. This is an important reason why experts have sought to develop studies with the purpose of creating methods with greater efficiency for the procedure of removing paint in plastic materials [8]. Research already developed on this subject indicates that aqueous surfactants demonstrate good results to meet this demand because of their biodegradable characteristic, besides being a nontoxic substance and without instability [14].

Studies on the use of natural substances in place of chemical-based surfactants have aroused greater interest on the part of the scientific community in recent years because of their compatibility with environmental principles, especially the low toxic index, among other

relevant benefits [13]. Surfactants based on biological factors become essential for contemporary efforts focused on sustainability related to the processes applied in the industrial sector, considering that such substances have balanced sustainable characteristics, especially by the low index (or non-existence) of toxic aspects, as well as due to the high biodegradable index detected in surfactant substances based on biological factors [16].

The expression associated with bio-based surfactant comes from the development of surfactant based on a chemical method [17]. Knowing that bio-based substances surfactants in general require additional materials to raise their level of performance, the integration of resources based on biological characteristics and petrochemical attributes is a strategy that has shown relevance to overcome challenges on the functions associated with green surfactant substances [18]. To strengthen the evaluation of the sustainable guidelines associated with bio-based surfactants, the European Commission of Standardization, by means of EN 17035:2021, established specific classes for biosurfactants: >95% totally bio-based; 50–94% majority bio-based; 5–49% minority bio-based; 5% non-bio-based [19].

In situations with printed plastic films, the ink from this printing – in mechanical recycling processes – generates discussions of great relevance due to the damage that can be caused by the application of this method. Scientific studies have been published with the purpose of creating methods with greater efficiency for the removal of paint in plastic particles [8]. In this evolutionary scientific process, water-based substances related to surfactants stand out, whose elements are effective measures for the removal of paint in plastic particles due to biodegradability, in addition to two other relevant characteristics: nontoxic; consistent [14].

The use of natural surfactants to replace the use of chemical surfactants becomes relevant due to its sustainable attributes, in addition to a reduced toxic index, in addition to other relevant benefits [13]. Surfactants of biological origin are part of a group of surfactants of extreme importance to the industrial sector, taking into account that these green surfactants meet much of the requirements associated with substances with reduced harmful effect to the ecosystem [15]. Surfactants of biological origin represent an important evolution for good industrial practices linked to sustainability, considering that these green surfactants do not attack – or attack very little – the environment due to the low – or non-existent – toxic index, in addition to the great value provided by its biodegradable characteristic [16].

The surfactant terminology of biological origin is associated with surfactants developed from chemical methods, or enzymatic techniques, with the application of renewable structures in the form of raw material [17]. According to ISO/DIS 21680, surfactants of biological origin refer to surfactants with partial or absolute derivation from biogenic carbon-based biomass [18]. Considering that surfactants of biological origin often require additives with the purpose of increasing their degree of functional efficiency, the integration between raw materials of biological origin and raw materials of petrochemical origin becomes an important strategy to overcome challenges related to functional limitations related to surfactants of biological origin [19]. In order to corroborate the evaluation of sustainable parameters associated with surfactants of biological origin, the European Commission for Standardization, by means of EN 17035:2021, established classes associated with surfactants of biological origin, in which: a) more than ninety-five percent are surfactants of absolutely biological origin; b) between fifty and ninety-four percent of surfactants are mostly of biological origin; c) between five and forty-nine percent of surfactants are of inferior biological origin; d) and, finally, five percent of surfactants have non-biological origin [20].

2.2. Ink removal on plastic films using bio-based deinking agents

When recovering rigid plastics or plastic films, deinking is a critical step toward valuing plastic waste in subsequent mechanical recycling stages. Considering that during their production operations, plastic film industries generate between 8% and 12% of printed scrap [21], it is key to develop and implement sustainable solutions to improve the circularity of such post-industrial waste.

On what refers to plastic films, such deinking even allows for recovering unwound film rolls to be reprinted and reused. To such an end, innovative solutions by Piolat [22] and Gamma Meccanica [23] allow foreseeing sustainability benefits by valuing post-industrial waste into new raw materials without the need for recycling, or to further value its recirculation. Nevertheless, such solutions still provide for revalued raw materials with low mechanical and optical properties [8].

Deinking, which involves the removal of various colors and layers of ink from the plastic film, might be considered a laundering process, as it requires the removal of ink from the surface, which is adhered to it by Van-der-Waals, electrical, and mechanical forces [24]. As above mentioned, most of the current deinking procedures for plastic films use non-biodegradable and non-renewable surfactants [11]. Nevertheless, increased research effort is being put towards the use of bio-based agents in the deinking of plastic films [24]–[26]. Furthermore, biosurfactants are more effective in reducing surface and interfacial tensions than synthetic counterparts, and they can withstand high temperatures as well as extreme pH and ionic strength [25].

To analyze and discuss the deinking efficiency on plastic films, different parameters and variables must be addressed. The performance of the deinking agent depends on many aspects like pH and temperature [27], type and concentration of the deinking agent [26], or time and mechanical action [24]. Therefore, to study the removal of ink from printed plastic films it is key to consider the impact and effects of such process variables.

When performing restoration procedures in rigid plastics, or in plastic films, deinking becomes a fundamental step in adding value to plastic waste at later levels associated with traditional recycling. In the industrial environment, during the production process, organizations producing plastic films are responsible for the formation of 8% to 12% of printed scrap, and for this reason, it is essential that managers of these industries create and apply strategies based on sustainability principles, with the purpose of increasing efficiency on the circularity of waste generated in their industrial production environment [20]. Deinking is also able to promote the restoration of plastic film rollers, so that after being unrolled, it is possible to perform the process of reprinting and reuse [21].

It is possible to consider deinking – a procedure associated with the extraction of various colors and ink levels related to plastic film – as a washing process, especially because it needs to extract the paint from the surface. Most of the contemporary techniques associated with deinking in plastic films involve the use of non-biodegradable and non-renewable surfactant substances [11]. On the other hand, we note the growth of scientific studies aimed at detecting the benefits promoted by the application of bio-based substances in deinking processes of plastic films [24]. Bio-based surfactants are more effective when it comes to

decreasing the stress index on surfaces and interfaces compared to synthetic substances, besides presenting a higher degree of tolerance to heat, extreme pH and ionic strength [23].

In order to evaluate and expand the discussions about the level of efficiency offered by the methodology of deinking in plastic films, it is essential to consider different guidelines and variables. Deinking performance is associated with several attributes, such as: pH and heat level [25]; classification and condensation associated with deinking [24]; periodicity and mechanical activity; among other relevant factors. In this sense, to carry out a coherent analysis of the procedures for extracting ink in printed plastic films, the consequences of all factors involved in the process should be included in the evaluation [22].

In the recovery of solid-form plastic materials – plastic films – the removal of paint in plastic particles is an extremely important step in order to promote value for plastic material waste, especially in consecutive phases on the mechanical recycling method. In the production process of plastic films, organizations operating in the industrial sector are responsible for issuing eight percent to twelve percent of printed scrap [21]; in this sense, it is essential to create and apply strategies based on sustainability principles, in order to promote a responsible circulation of waste materials generated after industrial production processes.

The removal of ink in plastic films also offers the possibility of restoring the plastic rolls used – reprinting and reuse. The innovation strategies described by Piolat [22] and Gamma Meccanica [23] are capable of providing sustainable advantages due to the creation of residual value after production processes in the industrial environment in virgin raw materials, and there is no need to adopt recycling techniques, or increase efforts on recirculation. It is important to note that these innovation strategies also offer raw materials with a strengthened value with reduced mechanical and optical characteristics [8].

The removal of paint in plastic films is a procedure responsible for the extraction of various colors of paint, in addition to ink coatings present in plastic material. Thus, removal of paint in plastic films represents a specific type of washing, when considering requires the extraction of paint on the surface of the material, with the support of Van-der-Waals forces, electrical impulses and mechanical events [24]. Most modes applied to the removal of paint in plastic films use non-biological surfactants, as well as non-renewable surfactants [11]. On the other hand, there is an increase in scientific research related to the use of substances of

biological origin for the removal of paint in plastic particles [24–26]. Green surfactants are more effective in reducing surface stresses and interfacial stresses compared to synthetic surfactants and, consequently, exhibit a much higher temperature, in addition to extreme pH and ionic force [25].

In order to present an efficient analysis, in addition to a more accurate discussion on the removal of paint in plastic particles, different criteria and clinical factors should be considered. The performance of the substance responsible for removing paint in plastic films is related to several specific attributes, such as pH and degree of temperature [27], species and agglomeration of the substance responsible for removing paint in plastic films, [26] period and mechanical activity [24]. To evaluate more objectively the aspects related to the removal of ink in printed plastic materials, it is necessary to reflect the consequences of all relevant issues involved in this method.

3. Materials and Methods

In this chapter, the main materials and methods for the three different research studies conducted throughout this thesis are presented and systematized.

3.1. Materials for the first research study

For this study, samples of a colorless clear transparent polyethylene film, printed by flexography with different conditions were analyzed. The clear transparent LDPE film was printed for commercial purposes with a final layer of 50 μm thickness. The printed film prints are constituted by the intermediate combined intermediate layers presented in Table 1.

Table 1. Summary of the print layers of the current case study.

LDPE film print
White
Yellow
Magenta
Black
Green
Blue

To perform the deinking of plastic films, surfactants may be needed to reduce the surface or interfacial tension at the air/water, ink/water, and plastic/water interface, and this can increase the wettability of the solution and allow alkali to penetrate between the ink particle and the plastic film. The surfactant used in this case study was the BIO 691 from the Bioloop product family, manufactured by Lankem Ltd. (UK). It is bio-based and, therefore, is not harmful to the environment, according to the EC regulation no. 1272/2008. The surfactant was used as supplied and diluted on deionized water for the testing conditions at approximately pH 8.

3.2. Deinking tests of the first research study

To carry out the experimental deinking test procedures, a total of 16 subsamples were cut into approximately 1 by 5 cm long strips. These tests were performed to collect results for 4 factors: Surfactant concentration, bath temperature, bath time, and brushing.

Half of the plastic film strips were submitted to a set of experimental deinking test procedures at room temperature, whereas the remaining samples were tested at 40 °C. With the use of a 1-5 mL M5000 adjustable volume manual pipette, tweezers, test tube, glass beakers, digital thermometer and a RCT Basic Safety Control magnetic agitation plate, the samples were submerged in each test tube of 30 ml for the 30 second- and 1-minute tests. The surfactant solutions of 5% and 2.5% were freshly prepared with distilled water for each sample, and the pH level of the aqueous surfactant solution was not adjusted. The samples were agitated using the magnetic stirrer.

After draining, the film strips were submitted to brushing, washed with water, and dried. The 16 plastic film strips were randomly collected to analyze the level of deinking. Each processed sample was visually and qualitatively assessed.

3.3. Design of experiments of the first research study

For the Design of Experiments (DoE) analysis, five levels of performance of the deinking process were assigned. The classification used for the deinking performance is shown in Table 2.

Table 2. Classification used for the deinking performance.

Classification	Description
No deinking (1)	No evident effects of the surfactant agent
Poorly deinked (2)	Low or no effect of the surfactant agent
Lightly deinked (3)	Slight and visible effects of the surfactant agent
Mostly deinked (4)	Evident effects of the surfactant agent, but not full deinking
Fully deinked (5)	Full deinking achieved

Table 3. Testing conditions for the DoE analysis.

StdOrder	Surfactant Concentration	Bath Temperature	Bath Time	Brush	
	[%]	[°C]	[s]	[iterations]	
1	2.5	25	30	1	
2	5	25	30	5	
3	2.5	40	30	5	
4	5	40	30	1	
5	2.5	25	60	5	
6	5	25	60	1	
7	2.5	40	60	1	
8	5	40	60	5	
9	2.5	25	30	5	
10	5	25	30	1	
11	2.5	40	30	1	
12	5	40	30	5	
13	2.5	25	60	1	
14	5	25	60	5	

The factorial design analysis created results on 14 condition tests to use on the Minitab software [28]. With performance as the response variable, the expected output was related to the increase in performance of the chemical reaction. To such end, four factors were tested, namely the bath temperature (25 °C and 40 °C), surfactant concentration (5% against 2.5%), bath time (30 seconds against 1 minute) and impact of brushing (once to five times), as listed in Table 3.

3.4. Materials of the second research study

For this study, samples of a colorless transparent and white low-density polyethylene (LDPE) film, printed by flexography with several layers of ink were analyzed. The transparent and white LDPE film was printed for commercial purposes with a final layer of

50 μm thickness. The printed film is constituted by several layers of ink presented in Table 1.

Table 4. Summary of the printed ink layers of the current case study.

Transparent LDPE film print	White LDPE film print
White	Beije
Yellow	Yellow
Magenta	Magenta
Black	Blue
Green	Black
Blue	Green

To perform the deinking of plastic films, surfactants may be needed to reduce the surface or interfacial tension at the air/water, ink/water, and plastic/water interface, and this can increase the wettability of the solution and allow the deinking agent to penetrate between the ink particle and the plastic film. The surfactant used in this study were acquired from Lankem Ltd. and Rokamin. The BIO 691 and BA6 are from the Bioloop product family, manufactured by Lankem Ltd. (UK). They are bio-based and, therefore, are not harmful to the environment, according to EC regulation no. 1272/2008. These surfactants were used as supplied and diluted on deionized water for the testing conditions at approximately pH 8. Manufactured by Rokamin (Poland), it was used the surfactants K15K, SRK8 and SRK8P4. They are cationic surfactants with antistatic properties. According to EC regulation no. 1272/2008, high concentrations of these kinds of products cause serious damage to the environment, toxic to aquatic life with long lasting effects. These surfactants are soluble in hot water and other solvents.

3.5. Deinking Tests of the second research study

To carry out the experimental deinking test procedures, the Design of Experiments (DoE) methodology was used to select the number of experiments and factors. A total of 32 subsamples, 16 of transparent film and 16 of white film, were cut into approximately 1 by 5 cm long strips. These tests were performed to collect results for 4 factors: surfactant concentration, bath temperature, bath time, and brushing.

Half of the plastic film strips were submitted to a set of experimental deinking test procedures at room temperature, whereas the remaining samples were tested at 40 °C and 70 °C. With the use of a 1-5 mL adjustable volume manual pipette, tweezers, test tube, glass beakers, digital thermometer and laboratory water bath equipment, the samples were submerged in each test tube of 30 ml for the 30 seconds and 1minute tests. The surfactant solutions of 5 % and 2.5 % were freshly prepared with deionized water for each sample, and the pH level of the aqueous surfactant solution was not adjusted. The samples were agitated using the magnetic stirrer.

After draining, the film strips were submitted to brushing, washed with deionized water, and dried. The 32 plastic film strips were randomly collected to analyze the level of deinking. Each processed sample was visually and qualitatively assessed.

3.6. Design of experiments of the second research study

Design of experiments will detect and quantify special relationships in which two or more factors act differently in how they affect the process together compared to how they affect it separately. Such relationships are called interactions. For the DoE analysis, five levels of performance of the deinking process were assigned. The classification used for the deinking performance is shown in Table 5.

Table 5. Classification used for the deinking performance.

Classification	Description
No deinking (1)	No evident effects of the surfactant agent
Poorly deinked (2)	Low or no effect of the surfactant agent
Lightly deinked (3)	Slight and visible effects of the surfactant agent
Mostly deinked (4)	Evident effects of the surfactant agent, but not full deinking
Fully deinked (5)	Full deinking achieved

Table 6. Testing conditions for the DoE analysis.

StdOrder	Surfactant Concentration	Bath Temperature	Bath Time	Brush
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	[%]	[°C]	[s]	[iterations]
1	2.5	25	30	1
2	5	25	30	5
3	2.5	40	30	5
4	5	40	30	1
5	2.5	25	60	5
6	5	25	60	1
7	2.5	40	60	1
8	5	40	60	5
9	2.5	25	30	5
10	5	25	30	1
11	2.5	40	30	1
12	5	40	30	5
13	2.5	25	60	1
14	5	25	60	5
15	2.5	70	30	1
16	5	70	30	5
17	2.5	70	60	1
18	5	70	60	5
19	2.5	70	30	1
20	5	70	30	5
21	2.5	70	60	1
22	5	70	60	5

The factorial design analysis created results on 22 condition tests to use on the Analysis ToolPack, supplement of Microsoft Excel software. With performance as the response variable, the expected output was related to the increase in the performance of the physico-chemical reaction. To such end, four factors were tested, namely the bath temperature (25 °C, 40 °C, and 70°C), surfactant concentration (5% and 2.5%), bath time (30 seconds and 1 minute) and impact of brushing (once to five times), as listed in Table 6.

3.7. Materials of the third research study

For this last study, samples of a colorless clear transparent and white polyethylene film, printed by flexography with different conditions were analyzed. The clear transparent and white LDPE film was printed for commercial purposes with a final layer of 50 μm thickness. The printed film prints are constituted by the intermediate combined intermediate layers presented in Table 7.

Table 7. Summary of the print layers of the current case study.

Transparent LDPE film print	White LDPE film print
White	Beije
Yellow	Yellow
Magenta	Magenta
Black	Blue
Green	Black
Blue	Green

To perform the deinking of plastic films, surfactants may be needed to reduce the surface or interfacial tension at the air/water, ink/water, and plastic/water interface, and this can increase the wettability of the solution and allow alkali to penetrate between the ink particle and the plastic film. The surfactant used in this case study was the BIO 691 and BA6 from the Bioloop product family, manufactured by Lankem Ltd. (UK). The two samples are shown below in Figure 1. It is bio-based and, therefore, is not harmful to the environment, according to the EC regulation no. 1272/2008. The surfactant was used as supplied and diluted on deionized water for the testing conditions at approximately pH 8.



Figure 1 - Surfactants samples.

3.8. Deinking tests of the third research study

To implement the experimental deinking test procedures, an number of subsamples were cut into pieces short strips, as shown in Figure 2 let's call it flakes of PE here. These tests were performed to collect results for 3 factors: Surfactant concentration, bath temperature and bath time agitation.

Half of the plastic film flakes were submitted to a set of experimental deinking test procedures at room temperature, whereas the remaining samples were tested at 60 °C. With the use of a 1-10mL M5000 adjustable volume manual pipette, tweezers, glass beakers, digital thermometer and a RCT Basic Safety Control magnetic agitation plate, the samples were submerged in each glass becker of 100 ml for the 3 minute and five minutes tests. The surfactant solutions of 5% and 10% were freshly prepared with distilled water for each sample, and the pH level of the aqueous surfactant solution was not adjusted. The samples were agitated using the magnetic stirrer.

After draining, the film flakes were submitted to washed with water, and dried. The plastic film flakes were randomly collected to analyze the level of deinking. Each processed sample was visually and qualitatively assessed.

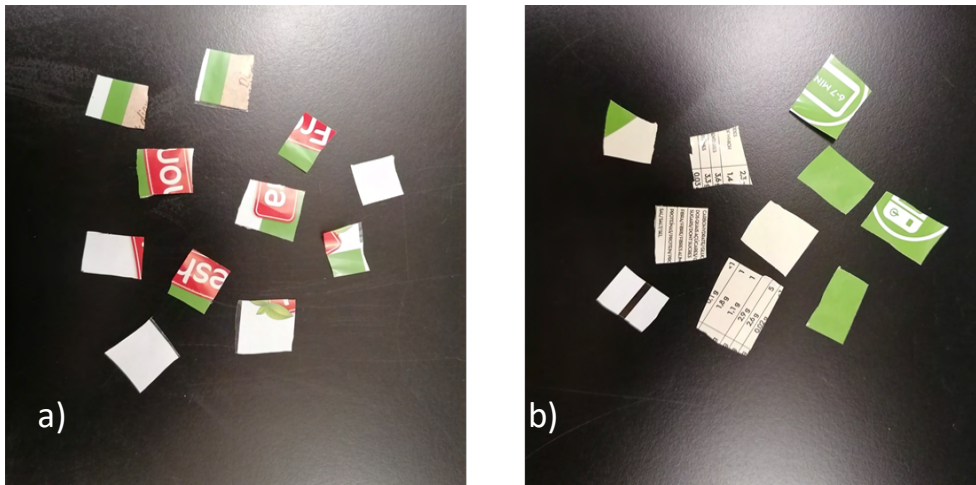


Figure 2 - a) Transparent plastic samples and b) white plastic samples.

3.9. Design of experiments of the third research study

For the Design of Experiments (DoE) analysis, five levels of performance of the deinking process were assigned. The classification used for the deinking performance is shown in Table 8.

Table 8. Classification used for the deinking performance.

Classification	Description
No deinking (1)	No evident effects of the surfactant agent
Poorly deinked (2)	Low or no effect of the surfactant agent
Lightly deinked (3)	Slight and visible effects of the surfactant agent
Mostly deinked (4)	Evident effects of the surfactant agent, but not full deinking
Fully deinked (5)	Full deinking achieved

Table 9. Testing conditions for the DoE analysis.

StdOrder	Surfactant Concentration	Bath Temperature	Bath Time Agitation
	[%]	[°C]	[m]
1	5	25	3
2	5	25	5

3	5	60	3
4	5	60	5
5	10	25	3
6	10	25	5
7	10	60	3
8	10	60	5

The factorial design analysis created results on condition tests to use on the Analysis ToolPack, supplement of Excel software [28]. With performance as the response variable, the expected output was related to the increase in performance of the chemical reaction. To such end, three factors were tested, namely the bath temperature (25 °C and 60 °C), surfactant concentration (5% against 10%) and bath time (3 minute against 5 minute) as listed in Table 9.

4. Results and Discussion

To better discuss all the conducted research experiments, the following results will be presented and discussed in three sections related to the three main research studies of this thesis, ending with a fourth section discussing the main characteristics of a prototype to carry-out the potential industrial approach to the proposed sustainable deinking processes to recover post-industrial printed plastic films.

4.1. An exploratory approach to remove ink layers from plastic films printed by flexography

Deinking relates to removing the printing layers on the plastic film. The strips were treated with 2.5% and 5% of surfactant solutions at approximately pH 8 and magnetically stirred. For the set of analyses carried out, the deinking level of the 16 samples was established and classified according to the criteria presented in Table 2.

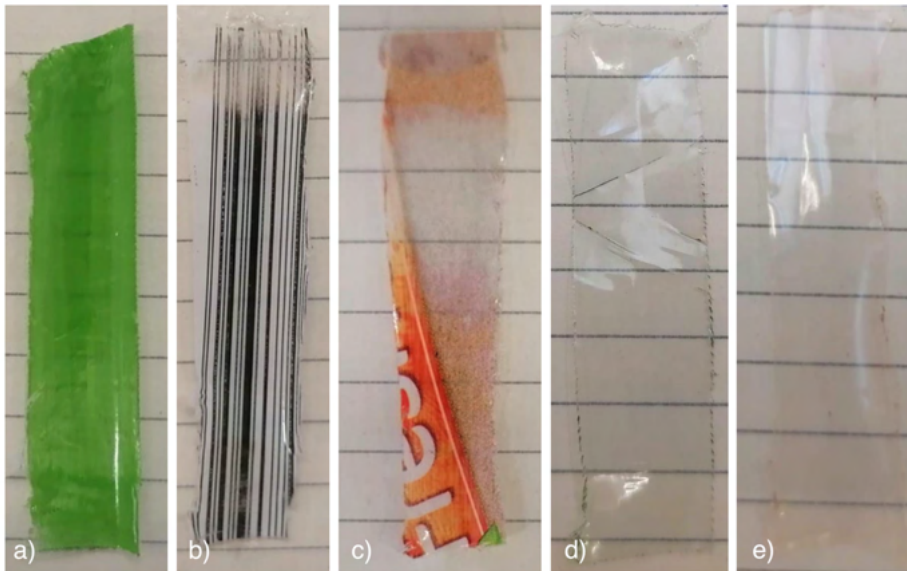


Figure 3 - Classification of the processed samples transparent film. a) No deinking (1); b) Poorly deinked (2); c) Lightly deinked (3); d) Mostly deinked (4); e) Fully deinked (5).

Figure 3.a) shows a sample where no evidence of deinking was observed due to the action of the surfactant, while in the sample Figure 3.b) it was possible to identify a reduced effect of the surfactant. Figure 3.c) depicts visible effects of deinking, but not too effective. Finally, Figures 3.d) and 3.e) show the best deinking results, particularly those of Figure 3.e), where complete deinking took place.

Table 10 shows the deinking performance results obtained for each testing procedure, ordered from the best deinking performance to the less performing condition.

Table 10. Deinking performance results.

StdOrder	Surfactant Concentration	Bath Temperature	Bath Time	Brush	Deinking Performance
	[%]	[°C]	[s]	[iterations]	
4	5	40	30	1	5
8	5	40	60	5	5
12	5	40	30	5	5
16	5	40	60	5	5
3	2.5	40	30	5	4
7	2.5	40	60	1	4
11	2.5	40	30	1	4
15	2.5	40	60	1	4
6	5	25	60	1	3
14	5	25	60	5	3
2	5	25	30	5	2
5	2.5	25	60	5	2
10	5	25	30	1	2
1	2.5	25	30	1	1
9	2.5	25	30	5	1
13	2.5	25	60	1	1

From Table 10, it is possible to observe that the bath temperature is the most critical factor in the effectiveness of the deinking process. Figure 4 plots the main effects of surfactant

concentration, bath temperature, bath time and brushing iterations for the deinking performance.

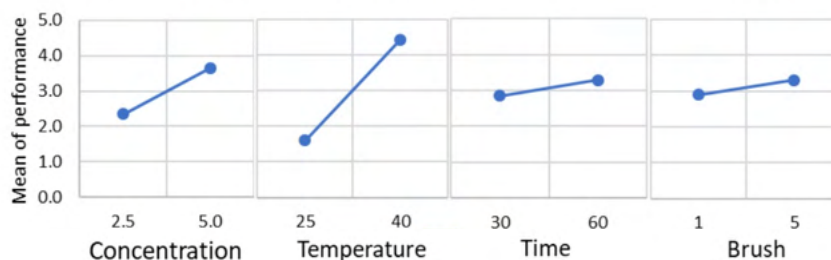


Figure 4 - Main effects plot for performance (fitted means)

The main effects on the impact of deinking performance are the bath temperature and the surfactant concentration, as can be observed in Figure 4. When the bath temperature is 40 °C, the deinking performance is significantly higher when compared to the same results for a temperature of 25 °C. Following the same trend, the deinking performance is significantly improved for the higher surfactant concentration. On what refers to the bath time and brushing iterations, the deinking performance is less affected but follows the same trend as the other factors for the higher values.

On what concerns the sustainability of the deinking process, a detailed analysis of the entire lifecycle of all materials involved would be required. For the current results, however, it is important to note that the most relevant factors for the deinking process are the same factors that need to be balanced.

A higher bath temperature requires additional energy when compared to the lower temperature condition. Considering that such increased demand for electric energy may have different economic and environmental impacts, namely, regarding alternative fossil fuel or renewable sources, further analysis of the life cycle impacts is required.

When considering the effect of the surfactant concentration, the use of an eco-friendly surfactant may be beneficial to the process not only from the standpoint of enhancing the deinking process but also from the sustainability perspective. Thus, the increased use of an eco-friendly surfactant may have a lower environmental impact when compared to the

alternative solution of increasing the bath temperature to 40 °C. Nevertheless, the energy required to produce the surfactant agent is not considered in this case study. This supports the need for a complete life cycle assessment of the proposed deinking process as further research.

4.2. Removing ink layers from plastic films printed by flexography

In this second research study, the use of dedicated surfactants was analyzed to remove ink layers from both transparent and white plastic films printed by flexography.

Design of experiment results

Deinking relates to removing the printing layers on the plastic film. The strips were treated with 2.5% and 5% of surfactant solutions at approximately pH 8 and magnetically stirred. For the set of analyses carried out, the deinking level of the 16 samples was established and classified according to the criteria presented in Table 2.

Figure 5 examples of white polyethylene film sample are presented, demonstrating the effectiveness of the Bio 691 surfactant in the deinking process. Both Bio691 and BA6 surfactants showed efficient deinking properties, with the only difference being the temperature influence on the BA6 surfactant. Deinking involves the removal of colored plastic paint layers, not the entire coating. Figure 5.a) displays a sample where no visible evidence of deinking was observed due to the surfactant's action, while Figure 5.b) shows a slight effect. In Figure 5.c) visible but less effective deinking effects can be observed. Finally, Figure 5.d) and Figure 5.e) showcase the most successful deinking results, particularly Figure 5.e), where complete deinking was achieved.

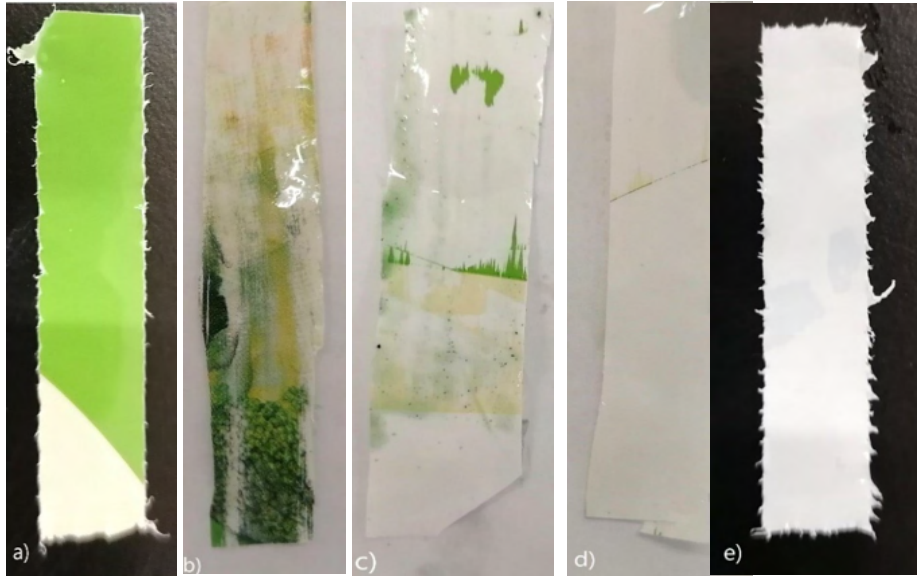


Figure 5 - Results of the processed samples white film with Bio691. a) No deinking (1); b) Poorly deinked (2); c) Lightly deinked (3); d) Mostly deinked (4); e) Fully deinked (5).

Rising temperature alone might increase the performance of deinking reaction, whereas higher concentration alone might decrease performance slightly, but if hotter temperature and higher concentration together greatly increase the performance, that would be an interaction, in this case positive one as shows In Figure 6 the effects of using BA6 surfactant at a concentration of 5% and a temperature of 70°C are demonstrated. Figure 6.a) presents a sample where no visible evidence of deinking was observed when using the surfactant. Figure 6.b) a reduced effect of the surfactant can be identified. Figure 6.c) show visible but less effective deinking effects. Finally, Figure 6.d) and Figure 6.e) exhibit the most successful deinking outcomes, particularly in Figure 6.e), where complete deinking was achieved.

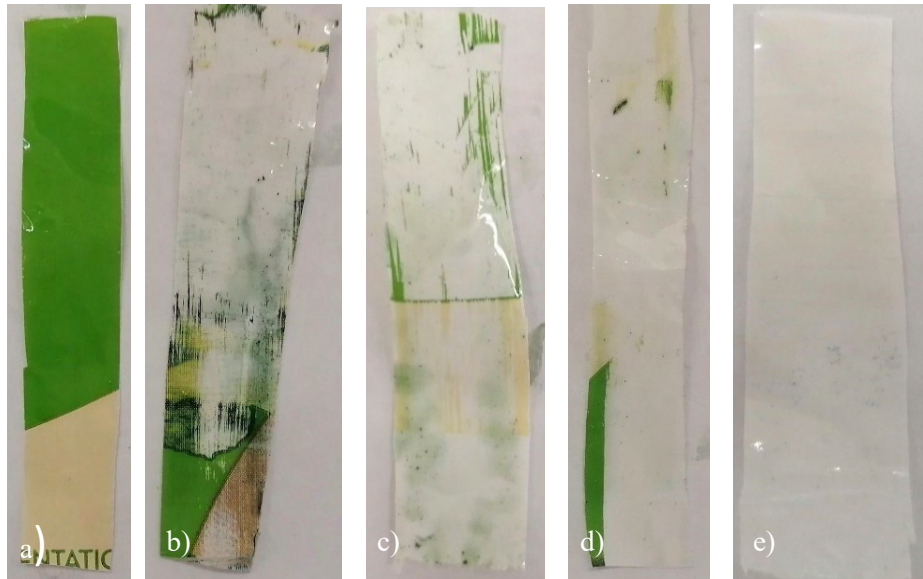


Figure 6 - Results of the processed samples white film with BA6. . a) No deinking (1); b) Poorly deinked (2); c) Lightly deinked (3); d) Mostly deinked (4); e) Fully deinked (5).

Figure 7 shows the performance of surfactant K15K at the higher concentration and temperature, 5% and 70 °C respectively, the efficiency of this surfactant was quite low, with a slightly removal in the last strip. Figure 7. a), b), c) and d) no evidence of deinking. Figure 7. e) slightly removal of deinking.

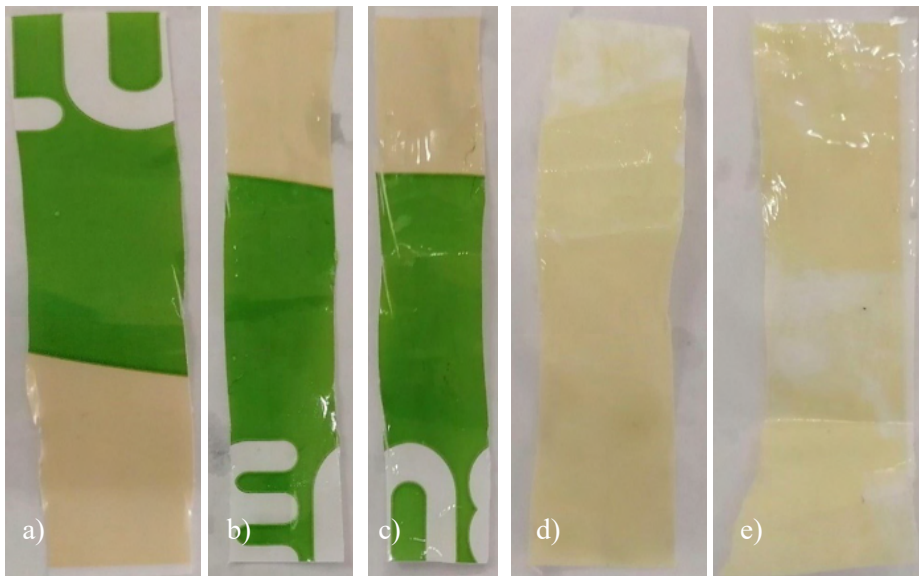


Figure 7 - Results of the processed samples white film with K15K. a) No deinking (1); b) Poorly deinked (2); c) Lightly deinked (3); d) Mostly deinked (4); e) Fully deinked (5).

Figure 8 and Figure 9 show the results of the application of the surfactants SRK8 and SRK8p4 from Rokamin, in which no deinking was observed with the experimental conditions considered in this work. The choice of these surfactants is not applicable for deinking process. Both Figure 8 and Figure 9 a), b), c), d) and e) shows a strip where no evidence of deinking with both surfactants SRK8 and SRK8p4.

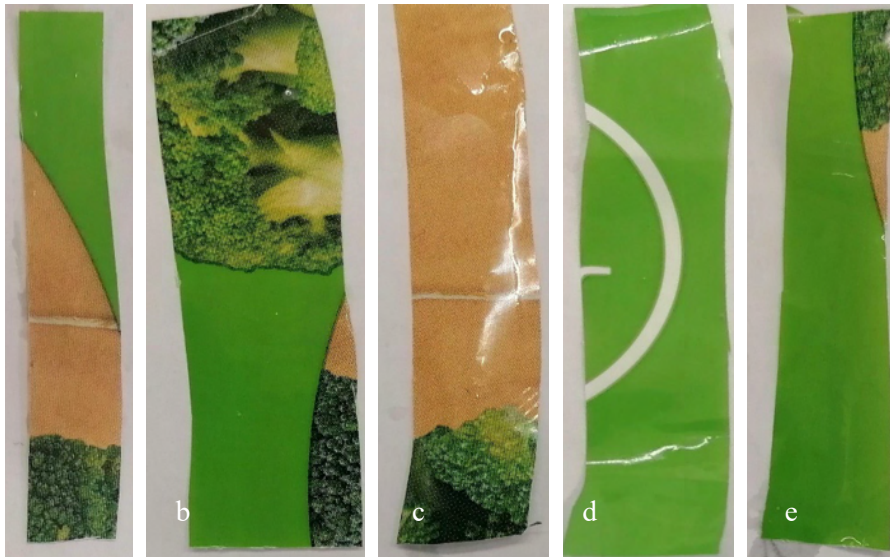


Figure 8 - Results of the processed samples white film with SRK8. a) No deinking (1); b) Poorly deinked (2); c) Lightly deinked (3); d) Mostly deinked (4); e) Fully deinked (5).

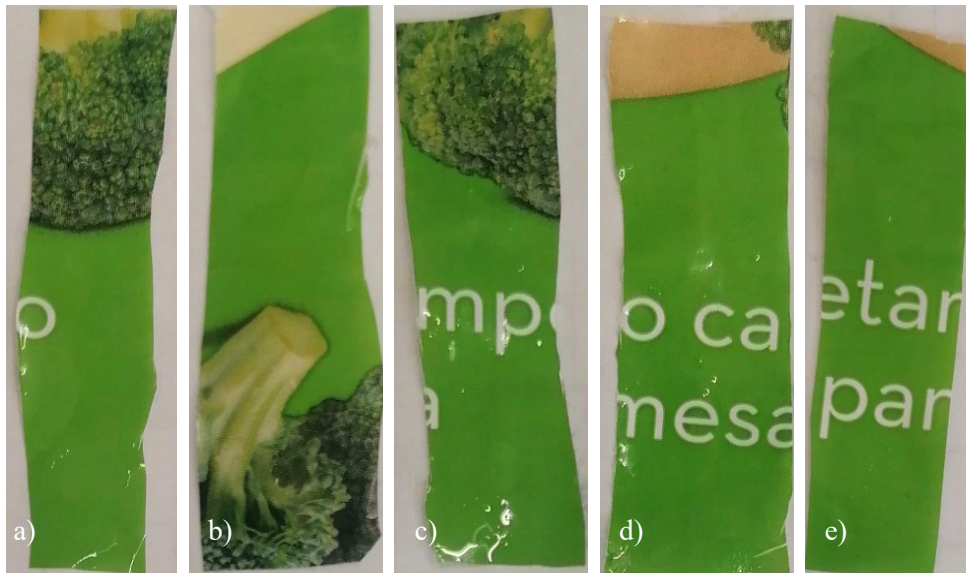


Figure 9 - Results of the processed samples white film with SRK8p4 a) No deinking (1); b) Poorly deinked (2); c) Lightly deinked (3); d) Mostly deinked (4); e) Fully deinked (5)

Table 11. Deinking performance results.

StdOrder	Surfactant	Bath	Bath	Brush	Deinking Performance				
	Concentration	Temperature	Time	[iterations]	BIO691	BA6	K15K	SRK8	SRK8P4
	[%]	[°C]	[s]						
1	5	40	30	1	5	4	1	1	1
2	5	40	60	5	5	5	1	1	1
2	5	40	30	5	5	4	1	1	1
4	5	40	60	5	5	4	1	1	1
5	2.5	40	30	5	4	3	1	1	1
6	2.5	40	60	1	4	3	1	1	1
7	2.5	40	30	1	4	3	1	1	1
8	2.5	40	60	1	4	3	1	1	1
9	5	70	30	1	4	3	1	1	1
10	5	70	60	5	5	5	2	1	1
11	5	70	30	5	4	4	2	1	1
12	5	70	60	5	5	5	2	1	1
13	2.5	70	30	5	4	4	2	1	1
14	2.5	70	60	1	4	4	1	1	1
15	2.5	70	30	1	4	4	1	1	1
16	2.5	70	60	1	4	4	1	1	1
17	5	25	60	1	3	2	1	1	1
18	5	25	60	5	3	2	1	1	1
19	5	25	30	5	2	1	1	1	1
20	2.5	25	60	5	2	1	1	1	1
21	5	25	30	1	2	1	1	1	1
22	2.5	25	30	1	1	1	1	1	1
23	2.5	25	30	5	1	1	1	1	1
24	2.5	25	60	1	1	1	1	1	1

Table 11. Shows the deinking performance results obtained for each testing procedure, ordered from the best deinking performance to the less performing condition. From Table 11, it is possible to observe that the bath temperature is the most critical factor in the effectiveness of the deinking process of Bio 691 and BA6.

Figure 10 shows the interactions between factors with the surfactant Bio691. The bath temperature presented the highest increase of performance, being the most important factor, since the higher the temperature, the better the efficiency of the surfactant solution. The main effects on the impact of deinking performance are the bath temperature and the surfactant concentration. When the bath temperature reaches 40 °C, the deinking performance is significantly higher when compared to the same results for a temperature of 25 °C. The bath time and brush had similar performance with a very low effect.

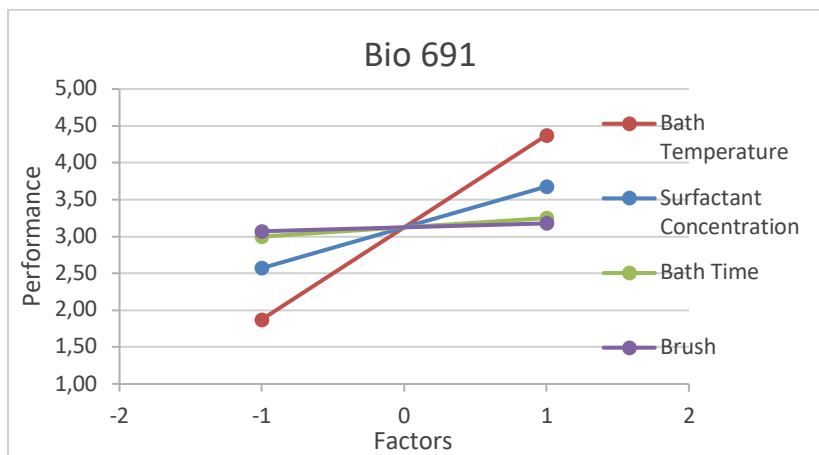


Figure 10 - Main effects plot for performance of Bio691 (fitted means).

Figure 11 shows the interactions between factors with the surfactant BA6. It is possible to observe that the bath temperature is the most important factor in the effectiveness of the deinking process, although fully deinked only at 70 °C. Following the same trend, the deinking performance is significantly improved for the higher bath time. On what refers to the surfactant concentration and brushing iterations, the deinking performance is less affected but follows the same trend as the other factors for the higher values. The main

effects on the impact of deinking performance are the most pronounced by the bath temperature.

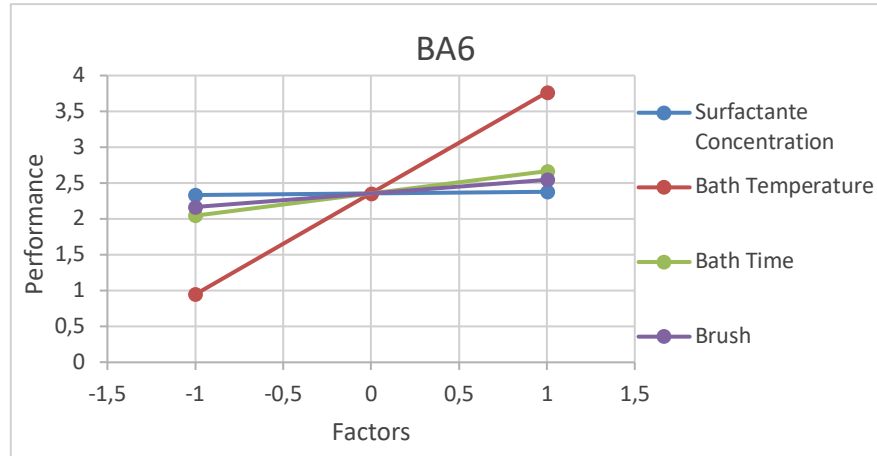


Figure 11 - Main effects plot for performance of BA6 (fitted means).

Figure 12 shows the cationic surfactant K15K, having antistatic properties, it can be used as a component of professional cleaning agents, served as hydrotrope. The solubility in water is good, however it is not effective on the deinking process. The capacity of deinking was demonstrated only at 70 °C and 5 % of surfactant, showing a very low performance of deinking within the chosen interval of temperature, concentration, time, and brush.

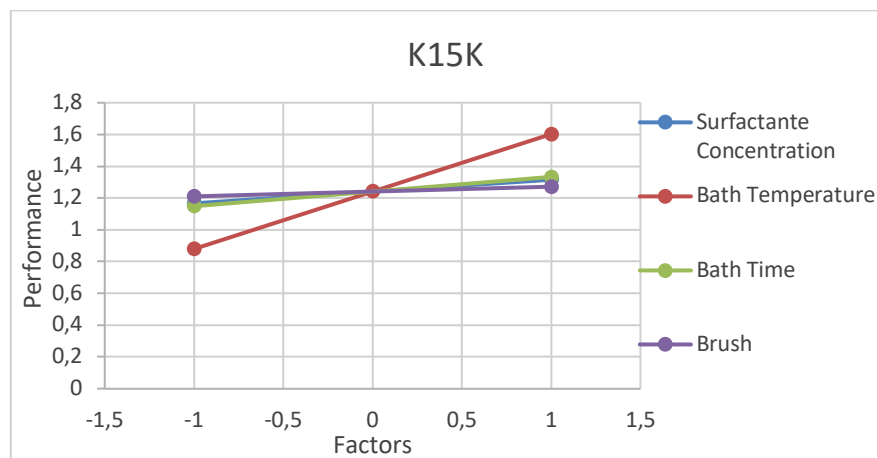


Figure 12 - Main effects plot for performance of K15K (fitted means).

The surfactants SRK8 and SRK8p4, both are soluble in hot water, nonetheless neither SRK8 nor SRK8p4 is effective of the deinking process, accordingly with design of experiments at TollPak. SRK8 is effective of the deinking using solvent benzene but the main goal of this study is the deinking with aqueous solutions.

The main effects on the impact of deinking performance are the bath temperature and the bath concentration for the surfactant Bio 691 and bath temperature and bath time for the surfactant BA6, as can be observed in Figure 7 and 8. Following the same trend, the deinking performance is significantly improved for the higher surfactant concentration. Brushing iterations, the deinking performance is less affected but follows the same trend as the other factors for the higher values.

A higher bath temperature requires additional energy when compared to the lower temperature condition. Considering that such increased demand for electric energy may have different economic and environmental impacts, namely, regarding alternative fossil fuel or renewable sources. However, the effectiveness of the surfactant concentration is also relevant, increasing temperature the surfactant concentration can be decreased to obtain similar results of deinking, further analysis of the life cycle impacts is required.

When considering the effect of the surfactant concentration, the use of an eco-friendly surfactant may be beneficial to the process not only from the standpoint of enhancing the deinking process but also from the sustainability perspective. Thus, the increased use of an eco-friendly surfactant may have a lower environmental impact when compared to the alternative solution of increasing the bath temperature to 40 °C and 70 °C. Nevertheless, the energy required to produce the surfactant agent is not considered in this case study. This supports the need for a complete life cycle assessment of the proposed deinking process as further research.

Multicriteria Analysis

The multicriteria analysis was performed using the Super Decision software, which is a software application designed for decision-making processes that involve multiple criteria. It is commonly used in fields such as operations research, project management, and strategic planning. Super Decisions is based on the Analytic Hierarchy Process (AHP), a widely recognized decision-making methodology. As for versions and authors, Super Decisions was developed by Thomas L. Saaty, who is a renowned mathematician and expert in decision sciences. The software has undergone several updates and enhancements over the years. The specific versions and their corresponding features may vary, depending on when the software was last updated.

The Analytic Hierarchical Process (AHP) make it possible to include intangibles in decision making. The analysis created results on clusters/nodes in the superdecision software what follows a brief recap:

- Alternatives: Bio691, BA6, K15K, SRK8 and SRK8p4.
- Criteria: Biobased, Costs and Performance.
- Goal: Buy Surfactant.

Table 5 presents the overall synthesized priorities for the alternatives. The normal indicated, are the priorities of the alternatives. The raw values (Total) come from the limit supermatrix.

Table 12. Alternatives rankings.

Ranking	Alternatives	Normal	Ideal	Total
1	Bio691	0.5167	1.0000	0.2584
2	BA6	0.3496	0.6765	0.1748
3	K15K	0.0584	0.1130	0.0292
4	SRK8	0.0376	0.0728	0.0188
5	SRK8p4	0.0376	0.0728	0.0188

The normalized values are obtained from the raw values by summing and dividing each by the sum. The ideals are obtained by dividing each normal values by the largest normal value.

Table 5 is a report for how alternatives fed up with the system to give synthesized values. This shows that the Bio 691 is the best surfactant.

4.3. Removing ink layers from plastic films printed by flexography without brushing

As mentioned above, deinking relates to removing the printing layers on plastic films. This set of tests relate to performing deinking test without the need for brushing operation. If successful, such procedure will allow for slipping the brushing steps, with all the related economic and efficiency enhancements that are expected.

For these tests, instead of film stripes, plastic flakes were used to test the overall efficiency of the proposed deinking experiments. The flakes were treated with 5% and 10% of surfactant solutions at approximately pH 8 and magnetically stirred about 700rpm. For the set of analyses carried out, the deinking level of the samples was established and classified according to the criteria presented in Table 2.

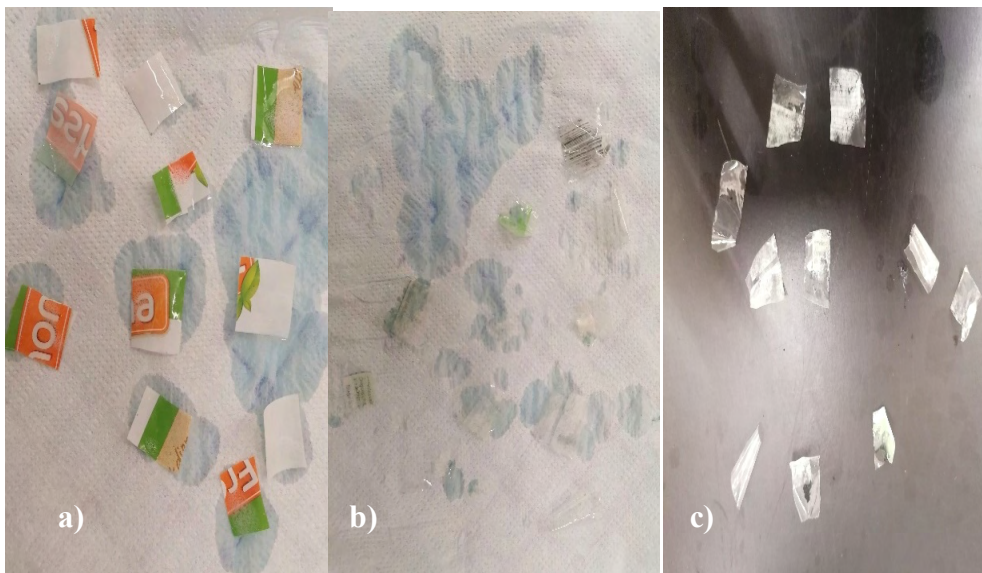


Figure 13 – Transparent plastic with Bio691.

Figure 13. Shows the best performance of surfactant Bio 691 with 10% concentration, 60°C and five minutes bath agitation with transparent plastic. Figure 13.a) shows a sample where no evidence of deinking was observed due to the action of the surfactant at room temperature, while in the sample Figure 13.b) it was possible to identify a reduced effect of the surfactant at 5% concentration. Figure 13.c) show the best deinking results, particularly those of Figure 13.c), where complete deinking took place (10% concentration and five minutes bath agitation with Bio 691).

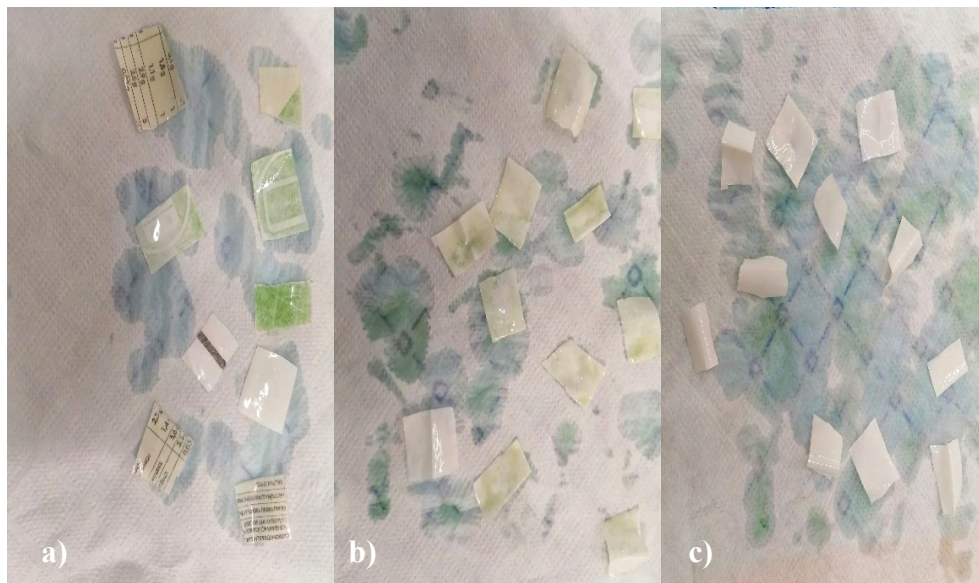


Figure 14 – White Plastic with BA6.

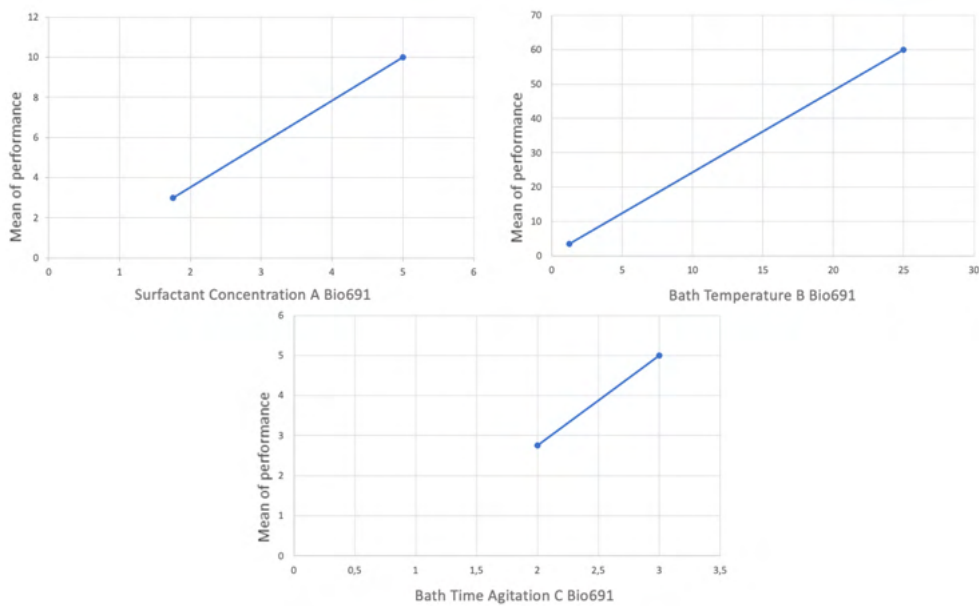
Figure 14. Shows the best performance of surfactant BA6 with 10% concentration, 60°C and five minutes bath agitation with white plastic. Figure 14.a) shows a sample where no evidence of deinking was observed due to the action of the surfactant at room temperature, while in the sample Figure 14.b) it was possible to identify a reduced effect of the surfactant at 5% concentration. Figure 4.c) show the best deinking results, particularly those of Figure 14.c), where complete deinking took place.

Table 13 shows the deinking performance results obtained for each testing procedure, ordered from the best deinking performance to the less performing condition.

Table 13. Deinking performance results.

StdOrder	Surfactant Concentration	Bath Temperature	Bath Time Agitat.	DeinkingBio691 Perf.	Deinking BA6 Perf.
	[%]	[°C]	[s]		
1	5	25	3	1	1
2	5	25	5	1	1
3	5	60	3	2	2
4	5	60	5	3	2
5	10	25	3	1	1
6	10	25	5	2	2
7	10	60	3	4	3
8	10	60	5	5	4

From Table 4, it is possible to observe that the bath temperature is the most critical factor in the effectiveness of the deinking process. Figure 15 and Figure 17 plots the main effects of surfactant concentration, bath temperature, bath time agitation iterations for the deinking performance of each surfactant.

**Figure 15 -** Main effects plot for performance Bio691(fitted means).

The main effects on the impact of deinking performance are the bath temperature and the surfactant concentration, as can be observed in Figure 15. When the bath temperature reaches 60 °C, the deinking performance is significantly higher when compared to the same results for a temperature of 25 °C

Figure 16 shows the interactions between factors with the surfactant Bio691, it is possible to observe that the bath temperature is the most important factor, since the higher the temperature, the better the efficiency of the surfactant solution.

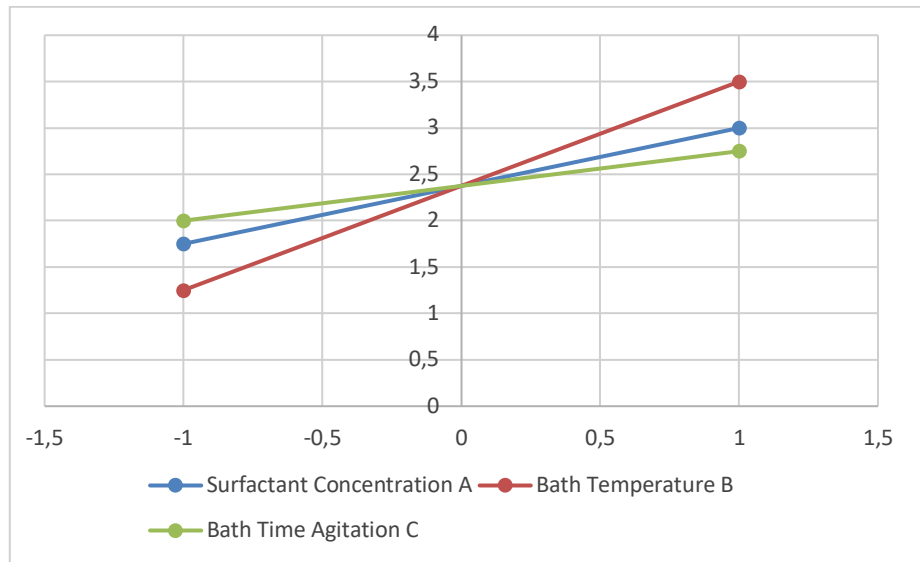


Figure 16 - Main effects plot for performance Bio691 (fitted means).

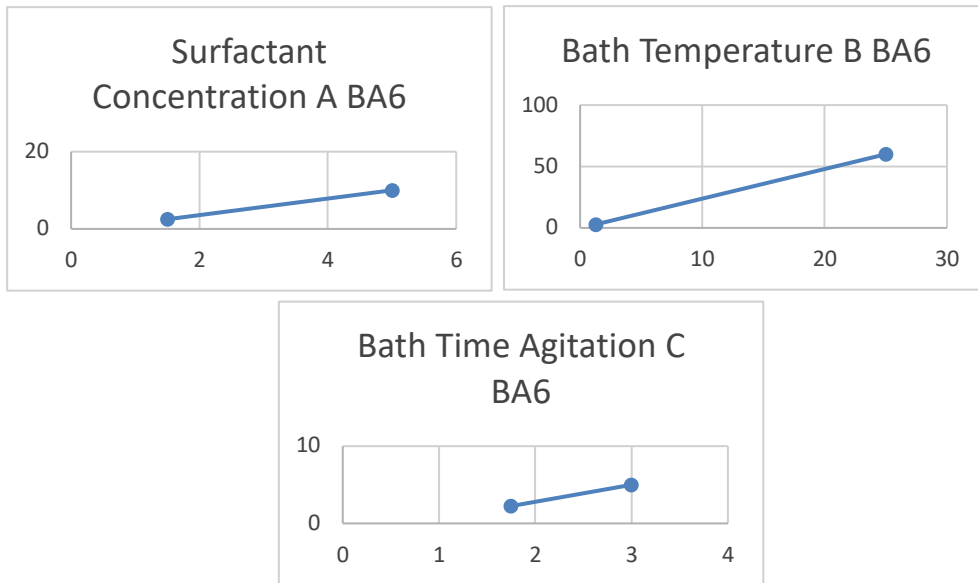


Figure 17 - Main effects plot for performance BA6 (fitted means).

The main effects on the impact of deinking performance continue be the bath temperature for BA6 and the surfactant concentration, as can be observed in Figure 17. All factors are important for BA6, the higher the factors, the better the effectiveness.

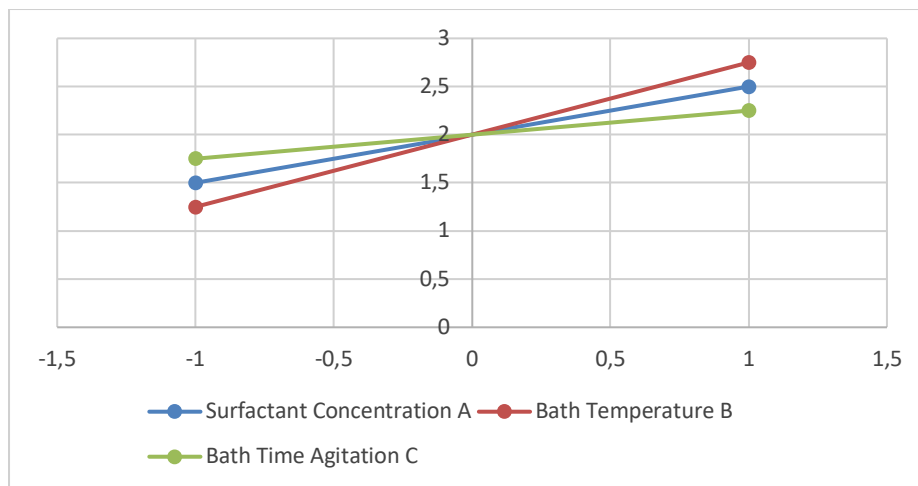


Figure 18 - Main effects plot for performance of BA6 (fitted means).

Figure 18 shows the interactions between factors with the surfactant BA6, it is possible to observe that the bath temperature is the most important factor in the effectiveness of the deinking process, it works from 60°C only. Following the same trend, the deinking performance is significantly improved for the higher bath time. On what refers to the surfactant concentration, the deinking performance is less affected but follows the same trend as the other factors for the higher values.

The main effects on the impact of deinking performance are the bath temperature and the surfactant concentration, as can be observed in Figure 6. When the bath temperature is 60 °C, the deinking performance is significantly higher when compared to the same results for a temperature of 25 °C. Following the same trend, the deinking performance is significantly improved for the higher surfactant concentration. On what refers to the bath time agitation, the deinking performance is less affected but follows the same trend as the other factors for the higher values.

On what concerns the sustainability of the deinking process, a detailed analysis of the entire lifecycle of all materials involved would be required. For the current results, however, it is important to note that the most relevant factors for the deinking process are the same factors that need to be balanced.

A higher bath temperature requires additional energy when compared to the lower temperature condition. Considering that such increased demand for electric energy may have different economic and environmental impacts, namely, regarding alternative fossil fuel or renewable sources, further analysis of the life cycle impacts is required.

When considering the effect of the surfactant concentration, the use of an eco-friendly surfactant may be beneficial to the process not only from the standpoint of enhancing the deinking process but also from the sustainability perspective. Thus, the increased use of an eco-friendly surfactant may have a lower environmental impact when compared to the alternative solution of increasing the bath temperature to 60 °C. Nevertheless, the energy required to produce the surfactant agent is not considered in this case study. This supports the need for a complete life cycle assessment of the proposed deinking process as further research.

4.4. Design proposals for a prototype to industrially deink plastic films printed by flexography

This last section aims at discussing the main characteristics of a prototype to carry-out the potential industrial approach to the proposed sustainable deinking processes to recover post-industrial printed plastic films.

The prototype proposal is designed to eliminate ink residue left behind by plastic film printing machines used in packaging, enhancing the profitability of recycling printed films. The outcome of this procedure is a film surface that is entirely free of paint residue. This prototype employs mechanical brushes and various ink removal apparatus and techniques to achieve this. Additionally, a specially crafted surfactant is utilized to facilitate ink removal.

It's important to note that this surfactant is both non-hazardous and environmentally friendly, as it can be renewed, recycled, and reused within the same technological process. This process is adaptable for a wide range of flexible printed material rolls that have been printed on or have surface contamination.

Furthermore, the film's minimum thickness must allow for material traction without causing surface deformations or tears when subjected to mechanical surface treatments.

The prototype incorporates an exceptionally environmentally conscious surfactant, resulting in an almost negligible waste output. The cleaning solution remains effective over extended periods, as it undergoes gradual evaporation during the washing process. Moreover, it boasts an innovative crossflow filtration system that constantly segregates ink from the liquid, guaranteeing a consistently fresh reservoir for optimal film cleaning. The ink particles are automatically directed to a waste container, where they are thoroughly dried and can subsequently be responsibly disposed of or even recycled. This filtration system plays a pivotal role in minimizing the consumption of cleaning fluids, further enhancing its sustainability.

The equipment is to be built in a mechanical structure manufactured from ST37/CK45 construction steel and AISI 304L, consists of 2 baths (1st in surfactant solution and 2nd in clean water), 1 set coiler (0.12 kW) and 1 decoiler (mandate), as presented in Figure 19.

The unwinded material is forced to pass in the surfactant solution by a set of inflection rollers with a capacity of 425 L, in order to prolong the contact time with it, following to the clean water tank with a capacity of 190 L, with the particularity that, at the exit of the 2 tanks, there is 1 roll of forced cleaning of the surface, with the rotation movement to be provided by rotating the winding roller by means of a chain transmission.

It should be noted that, in the 1st tank, there is a resistance assembly zone for the temperature rise of the solution, as well as a lower agitator (0.37 kW), which promotes the correct dissolution of the reagents.

In the winding, there is a zone with compressed air curtain, which will blow out excessive moisture in the material.

The brushes (Figure 20) are modular supplied in individual segments, used to create and adjust a cylindrical brush, roller, which results in a uniform surface and no openings between the modules. The main brush are made of PA6+ 15% Fiberglass (black), 45mm body diameter, 25mm inner hole, total length per brush module, 100mm, 20mm outer adapter.

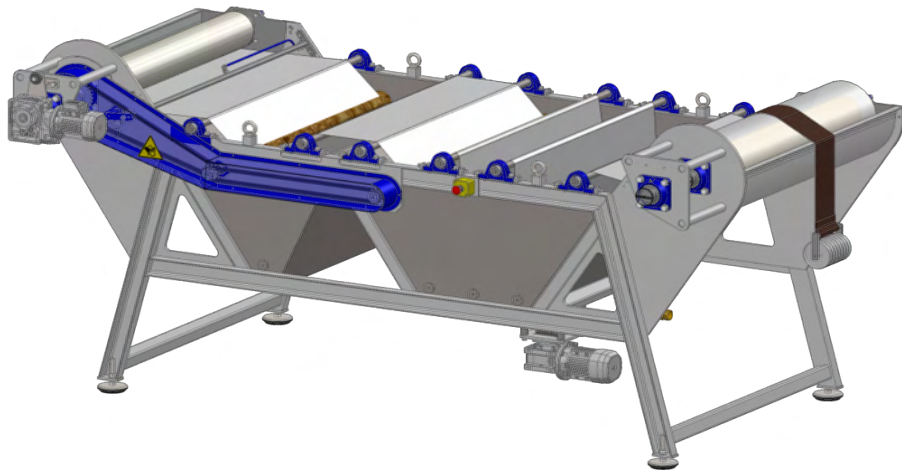


Figure 19 – Prototype proposal three-dimensional setup.

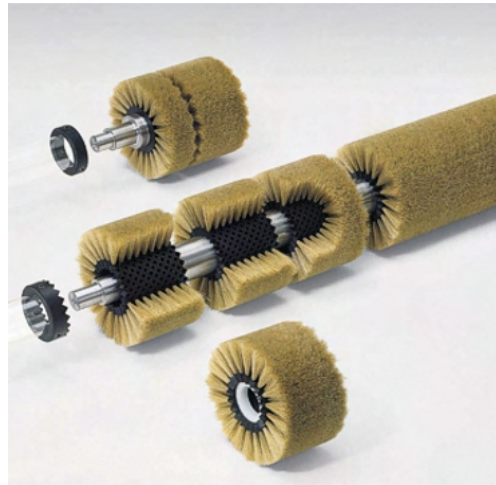


Figure 20 - Brush model EMR 45 low densities.

Why is ink removal a potential key process to enhance circular economy models for plastics? The Prototype System Cleaner cleans printed film and enables to reuse this film for the next set-up of a new print job. Instead of ending up with thousands of meters of waste set-up film we have developed a machine, which allows you to reuse your set-up film over and over again. Cleaning your set-up substrates is also beneficial even if don't want to reuse it but choose to recycle it instead. Clean film with no ink remaining will obtain a higher resale value compared to printed film. This process can be utilized for various plastic materials and inks, including PE and PP.

Advantages of the cleaning system: Fully automatic and requires little manpower, reduces film waste and therefore improves carbon footprint, clean and reuse printed film with speeds up to 25 meters per minute.

The cleaning system represents an exceptionally sustainable answer to the daily plastic waste generated by the film printing sector. The ability to recover post-industrial waste in such an efficient and sustainable proposal, allows foreseeing major benefits on the industrial sector of recycling and recovering printed plastic films.

5. Summary, Discussion and Conclusions

The current research case study focused on the process of ink removal on plastic films printed by flexography. Considering that the printed layers are some of the main challenges to address when discussing the circularity of recycling such coated plastics, the use of bio-surfactants was proposed to lower the environmental impacts on its deinking process.

Dedicated laboratory deinking procedures were undertaken with transparent polyethylene films printed by flexography with different conditions. Preliminary results showed the dedicated experimental ink removal procedure using bio-based surfactants to be effective in the removal of the coated layers on post-industrial waste films.

A design of experiments analysis was conducted with five levels of performance of the deinking process. To such end, four factors were tested, namely the bath temperature, surfactant concentration, bath time and the impact of brushing. The computed results showed the bath temperature and the surfactant concentration to have the highest impacts on the deinking performance.

As the main findings, it was highlighted that the higher bath temperature and the higher surfactant concentration were beneficial in maximizing the results of the deinking process. However, to discuss the environmental sustainability aspects of the proposed deinking process using bio-based surfactants, future research analyzing the life cycle assessment of the process is required.

The research study focused mainly on removing ink from plastic films printed with flexography. The challenge in recycling such coated plastics lies in dealing with the printed layers. To address this, the study proposed using bio-surfactants to minimize the environmental impact during the ink removal process.

In the main research tests, specific deinking procedures were conducted using transparent and white polyethylene films printed with flexography under various conditions. The initial results indicated that the experimental method, which utilized bio-based surfactants, effectively removed the coated layers from post-industrial waste films.

A design of experiments analysis was carried out, evaluating five levels of deinking performance. Four factors were tested: bath temperature, surfactant concentration, bath time, and brushing intensity. The results demonstrated that the bath temperature and surfactant concentration had the greatest influence on the deinking performance.

The key findings emphasized that higher bath temperatures and higher surfactant concentrations yielded better deinking results. However, in order to assess the environmental sustainability of the proposed deinking process using bio-based surfactants, future research should include a life cycle assessment of the entire process.

The last research case study focused on the process of ink removal on plastic flakes printed by flexography. Considering that the printed layers are some of the main challenges to address when discussing the circularity of recycling such coated plastics, the use of bio-surfactants was proposed to lower the environmental impacts on its deinking process.

Dedicated laboratory deinking procedures were undertaken with transparent and white polyethylene film printed by flexography with different conditions. Preliminary results showed the dedicated experimental ink removal procedure using bio-based surfactants to be effective in the removal of the coated layers on post-industrial waste films.

A design of experiments analysis was conducted with five levels of performance of the deinking process. To such end, three factors were tested, namely the bath temperature, surfactant concentration, bath time agitation. The computed results showed the bath temperature and the surfactant concentration to have the highest impacts on the deinking performance.

As the main findings, it was highlighted that the higher bath temperature and the higher surfactant concentration were beneficial in maximizing the results of the deinking process. However, to discuss the environmental sustainability aspects of the proposed deinking process using bio-based surfactants, future research analyzing the life cycle assessment of the process is required.

Considering that an industrial level, large amounts of printed film end up discarded each day. Most of such waste consists of initial production materials and printing errors. Dis-

posing of printed film waste poses limited recycling options and presents a significant challenge for both printers and recycling facilities. To address this issue, a dedicated prototype proposal was developed with distinctive features to deink and clean post-industrial printed films of plastic.

During such deinking and the cleaning process, the film can be repurposed as raw material for new productions or even for fulfilling commercial orders. The cleansed film can also undergo a complete recycling process, involving shredding, to transform it into pellets suitable for film extrusion. It is imperative to minimize plastic waste, and our company provides an exceptionally cost-effective and environmentally friendly solution of printers looking to reduce their plastic waste footprint. The creation of a circular economy is essential for our future sustainability.

During this research, two papers have been published, as can be found in this report's attachments. For further work proposal, the publishing of the remaining main findings is proposed to be carried-out.

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Attachments

Metadata of the chapter that will be visualized in SpringerLink








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Abstract	<p>Plastics are key engineering materials for our society and economy, mainly due to their multifunctionality and ease of processing. Nonetheless, their main drawback is related to the fact that when these cannot be reprocessed, they do generate waste, which leads to several environmental impacts. Therefore, considering plastics' circularity, minimizing their waste, and the resulting impacts, stresses the need for these to be recyclable. One of the main challenges that concern their recyclability is the deinking of plastic films when printed by flexography. The current technology uses non-bio-based surfactants and non-renewable surfactants, which are harmful to the environment. Therefore, the main objective of current research is to develop an environmentally sustainable process for ink removal on printed post-industrial flexible plastic films using bio-based surfactants. This process focuses on obtaining a deinked plastic that may be reprinted, avoiding this way for inappropriate disposal or reprocessing problems. The value increase of upcycling such post-industrial waste makes it possible to match the quality of the virgin plastic, which is key to carrying out an effective cost analysis of recycled plastic when compared to the new plastic films. Dedicated laboratory deinking procedures were undertaken with transparent polyethylene films printed by flexography with different conditions. Preliminary results show the dedicated experimental ink removal procedure using bio-based surfactants to be effective and environmentally sustainable.</p>	
Keywords (separated by '-')	Plastic film recycling - Biobased surfactants - Deinking - Solvent-based ink - Cationic surfactant	



Ink Removal on Plastic Films Printed by Flexography

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Abstract. Plastics are key engineering materials for our society and economy, mainly due to their multifunctionality and ease of processing. Nonetheless, their main drawback is related to the fact that when these cannot be reprocessed, they do generate waste, which leads to several environmental impacts. Therefore, considering plastics' circularity, minimizing their waste, and the resulting impacts, stresses the need for these to be recyclable. One of the main challenges that concern their recyclability is the deinking of plastic films when printed by flexography. The current technology uses non-bio-based surfactants and non-renewable surfactants, which are harmful to the environment. Therefore, the main objective of current research is to develop an environmentally sustainable process for ink removal on printed post-industrial flexible plastic films using bio-based surfactants. This process focuses on obtaining a deinked plastic that may be reprinted, avoiding this way for inappropriate disposal or reprocessing problems. The value increase of upcycling such post-industrial waste makes it possible to match the quality of the virgin plastic, which is key to carrying out an effective cost analysis of recycled plastic when compared to the new plastic films. Dedicated laboratory deinking procedures were undertaken with transparent polyethylene films printed by flexography with different conditions. Preliminary results show the dedicated experimental ink removal procedure using bio-based surfactants to be effective and environmentally sustainable.

[AQ1](#)

[AQ2](#)

Keywords: Plastic film recycling · Biobased surfactants · Deinking · Solvent-based ink · Cationic surfactant

1 Introduction

Plastic packaging accounts for approximately 40% of worldwide plastic use [1], with the corresponding waste posing a significant threat to nature and the environment, thus requiring the adoption of a greener, circular economy centered on waste avoidance and recycling [2]. As a result of such increased plastic usage, there is a corresponding exponential growth in plastic waste, which leads to greater demand for natural gas and oil as raw materials for plastic manufacturing [3]. Due to the general demand for raw materials, environmental concerns, and solid waste considerations, recycling plastic film from industrial and household waste streams is becoming ever more important [4].

Most of the plastics currently used are almost completely derived from petrochemicals produced from fossil oil and gas. Thus, to manufacture these plastics, significant amount of energy is required, which leads to a high consumption of corresponding volumes of fossil fuels [5]. To minimize the effect of raw material depletion the combined use of recycled and virgin plastics leads not only to minimize energy consumption and reduce environmental impacts, but also, in some cases, to improve their properties [6].

Plastic film waste has a variety of negative environmental consequences and is a high concern for the consumer goods industry, as large quantities of scrap plastic films are currently disposed of in landfills or incinerated [7]. Effective film deinking technology is a promising alternative to conventional recycling of plastic films as it allows for the reuse of scrap plastic films usually disposed of as industrial waste [8].

The deinking of plastic films produced by flexography is one of the most significant barriers to their recyclability as the current technology relies on non-biodegradable and non-renewable surfactants, which are harmful to the environment [9]. This severe constraint in the recyclability of plastic films requires urgent action to identify sustainable alternatives to the current deinking processes. Consequently, the primary goal of this research is to analyze and discuss the use of bio-based surfactants for ink removal on printed post-industrial flexible plastic films. In this research, the use of aqueous bio-based surfactant solutions for plastic film deinking was analyzed and discussed, since these surfactants are more environmentally friendly [10].

2 Deinking of Plastic Films

The conventional methods for deinking plastic films are mostly based on non-biodegradable and non-renewable surfactants, which require complex procedures that result in hazardous waste with negative impacts on the environment [4]. Most of the surfactants on the market are synthesized from petrochemical products [11]. However, the desire to reduce the use of products that are harmful to human health and the environment has led to the development of green surfactants, which are surfactants that are formulated with natural, biodegradable surfactant components of biological (plant or microbiological) origin or chemically synthesized from natural raw materials [12].

2.1 Bio-Based Surfactants

In the case of printed packaging, the presence of printing ink during mechanical recycling is a major issue that has a significant negative influence on the process. Given this,

research has often been conducted to develop more efficient ways to remove ink from plastics [8]. In this quest, it may be pointed out that aqueous surfactant solutions are considered suitable choices for such work because of their biodegradability, non-toxicity, and non-volatility [3].

The use of natural compounds instead of chemical surfactants has been explored due to their environmental sustainability and low toxicity, as well as a range of additional advantages [12]. These bio-based surfactants, also often referred to as green surfactants, are acknowledged to be the next generation of industrial surfactants, as they meet most of the requirements for low environmental impact solutions [13]. Bio-based surfactants are key in the current research effort towards greening industrial processes, as these compounds may be considered environmentally friendly due to their low (or absent) toxicity and high biodegradability [14].

The term bio-based surfactant refers to a surfactant produced by a chemical or enzymatic process that uses renewable substrates as raw materials [15]. According to ISO/DIS 21680, a bio-based surfactant is defined as a surfactant wholly or partly derived from biomass (based on biogenic carbon) [16]. Because bio-based surfactants frequently require extra features to increase their functional qualities, combining bio and petroleum-based feedstocks has been one approach for overcoming some of the green surfactants' functional constraints [15]. To support analyzing the bio-based surfactants' sustainability standards, the European Commission of Standardization in its EN 17035:2021 standard has defined categories for biosurfactants, including >95% totally bio-based, 50–94% majority bio-based, 5–49% minority bio-based, and 5% non-bio-based [17].

2.2 Ink Removal on Plastic Films Using Bio-Based Deinking Agents

When recovering rigid plastics or plastic films, deinking is a critical step toward valuing plastic waste in subsequent mechanical recycling stages. Considering that during their production operations, plastic film industries generate between 8% and 12% of printed scrap [8], it is key to develop and implement sustainable solutions to improve the circularity of such post-industrial waste.

On what refers to plastic films, such deinking even allows for recovering unwound film rolls to be reprinted and reused. To such an end, innovative solutions by Piolat [18] and Gamma Meccanica [19] allow foreseeing sustainability benefits by valuing post-industrial waste into new raw materials without the need for recycling, or to further value its recirculation. Nevertheless, such solutions still provide for revalued raw materials with low mechanical and optical properties [8].

Deinking, which involves the removal of various colors and layers of ink from the plastic film, might be considered a laundering process, as it requires the removal of ink from the surface, which is adhered to it by Van-der-Waals, electrical, and mechanical forces [4]. As above mentioned, most of the current deinking procedures for plastic films use non-biodegradable and non-renewable surfactants [4]. Nevertheless, increased research effort is being put towards the use of bio-based agents in the deinking of plastic films [4, 20, 21]. Furthermore, biosurfactants are more effective in reducing surface and interfacial tensions than synthetic counterparts, and they can withstand high temperatures as well as extreme pH and ionic strength [20].

To analyze and discuss the deinking efficiency on plastic films, different parameters and variables must be addressed. The performance of the deinking agent depends on many aspects like pH and temperature [3], type and concentration of the deinking agent [21], or time and mechanical action [4]. Therefore, to study the removal of ink from printed plastic films it is key to consider the impact and effects of such process variables.

3 Materials and Methods

3.1 Materials

For this study, samples of a colorless clear transparent polyethylene film, printed by flexography with different conditions were analyzed. The clear transparent LDPE film was printed for commercial purposes with a final layer of 50 μm thickness. The printed film prints are constituted by the intermediate combined intermediate layers presented in Table 1.

Table 1. Summary of the print layers of the current case study.

LDPE film print
White
Yellow
Magenta
Black
Green
Blue

To perform the deinking of plastic films, surfactants may be needed to reduce the surface or interfacial tension at the air/water, ink/water, and plastic/water interface, and this can increase the wettability of the solution and allow alkali to penetrate between the ink particle and the plastic film. The surfactant used in this case study was the BIO 691 from the Bioloop product family, manufactured by Lankem Ltd. (UK). It is bio-based and, therefore, is not harmful to the environment, according to the EC regulation no. 1272/2008. The surfactant was used as supplied and diluted on deionized water for the testing conditions at approximately pH 8.

3.2 Deinking Tests

To carry out the experimental deinking test procedures, a total of 16 subsamples were cut into approximately 1 by 5 cm long strips. These tests were performed to collect results for 4 factors: Surfactant concentration, bath temperature, bath time, and brushing.

Half of the plastic film strips were submitted to a set of experimental deinking test procedures at room temperature, whereas the remaining samples were tested at 40 °C.

With the use of a 1–5 mL M5000 adjustable volume manual pipette, tweezers, test tube, glass beakers, digital thermometer and a RCT Basic Safety Control magnetic agitation plate, the samples were submerged in each test tube of 30 ml for the 30 s and 1 min tests. The surfactant solutions of 5% and 2.5% were freshly prepared with distilled water for each sample, and the pH level of the aqueous surfactant solution was not adjusted. The samples were agitated using the magnetic stirrer.

After draining, the film strips were submitted to brushing, washed with water, and dried. The 16 plastic film strips were randomly collected to analyze the level of deinking. Each processed sample was visually and qualitatively assessed.

3.3 Design of Experiments

For the Design of Experiments (DoE) analysis, five levels of performance of the deinking process were assigned. The classification used for the deinking performance is shown in Table 2.

Table 2. Classification used for the deinking performance.

Classification	Description
No deinking (1)	No evident effects of the surfactant agent
Poorly deinked (2)	Low or no effect of the surfactant agent
Lightly deinked (3)	Slight and visible effects of the surfactant agent
Mostly deinked (4)	Evident effects of the surfactant agent, but not full deinking
Fully deinked (5)	Full deinking achieved

Table 3. Testing conditions for the DoE analysis.

StdOrder	Surfactant concentration [%]	Bath temperature [°C]	Bath time [s]	Brush [iteration]
1	2,5	25	30	1
2	5	25	30	5
3	2,5	40	30	5
4	5	40	30	1
5	2,5	25	60	5
6	5	25	60	1
7	2,5	40	60	1
8	5	40	60	5
9	2,5	25	30	5
10	5	25	30	1

(continued)

Table 3. (continued)

StdOrder	Surfactant concentration [%]	Bath temperature [°C]	Bath time [s]	Brush [iteration]
11	2,5	40	30	1
12	5	40	30	5
13	2,5	25	60	1
14	5	25	60	5
15	2,5	40	60	1
16	5	40	60	5

The factorial design analysis created results on 24 condition tests to use on the Minitab software [22]. With performance as the response variable, the expected output was related to the increase in performance of the chemical reaction. To such end, four factors were tested, namely the bath temperature (25 °C and 40 °C), surfactant concentration (5% against 2.5%), bath time (30 s against 1 min) and impact of brushing (once to five times), as listed in Table 3.

4 Results and Discussion

Deinking relates to removing the printing layers on the plastic film. The strips were treated with 2.5% and 5% of surfactant solutions at approximately pH 8 and magnetically stirred. For the set of analyses carried out, the deinking level of the 16 samples was established and classified according to the criteria presented in Table 2.

Figure 1.a) shows a sample where no evidence of deinking was observed due to the action of the surfactant, while in the sample Fig. 1.b) it was possible to identify a reduced effect of the surfactant. Figure 1.c) depicts visible effects of deinking, but not too effective. Finally, Figs. 1.d) and 1.e) show the best deinking results, particularly those of Fig. 1.e), where complete deinking took place.

Table 4 shows the deinking performance results obtained for each testing procedure, ordered from the best deinking performance to the less performing condition.

From Table 4, it is possible to observe that the bath temperature is the most critical factor in the effectiveness of the deinking process. Figure 2 plots the main effects of surfactant concentration, bath temperature, bath time and brushing iterations for the deinking performance.

The main effects on the impact of deinking performance are the bath temperature and the surfactant concentration, as can be observed in Fig. 2. When the bath temperature is 40 °C, the deinking performance is significantly higher when compared to the same results for a temperature of 25 °C. Following the same trend, the deinking performance is significantly improved for the higher surfactant concentration. On what refers to the bath time and brushing iterations, the deinking performance is less affected but follows the same trend as the other factors for the higher values.

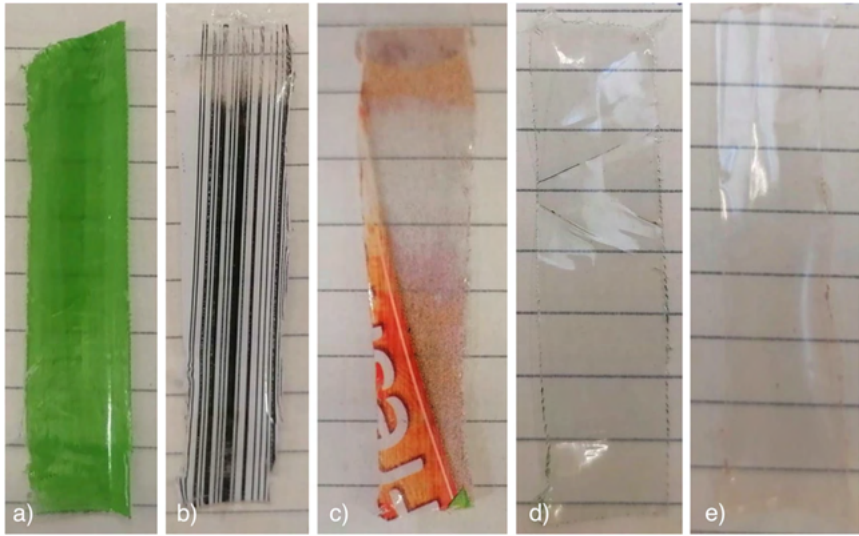


Fig. 1. Classification of the processed samples.

Table 4. Deinking performance results.

StdOrder	Surfactant concentration [%]	Bath temperature [°C]	Bath time [s]	Brush [iterations]	Deinking performance
4	5	40	30	1	5
8	5	40	60	5	5
12	5	40	30	5	5
16	5	40	60	5	5
3	2,5	40	30	5	4
7	2,5	40	60	1	4
11	2,5	40	30	1	4
15	2,5	40	60	1	4
6	5	25	60	1	3
14	5	25	60	5	3
2	5	25	30	5	2
5	2,5	25	60	5	2
10	5	25	30	1	2
1	2,5	25	30	1	1
9	2,5	25	30	5	1
13	2,5	25	60	1	1

On what concerns the sustainability of the deinking process, a detailed analysis of the entire lifecycle of all materials involved would be required. For the current results,

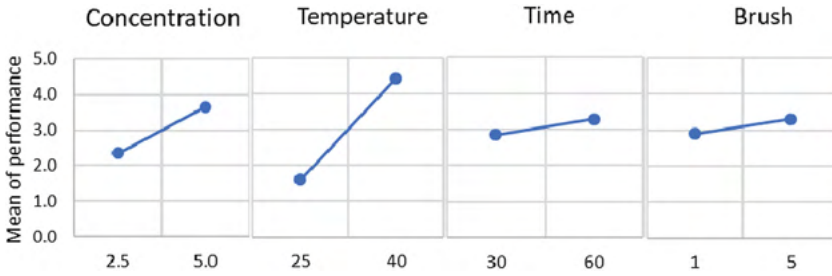


Fig. 2. Main effects plot for performance (fitted means).

however, it is important to note that the most relevant factors for the deinking process are the same factors that need to be balanced.

A higher bath temperature requires additional energy when compared to the lower temperature condition. Considering that such increased demand for electric energy may have different economic and environmental impacts, namely, regarding alternative fossil fuel or renewable sources, further analysis of the life cycle impacts is required.

When considering the effect of the surfactant concentration, the use of an eco-friendly surfactant may be beneficial to the process not only from the standpoint of enhancing the deinking process but also from the sustainability perspective. Thus, the increased use of an eco-friendly surfactant may have a lower environmental impact when compared to the alternative solution of increasing the bath temperature to 40 °C. Nevertheless, the energy required to produce the surfactant agent is not considered in this case study. This supports the need for a complete life cycle assessment of the proposed deinking process as further research.

5 Conclusion

The current research case study focused on the process of ink removal on plastic films printed by flexography. Considering that the printed layers are some of the main challenges to address when discussing the circularity of recycling such coated plastics, the use of bio-surfactants was proposed to lower the environmental impacts on its deinking process.

Dedicated laboratory deinking procedures were undertaken with transparent polyethylene films printed by flexography with different conditions. Preliminary results showed the dedicated experimental ink removal procedure using bio-based surfactants to be effective in the removal of the coated layers on post-industrial waste films.

A design of experiments analysis was conducted with five levels of performance of the deinking process. To such end, four factors were tested, namely the bath temperature, surfactant concentration, bath time and the impact of brushing. The computed results showed the bath temperature and the surfactant concentration to have the highest impacts on the deinking performance.

AQ3

As the main findings, it was highlighted that the higher bath temperature and the higher surfactant concentration were beneficial in maximizing the results of the deinking process. However, to discuss the environmental sustainability aspects of the proposed

deinking process using bio-based surfactants, future research analyzing the life cycle assessment of the process is required.

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Chapter 25

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Abstract








Circular economy principles focus on the need to preserve natural resources and foster the use of environmentally sustainable practices. Concerning the use of plastics in a circular economy, increasingly demanding solutions have to be developed towards the zero-waste goal sought after by researchers and society alike. Particular attention has been put into the recycling of PET, mainly due to its wide spectrum of use and, consequently, to large volumes of related waste. The PET mechanical recycling process requires these waste materials to be shredded into PET flakes. Following such a procedure, these flakes are pelletized to be used again as feedstock. Considering the main stages of the mechanical recycling processes, which include plastic screening, shredding and washing, significant amounts of end waste materials are generated. This end-waste integrates small scale particles that are designated by plastic fines. Concerning the PET recycling process, the PET fines resulting from its mechanical recycling are not currently valued due to several technical issues, such as their high contamination level and the complexity of sorting them from other small-size particles. Current research focuses on the feasibility of incorporating these PET fines into the film/injection extruders, avoiding this way the need for an intermediate pelletization stage. To allow for such direct incorporation of PET fines into recycling processes, different decontamination and sorting solutions were implemented and tested. The current study is based on analyzing the mechanical properties of PET fines, using laboratory tests such as FTIR, DSC, MFI, moisture content, tensile tests and bending tests. Preliminary results allow foreseeing the successful direct incorporation of PET fines into PET recycling.

Keywords
(separated by '-')

Plastic - Recycling - Circular economy - PET fines



Feasibility Study of the PET Fines Incorporation into Recycling Processes

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AQ1

Abstract. Circular economy principles focus on the need to preserve natural resources and foster the use of environmentally sustainable practices. Concerning the use of plastics in a circular economy, increasingly demanding solutions have to be developed towards the zero-waste goal sought after by researchers and society alike. Particular attention has been put into the recycling of PET, mainly due to its wide spectrum of use and, consequently, to large volumes of related waste. The PET mechanical recycling process requires these waste materials to be shredded into PET flakes. Following such a procedure, these flakes are pelletized to be used again as feedstock. Considering the main stages of the mechanical recycling processes, which include plastic screening, shredding and washing, significant amounts of end waste materials are generated. This end-waste integrates small scale particles that are designated by plastic fines. Concerning the PET recycling process, the PET fines resulting from its mechanical recycling are not currently valued due to several technical issues, such as their high contamination level and the complexity of sorting them from other small-size particles. Current research focuses on the feasibility of incorporating these PET fines into the film/injection extruders, avoiding this way the need for an intermediate pelletization stage. To allow for such direct incorporation of PET fines into recycling processes, different decontamination and sorting solutions were implemented and tested. The current study is based on analyzing the mechanical properties of PET fines, using laboratory tests such as FTIR, DSC, MFI, moisture content, tensile tests and bending tests. Preliminary results allow foreseeing the successful direct incorporation of PET fines into PET recycling.

AQ2

Keywords: Plastic · Recycling · Circular economy · PET fines

1 Introduction

Since the 1970s, when the concept of sustainable development was first introduced by United Nations Conference on the Human Environment [1], there has been a significant effort to find alternatives to existing products and processes to promote not only sustainability but also the circular economy, as both of these notions are key to foster sustainable development in our current and future society.

Among the various alternatives to the linear economy principles of take-make-dispose, the circular economy concepts of recycling and reuse are by far more sustainable. Thus, the ability to use waste materials to be transformed into new raw materials for the process brings positive impacts to all three main perspectives of sustainability, namely the economic, social, and environmental dimensions [2].

Particularly, when trying to apply the concepts of sustainability and circular economy to the plastics sector different challenges arise. Nonetheless, such efforts are critical since the plastics industry is one of the fastest-growing in recent years, with all the benefits and drawbacks of conventional and advanced manufacturing processes [3]. Again, one of the most promising solutions to be adopted to promote the sustainability of plastics is recycling [4].

When looking at the plastics industry, it's unavoidable to look for improvements in processes and alternatives that use fewer resources and/or allow these resources to be reintegrated into the production chain due to the production circumstances, which include the use of petroleum shunt raw material and its scarcity.

Even in the recycling chain, there is waste produced and some sub-materials that are not used during the process, thus generating by-products that don't get valued or reused. PET fines, which are the consequence of the breakage and washing of PET during its recycling process, are among those whose economic and energetic potential has not been considered in current value chains and that also can have harmful impacts on the environment [5]. The amount of PET fines generated from the mechanical recycling of PET bottles can reach 2 to 5% and from the mechanical recycling of PET trays can reach up to 20 to 30%. Because of their small size, these microplastic fines are not currently recycled with PET flakes, which result from the recycling of PET bottles.

As a result of the challenge of finding alternatives that allow integrating the highest amount of waste to be reused in the material recycling of PET while also optimizing the recycling process to minimize unwanted by-products, the current research focuses on characterizing the PET fines to study their properties and to discuss the feasibility of reintroducing this waste material into the production cycle.

2 PET Fines from Plastics Recycling

Plastics have become increasingly valuable since their discovery, serving as a cost-effective solution in a variety of industries, including construction, automotive, electrical and electronics, agricultural, domestic use, and packaging, among many others. So much so that, despite the 2020 crisis, Europe's plastics manufacturing dropped by barely 5%. And, while this figure appears significant, given that 58 million tons of plastics were manufactured in 2019 and 55 million tons in 2020, these figures can still be regarded

as very high. It's also worth noting that these figures just pertain to Europe; they don't necessarily imply that the scale has shrunk globally, given China's increase from 31% to 32% of global plastic manufacturing, as well as North America [6].

However, due to its future productivity shortfall, as well as the harm caused by high persistence under abrasive conditions, which transforms plastic into microplastics (plastic pieces smaller than 5 mm), it was decided that the Member States of the European Union (EU) should reduce disposable plastic consumption [7] and improve plastic waste management [8, 9].

According to Plastics Europe [10], to promote better waste management, more than 29 million tons of post-consumer plastic waste was collected in the EU27+3 in 2020. Nevertheless, only a third were delivered to recycling facilities within and outside the EU27+3, about 23% were sent to landfills and more than 40% were sent to energy recovery operations.

Given that the packaging industry produces around 40% of the total plastic waste, additional attention must be paid to encouraging recycling in this sector [10].

However, there are still many difficulties to be overcome in the recycling process. One of them would be, according to Elamri *et al.* [11], the fact that the post-consumer PET suffers during the recycling process: thermal exposure and shear degradation with the simultaneous presence of retained moisture and physical contaminants which lead to a significant average macromolecular weight loss during reprocessing at high temperatures, resulting in reduced mechanical properties. Besides, the intensive cleaning and drying of PET flakes before extrusion, the sorting of impurities and the use of chain extenders or modifiers are options to improve those properties.

Another relevant point is that PET fines are generated during the recycling operations, which are smaller fractions than flakes and are a by-product resulting from the shredding of the materials. Therefore, it can be inferred that there will be even greater structural and mechanical differences between PET fines and PET flakes. It has also to be noticed that PET fines cannot be included in the recycling process, as they melt before the larger dimension flakes, making material flow difficultly when producing pellets of rPET [12]. In other words, as these differences become greater and more evident, it requires increased effort on the search for solutions that make it possible to incorporate PET fines into recycling processes.

In a nutshell, it is key to look for ways to reuse this type of by-product materials from the PET recycling process to limit the amount of non-recycled PET and therefore contribute to the circular economy principles.

3 Experimental

3.1 Material

In this study, the sample of PET fines was collected after washing, in the drying process, resulting from several stages of the mechanical recycling of PET post-consumer waste. The mechanical recycling system is composed of NIR and manual sorting, shredding, washing and drying. These samples are known to contain contaminants such as different types of polymers, metals, and small pieces of wood. The maximum dimension of the PET fines is 4 mm.

It was important to conduct multiple tests to characterize the samples to gain a better understanding of their composition and, as a result, find acceptable methods to promote recycling. Initially, contaminants in the samples were examined. A sample of roughly 10 g of material was separated, measured on a precision balance from Precisa, model 262SMA-FR, and evaluated by manually removing metals, wood, colored and yellowish components, using tweezers, to get a sample just with white and blue PET material.

3.2 Density

Several tests were carried out to determine the density using the pycnometer method. The solvent was water at 23 °C with a density of 0.99751 g/cm³. The mass of sample and water in the picnometer of solids were measured on a precision balance from Precisa, model 262SMA-FR and the density was calculated by Eq. (1).

$$\text{Density} = \frac{m_{pic+sam} - m_{pic}}{\frac{m_{pic+w} - m_{pic}}{d_w} - \frac{m_{pic+sam+w} - m_{pic+sam}}{d_w}} \quad (1)$$

where m_{pic} is the mass of dried pycnometer of solids, $m_{pic+sam+w}$ is the mass of pycnometer with sample and water, $m_{pic+sam}$ is the mass of pycnometer with sample, m_{pic+w} is the mass of pycnometer full of water and d_w is the density of water at 23 °C.

3.3 Moisture Content

The subsequent set of tests followed the procedures outlined in ISO 15013:2007 [13] to determine the moisture content in the samples. The method is based on the gravimetric method by the measurement of the variation of mass between the mass of the sample as received and the mass of the sample after drying at 105 °C for 24 h. The mass was measured at ambient temperature with a precision balance from Precisa, model 262SMA-FR.

3.4 Melt Flow Index

The Melt Flow Index (MFI) was carried out at 265 °C, using ATS Faar equipment, according to the procedure prescribed in ISO 1133-1:2011 [14] with the 2.16 kg of weight to force the sample to flow through the flow chamber. To adapt the standard to the given experimental flow, the method was modified for 10 g of sample to be inserted into the equipment and a cutting time of 25 s.

3.5 DSC Analysis

The equipment DSC131 from Setaram Instrumentation was used to perform the Differential Scanning Calorimeter (DSC) analysis, test for determining thermal characteristics, glass transition temperature, T_g, crystallization temperature, T_c, melting temperature, T_m, and crystallinity, X_c %. The results were obtained after the second scan with a temperature range from 30 °C to 300 °C, without purge gas, with a scanning speed of 10 °C/min and sample weight ranging between 30 mg and 35 mg. The crystallinity was calculated based on the heat of fusion of 100% crystalline PET of 120 J/g.

3.6 FTIR

The presence of additives and contaminants, including polymers and monomers, was analyzed using the FTIR technique (Fourier-transform infrared spectroscopy). This technique allows identifying the composition of a material with high levels of precision. The FTIR spectrometer used was the Spectrum Two from PerkinElmer and the resulting spectrum was studied using the software Spectrum IR, in a multisearch analysis.

3.7 Bending and Tensile Tests

Bending and tension tests were also undertaken to characterize the mechanical properties of the samples, which were preceded by a step of specimen preparation in which 3.30 kg of dried PET fines were injected at two different pressures, 60 bar and 80 bar, at a temperature of 140 °C. The mold used to inject is in accordance with standards for 3-point bending and tensile tests, the ASTM D638 standard [15]. The 3-point bending tests were carried out using a Zwick/Roell Z100 universal test machine in accordance with the ISO 178:2003 standard [16], with a test speed of 5 mm/min, a load cell of 100 kN, and a distance between supports of 68 mm.

4 Results Discussion

According to the procedures presented in the previous section a set of tests was carried out to characterize contaminants in the samples, densities, moisture content, melt flow index, DSC, FTIR and tensile and bending tests.

Table 1 presents the analysis of visible contaminants on the samples, which were sorted by the manual removal method.

Table 1. Analysis of visible contaminants on the samples.

Test	Material	Mass (g)	Relative weight (%)
1	Metals and Wood	0.047	0.5%
	Miscellaneous materials	0.278	2.7%
	Blue and White	9.708	95.4%
	Yellowish	0.162	1.8%
2	Metals and Wood	0.242	2.1%
	Miscellaneous materials	0.271	2.9%
	Blue and White	9.420	93.5%
	Yellowish	0.140	1.5%

As a result of the foregoing analysis, it was possible to observe that most of the samples were composed of white and blue plastic. Nevertheless, a significant percentage of metal contaminants and pieces of wood were identified as specimen contaminants in various amounts. Other contaminants identified in the analyzed specimens relate to different percentages of various polymers that may be recognized and distinguished by their colors, as well as yellowish materials that indicate the presence of polyolefins.

Table 2 presents the density and moisture content of PET fines, measured in triplicate, according to the methods described in Sects. 3.2 and 3.3.

Table 2. Density and moisture content of PET fines.

Test	Density (g/cm ³)	Moisture content (%)
1	1.062	0.65
2	1.295	0.62
3	1.277	0.65

It can be observed from the results presented in Table 2 that the density of the samples is consistent, but they differ from the density values for virgin PET, which has values between 1.29–1.43 g/cm³ [17]. This can be explained by the presence of polymers like polystyrene and polyolefins and/or additives that can decrease the density of the sample.

It can be observed from Table 2 that the two tests had approximately the same moisture content. However, given the variability of the sample, a margin of 5% error level can be considered acceptable.

Table 3 presents MFI results, which were conducted using the procedure prescribed in ISO 1133-1:2011 and it was carried out at 265 °C, as described in Sect. 3.4.

Table 3. MFI results of PET fines.

Test	MFI (g/10 min)
1	355.72
2	191.02
3	67.250
4	50.866
5	82.094
6	88.238

The MFI results allowed identifying that the material under research had particles beyond the visible spectrum, given that the findings differed significantly from what had been expected based on the literature [18], which indicates that ground bottles have a Melt Flow Index of 15.98 g/10 min.

It should be noted that tests 1 and 2 of Table 3 were conducted without any contaminant removal treatment, with results that were about 12 to 22 times higher than expected. This may be due to the presence of metals and wood particles, which could disrupt the flow of the material due to the obstruction of the nozzle at the end of the flow chamber of the MFI equipment. Metal and wood contaminants were removed from Tests 3 and 4 as the initial step and the results were 3 to 4 times higher than expected. In tests 5 and 6, all visible contaminants were removed and the sample was the same as the one used for the contamination analysis where the fraction of white and blue plastics was used. The results of tests 5 and 6 are more consistent but still around 5 times higher than expected. Nevertheless, there should still be a significant presence of impurities, additives, or multilayer material, which would explain the wide range of readings. In addition, the irregular shape of the input material with lower dimensions in comparison to those of the pellets, that are usually used to measure MFI, may affect the final output.

Table 4 presents DSC results for 3 tests, in which T_g refers to the glass transition temperature, T_c refers to crystallization temperature, T_m refers to melting temperature and X_c % the crystallinity of PET fines.

Table 4. DSC results of PET fines.

Test	T_g (°C)	T_c (°C)	T_m (°C)	X_c %
1	97.97	161.76	267.10	12
2	102.62	156.92	269.60	5.1
3	99.52	157.25	265.71	10

The reported results in the literature [19] refer that the virgin PET has a glass transition temperature of 72.8 °C, a crystallization temperature of 135.7 °C and a melting temperature of 251.9 °C. However, the tests have divergences from the reported values, according to the DSC test analysis. It is possible to infer from the readings obtained in Test 2 as being the result of a non-fused particle, *i.e.*, a plastic substance that could not reach the melting point at 300 °C. On what concerns Test 3, since there are more colored materials, *i.e.*, materials that are not PET, thus having different values than expected.

Figure 1 shows the graph of heat flow versus temperature resulting from the DSC analysis of the PET fines.

In accordance with the presented in Fig. 1, the values were consonant with each other, however, it can be observed that there are differences in the graph which, as mentioned above, can be explained by the presence of other materials besides PET.

According to the FTIR analysis, most of the samples contain more than one layer of polymer and/or present additives or contaminants (80% of the samples), as well as materials that do not contain PET at all (16%) and only 4% of the samples analyzed were made entirely of PET, as shown in the chart of Fig. 2.

The FTIR tests also showed that Vinyl Acetate, Adhesive of Vinyl Chloride, Poly(trimethylene terephthalate (PTT), Poly(Phenylene Disulfide) and Quaternized Polyimidazoline are some of the components found in the analysis, here referred to as PET +, in reference to the presence of additives.

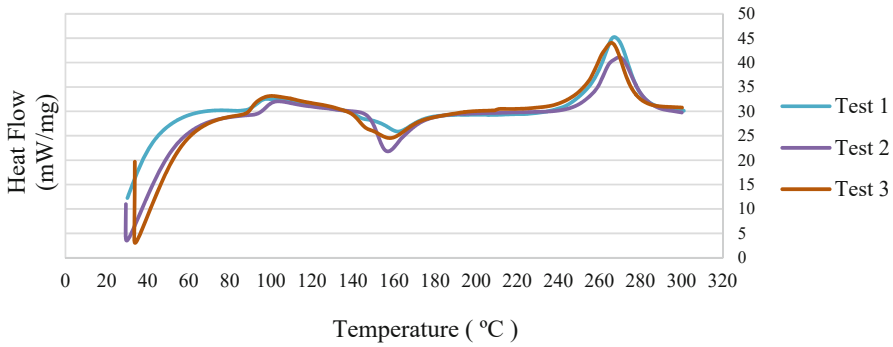


Fig. 1. DSC analysis of the PET fines.

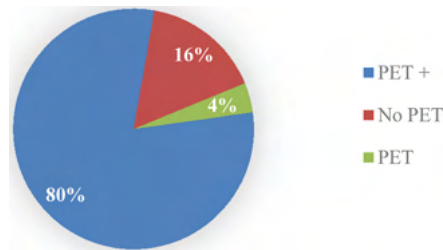


Fig. 2. Percentage of PET, PET samples with multilayers and/or contaminants and additives and non-PET materials.

On what concerns the mechanical characterization of the sample materials, 3-point bending tests were performed with the specimens injected at 60 and 80 bar and the results are presented comparatively in Fig. 3.

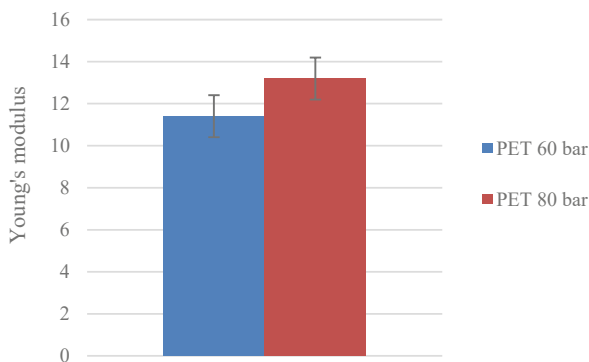


Fig. 3. Comparative graph of bending tests with specimens injected at 60 bar and 80 bar.

In Fig. 3 it can be seen that Young's Modulus has similar values for injection at 60 bar and 80 bar, indicating that there are no significant differences regarding the

injection pressure used. On what refers to the virgin material, the values found are above expectations, considering that, according to the literature, the values should oscillate between 2.76 and 4.14 Gpa [20].

Figure 4 shows the stress and strain curves until the limit of the fracture of samples of PET fines injected at 60 bar and Fig. 5 shows the stress and strain curves until the limit of the fracture of samples of PET fines injected at 80 bar.

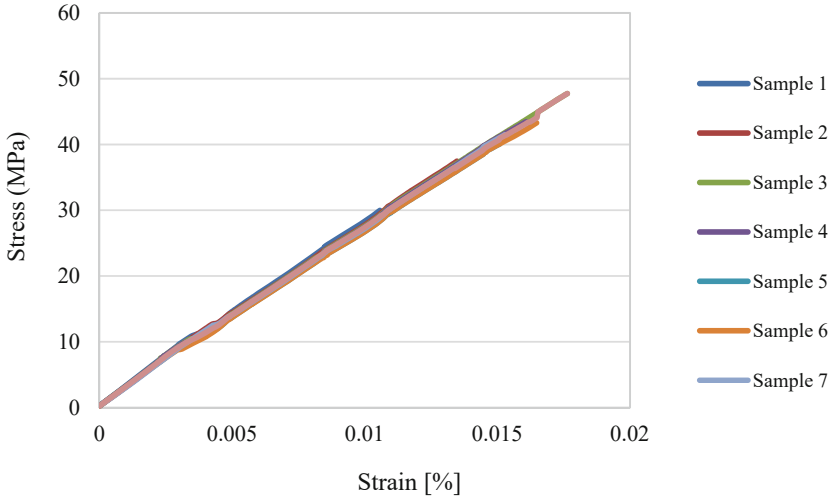


Fig. 4. Stress-strain curve of PET fines injected at 60 bar.

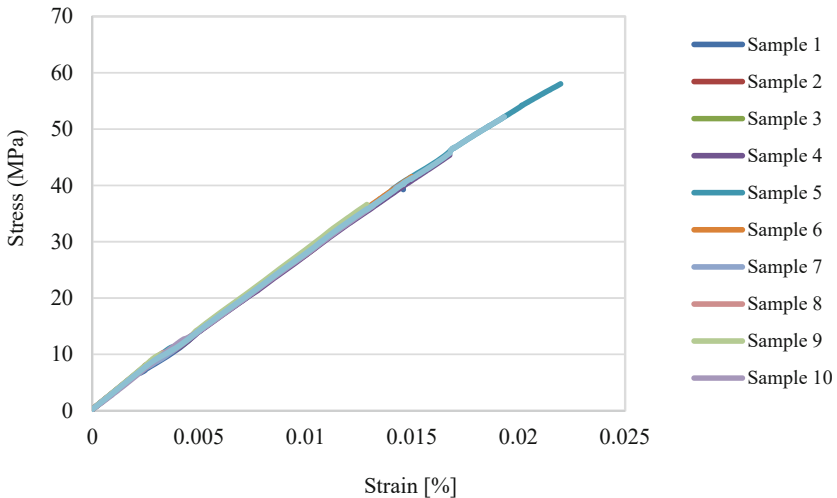


Fig. 5. Stress-strain curve of PET fines injected at 80 bar.

The specimen has a very low deformation with no significant differences regarding injection pressure.

The values found for both the 60 bar and the 80 bar samples are quite different from the values reported in the literature [18] for virgin PET, given that they support a maximum strain between 50 and 60 MPa, with a strain of more than 30%. It is also worth noting that the curves don't match those predicted from a PET-only material, and the material doesn't yield, making it impossible to determine its yield strength. This indicates the sample's brittleness by the fact that it breaks before yielding.

5 Summary and Discussion

The tests conducted with the PET fines collected after washing and drying PET residues resulting from several stages of the industrial recycling of PET post-consumer waste allowed finding that despite the number of visible contaminants found being relatively small (5%–7.5%), the presence of additives found from FTIR in the fraction of PET and other polymers that resemble PET is significant and may be the explanation for a large part of the differences in values found, as density, which has lower values because the polymers present have lower densities than PET, such as polystyrene and polyolefins.

The MFI values were substantially higher than expected according to the literature [18], in which the values should be close to 30 g/10 min. However, this result can be explained both by the material not being entirely composed of PET and by its smaller dimension than the standards, which facilitates its fusion.

On what concerns the DSC tests, the results showed to be higher than expected according to the literature [19], but the generated curves are similar to the pattern found in virgin PET. The crystallinity is significant, and it can contribute to increasing the stiffness found in the bending and tensile tests. The specimens for the bending and tensile tests were not subjected to DSC analysis but were injected into the mold at ambient temperature. In order to decrease the stiffness and avoid the crystallinity, the mold could be refrigerated to about 8 °C. On the other hand, refrigeration would increase the need for energy in the production of the specimen.

Finally, on what refers to the mechanical properties, the bending and tensile tests showed no significant differences regarding the injection pressure of the molds, but as there are large differences when comparing the results expected for virgin PET, being much more rigid, residual deformation and do not show yield.

6 Conclusion

One of the methods to increase the material's circularity is by improving its recyclability, thus extending its life. Nonetheless, the mechanical recycling of plastics must be improved to avoid significant amounts of rejected material. In the PET recycling process, after automatic and manual sorting, washing and drying, the sieving gets about 2 to 5% of PET fines, which are particles smaller than 4 mm. These PET fines are contaminated with metal, wood, sand, additives, organic contaminants, and other polymers in addition to PET.

In this study, several characteristics of the PET fines were assessed using different methods, such as FTIR, DSC, MFI, moisture content, tensile tests and bending tests.

The contaminants (metal, wood, yellowish and miscellaneous materials) were evaluated and although they are about 5%, they strongly affect the mechanical and thermal characteristics. Besides the contaminants, polymeric multilayers on the PET fines were detected by FTIR. This allows assuming that they can contribute to the deviation of the mechanical and thermal characteristics of PET fines when compared to virgin PET.

Given that the material analyzed is obtained from post-consumer packaging bottles, which still have labels attached to them, it's also possible to infer that the contaminants found in the samples are from such labels, which may not have been removed completely. Therefore, considering these results it is not possible to directly insert PET fines into recycling processes, given the significant differences in physical and mechanical properties when compared to virgin PET. Based on these results, the increase of the intrinsic viscosity may not be enough to successfully recover the PET fines properties.

It is recommended that to provide improvements to the material properties, the PET fines are subjected to a separation process to remove metal, wood and miscellaneous material, in order to obtain samples with a high degree of PET and multilayer material.

More research is needed to develop efficient methods to separate contaminants that, as known, are below 4 mm and magnetic, NIR sorters and others have limitations. Another recommendation would be the assessment of an additional step of mechanical drying before shredding to minimize fines production, although further research is required to quantify this aspect.

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Chapter 24

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LANSPERSE BIO691

Safety Data Sheet

according to Regulation (EC) No. 1907/2006 (REACH) with its amendment Regulation (EU) 2015/830
Revision date: 03/06/2021 Supersedes version of: 27/09/2018 Version: 2.0

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Product form : Substance
Substance name : LANSPERSE BIO691
Product code : LK-BIO691

1.2. Relevant identified uses of the substance or mixture and uses advised against

1.2.1. Relevant identified uses

Main use category : Industrial use
Use of the substance/mixture : BioLoop Surfactant

1.2.2. Uses advised against

No additional information available

1.3. Details of the supplier of the safety data sheet

Manufacturer
Lankem Ltd
Charles Street
SK164SD Dukinfield - United Kingdom
T 01613433355
technical@lankem.com - www.lankem.com

1.4. Emergency telephone number

Emergency number : +447932007892

SECTION 2: Hazards identification

2.1. Classification of the substance or mixture

Classification according to Regulation (EC) No. 1272/2008 [CLP]

Not classified

Adverse physicochemical, human health and environmental effects

To our knowledge, this product does not present any particular risk, provided it is handled in accordance with good occupational hygiene and safety practice.

2.2. Label elements

Labelling according to Regulation (EC) No. 1272/2008 [CLP]

No labelling applicable

2.3. Other hazards

No additional information available

SECTION 3: Composition/information on ingredients

3.1. Substances

Name : LANSPERSE BIO691

LANSERSE BIO691

Safety Data Sheet

according to Regulation (EC) No. 1907/2006 (REACH) with its amendment Regulation (EU) 2015/830

Name	Product identifier	%	Classification according to Regulation (EC) No. 1272/2008 [CLP]
BioLoop Surfactant	EC-No.: POLYMER	100	Not classified

3.2. Mixtures

Not applicable

SECTION 4: First aid measures

4.1. Description of first aid measures

- First-aid measures after inhalation : Remove person to fresh air and keep comfortable for breathing.
- First-aid measures after skin contact : Wash skin with plenty of water.
- First-aid measures after eye contact : Rinse eyes with water as a precaution.
- First-aid measures after ingestion : Call a poison center or a doctor if you feel unwell.

4.2. Most important symptoms and effects, both acute and delayed

No additional information available

4.3. Indication of any immediate medical attention and special treatment needed

Treat symptomatically.

SECTION 5: Firefighting measures

5.1. Extinguishing media

- Suitable extinguishing media : Water spray, Dry powder, Foam, Carbon dioxide.

5.2. Special hazards arising from the substance or mixture

- Hazardous decomposition products in case of fire : Toxic fumes may be released.

5.3. Advice for firefighters

- Protection during firefighting : Do not attempt to take action without suitable protective equipment. Self-contained breathing apparatus. Complete protective clothing.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

6.1.1. For non-emergency personnel

- Emergency procedures : Ventilate spillage area.

6.1.2. For emergency responders

- Protective equipment : Do not attempt to take action without suitable protective equipment. For further information refer to section 8: "Exposure controls/personal protection".

6.2. Environmental precautions

Avoid release to the environment.

6.3. Methods and material for containment and cleaning up

- Methods for cleaning up : Take up liquid spill into absorbent material.
- Other information : Dispose of materials or solid residues at an authorized site.

6.4. Reference to other sections

For further information refer to section 13.

LANSPERSE BIO691

Safety Data Sheet

according to Regulation (EC) No. 1907/2006 (REACH) with its amendment Regulation (EU) 2015/830

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Precautions for safe handling : Ensure good ventilation of the work station. Wear personal protective equipment.
Hygiene measures : Do not eat, drink or smoke when using this product. Always wash hands after handling the product.

7.2. Conditions for safe storage, including any incompatibilities

Storage conditions : Store in a well-ventilated place. Keep cool.

7.3. Specific end use(s)

Surfactants.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

8.1.1. National occupational exposure and biological limit values

No additional information available

8.1.2. Recommended monitoring procedures

No additional information available

8.1.3. Air contaminants formed

No additional information available

8.1.4. DNEL and PNEC

No additional information available

8.1.5. Control banding

No additional information available

8.2. Exposure controls

8.2.1. Appropriate engineering controls

Appropriate engineering controls:
Ensure good ventilation of the work station.

8.2.2. Personal protection equipment

Personal protective equipment symbol(s):



8.2.2.1. Eye and face protection

Eye protection:
Safety glasses

8.2.2.2. Skin protection

Skin and body protection:
Wear suitable protective clothing

Hand protection:
Protective gloves

8.2.2.3. Respiratory protection

Respiratory protection:
In case of insufficient ventilation, wear suitable respiratory equipment

LANSPERSE BIO691

Safety Data Sheet

according to Regulation (EC) No. 1907/2006 (REACH) with its amendment Regulation (EU) 2015/830

8.2.2.4. Thermal hazards

No additional information available

8.2.3. Environmental exposure controls

Environmental exposure controls:

Avoid release to the environment.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Physical state	: Liquid
Colour	: amber.
Odour	: Characteristic odour.
Odour threshold	: No data available
pH	: 6 – 8
pH solution	: 5 %
Relative evaporation rate (butylacetate=1)	: No data available
Melting point	: 10 °C
Freezing point	: No data available
Boiling point	: > 100 °C
Flash point	: > 150 °C
Auto-ignition temperature	: No data available
Decomposition temperature	: No data available
Flammability (solid, gas)	: Not applicable
Vapour pressure	: No data available
Relative vapour density at 20 °C	: No data available
Relative density	: 1.08
Solubility	: No data available
Partition coefficient n-octanol/water (Log Pow)	: No data available
Viscosity, kinematic	: No data available
Viscosity, dynamic	: 468 cP @ 25 degs C
Explosive properties	: No data available
Oxidising properties	: No data available
Explosive limits	: No data available

9.2. Other information

No additional information available

SECTION 10: Stability and reactivity

10.1. Reactivity

The product is non-reactive under normal conditions of use, storage and transport.

10.2. Chemical stability

Stable under normal conditions.

10.3. Possibility of hazardous reactions

No dangerous reactions known under normal conditions of use.

10.4. Conditions to avoid

None under recommended storage and handling conditions (see section 7).

10.5. Incompatible materials

No additional information available

10.6. Hazardous decomposition products

Under normal conditions of storage and use, hazardous decomposition products should not be produced.

LANSPERSE BIO691

Safety Data Sheet

according to Regulation (EC) No. 1907/2006 (REACH) with its amendment Regulation (EU) 2015/830

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity (oral)	: Not classified
Acute toxicity (dermal)	: Not classified
Acute toxicity (inhalation)	: Not classified
Skin corrosion/irritation	: Not classified ((OECD TG439 method)) pH: 6 – 8
Serious eye damage/irritation	: Not classified ((OECD 492 method)) pH: 6 – 8
Respiratory or skin sensitisation	: Not classified
Germ cell mutagenicity	: Not classified
Carcinogenicity	: Not classified
Reproductive toxicity	: Not classified
STOT-single exposure	: Not classified
STOT-repeated exposure	: Not classified
Aspiration hazard	: Not classified

SECTION 12: Ecological information

12.1. Toxicity

Ecology - general	: The product is not considered harmful to aquatic organisms nor to cause long-term adverse effects in the environment.
Hazardous to the aquatic environment, short-term (acute)	: Not classified
Hazardous to the aquatic environment, long-term (chronic)	: Not classified

BioLoop Surfactant

EC50 - Crustacea [1]	37.4 mg/l
EC50 72h - Algae [1]	167.4 mg/l

12.2. Persistence and degradability

LANSPERSE BIO691

Persistence and degradability	This surfactant complies with the biodegradability criteria as laid down in Regulation (EC) No.648/2004 on detergents.
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12.3. Bioaccumulative potential

LANSPERSE BIO691

Bioaccumulative potential	No bioaccumulation data available.
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12.4. Mobility in soil

No additional information available

12.5. Results of PBT and vPvB assessment

No additional information available

12.6. Other adverse effects

No additional information available

LANSPERSE BIO691

Safety Data Sheet

according to Regulation (EC) No. 1907/2006 (REACH) with its amendment Regulation (EU) 2015/830

SECTION 13: Disposal considerations

13.1. Waste treatment methods

Waste treatment methods

Dispose of contents/container in accordance with licensed collector's sorting instructions.

SECTION 14: Transport information

In accordance with ADR / IMDG / IATA / ADN / RID

ADR	IMDG	IATA	ADN	RID
14.1. UN number				
Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
14.2. UN proper shipping name				
Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
14.3. Transport hazard class(es)				
Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
14.4. Packing group				
Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
14.5. Environmental hazards				
Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
No supplementary information available				

14.6. Special precautions for user

Overland transport

Not applicable

Transport by sea

Not applicable

Air transport

Not applicable

Inland waterway transport

Not applicable

Rail transport

Not applicable

14.7. Transport in bulk according to Annex II of Marpol and the IBC Code

Not applicable

SECTION 15: Regulatory information

15.1. Safety, health and environmental regulations/legislation specific for the substance or mixture

15.1.1. EU-Regulations

No REACH Annex XVII restrictions

LANSPERSE BIO691 is not on the REACH Candidate List

LANSPERSE BIO691 is not on the REACH Annex XIV List

LANSPERSE BIO691 is not subject to Regulation (EU) No 649/2012 of the European Parliament and of the Council of 4 July 2012 concerning the export and import of hazardous chemicals.

LANSPERSE BIO691

Safety Data Sheet

according to Regulation (EC) No. 1907/2006 (REACH) with its amendment Regulation (EU) 2015/830

LANSPERSE BIO691 is not subject to Regulation (EU) No 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants

15.1.2. National regulations

No additional information available

15.2. Chemical safety assessment

No chemical safety assessment has been carried out

SECTION 16: Other information

Abbreviations and acronyms	
ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
ADR	European Agreement concerning the international Carriage of Dangerous Goods by Road
ATE	Acute Toxicity Estimate
BLV	Biological limit value
CAS-No.	Chemical Abstract Service number
CLP	Classification Labelling Packaging Regulation; Regulation (EC) No 1272/2008
DMEL	Derived Minimal Effect level
DNEL	Derived-No Effect Level
EC50	Median effective concentration
EC-No.	European Community number
EN	European Standard
IATA	International Air Transport Association
IMDG	International Maritime Dangerous Goods
LC50	Median lethal concentration
LD50	Median lethal dose
LOAEL	Lowest Observed Adverse Effect Level
NOAEC	No-Observed Adverse Effect Concentration
NOAEL	No-Observed Adverse Effect Level
NOEC	No-Observed Effect Concentration
OEL	Occupational Exposure Limit
PBT	Persistent Bioaccumulative Toxic
PNEC	Predicted No-Effect Concentration
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (EC) No 1907/2006
RID	Regulations concerning the International Carriage of Dangerous Goods by Rail
SDS	Safety Data Sheet
vPvB	Very Persistent and Very Bioaccumulative
WGK	Water Hazard Class

Safety Data Sheet (SDS), EU

This information is based on our current knowledge and is intended to describe the product for the purposes of health, safety and environmental requirements only. It should not therefore be construed as guaranteeing any specific property of the product.

Company Details

Lankem Ireland Limited
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Created Date 02/12/2021

Expiration Date 31/12/2021

Quote Name QO02122021

Prepared By Sarah Jiang
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Bill To Name Politécnico de Leiria
 Bill To Campus 2, Morro da Lena - Alto do Vieiro União das Freguesias de Parceiros e Azoia, conselho de Leiria, Codigo da Freguesia 2400-822 Leiria Portugal

Ship To Name Politécnico de Leiria
 Ship To Campus 2, Morro da Lena - Alto do Vieiro União das Freguesias de Parceiros e Azoia, conselho de Leiria, Codigo da Freguesia 2400-822 Leiria Portugal

Price quote per KG

Product	Product Code	Pack Type	Pack Size /Kg	Stock Status	Quantity	Sales Price
Lansperse BIO691	LK-BIO691-Sample	IBC	1,000	Stock Item	1,000.00	EUR 9.620
Lansperse BIO691	LK-BIO691-Sample	200Kg Plastic drum	200	Stock Item	200.00	EUR 9.778

Terms

For deliveries < 800Kg a delivery charge will apply

Delivery Term DDP
 Shipping and Handling EUR 264.880

A BioLoop dispersing agent for both aqueous and solvent systems

Description

Lansperse BIO691 is part of our new range of powerful dispersing agents containing components that are from renewable sources. Unlike many bio-based surfactants, this product offers excellent wetting and dispersing properties for a wide range of inorganic and organic pigments and powders. One of the main characteristics that make them different from conventional dispersing agents is how they can attach to a particle substrate. Conventional dispersing agents tend to be linear in structure and attach with one hydrophobe group. The BioLoops are different in the respect that they have two hydrophobes that attach onto a particle substrate making it twice as effective as a conventional dispersing. What makes this particular product unique is the ability to disperse particles in both aqueous and solvent-based mediums. An aqueous dispersion manufactured using Lansperse BIO691 can be incorporated in both solvent and aqueous based paints without any detriment to performance. This property is useful for universal tinters whilst also useful for formulators that want a multi-functional dispersing agent.

Applications

- Aqueous dispersions for inorganic and organic powders and pigments
- Dispersing agent for aqueous and solvent paint
- Solvent dispersions
- Universal tinting systems

Specification

Appearance:	Light amber liquid
Colour Gardner:	5 max
Cloud point (5g in 45g (BDG/water):	52 - 60
pH (5% aqueous):	5 - 8

Typical Properties

Composition:	BioLoop Surfactant
Solids content %:	100
Odour:	Characteristic
Viscosity at 25°C (cP):	468
Specific gravity at 20°C:	1.08
Pour point °C:	10
Flash point closed cup °C:	>150
Surface tension 0.1% (mN/m):	35.4

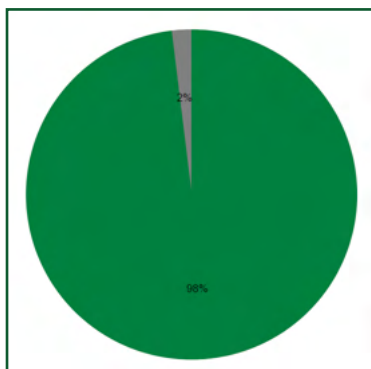
Key Features

- Based on BioLoop technology
- From bio-renewable sources
- Powerful dispersing properties
- Reduced addition levels
- No flocculation
- VOC free
- Fast particle size reduction
- Biodegradable
- Low ecotoxicity
- No skin or eye irritancy

Radio Carbon Dating

Percent modern carbon (pMC) : 98.4%

- Organic Carbon
- Fossil Carbon



Solubility Data

- Soluble
- Insoluble

Water	●	White Spirit	●	Shellsol A / Solvesso 100	●	Xylene	●	Butyl Acetate	●
Dowanol PMA	●	Ethyl Acetate	●	Isobutanol	●	MIBK	●	Dowanol PM	●
MEK	●	Acetone	●	N-Butyl Glycol	●	Mineral Oil	●	Soyabean Oil	●
Dowanol DPM	●	Ethanol	●	Soyabean Methyl Ester	●	DINP	●		

Packaging and Storage

Lansperse BIO691 can be supplied in IBC's, 200kg or 25kg nett drums.

Stainless steel, polyethylene or glass lined equipment is necessary for the storage of Lansperse BIO691 in order to prevent corrosion and subsequent contamination. This material can separate on standing and at low temperatures. May require agitation and warming prior to use.

All information, recommendations and suggestions appearing in the literature concerning the use of the product are based upon tests and data believed to be reliable. However it is the users responsibility to determine the suitability for their own use of the products described here. For non English datasheets translation has been carried out using translation software, Lankem accepts no liability due to errors that occur during translation. Typical properties are based on our own measurements and do not constitute part of the sales specification.

Company Details

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 D6W DK49
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Created Date 18/10/2022

Expiration Date 31/12/2022

Quote Name QO18102022

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Price quote per KG

Product	Product Code	Pack Type	Pack Size /Kg	No of Packs	Quantity	Sales Price
Lansperse BIO691	LK-BIO691-D25	25Kg Keg	25	1	25.00	EUR 15.217

Terms

For deliveries < 800Kg a delivery charge will apply

Shipping and Handling EUR 99.000