U.Porto Journal of Engineering, 8:5 (2022) 41-51
ISSN 2183-6493
DOI: 10.24840/2183-6493_008.005_0006

Received: 25 July, 2021
Accepted: 18 November, 2021
Published: 26 September, 2022

Chemical Product Design of a Sports Performance T-shirt using *Eucalyptus Globulus* Essential Oil

Eva S. M. Lora[1], Flávio M. A. Vieira[2], Inês A. Costa[3], M. Helena C. Teixeira[4], Matilde P. Albano[5], Yaidelin A. Manrique[6]

[1]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201604123@edu.fe.up.pt) ORCID 0000-0002-8062-5224; [2]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201912174@edu.fe.up.pt) ORCID 0000-0001-9781-8412; [3]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201603407@edu.fe.up.pt) ORCID 0000-0002-3854-5271; [4]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201705157@edu.fe.up.pt) ORCID 0000-0002-3842-5384; [5]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201703896@edu.fe.up.pt) ORCID 0000-0003-1332-447X; [6]LSRE-LCM-Laboratory of Separation and Reaction Engineering–Laboratory of Catalysis and Materials, Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (yaidelin.manrique@fe.up.pt) ORCID 0000-0002-7053-373X

Abstract

This project consists of developing a *Eucalyptus*-based product. The selected product is a sports performance T-shirt impregnated with eucalyptus essential oil. A Chemical Product Design approach was used to translate customer needs into the new product. This procedure is divided into four stages: Needs, Ideas, Selection and Manufacture. This product's target audience is athletics and hiking enthusiasts. Its main purpose is to valorize *Eucalyptus Globulus* essential oil's unique properties, providing fresh and decongestion sensations to the user. Finally, an economic analysis was performed to evaluate the product viability.

Author Keywords. Eucalyptus. Essential Oil. Sports Performance T-shirt. Chemical Product Design.

Type: Research Article

1. Introduction

A chemical product was developed based on *Eucalyptus,* aiming to expand the range of economic activities related to the forest sector. This raw material was chosen due to its high availability in the Portuguese forests, its relevance in the national market and its attractive and unexploited properties.

Initially, the product design team went through the four stages of product design: the identification of Needs, Ideas, Selection and Manufacture. This work aims to produce a novel product using extracts from Eucalyptus and describes a possible process to produce it. Market assumptions had to be made to evaluate the viability of the proposed product considering its manufacturing by a company in Portugal.

An economic analysis of the project was performed. Also, a Gantt diagram was used to illustrate the implementation of the entrepreneurial project over six years. It was necessary to consider several costs associated with the product's manufacturing to define the selling price of the final product. No experimental tests were carried out, so the data for economic analysis was estimated.

2. Raw Material

Eucalyptus is an evergreen forest species that contribute significantly to Portugal's environmental, social and economic development. There are several species, with *Eucalyptus Globulus* being the predominant one, occupying 26 % of the Portuguese forest area. It is mostly found in coastal and low-altitude areas, mainly in the regions of Aveiro and Porto. Moreover, it is a fast-growing tree that easily adapts to edaphoclimatic conditions, in other words, the country's soil and climate (The Navigator Company 2020).

The primary use of *Eucalyptus* is in the production of paper pulp and cardboard, and its high production yields are a result of high wood density, low consumption of chemical products and excellent fiber quality. *E. Globulus* fibers give excellent features to the paper produced and allow more recycles, leading to an extension of paper life (The Navigator Company 2020).

The paper industry is considered self-sustainable since 96.1 % of the electricity consumed in this sector is produced from its raw material biomass. The energy is resultant from the combustion of *Eucalyptus*' organic material originating from the pulp production process, such as bark and leaves. Portugal is considered the 3rd largest pulp producer in Europe and 11th for paper and cardboard production. Currently, there is a production of over 2.7 million tons of *Eucalyptus* fiber pulp. According to CELPA - *Associação da Indústria Papeleira* (Portugal), the sales volume in 2018 was 2.91 billion euros, corresponding to 1.44 % of the Gross Domestic Product – GDP (The Navigator Company 2020).

Besides, *Eucalyptus* is used in several other sectors, such as *Eucalyptus* honey; wood for furniture production; cellulose, which has several applications like textiles or decoration, and the essential oil that can be marketed pure or as candies (The Navigator Company 2020).

E. Globulus essential oil is a pleasant-smelling liquid that comes mainly from the leaves of the tree. It consists mostly of 1,8-cineole, also known as eucalyptol, 83.89 %, limonene, 8.16 %, α-pinene, 4.15 %, and *o*-cymene, 2.93 % (Maciel et al. 2010). These components, when combined, create a synergy between each other, enhancing the properties of the related compounds (Hąc-Wydro and Szydło 2016).

Each essential oil component has characteristic properties and is used in the most diverse areas, from the cosmetic, pharmaceutical or medicinal sectors to the domestic products industries. They can also be used as solvents for other chemical compounds' production or as flavoring agents in food or perfumes. In addition to the evident flavoring and decongestant properties, *Eucalyptus* essential oil has anti-inflammatory, antibacterial, repellent and insecticide properties (PubChem).

3. Chemical Product Design (CPD)

The chemical product design is a procedure in which customer needs are translated into new products. This procedure can be divided into four steps: Needs, Ideas, Selection and Manufacture. The first step is identifying the consumer's needs. The second step is the development of ideas that fulfill the needs formulated in the previous step. The third step consists of selecting the best ideas for commercial development. Finally, the last step is related to the manufacture of the chosen product (Cussler and Moggridge 2011).

3.1. Needs

The first step of CPD consists of identifying and analyzing the consumers' needs to develop a product that satisfies them. Then, these needs are classified as essential, desirable or useful.

For the product design to be successful, the product must fulfill all the essential needs. Furthermore, it should meet many desirable needs since they value the product versus other competitive products. Although the useful needs are not fundamental, they should be considered to increase its value (Cussler and Moggridge 2011). Table 1 shows the classification of the needs considered in the eucalyptus-based product's CPD.

Essential	Desirable	Useful
- Preservation of the Eucalyptus active principles' properties - Reuse of Eucalyptus residue	- Low environmental impact of the product and its production - National product	- Low-cost product

Table 1: Classification of the needs identified

In this project, preservation of the essential oil's properties was considered essential, namely its decongestant and antibacterial properties. In Portugal, *Eucalyptus* is essentially used as raw material for pulp production. This production creates a large quantity of *Eucalyptus* residue. Therefore, it is fundamental to reuse these residues without affecting pulp production. This can be accomplished through the extraction of essential oil from *Eucalyptus* leaves. Furthermore, the low environmental impact and the national origin of the product are increasingly important factors for consumers, so they were considered desirable. Finally, the design of a low-cost product is useful to arouse the interest of the consumers.

3.2. Ideas & Selection

The second step of CPD consists of brainstorming ideas that fulfill the market needs previously considered. Firstly, it is useful to devise a large number of ideas to increase the odds of having a good one. In this search, it is important to think out of the box and not to be concerned with restrictions. To some product designers, the recommended number of ideas originated is about one hundred. The next stage is to select the products that show the most potential, eliminating any repeated ideas and senseless ones (Cussler and Moggridge 2011).

Initially, thirty ideas were conceived for this project. Afterward, the less promising and senseless ideas were eliminated, restricting the original number to ten ideas organized in different categories.

The other method used to restrict the number of ideas was a ranking matrix (Table 2), which evaluates the general characteristics of each idea using several parameters. This matrix contained the following parameters: environmental impact of the product and its production, innovation, extraction method complexity, production cost, market competitiveness, quality-efficiency ratio, process scientific maturity, certification easiness and final product's longevity. The first six parameters were weighted with 13.3 % and the remaining with 6.7 %. Environmental impact was weighted with the higher factor because of its increasing importance for the consumer. Innovation and market competitiveness because the product must arouse the interest of the consumers. Finally, the extraction method complexity and production cost were considered essential for the product's commercialization viability. It is to highlight that weight for each parameter was defined according to the authors' knowledge.

Criterion	Environmental impact	Innovation	Extraction complexity	Production cost	Market competitiveness	Quality-efficiency ratio	Scientific maturity	Final product's longevity	Certification easiness	Total
Weight	**13.3 %**	**13.3 %**	**13.3 %**	**13.3 %**	**13.3 %**	**13.3 %**	**6.7 %**	**6.7 %**	**6.7 %**	
Anti-aging cream	3	4	5	3	2	3	3	4	4	3.4
Shaving cream	3	2	5	4	1	3	4	4	4	3.2
Facial serum	3	3	5	2	2	3	4	4	4	3.2
Lipstick	3	1	3	4	1	3	5	5	4	2.9
Air Fresheners	4	1	5	4	1	3	4	2	4	3.1
Antibacterial fabric	2	5	4	3	4	4	3	1	2	3.3
Muscle Pain Cream	3	4	4	4	2	2	3	4	3	3.2
Social mask	2	5	4	3	5	3	2	2	1	3.3
T-shirt	2	5	4	3	5	4	3	2	3	3.6
Repellent clothing	2	5	2	3	3	2	3	2	3	2.8

Table 2: Ranking matrix for the ten pre-selected ideas

After the matrix screening, the number of ideas was reduced to three: the sports performance T-shirt, the *anti-aging* moisturizing cream and the antibacterial tissue. The goal of the sports performance T-shirt is to provide fresh and decongestion sensations to the user. Furthermore, the antibacterial properties of the *Eucalyptus* essential oil inhibit the bacteria proliferation responsible for foul-smelling, discoloration and fabric wear. This product's target audience is athletics and hiking enthusiasts. The anti-aging moisturizing cream allows hydration and rejuvenation of the user's skin. However, its main purpose is to prevent skin aging due to exposition to ultraviolet radiation. Its target audience is mainly women of all ages. The antibacterial tissue was designed for hospital use and its goal is to protect wounds, prevent bacteria proliferation, and therefore the incidence of infections.

The viability of the product's production and commercialization should be analyzed until a viable idea is found. An idea can be considered non-viable for many reasons, such as elevated production costs or amounts of raw material per product. The sports performance T-shirt was the product with the higher score, so its viability was analyzed first. Since this product was considered a viable idea, the next step is to idealize its manufacturing process.

3.3. Manufacture

For this product's development, it is necessary to consider some process options for its several stages and choose the most advantageous one. It is essential to select an efficient process of essential oil extraction from the *Eucalyptus* leaves. Subsequently, it is also required a microencapsulation method to enable the utilization of the chosen active principle in the sports performance T-shirts. Besides, it is also necessary to select the most appropriate technique to fix the microcapsules on the T-shirts and the finishing treatments to enable this product's commercialization. After selecting *Eucalyptus* as raw material, it was decided to bypass the pulp production process to reuse its residues. *E. Globulus* leaves are mostly used as biomass for energy production, wasting its characteristic compounds. Thus, due to the large amount available, it is possible to obtain *Eucalyptus* leaves at a very low price for the essential oil extraction. Figure 1 shows a diagram of the general manufacturing process proposed for the sports performance T-shirts.

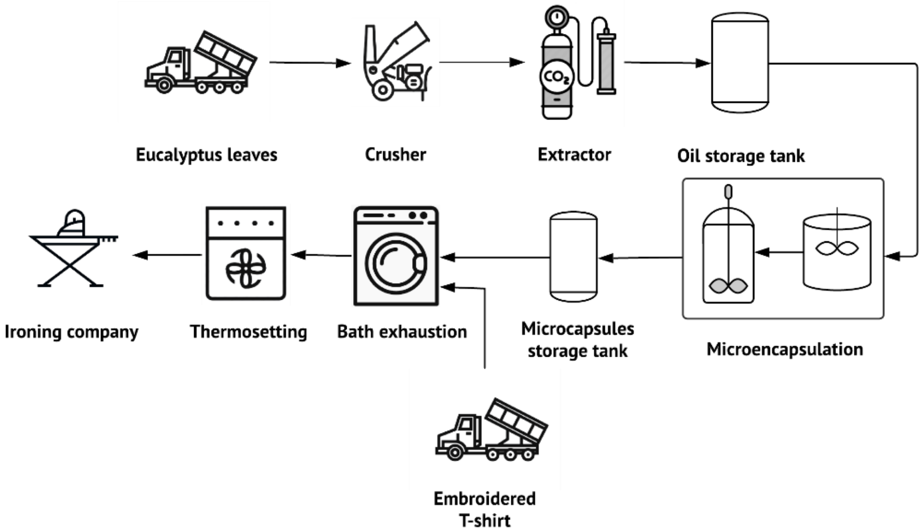

Figure 1: Production process diagram of the sports performance T-shirt

Obtaining the raw material's active principles is one of the essential steps in developing and producing a chemical product.

The selection of the extraction method to obtain the *Eucalyptus'* essential oil was based on the cost of the process, energy consumption, extraction yield, environmental impact, and, mainly, the conservation of the oil components. Four methods were considered, namely hydro-distillation, steam distillation, solvent extraction and supercritical fluid extraction (Khandge et al. 2019). After a brief analysis of all the proposed processes, hydro-distillation was rejected; its high temperatures can degrade thermally unstable compounds, cause partial hydrolysis of compounds and formation of undesirable compounds in the extract (Zhao and Zhang 2014). For solvent extraction, an additional separation step will be required; also, solvent residues would be present in the finished product, and this extraction method has also been excluded (Zhao and Zhang 2014). Steam distillation had a low extraction yield, between 0.6 and 1.3%, and supercritical extraction had a yield of ca. 3.6% (Singh, Ahmad, and Bushra 2016). Regarding the parameters mentioned, the best process was the supercritical fluid extraction using carbon dioxide as a solvent since the elevated costs of the equipment are paid off in the long term by the reduced energetic costs and it presents higher yields (Singh, Ahmad, and Bushra 2016).

In this method, carbon dioxide is submitted to pressures and temperatures above its critical point, passing to an intermediate phase. The fluid effuses through solids like a gas and dissolves substances like a liquid, becoming a solvent ("Supercritical Fluids", n.d.). Previously, *E. Globulus* leaves are crushed to increase the contact area and, consequently, the extraction efficiency. The supercritical carbon dioxide flows through the bed of leaves, dissolving and extracting the components. The resultant stream goes through a back pressure regulator and the components condense. The stream is then separated, and the essential oil is collected. The carbon dioxide stream is recovered, purified, and reused at a rate of 95 %. The high-quality essential oil stream contains no toxic waste and keeps the total integrity of all components (Salea, Veriansyah, and Tjandrawinata 2017).

The operating conditions are critical in this process since they influence the extracted oil quantity and quality. Thus, it should be used a carbon dioxide flow rate of 720 kg/h and the equipment must operate at 350 bar and 80 °C. This extraction process lasts 60 minutes with a yield of approximately 3.6 % (Singh, Ahmad, and Bushra 2016). Figure 2 shows a schematic of a supercritical carbon dioxide extraction process.

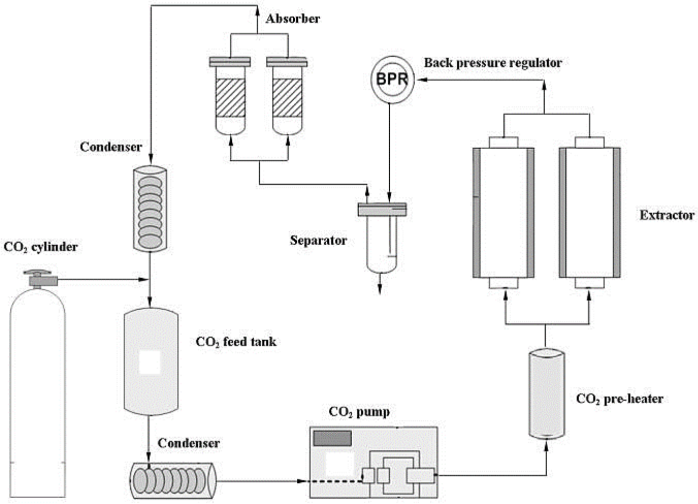

Figure 2: Schematic of a supercritical carbon dioxide extraction process
Reproduced with permission from Salea, Veriansyah, and Tjandrawinata (2017).
Copyright 2021, Elsevier.

Then, to prepare the microcapsules with the extracted essential oil, it is necessary to use a microencapsulation process. Microencapsulation is a technique that allows the isolation of active compounds through a membrane, forming small capsules that enable its controlled release (Souza and Pacheco 2016; Lima 2017). These capsules have dimensions between 1 and 1000 µm and comprise the core material and the membrane (Moreira 2014).

There are three categories of microencapsulation techniques: chemical methods, such as interfacial polymerization and in situ polymerization; physical methods, such as spray drying; and physical-chemical methods, including complex coacervation, simple coacervation and solvent evaporation (Brasileiro 2011). Interfacial polymerization was the chosen method due to its fast and easy scale-up and high efficiencies (Carvalho, Estevinho, and Santos 2016).

It is essential that the membrane material stabilizes and does not react with the substance encapsulated in the core and also be economically viable and stable (Lima 2017).

In the interfacial polymerization process, the membrane is formed through the polymerization reaction of two reactive monomers. The two monomers are dissolved separately in two immiscible liquids since one is soluble in the organic phase and the other in the aqueous phase (Brasileiro 2011). For this process, the reagents used, their function and the amount needed to prepare about 100 L solution are shown in Table 3 (Silva et al. 2017).

Reagent	Function	Amount
Hydrogenated Methylene Bis(4-cyclohexylisocyanate) (HMDI)	Isocyanate	3.2 L
Poly(vinyl alcohol) (PVA)	Protective colloid	0.9 kg
Poly(ethylene glycol) 400 (PEG 400)	Polyol	4.9 L
Dibutyltin Dilaurate (DBTDL)	Catalyst	0.1 L
Ethylenediamine (EDA)	Amine compound	0.9 L
Hydrazine Monohydrate (HYD)	Amine compound	0.3 L
Deionized Water	Solvent	81.5 L
Essential oil of E. Globulus	Core material	10.7 L

Table 3: Reagents used in the production of 100 L microcapsule solution

Firstly, the organic phase is prepared by mixing the essential oil with HMDI and adding this solution, in a mixer, to the aqueous phase with the colloid PVA. This colloid favors the stabilization of the drops formed and the uniform distribution of the particle size. Then, this oil-in-water emulsion is transferred to a polymerization reactor. A solution consisting of water, PEG 400 and DBDTL is added to form the polyurethane wall. This mixture is stirred for one hour at 80 °C. After this period, a solution of water with EDA is slowly added over an hour, starting to form urea. Finally, a more reactive amine, HYD, is added to achieve complete conversion of the isocyanate, which will react for one hour. The whole process is shown in Figure 3. After the formation of the microcapsules, it is necessary to wash them once with an ethanol solution and twice with distilled water (Silva et al. 2017).

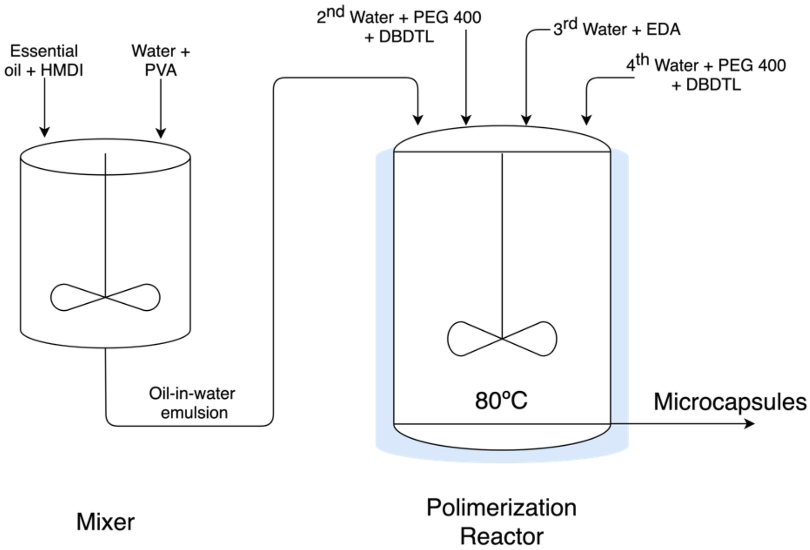

Figure 3: Representation of the microcapsule production process

Subsequently, to fix the microcapsules with essential oil on the T-shirts' fabric, it is necessary to select a fixation technique from the various existing ones: exhaustion, coating, impregnation or spraying (Rodrigues 2018).

All the techniques require the use of a binder to help the microcapsules' fixation, usually based on acrylics, polyurethanes or silicone resins (Li et al. 2008).

The selected technique was exhaustion, where the fabric is in frequent contact with an agitated bath for a determined amount of time and at a specific temperature. Initially, the microcapsules are absorbed on the substrate surface, followed by their diffusion into the fiber (Araújo 2016; Rodrigues 2018).

For the exhaustion technique is required a 2 L bath solution to impregnate about 0.1 kg of fabric. The amounts of microcapsules, binder and softener, are presented in Table 4. The fabric must be in contact with this solution for 40 minutes at 60 °C (Bonet Aracil et al. 2015).

Microcapsules	Polyurethane - Binder	Perisoft Nano-Softener
120 g	20 g	6.1 g

Table 4: Amounts for 2 L of bath

Then, it is essential to perform thermosetting to promote better microcapsules fixation. This procedure must be done in an oven at 110 °C for 20 minutes (Bonet Aracil et al. 2015).

It is to remark that this work developed a conceptual idea and there were no conducted experimental tests; before starting the production, laboratory tests need to be conducted to get an effective product.

4. Economic Analysis

After the development of the product, it is necessary to perform an economic analysis in order to organize and evaluate the project's viability. This is made by setting an industrial case with several stages defined over time, as presented in the Gantt diagram of Figure 4. This diagram demonstrates the time progression of the different stages of the project, which was evaluated for 6 years.

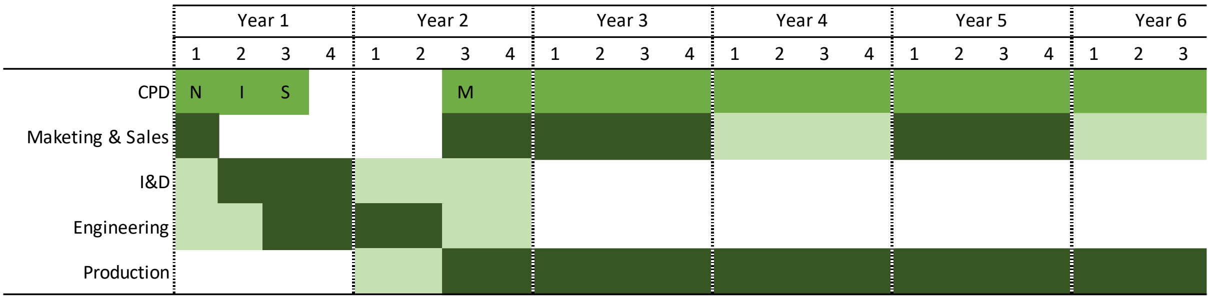

Figure 4: Gantt diagram (N - Needs, I - Ideas, S - Selection and M - Manufacture)

On the left side of this diagram are the project's main tasks, while at the top is the time scale, divided into years and quarters. The horizontal bars indicate the period in which the different activities are carried out. Furthermore, the color intensity is directly associated with the higher or lower contribution of the sector.

Figure 4 shows that CPD is predicted to last for the first three quarters of the first year with the Needs identification, Ideas and Selection stages and begin again in the third quarter of Year 2 and last years with the Manufacturing stage.

The Marketing and Sales sector is essential in the first stage of product development in order to perform market research to understand its needs and, posteriorly, for the product sales. Then, this sector is responsible for product promotion and should predict its success and approval by potential buyers. This is essential so that the product can be commercialized in the fourth quarter of Year 2. In addition to traditional marketing strategies, it is necessary to invest in the sponsorship of athletic teams and marathons and to use digital lifestyle influencers to reach the younger population. Due to the intention to increase production in Year 5, Marketing should have an intense activity to boost the product's promotion, enhancing its demand and sales.

Concerning the Investigation and Development sector, it has a significant role in the Ideas stage since it is dedicated to research, development and technology, ensuring a high-quality product for consumers. It also focuses on creating and developing a product that fulfills the market needs and ensures compliance with regulations.

The Engineering sector is important at the end of the first year and at the beginning of the following one. This sector evaluates the products' economic viability, assists in the decisions of the Selection stage, and, later, helps in the production process development.

Furthermore, as seen in the diagram, the Production sector will have a constant activity from the middle of Year 2 when it is expected to start shipping the product.

For the economic analysis, it was also necessary to consider and evaluate the costs associated with this project, namely the purchase of equipment for production, energy and water costs, the salaries of the company's employees, and marketing expenses. Some other costs were also considered, such as communications, insurance, administrative equipment, office supplies, professional training, cleaning, rent, transportation and the ironing company.

In the production of sports performance T-shirts, it is necessary to resort to several equipment types. In the extraction stage, the crusher for *Eucalyptus* leaves and the extractor with supercritical carbon dioxide. For the production of microcapsules, the mixer and the polymerization reactor. And finally, for fixing them on the fabric, the impregnating machines and the thermosetting equipment. It is also essential to have storage tanks and the deionizer for a more economical way to obtain deionized water, which is crucial to the entire process.

It was considered an initial investment of 500 thousand €, being 250 thousand € for the equipment. It is to remark that this economic analysis is a rough initial estimate. The initial production of T-shirts begins with 25 thousand units to be sold in the last fourth quarter of 1^{st} year. It is expected 125 thousand in the following year. It was considered an increase of 15 % and 25 % in the following years.

It was assumed a retail price of 30 € for each T-shirt, containing approximately 8.7 g of *E. Globulus* essential oil.

5. Conclusions

In this work, it was proposed to produce a sports performance T-shirt impregnated with *Eucalyptus* essential oil. Its main purpose is to provide a fresh feeling and decongest the airways of the users. It also prevents the proliferation of bacteria responsible for foul odors due to the essential oil's antibacterial properties. This product's target audience is athletes and hiking enthusiasts.

The production process for the sports performance T-shirts consists of 3 steps: extracting the essential oil, the microcapsules' formation, and their fixation on the fabric. Supercritical carbon dioxide extraction was selected to obtain the *Eucalyptus* essential oil. On the other hand, interfacial polymerization was considered the most advantageous microencapsulation method. Finally, the exhaustion technique was selected to fix the microcapsules in the fabric.

In order to promote the developed product and raise the interest of the target audience, it was necessary to define some marketing strategies, such as sponsoring marathons and digital influencers. After analyzing all the associated costs and considering a gross margin of 75 %, the selling price for sports stores was defined at 22.5 € and for the final consumer at 30 €.

References

Araújo, I. M. V. de C. de. 2016. "Funcionalização do Algodão em Rama". Master's thesis, Faculty of Engineering, University of Porto. https://hdl.handle.net/10216/95941.

Bonet Aracil, M. Á, P. Monllor, L. Capablanca, J. Gisbert, P. Díaz, and I. Montava. 2015. "A comparison between padding and bath exhaustion to apply microcapsules onto cotton". *Cellulose* 22, no. 3: 2117-27. https://doi.org/10.1007/s10570-015-0600-8.

Brasileiro, J. S. L. 2011. "Microencapsulação de composto bioativos: inovação em diferentes áreas". Master's thesis, Faculty of Health Sciences, Universidade Fernando Pessoa. http://hdl.handle.net/10284/2457.

Carvalho, I. T., B. N. Estevinho, and L. Santos. 2016. "Application of microencapsulated essential oils in cosmetic and personal healthcare products - A review". *International Journal of Cosmetic Science* 38, no. 2: 109-19. https://doi.org/10.1111/ics.12232.

Cussler, E. L., and G. D. Moggridge. 2011. *Chemical Product Design*. 2nd ed. Cambridge Series in Chemical Engineering. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139035132.

Hąc-Wydro, K., and K. Szydło. 2016. "The influence of environmentally friendly pesticide – Eucalyptol – alone and in combination with terpinen-4-ol–on model bacterial membranes". *Colloids and Surfaces B: Biointerfaces* 146: 918-23. https://doi.org/10.1016/j.colsurfb.2016.07.044.

Khandge, R., S. Sane, N. Khatri, and N. Satao. 2019. "Extraction of essential oil: Eucalyptus oil". *International Journal of Emerging Technologies and Innovative Research* 6, no. 1: 701-06. https://www.jetir.org/view?paper=JETIR1901083.

Li, S., J. Lewis, N. Stewart, L. Qian, and H. Boyter. 2008. "Effect of finishing methods on washing durability of microencapsulated aroma finishing". *Journal of the Textile Institute* 99, no. 2: 177-83. https://doi.org/10.1080/00405000701489701.

Lima, C. S. A. de. 2017. "Estudo do Desenvolvimento de Microcápsulas de Polímeros Naturais para Aplicação em Têxteis Médicos". Postgraduate Course in Textile and Fashion, College of Arts, Sciences and Humanities, University of São Paulo. https://www.teses.usp.br/teses/disponiveis/100/100133/tde-01112017-144224/pt-br.php.

Maciel, M. V., S. M. Morais, C. M. L. Bevilaqua, R. A. Silva, R. S. Barros, R. N. Sousa, L. C. Sousa, E. S. Brito, and M. A. Souza-Neto. 2010. "Chemical composition of Eucalyptus spp. essential oils and their insecticidal effects on Lutzomyia longipalpis". *Veterinary Parasitology* 167, no. 1: 1-7. https://doi.org/10.1016/j.vetpar.2009.09.053.

Moreira, A. C. G. 2014. "Microencapsulação de óleos essenciais". Master's thesis, Faculty of Engineering, University of Porto. https://hdl.handle.net/10216/84849.

The Navigator Company. 2020. *The Newsletter - Conhecer o eucalipto: do imaginário florestal, coletivo ao desenvolvimento ambiental, social e económico do país.* The Navigator Company.

PubChem. Bethesda, MD: US National Library of Medicine-National Center for Biotechnology Information. Accessed October 2020. https://pubchem.ncbi.nlm.nih.gov/.

Rodrigues, R. V. 2018. "Aplicação do design funcional e da moda sustentável na dermatite atópica infantil". Master's thesis, Masters in Fashion Design, University of Beira Interior. http://hdl.handle.net/10400.6/9342.

Salea, R., B. Veriansyah, and R. R. Tjandrawinata. 2017. "Optimization and scale-up process for supercritical fluids extraction of ginger oil from Zingiber officinale var. Amarum". *Journal of Supercritical Fluids* 120: 285-94. https://doi.org/10.1016/j.supflu.2016.05.035.

Silva, M., I. M. Martins, M. F. Barreiro, M. M. Dias, and A. E. Rodrigues. 2017. "Functionalized textiles with PUU/limonene microcapsules: effect of finishing methods on fragrance release". *Journal of the Textile Institute* 108, no. 3: 361-67. https://doi.org/10.1080/00405000.2016.1166823.

Singh, A., A. Ahmad, and R. Bushra. 2016. "Supercritical carbon dioxide extraction of essential oils from leaves of Eucalyptus globulus L., their analysis and application". *Analytical Methods* 8, no. 6: 1339-50. https://doi.org/10.1039/c5ay02009c.

Souza, F. A., and N. Pacheco. 2016. "Funcionalização de materiais têxteis". *Revista Icônica* 2, no. 1: 107-22. http://revistas.utfpr.edu.br/ap/index.php/iconica/article/view/70.

"Supercritical Fluids". n.d. In *Introduction to Chemistry – Liquids and Solids.* Accessed November 2020. https://www.coursehero.com/study-guides/introchem/supercritical-fluids/.

Zhao, S., and D. Zhang. 2014. "Supercritical CO_2 extraction of Eucalyptus leaves oil and comparison with Soxhlet extraction and hydro-distillation methods". *Separation and Purification Technology* 133: 443-51. https://doi.org/10.1016/j.seppur.2014.07.018.

Acknowledgments

This work was developed under the scope of the course unit of Chemical Product Engineering of the Integrated Master in Chemical Engineering at the Faculty of Engineering of the University of Porto, during the 1st semester of the 2020/2021 academic year. Gonçalo Silva was part of the working group, and we show our gratitude for his contribution. Professor Cláudia Gomes, Doctor Ricardo Santos and Doctor Yaidelin Manrique, supervisors of this work, are members of the Associate Laboratory LSRE-LCM funded by national funds through FCT/MCTES (PIDDAC): Base-UIDB/50020/2020 and Programmatic-UIDP/50020/2020 Funding.