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Steam Distillation for Essential Oil Extraction: An Evaluation of Technological Advances Based on an Analysis of Patent Documents

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Abstract: The most-used method for essential oil extraction is steam distillation due to its simplicity and low investment requirements. Due to the importance of this extractive method, technological updates represent an immense opportunity for improving this component of essential oil production. In order to evaluate how such updates have been applied to essential oil production, in this study, we conducted a technological prospection. A total of 490 patent documents were retrieved and indicators were evaluated, which included publication trends, main applicants and inventors of the prospected technologies, main depositing countries and potential markets for the inventions, and classification codes assigned to the patent documents. The results indicated that steam distillation is used by different sectors and that it is an important industrial process that has been growing in recent years. In terms of associated technological updates, we observed that only some patent documents referred to the application of technological updates, indicating that processes could still be investigated and incorporated into the technology. Thus, the advancement of studies to improve this process could contribute even more to its visible growth, increasing its application potential and process yield.

Keywords: plant oil; essential oil; steam distillation; technological updates; patents; channeling; process duration

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1. Introduction

Essential oils (EOs) are products extracted from different parts of plants, such as leaves, stems, roots, and barks. Chemically, essential oils are homogeneous mixtures composed of a range of fractions from the most volatile to the heaviest terpenoids, which are natural compounds that are usually produced as secondary metabolites and act as defense phytochemicals for plants [1]. Terpenoids have a pronounced aroma, often pleasing to the human sense of smell and, with rare exceptions, a density lower than water, with a characteristic color for each species that also varies in intensity, and, therefore, its presence is important in plant species [2,3]. Due to these and other characteristics, as well as associated application possibilities, the EO market has been growing intensely. The odorous, flavoring, and pharmaceutical properties of EOs play important roles in different industry sectors, such as supplying raw materials for cosmetics, pharmaceuticals, aromatherapy, food flavorings, preservation, and homecare businesses [4]. Large-scale production of EOs has been a driving force in the global market; however, high market prices are often a major restraint on the market. Nevertheless, the high demand for EOs, especially for use as natural preservatives, has provided growth opportunities in the global market [5].

The global EO market size was estimated to be USD 10.3 billion in 2021 and is expected to reach USD 16.0 billion by 2026 [6]. Increased consumption of natural products due to their health benefits has motivated manufacturers to invest in EOs instead of using synthetic substances in their commercial products, including cosmetics, pharmaceuticals, food, and others. Therefore, continued growth in the EO market is expected [7].

In order to contribute to the potential commercialization of EOs, the production process needs to be aligned with conditions that provide a good process yield and high quality. One of the main challenges in the scale-up of EO production is the extraction process, due to its long time and high energy demands. Generally, the extraction process involves either azeotropic distillation or solvent extraction. Azeotropic distillation includes hydrodistillation, hydrodiffusion, and steam distillation [8]. Steam distillation extraction is characterized by yield and process uncertainties; however, it is still the most applied extraction method due to its low investment requirements and operational costs as compared with other extraction methods, such as carbon dioxide in a subcritical state, microwaves, ultrasound, and nonpolar solvents. Steam distillation extraction is a clean method, environmentally speaking, given that the solvent is water steam, that is, as compared with organic solvents that require post separation, generate waste, require air treatment, as well as exhaust, and sometimes, ex-proof installations [9,10]. Steam distillation extraction in the EO industry usually results in low yields and long extraction times relative to the high consumption of all other resources. However, at the laboratory scale, experiments have demonstrated that the amount of oil in the green matrix is higher than that normally obtained by the industry. This indicates that the industrial equipment for steam distillation extraction could be modified to achieve higher yields, better quality, and shorter extraction periods [11]. Few modifications were made to control and optimize the process. The progress made was aimed at mechanical improvements in order to reduce energy consumption. Thus, understanding and prediction of the physical phenomena that occur within the equipment has not been explored [12].

The application of technological updates to the steam distillation process for EO extraction could improve process control and results, bringing important opportunities to the industrial sector. These updates are part of the wave called Industry 4.0, which is a trend directly associated with process reliability and availability issues and driving industrial innovations. Given the aforementioned growth in the use of natural products such as EOs, there is a need to achieve higher yields, better quality, and shorter extraction periods [13]. Technological updates could enhance features of the steam distillation process, such as reducing degradation of substances, increasing the quality of the final product, and obtaining higher yields of EO. In addition, other quantitative benefits could be obtained such as lower energy and water consumption, optimized capacity utilization, and overall product cost reduction. In terms of EO quality, substance degradation and loss of volatile compounds can occur during the extraction process when plant material is overexposed for a prolonged period of time to high temperatures [10]. Within this context, technological updates imbed smart instrumentation into the design of production systems, including automatic control and process monitoring. Furthermore, an intense dependence on manpower requires continuous action from operators to control important process parameters [14].

The steam distillation process, commonly installed on farms, does not have access to technological development or suppliers of technical elements that would help in control, prediction, and process autonomy. For important points, such as the detection and correction of vapor channels (channeling), which occur naturally due to the anisotropy of the raw material, decisions, based on data and machine learning, that determine the ideal time to complete the process or to apply temperature-controlled water for condensation, bring quantitative and qualitative impacts. As a result, more competitive costs and improved sustainability attributes can be attributed to the business.

For perspective, the flow of steam through a green mass can be explained by multiphase flow in an anisotropic porous medium. The Darcy equation (Equation (1)) and suitable boundary conditions for an anisotropic medium (the green mass of the raw material) could be considered. Nevertheless, for a complete explanation, a complex set of assumptions should be established on the dynamics of the composition of the multiphase fluid (vapor–liquid) on the way from the bottom to the top of the distillation vessel (just before the condenser). Even so, Darcy's law explains the phenomena. The greater the pressure difference ($\Delta\rho$) and the greater the permeability (k), the greater the flow through the porous medium (q), since the viscosity of the fluid (vapor, μ) and the length (L) of the vessel are constant in that case.

$$q = -\frac{k}{\mu L}\Delta\rho \quad (1)$$

Thus, in this paper, we summarized the research in a portal of patents. We aimed to search for patent documents on the steam distillation process applied to EO extraction in order to evaluate indicators that could be used to assess technological scenarios of the process. In addition, possible technological updates applied to the EO extraction process are also evaluated to identify advances in the area that could promote improvements in yield and quality.

2. Materials and Methods

This study was based on the performance of a technological prospection with a focus on patent documents in order to collect information about technological advances in the area of EO extraction by steam distillation. The prospection was conducted on 30 November 2021 using the Derwent World Patents Index (DWPI) database, Thomson Innovation© (Toronto, ON, Canada), licensed by the SENAI CIMATEC University Center (Salvador, Brazil).

Initially, a scope table was constructed (data not shown) containing the different search strategies evaluated and the number of patent documents retrieved. This evaluation included a search for patent documents on technological updates such as digital technologies applicable to the steam distillation method for EO extraction; however, keywords associated with this search did not retrieve any documents. Therefore, a more comprehensive search strategy was chosen, and the retrieved patent documents were analyzed to assess whether any technology related to the application of digital technologies or other types of process controls were identified in its scope. For this search strategy, the keywords used were as follows:

essential oil AND extraction AND steam distillation*

The search was performed in the titles, abstracts, and claim fields of the patent documents, with no restriction on the period of data collection. The graphs were constructed using the GraphPad Prism 9.2 software (San Diego, CA, USA) based on the results collected from the database, and the following indicators were evaluated: year of publication and year of expiration, main applicants, main inventors, main countries (maps obtained directly from DWPI), and main codes of the International Patent Classification (IPC) used in the classification of the document.

3. Results and Discussion

The growing interest in natural extracts to replace synthetic additives has generated an incremental demand in the EO market, mainly due to the potential applications of these substances in different industrial fields [15]. The market growth is due to increasing demand from industries (food and beverage, personal care and cosmetics, and aromatherapy) [7]. Unlike most conventional medicines and drugs, EOs have no major side effects. Therefore, the extraction process used to obtain these products must allow high yields and high quality so that the commercial value of the EOs is maximized. Generally speaking, advantages or disadvantages in the extraction process are commonly linked to extraction yield/extraction time, which are longer or shorter, to reduce the possibility of degradation of the products and to increase the possibilities of bringing so-called alternative methods to an industrial scale [16]. Among the main methods, steam distillation is the most widespread process used for extraction, producing 93% of the world's volume of EOs [10,17]. It should be highlighted that there are different classifications of steam distillation, where their classification is mainly based on the type of contact with the matrix, as presented in Table 1. In addition, Figure 1 presents an overview of the steam distillation process.

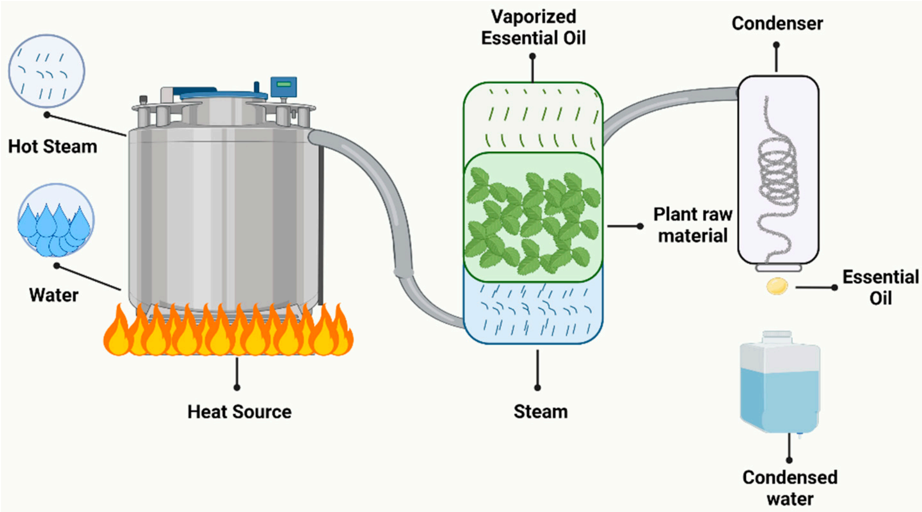

Figure 1. Overview of the steps involved in the steam distillation process. Adapted from Tongnuanchan and Benjakul [20]. Created with BioRender.com (accessed on 22 May 2022).

Table 1. Different classifications of steam distillation.

Classification	General Characteristics	Reference
Dry steam distillation	In dry distillation, steam generated outside the still at moderate pressures is able to pass through the matrix without it coming into direct contact with the water.	[12]
Direct steam distillation	Direct steam distillation does not allow the matrix to have direct contact with water as distillation occurs, with steam generated outside the still. Due to this, its components do not easily undergo thermal degradation.	[18]
Hydrodistillation (water distillation)	In hydrodistillation, EO extraction occurs through solid–liquid interaction, where the matrix comes into direct contact with water. For this reason, it is important to control the conditions of this process when it is employed, since some EO components may undergo hydrolysis	[19]

The patent search for the application of the steam distillation method of EO extraction found 490 documents. Among these, 294 (60%) documents were active, while 187 (~38.16%) documents had expired and another 9 (~1.83%) documents had an undetermined legal status. As presented in Figure 2a, according to the search strategy used, the date of the first published documents was 1997. From this year, it was possible to observe a growth over time in the filing and publication of patent documents related to the application of the steam distillation method of EO extraction, peaking in the year 2020 with 81 publications. In 2021, a reduction in the number of publications could be observed, with 62 publications; however, it is worth noting that after the filing of a patent application there is a secrecy period before publication, the duration of which depends on each patent office. In most countries the patent document is published 18 months after the date of the first filing [21]. Therefore, documents from the last period may not have been retrieved in the patent search.

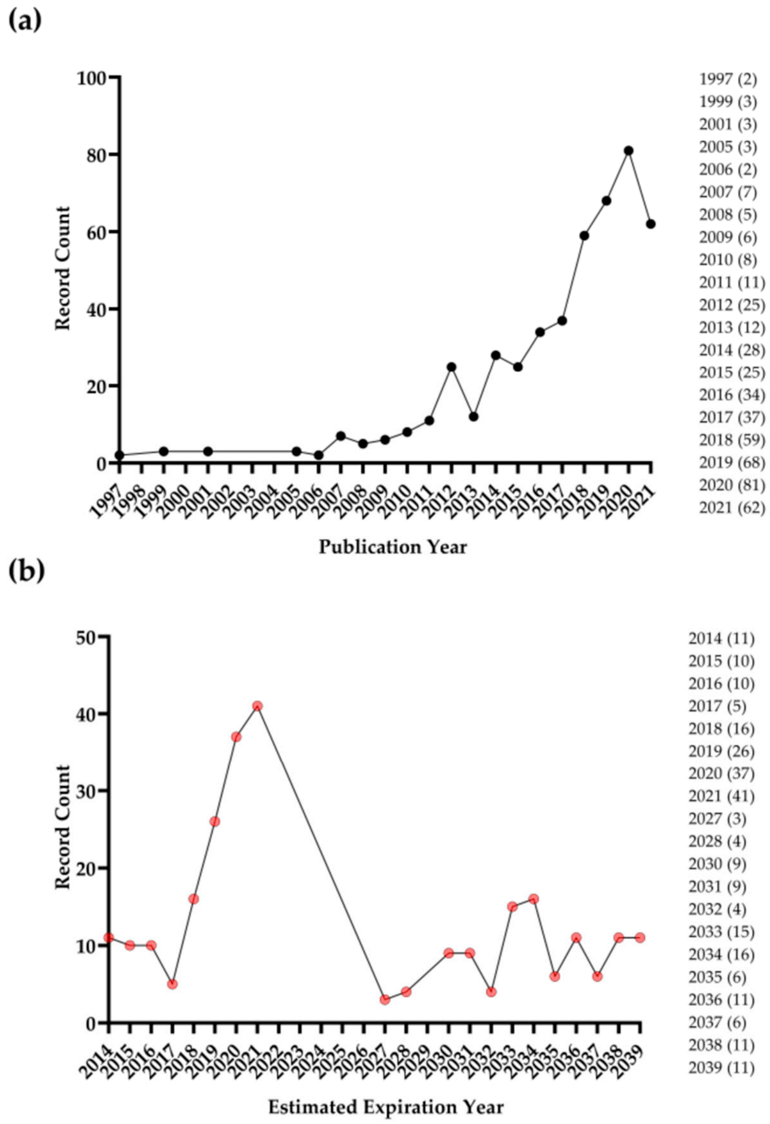

Figure 2. Publication trend of patent documents: (**a**) publication year; (**b**) estimated expiration year.

Patent document expiration (Figure 2b) was another important indicator to analyze, since expiration allows previously protected technologies to be made available in the public domain, providing technical and scientific information about the technologies developed, which could be used by other companies to improve their steam distillation process for EO extraction, or applied to other types of processes. As presented in Figure 2b, in 2021, 41 patent documents expired and their technologies fell into the public domain. This meant that the information contained in these documents could be exploited by researchers and companies for the purpose of extracting some important indicators, such as the value stimulation of the associated products and processes. Furthermore, expired patents could lead to new business opportunities and could be used for the benefit of the public [22].

The analysis of the (ten) main applicants of the identified patent documents (Figure 3) showed that Jiangxi University of Traditional Chinese Medicine (JXUTCM) (Nanchang, China) accounted for the largest number of filed applications, with a total of 12 documents. JXUTCM is a higher education institution under the leadership of the Jiangxi provincial government, which apparently has a strong presence in the prospective technology area. Among the 12 patent documents, 11 patent documents were active and only 1 patent document had expired. The most recently published technologies referred to the application of the extraction process for EO, but focused on the potential evaluation of the oils in relation to their applications as antimicrobial agents, as well as cosmetic and pharmacological (treatment of constipation, depression, and memory loss) uses [23]. Dongguan Huaipu Plant Essential Oil Co., Ltd. (Dongguan, China), which is part of the grain and oilseed milling industry group that operates in food manufacturing sectors, such as oilseed and cereal milling, refining and blending of oils and fats, and the manufacture of cereal-based products [24], was in second place with eight patent documents. The Institute of Medicinal Plant Development (IMPLAD) (Beijing, China) affiliated with the Chinese Academy of Medical Sciences (CAMS) was in third place with six documents; IMPLAD is the only national public service research institution specializing in the protection, development, and utilization of medicinal plant resources, and is recognized worldwide in this area of research, leading investigations on Chinese herbs [25].

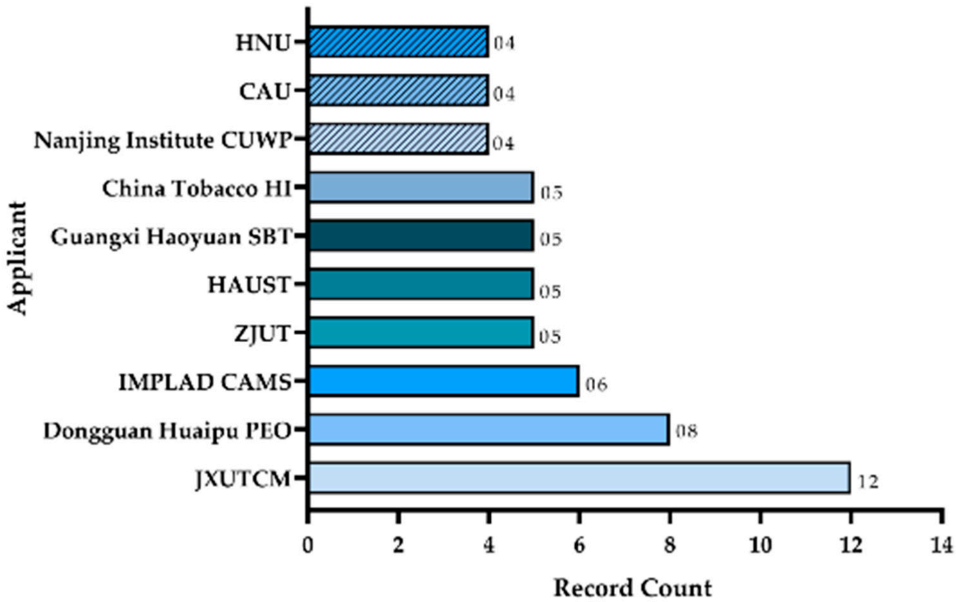

Figure 3. Main applicants of patent documents.

In addition to the first, second, and third place applicants, the other main applicants of patent documents were from China, which is one of the leading producers of EO worldwide. China is a developed country with rapid industrialization, which is one of the reasons it stands out in this market [26], placing it as an important player in the EO market and in the scope of using steam distillation processes. Highlights of the technological prospection of patents included the following: EO producing companies participated in patent applications involving steam distillation, universities and research institutes had an important role as applicants of patent documents, academic authors were involved in patent documents, and Chinese inventors were predominant in this sector (Figure 4). Universities and research institutes have important roles in disseminating scientific knowledge to society, as well as supplying scientific and technological knowledge to the production sector through the promotion of innovation [27,28]. The advances in technological innovation associated with the relationships among universities/research institutes with companies/industries and the transfer of technology between them and the production sector contributes to the process of patent filing [29,30].

The relevance of China in the world scenario in terms of being an applicant country, as well as a potential market for the application of the inventions, can be observed in Figure 5. Figure 5a presents the main applicants of the prospected technologies, where China can be highlighted with the publication of most documents (402), followed by South Korea (23), and Japan (12). The Asia-Pacific region is predicted to grow at a compound annual growth rate (CAGR) of 8.4% in the EO market by the year 2028; there are favorable characteristics in this region that support this growth, such as good climatic conditions for agriculture, bioavailability of raw materials, and low-cost labor. Moreover, increased consumer preference for healthy food and beverages is important, especially in China, since it can present important profitable opportunities for the country, as well as for the Asia-Pacific market [7]. Overall, the global EO market is expected to grow at a CAGR of 7.4% in terms of revenue, driven by the high demand for these raw materials, primarily, for applications in the food and cosmetics industries, and for the production of aromatherapy products. In addition, applications in the pharmaceutical industry are also expanding due to the search for drugs with less adverse effects, a characteristic associated with natural products [7].

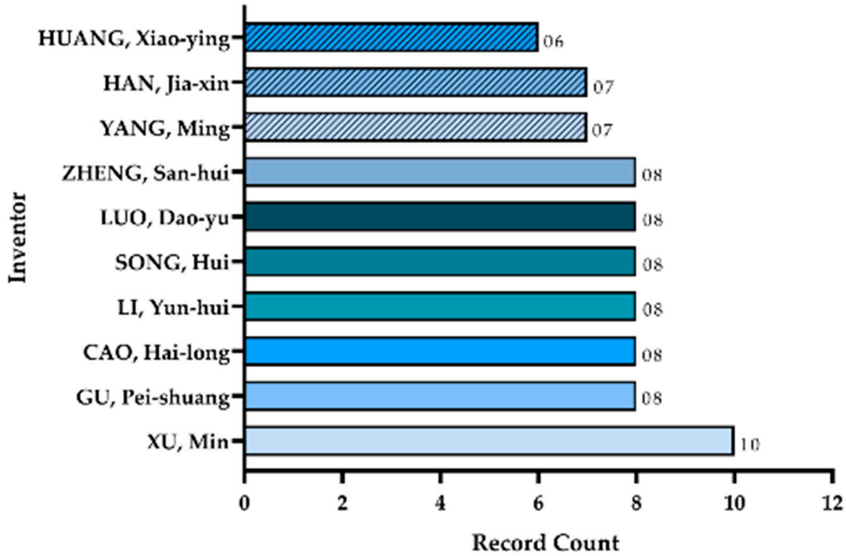

Figure 4. Main inventors of the technologies found in the patent documents.

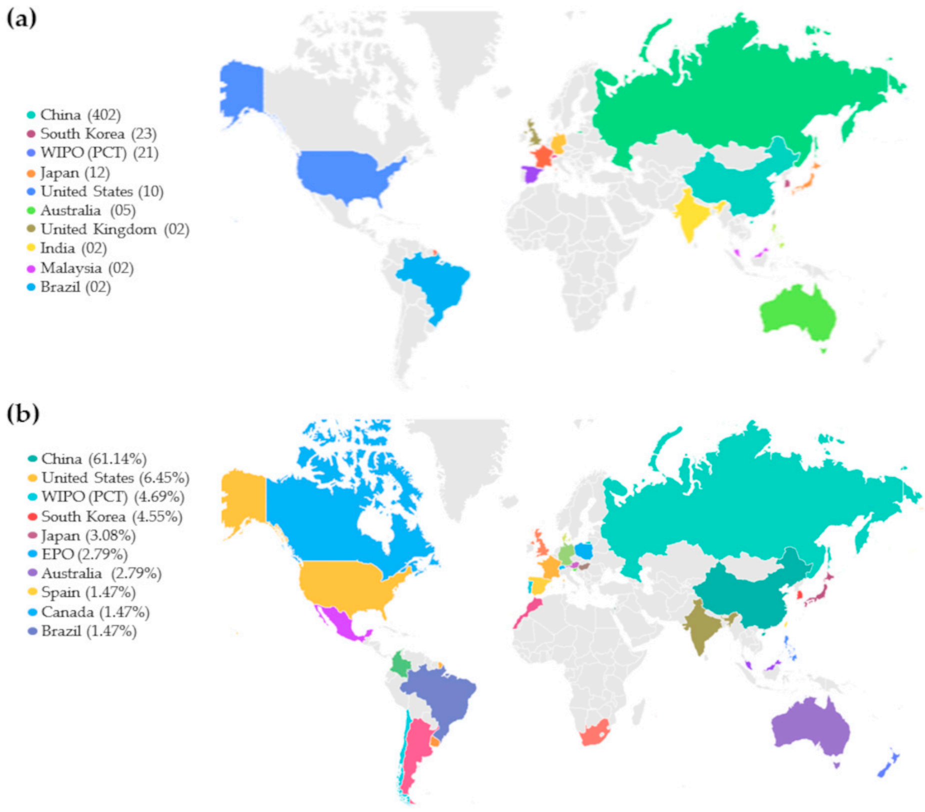

Figure 5. Geographical distribution of (**a**) patent document applicant countries and (**b**) potential markets for inventions. WIPO, World Intellectual Property Organization; EPO, European Patent Office.

Regarding the market analysis of steam distillation systems, the market was valued at USD 5.94 billion in 2017, with CAGR growth projections of 5.1% by the year 2023. The use of steam distillation, in addition to the extraction of EOs, spans a range of industrial segments, such as petroleum and biorefineries, food, chemical, pharmaceutical, and cosmetics. Likewise, the Asia-Pacific market is showing a high growth rate in the incorporation of distillation systems in its processes, presenting itself as an emerging market with fast growth rates. According to market analyses, countries such as China, India, South Korea, Australia, and Japan are among the main production centers in the region [31]. India and Australia were also identified (Figure 5a) as countries using the steam distillation process applied to EO extraction, with two and five patent documents, respectively. It was also important to highlight the presence of the United States in the technological prospection, with ten patent documents, as well as Brazil, with two patent documents. However, the patent documents from these countries were focused on the pharmaceutical composition of the essential oils (US20050244522A1, BR102015005040A2) [32,33], as well as proposed process modifications that included the use of additional solvents (US6450935B1) [34] or surfactants (US5891501A) [35], with no mention of the use of new technological updates. Other countries were also identified, however, with a less expressive number of patents, such as South Africa, Denmark, Spain, France, Israel, Iran, New Zealand, Philippines, Portugal, Russia, and Taiwan, each accounting for one to two applications.

Figure 5b presents the potential markets for the inventions prospected, where the technologies were protected and there were open markets to absorb them. According to the results, China had the highest percentage (61.14%), characterizing it as the main market for protection of the technologies and highlighting it as the main depositor of patent applications, followed by the United States, which was characterized by 6.45%. South Korea (4.55%) and Japan (3.08%), despite being highlighted as second and third among the top depositors of patent applications (Figure 5a), in terms of open markets for the technologies, lagged behind the United States. In both maps, it is possible to identify the World Intellectual Property Organization (WIPO). Through the WIPO, it was possible to realize the international application of patent applications when protection was sought in more than one country, through the Patent Cooperation Treaty (PCT) [36]. Thus, the results indicated that 21 patent documents were filed via PCT (Figure 5a), in which the technologies involved were protected in more than one country, characterized by 4.69% (Figure 5b). In addition to WIPO, another organization appears in Figure 5b with a 2.79% share of the open market, the European Patent Office (EPO). The filing of patent applications via the EPO occurred when an applicant sought to protect its technology from the European Union [37].

The analysis of the result set from the DWPI database showed that 37% of the worldwide filings were granted, which indicated protection for active (alive) patents in the relevant markets and that 63% were pending applications. A higher percentage of applications pointed to a new or growing market, whereas lower application rates pointed to already-established markets or low growth areas. Thus, it was possible to affirm the wide use of the steam distillation process for EO extraction and that the market for the development of associated technologies was still growing.

The analysis of the patent documents showed the codes assigned to the documents according to the International Patent Classification (IPC), as shown in Figure 6. This classification was established by the WIPO and is used to classify patents and utility models according to the technological areas to which they belong [38]. It could be observed that the most used code was CB11 9/02, which was attributed to 173 patent documents. In addition to this, other codes were identified in the technological prospection, which are described in Table 2. Through the classification, it was possible to identify that the patent documents were concentrated in the macro-areas of human necessities (A), chemistry (B), and metallurgy (C), with a greater number of documents belonging to area A. It was important to note that the same document could receive more than one classification.

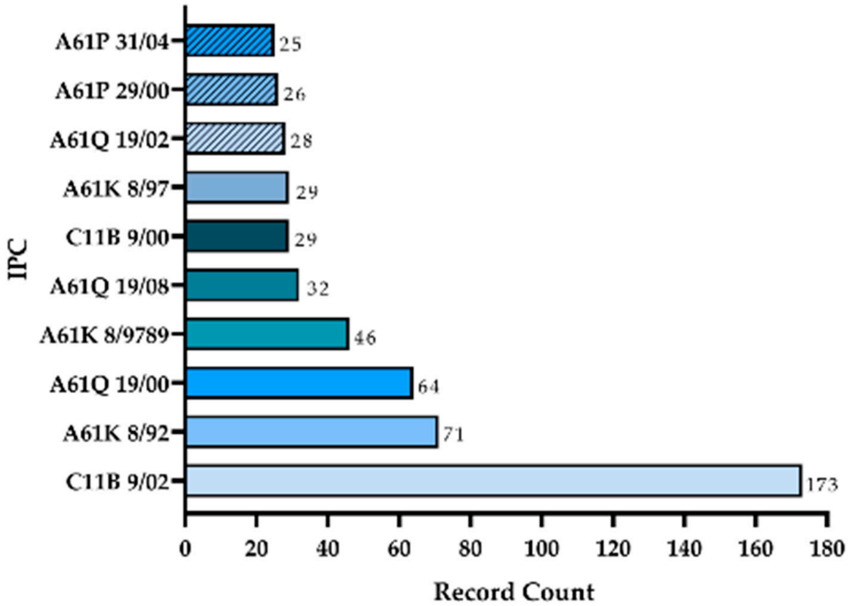

Figure 6. Main IPCs used in the classification of patent documents.

Table 2. Description of the IPCs used in the classification of the technological areas of the patent documents.

Item	IPC Code	Definition
1	A61P 31/04	Medical or veterinary science; hygiene, specific therapeutic activity of chemical compounds or medicinal preparations; anti-infectives, i.e., antibiotics, antiseptics, chemotherapeutics—antibacterial agents.
2	A61P 29/00	Medical or veterinary science; hygiene, specific therapeutic activity of chemical compounds or medicinal preparations—noncentral analgesic, antipyretic or anti-inflammatory agents, e.g., antirheumatic agents; non-steroidal anti-inflammatory drugs (NSAIDs).
3	A61Q 19/02	Medical or veterinary science; hygiene, specific use of cosmetics or similar toilet preparations—preparations for care of the skin.
4	A61K 8/97	Medical or veterinary science; hygiene, preparations for medical, dental, or toilet purposes—from algae, fungi, lichens, or plants and from derivatives thereof.
5	C11B 9/00	Animal or vegetable oils, fats, fatty substances, or waxes and fatty acids from these substances; detergents; candle production, e.g., by pressing raw materials or by extraction from waste materials, refining or preserving fats, fatty substances, e.g., lanolin, fatty oils, or waxes; essential oils; perfumes—essential oils and perfumes.
6	A61Q 19/08	Medical or veterinary science; hygiene, specific use of cosmetics or similar toilet preparations, preparations for care of the skin—anti-ageing preparations.
7	A61K 8/9789	Medical or veterinary science; hygiene, preparations for medical, dental, or toilet purposes, cosmetics or similar toilet preparations—magnoliopsida [dicotyledons].
8	A61Q 19/00	Medical or veterinary science; hygiene, specific use of cosmetics or similar toilet preparations—preparations for care of the skin.
9	A61K 8/92	Medical or veterinary science; hygiene, preparations for medical, dental, or toilet purposes, cosmetics or similar toilet preparations—oils, fats, or waxes and derivatives thereof, e.g., hydrogenation products.
10	C11B 9/02	Animal or vegetable oils, fats, fatty substances, or waxes and fatty acids there from; detergents; candle production, e.g., by pressing raw materials or by extraction from waste materials, refining or preserving fats, fatty substances, e.g., lanolin, fatty oils, or waxes; essential oils; perfumes for essential oils; perfumes—recovery or refining of essential oils from raw materials.

As part of this research, all documents were analyzed to investigate the application of technological updates applied to the steam distillation method with a focus on the optimization of the extraction process. Table 3 presents the results of the analysis divided into 12 subgroups. Despite China being the country with the highest number of patents (Figure 5a), globally the massive majority of patents did not access the technological possibilities investigated in this research. The majority of documents (320) were related to health care and cosmetic areas, followed by those covering raw material preparation and EO post-treatment specifics (33 documents), use of other extraction methods in conjunction with steam distillation (29), mechanically improved flow and flow optimization (27), multipurpose steam distillation with solvents and/or ultrasonic pretreatment (25), those with a focus on the raw material itself (20), the use of other media for supercritical CO_2 or subcritical water (12), and others (14). In fact, Subgroup 4 was the only subgroup presenting some patents regarding process improvements aimed at yield and quality enhancement based on mechanical improvements, steam flow optimization, and proposed extraction procedures. However, as an example of the application of digital technology to detect and correct channeling (even those about steam flow optimization did not mention channeling) and to determine the optimum process duration, none of these works were related. Some patent documents with technological ideas, from Subgroup 4, are shown in Table 4.

Table 3. Analysis of the patent documents to evaluate the documents that applied technological updates to the process.

Item	Classification	Number of Documents
1	Human and animal healthcare; cosmetics; repellent; taste improvement; disinfectant; sterilizing agent; acaricide; skin and acne care; tobacco flavoring; beverage additive; air freshener; food preservative; laundry fragrance.	320
2	Raw material preparation and product post treatment (membrane; purification; fractioning; ultrasound; fermentation; concentration; mechanical expression).	33
3	Extraction with organic solvents; use of surfactants; vacuum; salt solution.	29
4	Mechanically improved distiller; flow improvement; optimized procedures.	27
5	Multipurpose steam distillation with solvents or ultrasonic pretreatment.	25
6	Focus on raw materials (for example, pistachio; mandarin; garlic; green tea; oak bark; passion fruit; cinnamon; lavender; cardamomum; angelica; camphor).	20
7	Supercritical state CO_2 and subcritical state water.	12
8	Focus on hydrosol and fragrant water.	5
9	Others were as follows: paper additive; fire retardant; air cleaner (bactericide); fuel additive; natural colorant; fertilizer; silicon rubber additive.	14
10	Microbial contact to improve yield.	2
11	Dry extract.	1
12	Steam pressure control.	1
13	Analytical method.	1

Table 4. Example of patent documents that applied the technological update to the process.

Publication Number	Applicant	Inventor	Description	Overview (Strengths and Weaknesses Analysis)
CN113150873A	Fujian Agriculture and Forestry University Fujian Tianwu Forestry Development Co., Ltd. (Fuzhou, China) Quanzhou Mingdao Agriculture and Forestry Development Co., Ltd. (Quanzhou, China)	Ding, L. Li, Y. Lin, M. Ni, L. Wu, Q. Xu, H. Zhang, X. Zou, S.	This patent consists of a split body distillation vessel to ease the loading and unloading operation. The steam outlet, just before the condensation process, was designed to allow a smooth flow [39].	The strength of this mechanical proposition lies in the practicality and time reduction of its loading and unloading operations. It also makes the cleaning between batches easier.
CN113073008A	Zhangzhou Institute of Technology (Zhengzhou, China)	Gao, Z. Huang, Y. Pang, J. Wu, Z. Xie, J. Zhang, G. Zheng, J.	This patent consists of a multilayer plate distillation vessel. These plates are rotated by an electrical driver aiming at avoiding the contact among the passion fruit peels, which decreases the contact with steam [40].	The relative movement among the layers allow the steam flow to more efficiently contact the passion fruit peels. This mechanical improvement presents the potential to increase yield and reduce extraction time. Nevertheless, the controlling actions from a properly programmed process computer would improve this endeavor.
CN112029589A	Yingkou Chenguang Plant Extraction Equipment Co., Ltd. (Yingkou, China)	Han, S. Hu, B. Kong, W. Li, H. Liu, F.	This patent consists of a horizontal fresh-flower extractor with a belt conveyor that claims to be a continuous extraction system. It moves the raw material inside the distiller [41].	A continuous system, applied to fresh flowers. It is an interesting way of controlling the residence time inside that main equipment. Basic controllers such as timers and position switches should be part of the invention. However, the main command from a process control computer could be helpful in this system.
CN108517258A	Yingkou Chenguang Plant Extraction Equipment Co., Ltd. (Yingkou, China)	Fan, Z. Han, S. Kong, W. Li, Y. Liu, F. Yang, Z. Zhang, Y.	This patent is a continuous distillation system for woody material with several plates for raw material accommodation [42].	Specifically for wood material extraction, this idea brings interesting propositions for exposing the raw material to the steam flow. It is, nevertheless, a mechanically improved system without mentioning process control attributes.
CN106833901A	Request by inventor	Ji, W.	This patent consists of a rolling hydro-distillation extraction device, where the sandalwood plant material is fed and during the process alternates between immersed in the water and exposed to steam, with the aim of improving yield [43].	The idea of a rotating distillation vessel brings a new geometry to the conventional process. It is, nevertheless, a mechanical change. The application of digital smart technologies is not mentioned.

Table 4. *Cont.*

Publication Number	Applicant	Inventor	Description	Overview (Strengths and Weaknesses Analysis)
CN105925377A	Mo, Z.	Liang, H.	This patent brings an extraction device for agarwood EO, with rotating perforated plates to extract via steam distillation and compression between the plates [44].	As this idea is designed to extract essential oil from agarwood, the mechanical improvement of the pressing device is interesting. The liquid from this pressing is hot and eases the EO extraction. The equipment is mechanically improved and dedicated to wood extraction.
CN214115463U	Hubei Weilaijiayuan High-Tech Agriculture Co., Ltd. (Wuhan, China)	Ge, B. Liu, P. Lu, D. Yin, W. Yin, Y. Zhang, M.	This patent is a utility model. It consists of a distillation device composed of two layers. Its claims are related to improving productivity and reducing process time by obtaining both the light fractions, from the upper part of the device, and the heavier fractions from the bottom part. Both extractions are mixed to deliver the whole essential oil [45].	Even though this system pursues higher yields and, as a consequence of reduced time, better quality, it consists of a mechanically changed distillation vessel. This means that technological control elements were not applied by the author.
CN212152220U	Zhejiang Jinghui Cosmetics Co., Ltd. (Yiwu, China)	Jin, J.	This patent is a utility model. It claims to have performance improvements with the use of compressed air to clean the holes in the perforated plate where the steam passes [46].	This is an interesting idea where the full passage of steam, provided by compressed air blowing the herb, indeed improves the extraction efficiency. Despite the possibility of undesired effects, such as oxidation of the plant material (to be proven by analysis), the proposition, if it would be properly commanded by process controllers, moves the raw material within the distillation vessel and fixes the channeling effects.

This investigation about the application of technological updates was motivated by the development of a research project involving the application of a technological update to the steam distillation process for EO extraction developed by the authors of this paper, i.e., the creation of a proposal for the optimization of EO extraction processes by steam distillation based on intelligent digital technologies. Given the publication and market indicators found, it was possible to understand the market importance of this technology and its application in different sectors. Thus, in order to deal with existing variations in production systems, such as variations in the extraction cycle, uncertainties of material and energy yield, and undesired operational occurrences that were not detected, and therefore not corrected, the development of research that seeks solutions to contribute to the reduction of these problems is important for the process of innovation and contribution to market growth [47].

Based on pilot-scale experiments of EO extraction by steam distillation, previous results have shown consistent improvements in material and energy yields, in addition to an extraordinary positive impact on productivity. The study proposals highlight the relevance of technological improvements such as condensation control, the determination of the optimum points for process duration, detection, and correction of preferred steam paths, and the continuous search for optimized process parameters. In this way, the development of new process improvements could be applied in the industry and contribute to all aspects of technology management, such as safety, quality, reliability, repeatability, traceability, as well as environmental and market effects [48,49].

4. Conclusions

This technological prospection with a focus on patent documents highlighted the important growth in the development of inventions based on the use of the steam distillation process for EO extraction, as well as the interesting increase in market-related percentages that places China as the main developing country and open market for the technologies. The results also indicated the main sectors in which the technologies were applied, demonstrating the versatility of use, as well as the widespread use of EO in different areas. In terms of technological updates to the process, the objectives were higher yields, quality improvement, and cost reduction as key factors in the industry overall. The essential oil segment is no exception. Steam distillation extraction is the most used method worldwide and lacks the use of state-of-the-art technology. This work on the EO production process demonstrated an important gap to be filled by the addition of intelligent technologies and process control, with the application of recent technology developments. There were key opportunities, first, in the detection and correction of preferred steam paths (channeling) and, second, in the de-termination of the optimum time to finish the process, both with quantitative and qualitative impacts and cost reductions. The first allowed the steam to have a homogeneous distribution, maximizing the yield and preventing raw material deterioration in these channels. Channeling could be detected by conventional thermocouples, however, it was installed without the wells, that is, inserted directly into the green mass to reduce the temperature data transmission time. The channeling correction was performed by an actuator, such as a stepper motor, and a system of paddles to re-accommodate the raw material inside the distillation vessel. The latter, shortened the extraction time applying, for example, an image processing system that detected the essential oil column and stopped the process once it had stabilized. The exact extraction endpoint contributed to optimizing costs; maximizing material yield, since the loss of volatiles was minimized; and avoided deterioration due to excessive exposure to steam temperature. These modifications would help the continuity of the consolidation of this process and its use in the world market, considering that the improvements promoted would enhance the process yield and the quality of the product obtained.

This research might present limitations similar to those of any other that is based on patent analysis, often related to the search strategy, which limited the results to documents related to the selected keywords. However, it is important to emphasize that the proposed analysis allowed the presentation and discussion in a cohesive and robust manner regarding the extraction of EO through steam distillation, exposing, especially, the challenges of this sector. Further research is needed to contribute to the clarifications within this area.

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