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The Preservation and Development of Fragrance Retention Technology

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Abstract. Since fragrance retention technology plays an important role in customer satisfaction and market competitiveness, the science and industry have increasingly focused on it in recent years. Olfactory perception has a significant impact on consumers' purchasing decision compared with other senses, packaging and appearance. However, the volatility of the fragrance molecule is inherent, and the skin has a protective film. In addition, textiles are often washed, which hinders the lasting scent effect. In this paper, we study the physicochemical basis, technology and strategy, and sustainable development of fragrance retention technology in sequence. The physicochemical mechanism of the relationship between the molecular property and property is explored by using the Quantitative Structure–Property Relationship (QSAR) analysis. The result can give some instructions for the molecular design, and it shows how the molecular structure can significantly influence the retention performance with a slight modification. For the problem of volatility, the advanced delivery system of microencapsulation technology is studied in detail. With the rapid development of advanced technology, new advanced carriers are synthesized by interfacial ethylene polymerization, and bio-derived materials such as chitosan have been reported. The stimuli-response release can prolong the fragrance persistence from several hours to days or weeks. The result shows that there is a clear relationship between molecular structure and retention efficiency, and it reflects an increasing market demand for extending fragrance persistence and product personalization. In the future, the development of fragrance technology lies in green chemical synthesis and bio-based materials. That is to say, ecological environment should be considered in the development of technology.

Keywords: Fragrance, Retention, Fragrance molecules

1. Introduction

Fragrance molecules are small organic compounds. They are mostly released depending on their physicochemical properties such as molecular weight, polarity, boiling point and some functional groups. They belong to volatile organic compounds (VOCs) with low molecular weight and low boiling point, and the molecular weight and boiling point determine the vapor pressure of the molecule. They are easily evaporated and decomposed when exposed to heat, humidity and light [1].

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Due to the above physicochemical characteristics, the control of release under different environmental conditions is a technically challenging issue in the fragrance and cosmetic industry, which is important for the product and customer. Now, the ways to control the release are polymer microcapsules and nanocapsules, cyclodextrin complex, porous carrier, and composite structure.

Polymer microcapsules and nanocapsules are typically synthesized by interfacial polycondensation or spray drying; they can retain fragrance molecules and release them gradually [1]. Cyclodextrin complexes can shield fragrance molecules by enhancing their thermal stability and water solubility. Porous carriers and composites such as silica, zeolite, and activated carbon can control the release through physical adsorption. Smart release systems can release fragrance molecules in response to certain triggers such as temperature, humidity, pH, or light. These systems have great prospects in fields such as textiles and cosmetics [2-5].

Although research has made some progress, there are still many obvious gaps. Most of the research only focuses on the short-term retention or investigates only one type of carrier. There is little comparison of how the fragrances behave in different environments such as skin, fabrics, or air. The safety of green and biodegradable carriers is also not well investigated. Especially, there is no clear study on their toxicity and biodegradability, which limits the wide application of these carriers in modern sustainable industries. Moreover, smart release systems are not yet well integrated into real market needs, and there are few studies on the application of laboratory results to industrial-scale fragrance technology.

This study will explain the physicochemical mechanism of fragrance release. Furthermore, we will evaluate current controlled release strategies and compare their performance. In addition, we will promote the construction of more sustainable fragrance technologies by highlighting the potential of green and stimuli- responsive systems

2. Presentation of key findings

The retention of fragrance are key factor of the user experience and the consumer market. Previous research confirmed that the smell significantly affects consumers' choices and consumption decisions [6,7]. Quantitative analysis demonstrates that two synergistic technical pathways: molecular structure optimization and advanced delivery systems extend retention rate and performance.

2.1. Foundational pillars of longevity: molecular design and controlled delivery

There are two major technologies currently improve scent retention on substrates such as skin and fabric.

2.1.1. Molecular optimization and physicochemical analysis

The inherent durability of fragrance compounds is mainly decided by their physical and chemical properties, including molecular weight, lipophilicity, and volatility. Predicting and optimizing the retention behavior of flavoring molecules and providing a powerful framework for that are depended on Quantitative Structure–Property Relationship (QSAR) analysis [8]. A detailed understanding of absorption and diffusion dynamics across the skin are the basic scientific design of extending retention time. The rate and extent of fragrance absorption are predicted through kinetic modeling of skin retention and diffusion. Then the result of it will be used for guiding molecular optimizing to improved stability and performance [9].

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2.1.2. Microencapsulation technology

Microencapsulation technology represents a significant technical breakthrough in fragrance retention. The presence of it helps the duration of flavoring molecule from a matter of hours to several days and even weeks. In this method fragrance oils compounds are encapsulated in a protective polymer shell, such as those created via interfacial thiol-Ene polymerization [10] or using bio-friendly materials like chitosan [11]. The core mechanism is a delayed, triggered release, which is often initiated by friction, humidity, or a change in pH. This prevents the scent molecules from rapid evaporation.

Successful application of microcapsules has appeared such as functional textiles. This application significantly provides sustainable release that is much better than direct application [12].

Technology	Core Principle	Mechanism of Action	Estimated Retention Time (on fabric/skin)	Primary Application Focus
Traditional Fragrance Layering	Differential Volatility/Molecular Weight	Sequential evaporation (Top, Middle, Base)	1–12 hours	Fine Fragrance (Skin)
Molecular Structure Optimization (QSAR)	Tuning logP and MW	Reduced volatility and optimized skin/substrate absorption	4–8 hours	Fine Fragrance Formulation
Polymeric Microencapsulation	Core-shell encapsulation	Delayed/Triggered release (e.g., friction, moisture)	24–168+ hours	Textiles, Functional Fabric, Skin Patches

Figure 1. Comparative analysis of fragrance retention technologies

2.2. Market impact and future trends

Looking back to previous researches of market competitiveness. It is significantly and positively impacted by the retention rate of fragrance molecules. While in real life situations, case studies focusing on symbolic interaction can suitably indicates consumer perception of fragrance is similar as that case, an enhanced self-expression and ritual is brought by appearance of a durable fragrance [13].

Looking ahead, the industry is increasingly driven by the material innovation, market trends, and sustainable practices. This includes the development of new materials in specialized situation like functional cloth [14] and the application of green chemical synthesis [15]. These all significantly shows the industry's development direction in seeking a balance between retention time and ecological responsibility.

3. Discussion

This section analyzes and compares the main research results with previous studies and discusses their broader implications.

3.1. Summary of key findings

This study delves into the basic scientific principles and technological means for fragrance retention and puts forth three findings.

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It is first important to use the molecular structure to control persistence. Molecular size alters so that aromas' volatility rates equal their emission rates, and we get the base to last [16,17]

Second, microencapsulation technique (polymer-, chitosan- based carrier) is a breakthrough for prolonging fragrance retention. if we protected active compounds from environmental interference we would get much better results on fabric and skin [17,18].

Finally the top note, mid note, base note. Different levels of what the molecule could volatilize with time creates the different structure the way the fragrance is getting out [19,20].

All of these results together tell us that the way molecules are arranged, and how they're put into a substance and how easy they are to move out of it is super important for how long the smell lasts.

3.2. Comparison with previous studies

Before the work mostly relies on the use of natural essential oils and solvents, which although have a fragrance, they are unstable and fleeting [21,22]. It is recently discovered that micro-encapsulation with solid carrier can make a huge difference when it comes to extending the lifetime and stables of molecules trapped in places like porous textiles and fatty skin [17,21,23]. Works about perfume have mainly targeted the environment, the consumer uses, this work focuses more on the environment and consumer safety.

In this study the comparison is continued, refined and added technical and experiment conditions, environments as follows.

From a technical perspective: traditional method (essential oil+solvent) is affected by instability (sensitive to heat and humidity) short duration (<4h), and poor environmental compatibility (petrochemical solvents) [21,22]. In contrast, encapsulation and solid carriers could achieve higher retention more than 60 % in complicated situation [24], longer duration about 8-24 hours, and better eco-profiles (natural carriers>50%) [25] with slight increase in cost [17,21,23].

Under experimental conditions: Previous works often test in single environment and did not control variable factors such as temperature and humidity. This work has shown that there is a difference in fragrance retention between skin and fabric which is as high as 30%. It also calls for the establishment of standardized experimental conditions [26].

Technology Type	Stability (Retention)/%	Cost	Safety (Skin Irritation)	Environmental Performance
Essential oils + Solvent	<40	Low	Medium (some allergens)	Poor (petrochemical solvents)
Microencapsulation	60–80	Medium	Low (biocompatible)	Excellent (natural carriers dominant)
Solid carrier adsorption	50–70	Medium-Low	Medium (residue risk)	Moderate (partly petrochemical)

Figure 2. Comparative performance of different fragrance delivery technologies [24,25,27]

3.3. Implications of the findings

The findings not only improve the competitiveness of the fragrance in consumer products [9,10], but also opens a new window for sustainable innovation. From the view of materials chemistry, the relationship between carrier structure (molecular size) and release rate could offer the theoretical support for the rational design of functional delivery system [18]. From the view of fragrance

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chemistry, this work helps to better understand the molecular volatility and fragrance olfactory layering, and clarifies the mechanism of "dynamic release–sensory experience" [19].

From the perspective of sustainability, the use of natural and biodegradable carriers could support global carbon-reduction actions and drive the green transition of the daily chemical industry [10]. On the industrial level, the findings could support the dual optimization of performance and regulation. For example, the detergent with microencapsulation could keep the fragrance on the clothes for more than twelve hours, and meet the EU biodegradability regulation [9,28]. In addition, the natural polymer-based capsule could also show both biocompatibility and biodegradability [10,18]. Its use could support the scientific development of sustainable materials and personalized fragrance, and help the industry move toward more intelligent and environment-friendly directions [28,29].

3.4. Limitations of the study

Although the present work has achieved certain progress, the following issues still need to be further explored:

1. Application scenarios: Data are insufficient regarding long-term (more than 72 hours) skin absorption and safety (e.g., allergenic risks under repeated exposure) [11,30].
2. Implementation bottlenecks: In fabric applications [19], wash resistance after ten washing cycles or more and precise release control remain difficult to optimize simultaneously.

Furthermore, large-scale production has not yet demonstrated the cost advantage of natural carriers, which constrains the widespread adoption of green materials [7,12,18].

3.5. Suggestions for future research

Future research should prioritize the integration of nanotechnology with smart polymers to achieve precise, on-demand fragrance release in diverse environmental contexts. Over- all, a multidisciplinary approach combining material science, green chemistry, and sensory analysis will be essential for advancing this field.

4. Conclusion

In this study, the molecular, physicochemical, and technological behaviors of retaining and releasing fragrance molecules were thoroughly explored. It was demonstrated that molecular optimization (i.e. M W and lipohility variations) could modulate the corresponding volatilities and persistences and thus provide the theoretical basis for the synthesis of long-lasting molecular fragrances. Furthermore, the coupling of microencapsulation and bio-based carriers could realize on-demand, prolonged, and stimuli-responsive release, which could markedly improve the corresponding scents on skin and textile substrates. The molecular structure and volatility gradient as well as the olfactory layering could be considered as the technological basis for the performance of the corresponding fragrances. Thanks for the technological shift from conventional solvent application to advanced encapsulation and adsorptions. Compare with previous reports, their changes are highly evident. The new strategies can not only improve the related stabilities and the scents that remain but also contribute to the principles of environmental sustainability and consumers. Experimental results also show considerable differences in scents between applications. Therefore, for the future of this, setting up unified testing scenarios and more comprehensive evaluation procedures matters a lot. Moreover, there is a significant trend in both industry and research. The technological applications

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will get more accessible as more efforts are dedicated on balancing function and eco-friendly material designs. In the future, nanostructured materials, quick-witted polymers, and computational molecule design were used on relevant technological platforms. At that time, successes in advanced fragrance technologies might be realised. The corresponding release kinetics and enhanced scalability in industrial applications can controlled by the cross-field studies. Meanwhile, the long-term safety and environmental influence of the corresponding biodegradable carriers are still considerably needed for invest greater efforts on it. Material innovation is depended by satisfying a higher goal in efficiency and environment sustainability. So, it can only be integrated with the market-focused agreements when they reach these needs. And finally, advanced fragrance delivery systems can get realized.

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All the authors contributed equally and their names were listed in alphabetical order.

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