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Review Article

Heat Sensitive Magic: Unveiling Thermochromic Substances in Pharmacy

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ABSTRACT

Thermochromic substances are materials that change it's colour when there is change in external stimuli like temperature or excessive heat1, this unique property can be used for transport and packaging of pharmaceuticals2 . Thermochromic substances are type of chromogenic materials1 , This system can be used for temperature sensitive drugs and pharmaceutical materials that need suitable environmental conditions for storage and transport6, In pharmaceutical market use of this materials are increasing as it can be cost effective to use and easily detectable, this review focuses on Introduction of Thermochromic substances it's system, pharmaceutical growth of this substances, Applications in varies field, future trends and challenges in pharmaceuticals market14.

INTRODUCTION

1.1 Chromogenic Materials:

Chromogenic materials are the materials that undergone changes in there molecular structure, appearance, colour, bonding as well as optical activities when external stimuli apply to them1

They classified based on their response to external stimuli:

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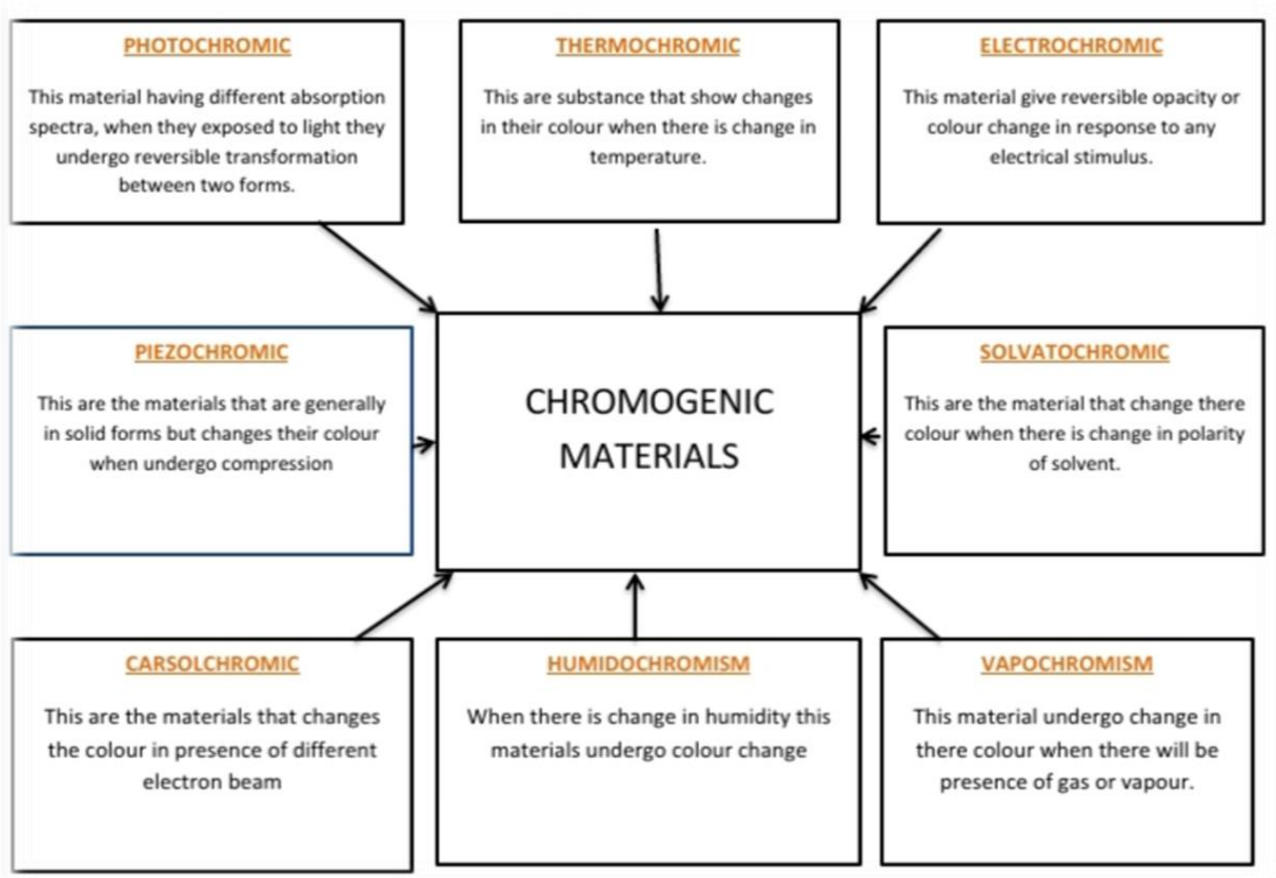


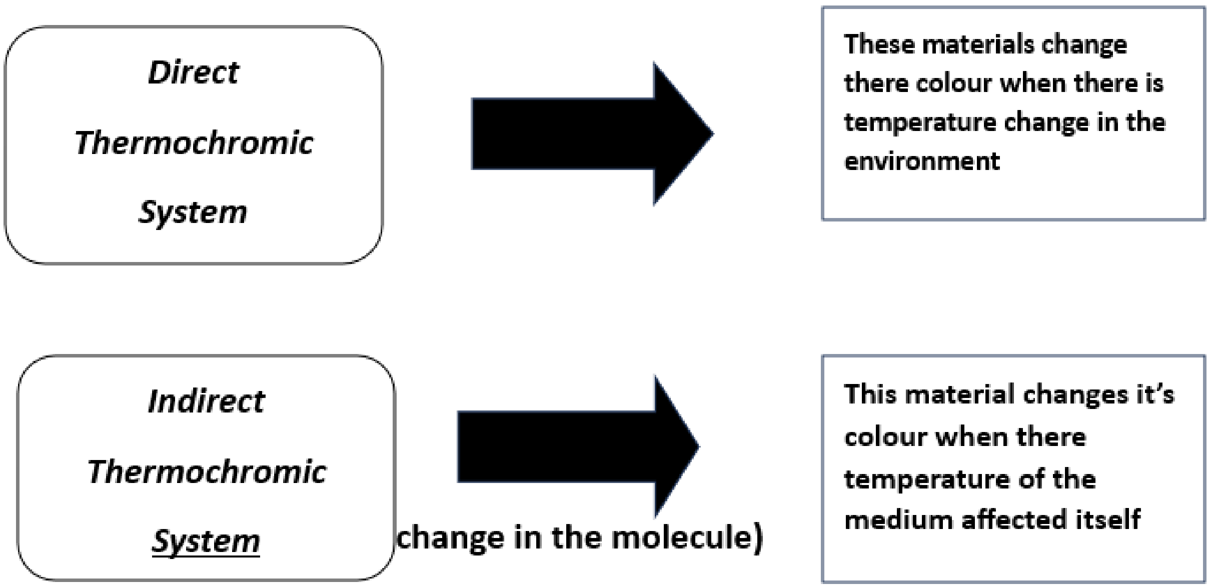
Fig:1.1) Types of Thermochromic Substances.

- Photochromic materials: These are the materials Having different absorption spectra when they exposed to light they undergone reversible transformation [2]
- Thermochromic materials: These are the substances that show changes in colours when there is fluctuations in temperature [1]
- Electrochromic materials: These are the materials that give reversible opacity or colour change in response to any electrical stimulus [3]
- Solvatochromic materials: These are the materials that change there colour when there is change in polarity of solvent [1]
- Halochromic materials: This materials undergo change in colours when there will be presence of gas or vapour [2]
- Humid chromic materials: When there will be change in the humidity this material undergo colour changes [1]
- Carsolchromic materials: This materials changes its colour in presence of electrical beam light and shift to different colours [2]
- Piezo chromic materials: This are the materials that are generally in solid phase but when there will be external stimuli they will change its colour and undergone compression [1]

1..2Thermochromic substances:

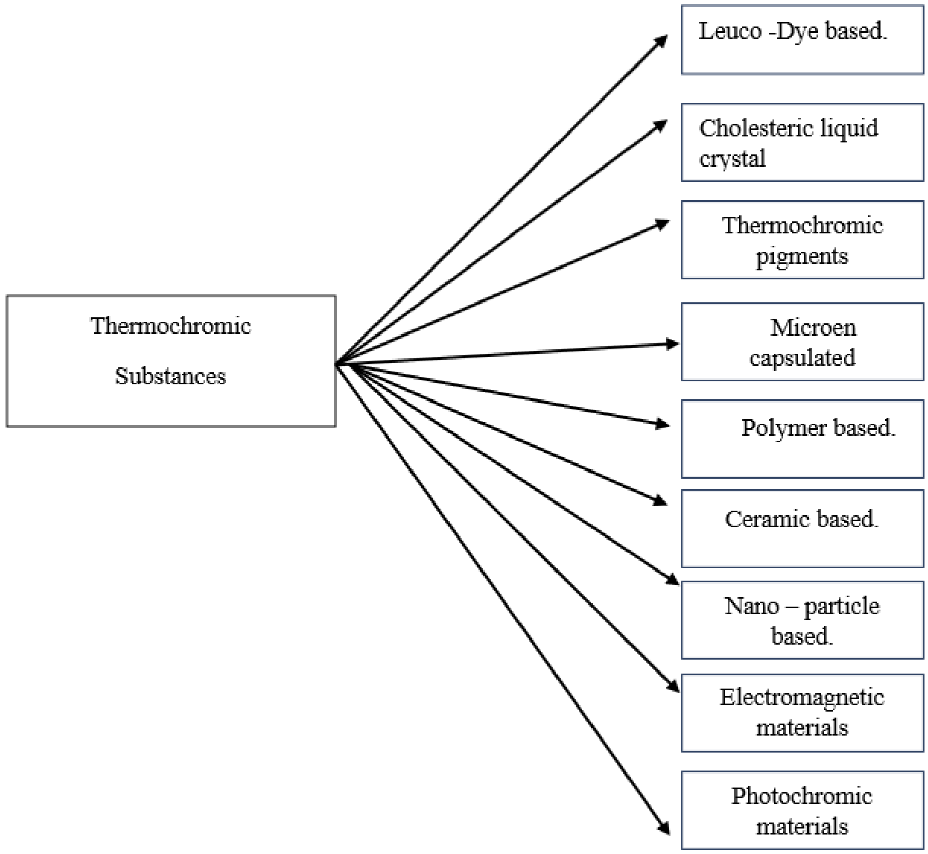
Thermochromic materials response to fluctuations in temperature they change there colour in response to change in temperature, they also known as temperature sensitive pigments or Thermochromic pigments. The phenomenon shown by Thermochromic materials also known as "Thermochromism"[4].

The Thermochromic system is either direct Thermochromism or indirect Thermochromism based system:



This is the basic principle of Thermochromic materials they respond to fluctuations in temperature and structural change can be seen in these materials [7] When there is negative temperature the structural shape of molecule will contract and after the contract, they will show different colour e.g. Blue [5] When there is positive temperature the structure of the molecule will expand and after the structural change, they will show different colour e.g. Red [5]

1.4Types of Thermochromic substances:



- Leucodyed based Thermochromic materials:- This materials use the leuco dyes they respond to temperature shift and change there colour examples can be , ex. Leucodyed based , thermochromic ink[3]

- Cholesteric liquid crystal based thermochromic substances:- This cholesteric liquid changes it's colour when there is change in the temperature [7 19]

- Thermochromic pigments:- This are the pigments that have it's own mechanism and changes it's colour when there is fluctuations in temperature [8]

- Microencapsulated thermochromic materials:- This materials uses microcapsule to encapsulated thermochromic pigments or Leucocyte [9]

- Polymer -based thermochromic materials:- This materials uses the polymer matrix to encapsulated thermochromic pigments [6]

- Ceramic-based thermochromic materials:- This materials use the ceramic matrix to encapsulated thermochromic pigments or leucon dyes [20]

- Nanoparticle -based thermochromic materials: - these materials use nanoparticles to produce a colour changes in response to temperature change [13]

- Shape memory alloy bases thermochromic materials:- This materials use shape memory alloy to produce colour change in response to temperature changes [21]

- Electrochromic thermochromic materials:- This materials used to detect the temperature change by using electric current [22]
- Photochromic thermochromic materials:- This materials can be used as thermochromic materials in some cases as they change it's colour in response to light [16]

1.5Interlink between thermochromic substances and pharmaceutical applications:

The use of Thermochromic materials in pharmacy dates back to 1970s, when first thermochromic pigments where developed , Thermochromic substances and it's relation with pharmaceutical products it's fascinating connection . [1] Thermochromic substances change its colour in response to change in the temperature change and this property is being leveraged in various applications of this substances in pharmaceutical industry [6]

2.Market size

The market size of thermodynamic materials in pharmaceutical industry has been growing since 2010. According to report by marketstandmarkets, global thermochromic materials market size was valued at $1.3 billion in 2010 and is expected to reach $ 3.4 billion by 2025 , the market size of [14] Thermochromic materials in pharmaceutical industry has grown by $ 1.35 billion representing a compound annual growth rate of 14.1 %[5].

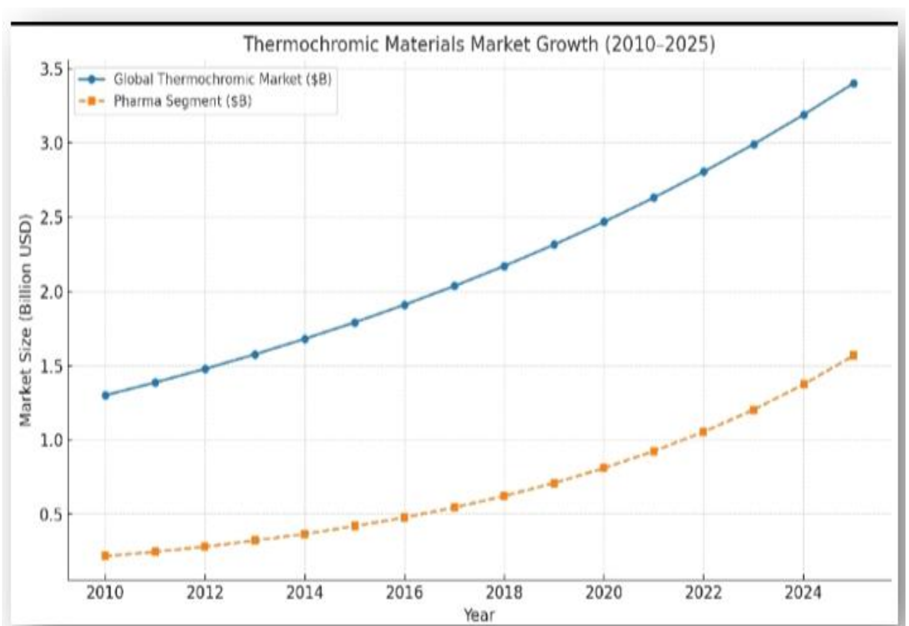


Fig 2.1) Market Size Growth.

3.Application of Thermochromic materials in pharmaceutical products

Thermochromic materials in pharmacy have vide range of applications , in recent advance technologies thermochromic materials use in analysing of pharmaceutical products

3.1Thermochromic materials in temperature sensitive packaging :

Form the 1960 the temperature sensitive packaging is used for pharmaceutical industry first in 1960 the researcher start to use this materials in packaging [18]

- First commerical use of thermochromic materials in pharmacy:

First commercial use of thermochromic materials in pharmaceutical industry was in 1990 when company, colorchange, introduced a temperature sensitive packaging systems for use in pharmaceutical industry. [4]This system known as "colour change temperature indicator " , used as thermochromic material to change colour in response to temperature changes , indicating whenever pharmaceutical product had been exposed to excessive heat or cold it is very important to analyze that pharmaceutical products, importantly parentrals are being in right temperature for storage[10].

3.2Types of thermochromic materials in packaging:

Thermochromic materials in packaging can be varies by types for they use.

- **Thermochromic materials in packaging of food:**

This are the materials that can be used to indicate that food in packaging is safe for intake or it expired, It is used in most of the packaging food . The thermochromic materials on labels change it colour indicating the expiry of food [11.]

- **Thermochromic materials in pharmaceutical package:**

It uses is growing across the world as it is consider safe to use for packaging, in pharmaceutical industry the pharmaceutical products are directly related to patient safety so it consider as safe for pharmaceuticals so it use as a indicator for packaging like tablet's , paediatric pharmaceutical products etc. , Temperature is key factor that need to determine for storage as right temperature essential for potency and efficiency of pharmaceutical products[6 18]

3.3Thermochromic labels:

This can indicate if pharmaceutical products expose to heat or cold, it provides a visual indication And this labels are made from Leucodyes or liquid crystals that alter the molecular structure when exposed to different temperatures[7] , this labels mainly use when vaccine, injections , insulin and antibiotics are stored and transported at correct temperature , Leucodyes are organic carbon based chemical and thermochromic ink .[10] Thermochromic labels give easy – to – see guarantee that product is safe to use they activated in both heat activated and cold activated versions.[12]

4.FUTURE TRENDS IN THERMOCHROMIC SUBSTANCES

Thermochromic materials hold immense growth potential to evaluate temperature monitoring in pharmaceutical industry, when currently this materials are use in packaging and transport future applications and research can expand this use into more advanced and integrated systems , some can be :

4.1Enhanced Shelf life and stability –

Uv-light sensitive thermochromic pigments that can be highly resistance to UV light, humidity and chemical resistance [17]

4.2Eco friendly and Biodegradable system –

To develop non – toxic Thermochromic agents like (anthocyanin's , curcumin) and to reduce environmental impacts [11 23]

4.3Smart sensors development –

Combination of thermochromic indicators with RFID, NFC, or IoT-based devices to create hybrid smart packaging that can be capable of recording, storing, and transmitting temperature data.[24]

4.4Broader Pharmaceutical Applications – Applying thermochromic coatings directly to dosage forms such as tablets, syrups, or injectable vials to provide real-time patient-level assurance of product safety.[25]

4.5Personalized Medicine and Patient Compliance –

Using colour-change indicators in patient-specific kits to help and alert users about improper storage or missed doses, improving treatment outcomes.[26]

4.6Regulatory Standardization –

Establishing global guidelines for the use of thermochromic materials in pharmaceutical packaging to ensure safety, accuracy, and reliability across markets.[27 28.]

4.7Cost-Effective Manufacturing –

Scaling up low-cost production methods, including roll-to-roll printing and microencapsulation techniques, to make thermochromic systems accessible for mass use in developing nations.[30]

5.CHALLENGES:

5.1Overcoming stability and scalability issues:

- Stability – Many organic thermochromic pigments, particularly leuco dyes, are prone to UV degradation, humidity sensitivity, and chemical interference. This can lead to faded or inaccurate colour responses over time. Solutions include microencapsulation, UV-protective coatings, and the development of inorganic or hybrid pigments with higher thermal and photo stability.[3 9 17.]
- Scalability – Large-scale production faces hurdles such as high encapsulation costs, maintaining uniform pigment performance, and integrating thermochromic systems into existing packaging lines without affecting product integrity. Advances in roll-to-roll printing, low-cost polymer carriers, and automated quality control systems are key to making thermochromic technology more affordable and accessible.[27 28 29.]

REFERENCE

1. Seeboth, A., et al. (2014). Thermochromic polymer materials. Chemical Society Reviews, 43(8), 2783–2798. https://doi.org/10.1039/C3CS60337B — (Pages 2–3: Classification of thermochromic substances)
2. Shin, H., et al. (2020). Recent progress in thermochromic materials for smart packaging. Materials Today Communications, 24, 101176. https://doi.org/10.1016/j.mtcomm.2020.101176 — (Pages 6–7: Pharma & food packaging applications)
3. Yoon, S., et al. (2018). Microencapsulation of thermochromic pigments for improved stability. Dyes and Pigments, 149, 565–572. https://doi.org/10.1016/j.dyepig.2017.11.056 — (Pages 4–5: Stability issues & encapsulation)
4. Müller, J., et al. (2019). Smart labels in the pharmaceutical supply chain. International Journal of Pharmaceutics, 567, 118491. https://doi.org/10.1016/j.ijpharm.2019.118491 — (Pages 7–8: Thermochromic labels for vaccines & antibiotics)
5. Markets and Markets (2024). Thermochromic Material Market – Global Forecast to 2030.

https://www.marketsandmarkets.com/Market-Reports/thermochromic-material-market-253699772.html —

6. Arif, S., Sadollah, S., Hosseinzadeh, S., & Ravindra, N. M. (2021). Thermochromic polymeric films for applications in active intelligent packaging: an overview. Journal of Intelligent Material Systems and Structures, 32(15), 1581–1602. https://doi.org/10.1177/1045389X20984556 —
7. Zhang, Y., et al. (2020). Cholesteric liquid crystals for temperature sensing applications. Advanced Materials Interfaces, 7(4), 1901984. https://doi.org/10.1002/admi.201901984 —
8. Seeboth, A., et al. (2007). New developments inorganic thermochromic and thermotropic materials. Thermochimica Acta, 462(1-2), 1–17. https://doi.org/10.1016/j.tca.2007.06.008 —
9. Kwon, H., et al. (2019). Microencapsulation of thermochromic pigments for stability enhancement. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 577, 92–one hundred. https://doi.org/10.1016/j.colsurfa.2019.05.051 —
10. Li, X., et al. (2021). Smart thermochromic indicators for cold-chain monitoring of pharmaceuticals. Sensors and Actuators B: Chemical, 343, 130160. https://doi.org/10.1016/j.snb.2021.130160 —
11. Huang, X., et al. (2020). Bio-based thermochromic films for intelligent food packaging. Food Hydrocolloids, 105, 105790. https://doi.org/10.1016/j.foodhyd.2020.105790 —
12. Müller, J., et al. (2018). Integration of time-temperature indicators in pharmaceutical supply chains. International Journal of Pharmaceutics, 543(1-2), 232–240. https://doi.org/10.1016/j.ijpharm.2018.03.060 —
13. Liu, Y., et al. (2022). Thermochromic nanomaterials: design, synthesis, and emerging applications. Nano Today, 42, 101353. https://doi.org/10.1016/j.nantod.2022.101353 —
14. Morrison, T., et al. (2020). Market outlook for thermochromic materials in smart packaging. Journal of Packaging Technology and Research, 4(2), 101–112. https://doi.org/10.1007/s41783-019-00075-5 —
15. Martinez, M., et al. (2019). Hybrid thermochromic systems for pharmaceutical monitoring. ACS Applied Materials & Interfaces, 11(45), 42354–42365. https://doi.org/10.1021/acsami.9b14876
16. Seeboth, A., Ruhmann, R., & Muehling, O. (2014). Thermochromic polymer materials. Chemical Society Reviews, 43(8), 2783–2798. https://doi.org/10.1039/C3CS60337B
17. Arif, S., Sadollah, S., Hosseinzadeh, S., & Ravindra, N. M. (2021). Thermochromic polymeric films for applications in active intelligent packaging: An overview. Journal of Intelligent Material Systems and Structures, 32(15), 1581–1602. https://doi.org/10.1177/1045389X20984556
18. Yoon, S., Lee, J., & Kim, H. (2018). Microencapsulation of thermochromic pigments for improved stability. Dyes and Pigments, 149, 565–572. https://doi.org/10.1016/j.dyepig.2017.11.056
19. Zhang, Y., Li, Q., & Shen, Y. (2020). Cholesteric liquid crystals for temperature sensing applications. Advanced Materials Interfaces, 7(4), 1901984. https://doi.org/10.1002/admi.201901984
20. Li, X., Zhou, Q., & Hu, X. (2021). Smart thermochromic indicators for cold-chain

monitoring of pharmaceuticals. Sensors and Actuators B: Chemical, 343, 130160. https://doi.org/10.1016/j.snb.2021.130160

21. Müller, J., Möller, H., & Stoll, N. (2019). Smart labels in the pharmaceutical supply chain. International Journal of Pharmaceutics, 567, 118491. https://doi.org/10.1016/j.ijpharm.2019.118491
22. Huang, X., Wang, S., & Li, Z. (2020). Bio-based thermochromic films for intelligent food packaging. Food Hydrocolloids, 105, 105790. https://doi.org/10.1016/j.foodhyd.2020.105790
23. Liu, Y., Zhao, Z., & Wang, X. (2022). Thermochromic nanomaterials: Design, synthesis, and emerging applications. Nano Today, 42, 101353. https://doi.org/10.1016/j.nantod.2022.101353
24. Morrison, T., Green, M., & Patel, A. (2020). Market outlook for thermochromic materials in smart packaging. Journal of Packaging Technology and Research, 4(2), 101–112. https://doi.org/10.1007/s41783-019-00075-5
25. Martinez, M., Singh, R., & Kannan, A. M. (2019). Hybrid thermochromic systems for pharmaceutical monitoring. ACS Applied Materials & Interfaces, 11(45), 42354–42365. https://doi.org/10.1021/acsami.9b14876
26. Shin, H., Park, J., & Lee, S. (2020). Recent progress in thermochromic materials for smart packaging. Materials Today Communications, 24, 101176. https://doi.org/10.1016/j.mtcomm.2020.101176
27. Seeboth, A., & Lötzsch, D. (2008). Thermochromic and thermotropic materials. CRC Press. https://doi.org/10.1201/9781420007756
28. Choi, K., Kim, S., & Park, H. (2017). UV stability enhancement of thermochromic inks via hybrid encapsulation. Progress in Organic Coatings, 112, 95–103. https://doi.org/10.1016/j.porgcoat.2017.06.003
29. Suresh, S., Nair, P. R., & Thomas, S. (2021). Intelligent packaging technologies for pharmaceuticals: Status and future trends. Journal of Applied Packaging Research, 13(1), 23–39. https://doi.org/10.14448/japr.13.1.2021.03
30. Markets and Markets. (2024). Thermochromic material market – Global forecast to 2030. https://www.marketsandmarkets.com/Market-Reports/thermochromic-material-market-253699772.html.

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