DOI: https://doi.org/10.33216/1998-7927-2025-290-4-63-71

UDC [678.742:66.095.26]:661.183

CURRENT STATE OF THE ART IN POLYLACTIDE POLYMER WATER EMULSIONS DEVELOPMENT

Khlystun S.O., Myronyuk O.V.

ОСТАННІ ДОСЯГНЕННЯ У СТВОРЕННІ ВОДНИХ ЕМУЛЬСІЙ НА ОСНОВІ ПОЛІМЕРУ ПОЛІЛАКТИДУ

Хлистун С.О., Миронюк О.В.

The current trend towards green and sustainable development has prompted researchers and scientists to devote more and more of their time to studying and improving potential biopolymers as alternatives to traditional polymers. While renewable resource-based polymers are already widely used in medicine and packaging, they still need further research to meet certain requirements on par with conventional polymers for a wider range of applications.

Poly(lactic acid) (PLA) emulsions have gained significant attention in the coatings industry due to their biodegradability, sustainability, and potential to replace conventional solvent-based systems and fossil-based polymers. This study aims to provide a comprehensive overview of recent research and advancements in PLA emulsion preparation, focusing on fundamental properties of the emulsions, different synthesis methods, including solvent evaporation, emulsification-solvent diffusion, and high-pressure homogenization. The role of stabilizers and solvents in ensuring emulsion stability and performance is analyzed, and their ability to influence the final coating properties are analyzed. Widely used surfactants and bio-based stabilizers are highlighted.

Despite their advantages, PLA emulsions face key challenges such as hydrophobicity, phase separation, and limited mechanical properties, which hinder their broader industrial application. This review identifies these challenges and explores potential solutions, including the use of nanotechnology, bio-based stabilizers, and optimized processing techniques. Additionally, strategies for improving scalability, reducing the environmental impact of PLA emulsions and promising applications are discussed. By addressing these limitations, PLA-based coatings could become a viable alternative in the development of sustainable materials. The current literature remains largely fragmented, and this review aims to synthesize existing findings into a structured, comparative analysis. In doing so, it lays the groundwork for future research and innovation in the field of environmentally friendly coating technologies.

Keywords: *poly(lactic acid); polymer; water dispersions; film formation.*

Introduction. The environmental impact of petroleum-based plastics has become a critical global concern, with plastic production exceeding 400 million tons per year and a significant portion ending up in landfills or the natural environment [1]. This massive accumulation contributes to pollution and greenhouse gas emissions, intensifying global warming and ecological degradation. In response, researchers and industries are increasingly turning to sustainable, biodegradable alternatives – particularly biopolymers such as poly(lactic acid) (PLA).

PLA is a bio-based, biodegradable polyester derived from renewable resources like corn starch or sugarcane [2]. Its advantages include high mechanical strength, biocompatibility, and reduced carbon footprint compared to conventional polymers. In recent years, interest has grown in adapting PLA for use in coatings – a field traditionally dominated by fossil-based resins. However, the utilization of PLA in coating applications is not without challenges. One significant limitation is its relatively low thermal stability, with a glass transition temperature around 60–65°C and a melting point between 130–180°C, which can restrict its use in high-temperature environments [3]. Additionally, PLA exhibits brittleness and limited elongation at break, leading to concerns about its mechanical performance in flexible coating applications.

Another critical issue is PLA's hydrophobic nature, which poses challenges in achieving stable aqueous emulsions necessary for water-based coatings. Moreover, while PLA is biodegradable under industrial composting conditions, its degradation in natural environments is significantly slower, raising questions about its environmental impact [4, 5].

The problem statement. To address these challenges, researchers are exploring the preparation of PLA emulsions as a promising strategy to enable its use in coating formulations. Strategies include blending with other polymers, incorporating plasticizers, and developing novel emulsion techniques to improve its mechanical properties and processability. Emulsification not only allows the dispersion of PLA in aqueous media but also opens possibilities for tuning film properties such as flexibility, adhesion, and degradation rate. Emulsion-based PLA coatings are particularly attractive for applications in wood protection, packaging, and biomedical surfaces where biodegradability and environmental safety are paramount.

Despite the growing body of research, the majority of existing results are presented in the form of isolated experimental studies with limited cross-comparison or synthesis. These works often focus on specific formulations or techniques without providing broader conclusions about general trends, performance factors, or optimization strategies. Therefore, there is a clear need for a systematic review that organizes and analyzes these findings, identifies gaps in knowledge, and offers a cohesive understanding of the preparation methods, stabilization approaches, and application prospects for PLA emulsions.

The aim of the research. This review systematizes the strategies for preparing PLA emulsions suitable for coating applications, examining their formulation, stability, film-forming behavior, and potential environmental and functional advantages. To achieve the goal of this work, several key tasks were set and accomplished. First, the environmental motivation and scientific relevance of developing PLA-based emulsions as an alternative to petroleum-derived coatings are outlined. Next, the main approaches used to prepare polymer emulsions were described, focusing on physical methods and their relevance to biopolymer systems. Specific methods applied to PLA were reviewed, highlighting their mechanisms, advantages, and limitations. After that, key factors affecting emulsion stability, such as droplet size, phase behavior, and interfacial phenomena, were investigated. The role of various emulsifiers in stabilizing PLA emulsions is analyzed and the most commonly used surfactants are reviewed. Additionally, critical barriers to the practical use of PLA emulsions in coatings were identified, including issues of materials, processes, and performance characteristics, and current and emerging uses of PLA emulsions in various industries were discussed, with a focus on coating technology.

Statement of the basic material of the study. Emulsion systems are commonly prepared using two principal categories of methods: high-energy and low-energy techniques [6]. Each method is distinguished by the way energy is introduced into the system to create and stabilize the dispersed phase.

General methods for preparing emulsions. High-energy methods utilize mechanical input to forcibly break one phase into fine droplets within another. Techniques such as high-shear mixing, ultrasonication, and high-pressure homogenization are effective tools to overcome interfacial tension, particularly when creating emulsions from hydrophobic polymers or pre-polymer solutions. These methods are suitable for forming small, uniform droplets and are often used when emulsifying organic solutions of polymers like PLA into aqueous phases.

In contrast, low-energy methods depend on changes in system composition or temperature to drive emulsification. Techniques such as emulsification by solvent diffusion and emulsification-evaporation are valuable approaches, especially when working with biodegradable or thermally sensitive polymers. These methods typically involve dissolving the polymer in a volatile or partially water-miscible organic solvent, followed by dispersion into water and removal of the solvent to form stable emulsions or particles.

Another noteworthy approach is condensation-based emulsification, where emulsion formation occurs concurrently with polymer growth, leading to enhanced stability and control over droplet architecture. This technique is relevant for systems requiring in-situ polymerization or step-growth polymer formation and supports the development of advanced emulsified structures for coatings and functional materials.

Due to the hydrophobic nature and solvent dependency of poly(lactic acid) (PLA), the preparation of its emulsions commonly relies on both low-energy solvent-based techniques and high-energy mechanical dispersion. The choice of method depends on desired emulsion properties, application requirements, and formulation constraints.

Methods for preparing PLA emulsions. One of the most widely used techniques is the emulsification–evaporation method. PLA is dissolved in a volatile, water-immiscible organic solvent such as dichloromethane, and the resulting organic phase is emulsified into an aqueous phase containing a stabilizer like polyvinyl alcohol (PVA) using high-shear mixing or ultrasonication. As the organic solvent evaporates, typically under reduced pressure or ambient conditions, PLA precipitates into fine droplets suspended in water [7].

Advantages of this method include its simplicity, compatibility with hydrophobic drugs or additives, and good control over particle size. Limitations involve the use of toxic solvents and the need for effective solvent removal. It is widely applied in biomedical formulations and in coating systems where precise particle morphology is needed.

The emulsification–diffusion method uses a partially water-miscible solvent such as ethyl acetate, which diffuses into the continuous aqueous phase after emulsification and is then removed by evaporation [8]. This approach avoids chlorinated solvents and operates under milder conditions, making it more environmentally friendly. It is ideal for forming emulsions containing thermally sensitive components or bioactive molecules. However, solvent selection is limited, and slower solvent diffusion can result in broader particle size distributions.

Ultrasonication, often used to assist emulsification, employs high-frequency sound waves to generate cavitation, which breaks large droplets into smaller ones [9]. This method is highly effective in producing nano-sized emulsions with narrow particle distributions and requires minimal surfactant. It is especially suitable for applications needing high precision in droplet size, such as nanocoatings or PLA-based delivery systems. The main drawback is the limited scalability and potential for polymer degradation due to localized heating.

High-pressure homogenization involves forcing the emulsion through a narrow gap at high pressure, causing intense shear and turbulence that break down droplets to submicron sizes [10]. This method produces highly uniform emulsions and is scalable for industrial use. It is beneficial in continuous coating production or when long-term emulsion stability is essential. However, the method is energy-intensive and may not be suitable for heat-sensitive compounds.

Each technique offers unique benefits depending on the formulation goals – whether it's enhanced stability, environmental safety, process scalability, or compatibility with sensitive additives in coating systems.

Emulsion stability. But after preparing the emulsion, it is necessary to ensure its stability. The stability of emulsions is a critical parameter for their practical use in coatings, pharmaceuticals, and food systems. Emulsion stability refers to the system's ability to resist changes in droplet size distribution and phase separation over time. Several physical phenomena can destabilize emulsions, including coalescence, flocculation, creaming/sedimentation, and Ostwald ripening [11].

Emulsion stability is influenced by several interrelated factors. (Fig. 1).

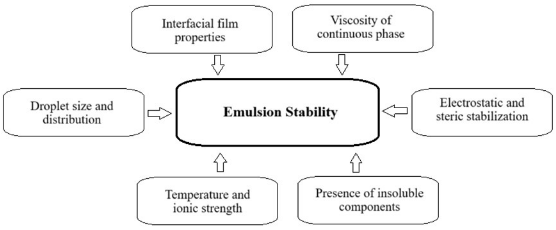

Fig. 1. Factors affecting emulsion stability

One of the primary considerations is droplet size and distribution: smaller droplets tend to resist gravitational separation and coalescence more effectively, while a narrow size distribution enhances uniformity and minimizes the likelihood of phase separation. The properties of the interfacial film also play a critical role; the strength and elasticity of the stabilizing layer formed at the oil/water interface – usually by surfactants or polymers – are key to preventing droplet coalescence. Additionally, the viscosity of the continuous phase, typically aqueous, significantly affects droplet mobility; increased viscosity reduces the rate of creaming and lowers the frequency of droplet collisions. Electrostatic and steric stabilization mechanisms are also important. Surfactants may impart charges to droplets, causing electrostatic repulsion, while adsorbed polymer layers can create steric hindrance that physically blocks droplet aggregation. Environmental factors such as temperature and ionic strength further impact stability. Higher temperatures tend to lower the rigidity of the interfacial film and enhance droplet motion, thereby promoting instability. Likewise, high ionic strength can compress the electric double layer around droplets, weakening electrostatic stabilization. Finally, the presence of insoluble components like pigments or crystalline particles can influence the rheological behavior of the emulsion. These additives may stabilize the system through Pickering stabilization or, conversely, cause destabilization through bridging flocculation, depending on their nature and interactions within the emulsion.

Designing stable emulsions requires a balance of interfacial engineering, viscosity modification, and environmental control to suppress the mechanisms of destabilization.

Emulsifiers used in PLA-based emulsions. Emulsifiers play a critical role in the stabilization of emulsions by reducing interfacial tension between immiscible phases and forming protective layers around dispersed droplets. Emulsifiers can be broadly categorized by their molecular structure and mechanism of action, including low molecular weight surfactants, polymeric stabilizers, and naturally derived compounds [12]. Among these, nonionic surfactants such as Tween 20, Tween 80, and Span 60 (Fig. 2) are widely used in emulsion systems due to their mildness, compatibility with a wide pH range, and low toxicity. These surfactants are particularly effective in stabilizing emulsions through steric hindrance and have demonstrated high efficiency in preparing PLA-based emulsions. Tween 80, for example, has been frequently applied in PLA nanoemulsion formulations, ensuring droplet stabilization and suppressing aggregation [13].

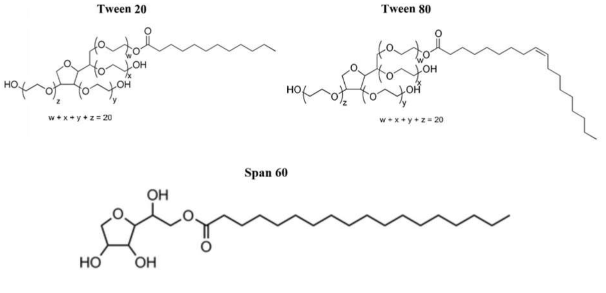

Fig. 2. Chemical structure of Tween 20, Tween 80, Span 60

Ionic surfactants such as sodium dodecyl sulfate (SDS) and cetyltrimethylammonium bromide (CTAB) (Fig. 3) also serve as effective emulsifiers by imparting electrostatic repulsion among droplets [14]. SDS, in particular, has been used in various PLA emulsion formulations, although its sensitivity to changes in pH and ionic strength can limit its applicability in certain coating systems [15]. In contrast, polymeric emulsifiers such as polyvinyl alcohol (PVA) provide enhanced stability through the formation of robust interfacial films. PVA is one of the most commonly used stabilizers in PLA emulsion preparation due to its excellent film-forming ability and strong steric stabilization, making it suitable for applications requiring long-term dispersion stability. A number of scientific papers support its widespread use in PLA emulsions intended for controlled release systems and coatings [16].

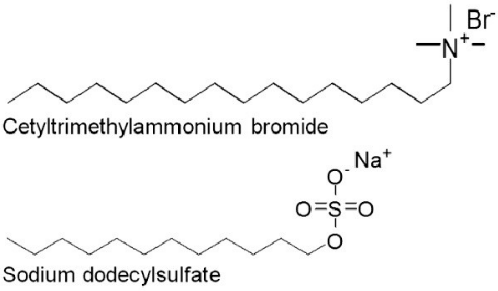

Fig. 3. Chemical structure of cetyltrimethylammonium bromide (CTAB) and sodium dodecyl sulfate (SDS)

Another class of polymeric stabilizers includes poloxamers, such as Pluronic F68 (Fig. 4), which are amphiphilic block copolymers offering both steric and, in some cases, thermoresponsive stabilization. These have been explored in PLA nanoparticle dispersions for biomedical and environmentally friendly coating applications [17]. Natural emulsifiers such as lecithin, gum arabic, and casein have also been investigated for stabilizing emulsions, particularly where biocompatibility and biodegradability are essential. Lecithin, a phospholipid-based emulsifier, has shown promise in PLA systems but often provides weaker interfacial strength compared to synthetic polymeric emulsifiers.

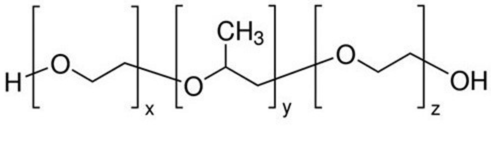

Fig 4. Chemical structure of Pluronic F68

Overall, the choice of emulsifier for PLA emulsion preparation depends on the required stability, particle size distribution, biocompatibility, and application context. Among the available options, polyvinyl alcohol and nonionic surfactants like Tween 80 remain the most suitable and widely adopted stabilizers for preparing PLA emulsions intended for coating formulations.

Challenges and limitations. While poly(lactic acid) (PLA) is an attractive candidate for developing sustainable coatings due to its biodegradability and renewable origin, several limitations continue to hinder its broader application, especially in emulsion-based systems.

One of the primary challenges lies in PLA’s intrinsic brittleness and low toughness, which results in coatings with poor flexibility and resistance to mechanical stress. This restricts the standalone use of PLA in structural or load-bearing applications, unless modified through blending or plasticization [18]. However, such modifications can reduce environmental compatibility or lead to phase separation within emulsified systems.

Another significant barrier is PLA’s limited thermal and hydrolytic stability. The polymer begins to degrade at elevated temperatures and is sensitive to hydrolysis under humid or aqueous conditions, which complicates its use in water-based emulsions. This property affects the long-term durability of coatings and can lead to instability during processing, storage, or application.

In aqueous systems, PLA’s hydrophobic nature presents an additional formulation challenge. Achieving a stable and uniform dispersion in water often requires careful selection of surfactants or co-solvents, and even then, issues such as droplet coalescence or sedimentation can arise. This makes the design of long-term stable PLA emulsions technically demanding and often reliant on trial-and-error stabilization strategies.

Moreover, PLA exhibits slow crystallization kinetics, which can lead to poor film formation, delayed curing, or inconsistent adhesion on substrates. This limitation is particularly relevant for coating applications that demand fast setting times or require specific surface interactions. Techniques such as nucleating agents or copolymerization have been explored, though they add complexity and may affect the clarity or biodegradability of the final product [19].

Finally, economic constraints remain a consideration. The production cost of high-purity PLA is still higher than that of conventional petrochemical-derived polymers, especially in regions without local biopolymer infrastructure. This limits PLA’s competitiveness in price-sensitive markets, despite its ecological advantages.

These challenges illustrate the importance of continued material innovation and formulation optimization to unlock the full potential of PLA emulsions in coatings and related fields.

Potential applications. Poly(lactic acid) (PLA) emulsions offer promising applications across various industries due to their biodegradability, biocompatibility, and eco-friendly profile. In the field of coatings, PLA emulsions can be used for environmentally sustainable surface finishes on a wide range of substrates, including wood, paper, textiles, and metals. These coatings offer not only durability and water resistance but also the advantage of biodegradability upon disposal, making them ideal for applications where environmental impact is a key concern.

In the pharmaceutical and biomedical industries, PLA emulsions are utilized for controlled drug release systems. The polymer's biocompatibility and ability to form stable emulsions allow for the encapsulation of active compounds in a manner that facilitates sustained release over time [20]. Additionally, PLA emulsions are used in cosmetic formulations, particularly in skin-care products, due to their non-toxic nature and the ability to form smooth, uniform coatings on the skin [21].

PLA emulsions are also finding growing use in food packaging and agricultural films, where their biodegradability provides a sustainable alternative to traditional plastic films. Their ability to form thin, protective layers that degrade naturally offers a promising solution for reducing plastic waste.

As research and development in PLA-based emulsions advance, their applications are expected to expand into new areas such as electronic devices, where they can be used as coatings for environmentally friendly, biodegradable electronics.

Recent findings and further development of technology. Recent advancements in the field of poly(lactic acid) (PLA) emulsions have underscored their significant potential in diverse applications, including coatings, biomedical devices, food packaging, and environmental solutions. However, the development of stable and efficient PLA emulsions continues to face challenges, particularly in terms of thermal sensitivity, brittleness, hydrophobicity, and limited mechanical properties. As researchers continue to explore the full potential of PLA, it is evident that overcoming these limitations is critical for broadening its commercial viability and performance.

One promising strategy to address these limitations involves incorporating nanofillers and surface-active agents to enhance mechanical, thermal, and barrier properties of PLA emulsions.

Recently, scientists have been carefully considering the possibilities of modifying PLA with various nanofillers, such as nanoclays, carbon nanotubes, and cellulose-based materials [22]. These modifications can significantly improve PLA's stiffness, heat resistance, and overall performance, and such strategies can be effectively transferred to emulsified systems to improve film properties after application.

Additionally, investigating eco-friendly stabilizing agents, such as bio-based surfactants or polysaccharides, could improve emulsion stability without compromising biodegradability. The use of PEG-PLA-PEG block copolymer surfactants has shown to enhance the water compatibility and stability of PLA emulsions, which is especially valuable for applications in high-solid, waterborne coating systems [23]. These amphiphilic surfactants contribute to improved dispersion and emulsion shelf-life, while maintaining the biodegradability and environmental friendliness of the system.

Moreover, recent findings emphasized the importance of modifying PLA through blending and composite strategies to improve its mechanical and thermal properties, which is crucial for the performance of PLA emulsions in demanding applications [24]. The combination of PLA with nanofillers and bio-based surfactants has shown promise in enhancing the strength, flexibility, and overall durability of the emulsions, making them more suitable for industrial use.

As the field progresses, further research into the optimization of PLA emulsions is essential to unlock their full potential across a wide range of applications. Key directions for future development include the design and use of more efficient and environmentally friendly surfactants, particularly those derived from renewable or biodegradable sources, which can replace conventional synthetic emulsifiers and reduce ecological impact. Additionally, advances in polymer modification – such as copolymerization, surface grafting, or functionalization with reactive groups – offer opportunities to enhance the stability, mechanical properties, and interfacial compatibility of PLA-based emulsions. The integration of nanotechnology, for example through the incorporation of nanoscale fillers or active agents, also presents promising avenues for creating multifunctional PLA coatings with antimicrobial, barrier, or self-healing properties.

Moreover, adapting formulation strategies to meet specific industrial demands – such as improving film-forming ability, water resistance, or adhesion to different substrates – will expand the usability of PLA emulsions in sectors like packaging, biomedical coatings, agriculture, and wood protection. To support commercial implementation, scalable and energy-efficient production methods must also be refined, including the use of continuous processing technologies and real-time emulsion monitoring systems.

With continued interdisciplinary innovation, PLA emulsions could evolve from niche research products into widely adopted alternatives to petroleum-based coatings. Their potential to reduce the environmental footprint of polymer-based materials makes them a critical component in the transition toward a circular, bio-based economy and the broader goal of sustainable materials science.

Conclusions. This review provides a systematic examination of polylactic acid (PLA) emulsions as a sustainable alternative to petroleum-derived coating materials. Through an in-depth analysis of the current literature and technical developments, the study highlights the significant potential of PLA emulsions while also acknowledging the complex challenges that remain. The main objective – to assess the state of the art in PLA emulsion preparation, stabilization, and application – has been fulfilled by addressing several interrelated research tasks that collectively offer a structured perspective on this promising but still-developing area.

Environmental motivations behind the shift from petroleum-based polymers to biodegradable alternatives such as PLA were established. The growing global plastic waste crisis and increasing legislative pressure for eco-friendly materials underscore the urgency of finding sustainable coating solutions. PLA stands out due to its biodegradability, biocompatibility, and origin from renewable resources, yet its direct use in coating applications is limited by factors such as brittleness and hydrophobicity – hence the need for emulsion-based strategies.

It was provided a foundation by discussing the general physical approaches employed to create emulsions, including high-shear mixing, ultrasonication, high-pressure homogenization, and condensation methods. These techniques are essential for controlling droplet size and stability, which are critical for the performance of polymer emulsions. Understanding these basic methods helped contextualize their suitability and adaptability for biopolymers like PLA.

The specific application of general techniques preparing emulsions to PLA systems was explored. Methods such as emulsification-evaporation, emulsification-diffusion, ultrasonication and high-pressure were examined in terms of their mechanisms, processing conditions, and resulting particle characteristics. Each approach offers trade-offs in terms of particle size control, process complexity, and compatibility with encapsulated actives or additives. These insights are essential for selecting appropriate methods tailored to specific end-use requirements in coatings.

It was highlighted the multifactorial nature of emulsion stability and analyzed how factors such as droplet size, viscosity of the continuous phase, interfacial film strength, and external conditions (e.g., temperature and ionic strength) influence the physical and thermodynamic stability of PLA emulsions. Understanding these variables is key to formulating stable systems with consistent performance, particularly in demanding application environments like coatings.

A variety of surfactants and stabilizing agents that have been used in the recent studies, such as Tween 20, Span 60, SDS, and lecithin were identified and evaluated. It was discussed their roles in reducing interfacial tension and providing electrostatic or steric stabilization. The suitability of each emulsifier depends on system pH, ionic strength, and desired release or degradation profiles. This analysis also pointed to the growing interest in developing bio-based and biodegradable emulsifiers compatible with PLA.

The main barriers to the widespread adoption of PLA emulsions in coatings were reviewed. These include PLA’s inherent hydrophobicity, limited water dispersibility, sensitivity to thermal degradation, and difficulties in achieving long-term emulsion stability. Technical constraints in processing methods and limitations in film-forming behavior were also discussed. Overcoming these barriers will require innovation in material design, surfactant chemistry, and processing technologies.

Lastly, current and emerging uses of PLA emulsions, particularly in coating technologies were outlined. PLA emulsions have shown promise in areas such as biodegradable packaging films, controlled-release systems in agriculture and pharmaceuticals, and environmentally benign wood and paper coatings. The ability to tailor emulsion properties opens the door for a wide array of functional coatings that align with circular economy principles.

Overall, while many advancements have been made, existing results are predominantly experimental and fragmented. This review demonstrates a clear need for further systematization and investigation to identify optimal formulations, scalable production techniques, and application-specific performance benchmarks. Continued interdisciplinary collaboration will be essential to transition PLA emulsions from laboratory research to viable industrial solutions that contribute meaningfully to sustainability goals.

This research was funded by Ministry of Education and Science of Ukraine, agreement number PH/53-2024 (26.09.2024) (European Union aid instrument for fulfilling Ukraine's obligations in the Framework Program of the European Union for Scientific Research and Innovation "Horizon 2020).

Література

1. Ritchie H., Roser M. Plastic pollution / H. Ritchie, M. Roser // Our World in Data. 2018. https://ourworldindata.org/plastic-pollution.
2. Poly(Lactic acid) / ed. by R. Auras et al. Hoboken, NJ, USA : John Wiley & Sons, Inc., 2010. URL: https://doi.org/10.1002/9780470649848.
3. Farah S., Anderson D. G., Langer R. Physical and mechanical properties of PLA, and their functions in widespread applications – A comprehensive review. Advanced drug delivery reviews. 2016. Vol. 107. P. 367–392. URL: https://doi.org/10.1016/j.addr.2016.06.012.
4. Recent advances in biodegradable polymers for sustainable applications / A. Samir et al. Npj materials degradation. 2022. Vol. 6, no. 1. P. 1–28. URL: https://doi.org/10.1038/s41529-022-00277-7.
5. Plastics of the future? The impact of biodegradable polymers on the environment and on society / T. P. Haider et al. Angewandte chemie international edition. 2019. Vol. 58, no. 1. P. 50–62. URL: https://doi.org/10.1002/anie.201805766.
6. Bararnia H. Synthesizing emulsions via condensation : PhD thesis in Mechanical Engineering / H. Bararnia. University of Illinois at Chicago, 2021. 221 p., URL:https://indigo.uic.edu/articles/thesis/Synthesizing_Emulsions_via_Condensation/15270372/1/files/29252910.pdf
7. Rheological response of polylactic acid dispersions in water with xanthan gum / S. Buoso et al. ACS omega. 2022. Vol. 7, no. 15. P. 12536–12548. URL: https://doi.org/10.1021/acsomega.1c05382.
8. Uniform-sized PLA nanoparticles: preparation by premix membrane emulsification / Q. Wei et al. International journal of pharmaceutics. 2008. Vol. 359, no. 1-2. P. 294–297. URL: https://doi.org/10.1016/j.ijpharm.2008.03.027
9. Shetgaonkar G. G., Kumar L. Ultrasound-Activated nanoparticles. Emerging technologies for nanoparticle manufacturing / ed. by J. K. Patel, Y. V. Pathak. Cham, 2021. P. 301–332. URL: https://doi.org/10.1007/978-3-030-50703-9_13.
10. Preparation of nanoemulsions by high-energy and lowenergy emulsification methods / H. Jasmina et al. Cmbebih 2017 / ed. by A. Badnjevic. Singapore,

2017. Vol. 62. P. 317–322. URL: https://doi.org/10.1007/978-981-10-4166-2_48.

11. Mcclements D. J. Critical review of techniques and methodologies for characterization of emulsion stability. Critical reviews in food science and nutrition. 2007. Vol. 47, no. 7. P. 611–649. URL: https://doi.org/10.1080/10408390701289292.
12. Emulsions and emulsifiers / K. Sarathchandraprakash et al., Asian J. Exp. Chem., vol. 8, no. 1&2, pp. 30-45, 2013.
13. Influence of stabilizing agents and preparative variables on the formation of poly(d,l-lactic acid) nanoparticles by an emulsification-diffusion technique / D. Quintanar-Guerrero et al. International journal of pharmaceutics. 1996. Vol. 143, no. 2. P. 133–141. URL: https://doi.org/10.1016/s0378-5173(96)04697-2.
14. Interfacial and thermodynamic approach of surfactants with α-chymotrypsin and trypsin: a comparative study / R. Banjare at el., Indian journal of chemistry section a. 2020.
15. Sizing down and functionalizing polylactide (PLA) resin for synthesis of PLA-based polyurethanes for use in biomedical applications / B. Nim et al. Scientific reports. 2023. Vol. 13, no. 1. P. 2284. URL: https://doi.org/10.1038/s41598-023-29496-x.
16. Preparations of poly(lactic acid) dispersions in water for coating applications / G. Belletti et al. Polymers. 2021. Vol. 13, no. 16. P. 2767. URL: https://doi.org/10.3390/polym13162767.
17. Astete C., Sabliov C. Synthesis and characterization of PLGA nanoparticles. Journal of biomaterials science. Polymer edition. 2006. Vol. 17. P. 247–89. URL:https://doi.org/10.1163/156856206775997322
18. Jem K. J., Tan B. The development and challenges of poly (lactic acid) and poly (glycolic acid). Advanced industrial and engineering polymer research. 2020. Vol. 3, no. 2. P. 60–70. URL: https://doi.org/10.1016/j.aiepr.2020.01.002
19. The development of poly(lactic acid) (pla)-based blends and modification strategies: methods of improving key properties towards technical applications–review / J. Andrzejewski et al. Materials. 2024. Vol. 17, no. 18. P. 4556. URL: https://doi.org/10.3390/ma17184556.
20. Lassalle V., Ferreira M. L. PLA nano- and microparticles for drug delivery: an overview of the methods of preparation. Macromolecular bioscience. 2007. Vol. 7, no. 6. P. 767–783. URL: https://doi.org/10.1002/mabi.200700022
21. Biswal T. Recent progress in PLA-based composite and their application to biomedical and cosmetic fields. Biopolymers in pharmaceutical and food applications / ed. by S. Jana. 2024. P. 497–530. URL: https://doi.org/10.1002/9783527848133.ch23
22. Recent advances in the investigation of poly(lactic acid) (PLA) nanocomposites: incorporation of various nanofillers and their properties and applications / N. D. Bikiaris et al. Polymers. 2023. Vol. 15, no. 5. P. 1196. URL: https://doi.org/10.3390/polym15051196.
23. Preparation of high-solid PLA waterborne dispersions with PEG-PLA-PEG block copolymer as surfactant and their use as hydrophobic coating on paper / M. Calosi et al. Progress in organic coatings. 2024. Vol. 193. P. 108541. URL: https://doi.org/10.1016/j.porgcoat.2024.108541.
24. Enhancing polylactic acid (PLA) performance: A review of additives in fused deposition modelling (FDM) filaments / I. Plamadiala et al. Polymers. 2025. Vol. 17, no. 2. P. 191. URL: https://doi.org/10.3390/polym17020191.

Хлистун С.О., Миронюк О.В. Останні досягнення у створенні водних емульсій на основі полімеру полілактиду

Сучасна тенденція до екологічного та сталого розвитку спонукає дослідників і науковців все більше приділяти уваги вивченню та вдосконаленню потенційних біополімерів як альтернативи традиційним полімерним матеріалам. Хоча полімери на основі відновлюваної сировини вже широко застосовуються в медицині та пакуванні, вони все ще потребують подальших досліджень для досягнення характеристик, порівнянних із традиційними полімерними системами, з метою розширення сфер їх застосування. Емульсії на основі полі(молочної кислоти) (PLA) привертають значну увагу у лакофарбовій промисловості завдяки своїй біорозкладності, сталості та потенціалу заміни традиційних систем на основі розчинників і полімерів з викопної сировини. У цьому огляді представлено всебічний аналіз сучасних досліджень і досягнень у галузі підготовки емульсій PLA з акцентом на фундаментальні властивості емульсій та різні методи синтезу, зокрема випаровування розчинника, емульгування з дифузією та гомогенізацію під високим тиском. Проаналізовано роль стабілізаторів і розчинників у забезпеченні стабільності емульсій і їхнього впливу на кінцеві властивості покриттів. Окремо розглянуто широко вживані ПАР та біоосновні стабілізатори.

Попри численні переваги, емульсії PLA мають низку викликів, зокрема гідрофобність, фазове розшарування та обмежені механічні характеристики, що стримує їхнє широке промислове застосування. У цьому огляді ідентифіковано основні проблеми та розглянуто потенційні шляхи їх подолання, включаючи використання нанотехнологій, біоосновних стабілізаторів і оптимізованих технологій обробки. Також обговорюються стратегії покращення масштабованості, зменшення екологічного впливу емульсій PLA та перспективні напрями застосування. Оскільки наявні дослідницькі результати здебільшого представлені у вигляді окремих експериментальних робіт, цей огляд має на меті систематизувати накопичену інформацію у *вигляді структурованого та порівняльного аналізу. Таким чином, він закладає підґрунтя для подальших досліджень і впроваджень у сфері екологічно безпечних покривних матеріалів.*

Ключові слова: *полі(молочна кислота); полімер; водні дисперсії; плівкоутворення.*

Хлистун Сергій Олегович – аспірант кафедри хімічної технології композиційних матеріалів Національного технічного університету України «Київський політехнічний інститут імені Ігоря Сікорського», s.khlystun@kpi.ua

Миронюк Олексій Володимирович – д.т.н., доцент, в.о. завідувача кафедри хімічної технології композиційних матеріалів Національного технічного університету України «Київський політехнічний інститут імені Ігоря Сікорського», o.myronyuk@kpi.ua

Стаття подана 15.04.2025.