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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Green processing, an environmentally friendly and non-toxic approach, has attracted attention for its potential across various industries. Global organizations aim to achieve carbon neutrality and a closed-loop circular economy by 2050. However, recent reports from several governments and organizations suggest that these goals face significant challenges and potential delays. Therefore, it is crucial to transform conventional processing methods, which generate high waste, pollution, and energy consumption, to green processing, especially for essential productions that cannot be avoided. This is particularly important for processes related to good health and well-being, as stated in the United Nations Sustainable Development Goals (SDGs). One such process is the production of nanoparticles (NPs), which are integral to everyday life and must be improved for long-term sustainability.

NPs can be classified into organic and inorganic types based on their structures, each offering distinct advantages. Organic NPs are non-toxic and biodegradable, making them ideal carriers for localized drug delivery. In contrast, inorganic NPs, such as metal or metal oxide NPs, exhibit properties like hydrophilicity, biocompatibility, and stability, making them useful for various biomedical applications such as magnetic resonance imaging, hyperthermia, and antimicrobial therapy. This research aims to promote the use of green chemicals like supercritical CO_2 ($scCO_2$) and water in surface modification and extraction processes for biomedical NP production, ensuring efficient fabrication and high-quality NP products, thereby aligning with the principles of green chemistry and a circular economy.

For organic NPs production, a micro-flow process combining emulsification and supercritical fluid emulsion extraction (SFEE) was developed to produce stearic acid lipid NPs (SLNs) in an aqueous solution. The dispersion quality was controlled by adjusting the total flow rate, surfactant types, and pressure conditions. Tween 80, a hydrophilic surfactant, was crucial for forming a homogeneous emulsion, while lecithin, a hydrophobic surfactant, was essential for producing uniform SLNs and preventing aggregation. A combined surfactant system proved to be preferable for fabricating stable SLNs in water. Lower pressure conditions maintain SLN stability, as higher pressures resulted in larger SLNs.

For inorganic NPs production, surface-modified iron oxide NPs (IONPs) with single crystallinity were synthesized under hydrothermal conditions using monocarboxylic acids of varying chain lengths. Short-chain modifiers produced uniform NPs in size and shape, whereas long-chain modifiers resulted in non-uniform NPs, comprising small-medium spheres and large hexagonal plates. These variations were attributed to differences in modifier solubility and Ostwald ripening rates, supported by phase state analyses in hot compressed water. Furthermore, obtained IONPs were used as models to develop a particle extraction process using $scCO_2$. Extractions of unmodified and surface-modified IONPs from the water phase using solvents like hexane, cyclohexane, cyclopentane, and $scCO_2$ were investigated both visually and quantitatively. Long-chain modifier cases resulted in a water phase without precipitation and a dark brown solvent phase, correlating with an increase in extraction efficiency (*EE*) with chain length. *EE* in the water phase was significantly larger than in the solvent phase, indicating three potential NP locations post-extraction: water phase, interface, and solvent phase. $scCO_2$ extraction showed high efficiency for hydrophobic-surface NPs, with the highest EE of 96.0%. Kinetic analysis indicated $scCO_2$ provided the highest extraction rate, with an *EE* of 99.8% at 100 min.

The analysis of products from these developed processes suggests potential biomedical applications, such as β-carotene encapsulated in SLNs from the micro-flow process of emulsification and SFEE, and magnetic properties of IONPs from hydrothermal synthesis. Additionally, a simple and low-cost analytical screening method using time-dependent RGB values was proposed for studying interactions in biomolecule-nanoparticle conjugate systems. This method aims to reduce waste from biomedical research by providing an interaction screening platform before performing detailed analyses.

Overall, this dissertation demonstrates that green processing for biomedical NP production can be achieved through the use of green chemicals and engineering design. For future outlook, feasibility studies such as economic analysis, life cycle assessment, data science analysis, and further exploration of time-dependent RGB analysis for various biomolecule-nanoparticle conjugates are recommended. These efforts aim to achieve the transformation to a circular economy by 2050, in line with common targets set by various global organizations and governments.