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Study on the Stabilization and Improved Usability of W/O Foundation Formulations Containing High Concentration Pigments Using Naturally Derived Emulsifiers and Polymers

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Abstract

As consumers' interest in naturally derived raw materials, such as naturally derived emulsifiers, oils, and sunscreen ingredients that are harmless to the human body and the environment, increases, the cosmetics industry is also actively developing products that utilize these ingre-dients. However, in makeup products, ensuring stability solely with naturally derived emulsifiers remains a challenge, particularly in W/O foundation formulations containing a high amount of powder, which tends to hinder dispersibility, stability, and usability. Moreover, there is still a lack of technical research and data to address these issues. This study explored a technical ap-proach aimed at improving the stability, dispersibility, and usability of W/O foundation formula-tions containing high concentrations of pigments. The pigment concentration was set at 15%, 20%, and 25%, and a non-ionic surfactant was used in which a polyglyceryl-based emulsifier was adsorbed on the surface of Distardimonium Hectorite that provides a pickering emulsion effect. In addition, after roll-milling the powders, a natural polymer, Bis-Behenyl/Isostearyl/Phytosteryl Dilinoleyl Dilinoleate, was dispersed in the powder to make three W/O foundation formulations with different powder concentrations. The manufactured formulation was confirmed to be stable through centrifugation, and the viscosity and stability over a 4 week period were monitored, and all concentrations of the formulation were stable. In addition, the particle state immediately after manufacturing and 4 weeks later was confirmed to be similar through an optical microscope, and the formulation demonstrated high coverage and 6-hour durability through a skin analyzer. This study presents a new technological approach to address the issues of dispersibility, stability, and usability that may arise in W/O foundation formulations containing high-concentration pigments (15% to 25%). Furthermore, it provides important data for the development of sustainable makeup products using natural ingredients, and will serve as a key reference for the develop-ment of cosmetic formulations based on naturally derived ingredients.

Keywords: Natural Make up, foundation, Natural Emulsifier, Natural polymer, dispersion, long lasting wear

1. Introduction

The modern cosmetics industry is experiencing a rapid increase in consumer demand for safer, naturally derived, and environmentally friendly products. At the same time, it faces the challenging task of complying with increasingly stringent global regulations [1]. In the past, synthetic ingredients played a key role in cosmetic formulations by offering excellent sensory properties and formulation stability. However, as concerns have grown over issues such as skin irritation, bioaccumulation, and toxicity to the marine ecosystem, regulations on these ingredients have been progressively strengthened worldwide.

As a result, cosmetic manufacturers are actively exploring and developing more sustainable and environmentally friendly ingredients to replace conventional synthetic materials [2]. In particular, numerous studies have been conducted on formulation development using polyglyceryl-based emulsifiers and naturally derived polymers as alternative ingredients[3],[4],[5]. However, in makeup formulations—especially W/O (water-in-oil) formulations containing UV-filtering agents, and more specifically in W/O foundations with high pigment content, the application of such alternative ingredients remains limited, and significant technical barriers still exist[6].

Achieving stable emulsions in W/O systems is inherently difficult. Moreover, formulations must meet high consumer expectations for smooth application, strong coverage, and long-lasting wear. Despite these needs, technical approaches and formulation data addressing such challenges remain insufficient.

This study aims to enhance the stability and usability of high-pigment-content W/O foundation formulations by incorporating polyglyceryl-based emulsifiers and naturally derived polymeric materials as alternatives to conventional PEG-based systems. Through this approach, we seek to contribute to the development of next-generation makeup products that are both sustainable and commercially viable.

2. Materials and Methods

Materials

The powder ingredients used in this study were titanium dioxide (200–300 nm), nano-sized titanium dioxide (15 nm), iron oxide yellow (CI 77492), iron oxide red (CI 77491), iron oxide black (CI 77499), and mica. As the emulsifier, a non-ionic surfactant system was used, in which polyglyceryl-based emulsifiers were adsorbed onto the surface of disteardimonium hectorite. Specifically, combinations of Polyglyceryl-6 Polyricinoleate, Polyglyceryl-2 Isostearate, Disteardimonium Hectorite, and Polyglyceryl-3 Polyricinoleate with Disteardimonium Hectorite were used. As a natural polymer, Bis-behenyl/isostearyl/phytosteryl dimer dilinoleyl dimer dilinoleate was employed.

Methods

Emulsion Preparation

Titanium dioxide (200–300 nm), iron oxides, and mica were dispersed in coco-caprylate/caprate. This mixture was processed using a three-roll mill (ZYN, ZYTR-50), followed by dispersion of a natural polymer to prepare a pigment base with uniformly dispersed particles. Based on this pigment base, three W/O foundation formulations were prepared with pigment contents of 15%, 20%, and 25%.

Table1. Ingredients and composition of emulsion

Phase	Ingredients	wt%		
		A	B	C
A	Disteardimonium Hectorite/Polyglyceryl-2 Isostearate/Polyglyceryl-6 Polyricinoleate		5.00	
A	Disteardimonium Hectorite/Polyglyceryl-3 Polyricinoleate/C13-15 alkane		6.00	
A	C9-12 alkane		15.00	
A	Coco-Caprylate/Caprate		8.00	
A	Caprylic/Capric Triglyceride		3.00	
A	Squalane		8.00	
B	Pigment Base +Titanium Dioxide(Nano)	15.00	20.00	25.00
C	Water		to 100	
C	Propanediol		5.00	
C	Caprylyl Glycol		0.20	
C	1,2-Hexanediol		0.80	
C	Sodium Chloride		1.00	

Evaluation of Formulation Stability and Dispersibility

The formulations were evaluated for short-term dispersibility and physical stability by centrifuging at 4,000 rpm for 10 minutes using a centrifuge (Fleta 4). Visual inspections were conducted in a stability chamber at different temperatures to monitor any changes in appearance. Viscosity changes over the course of 4 weeks were measured using a viscometer (Brookfield LVT). The particle state of the formulations was compared immediately after preparation and after 4 weeks of storage at 25℃ using an optical microscope (CX33, Olympus) to assess the particle stability of the formulation.

Evaluation of Application Performance

To ensure consistency in measurement conditions, each participant was stabilized for at least 30 minutes in an environment maintained at 22 ± 2℃ and 40–60% relative humidity before testing. A skin analysis device (VISIA-CA) was used to measure each sample three times: before application, immediately after application, and 6 hours post-application. The analysis focused on changes in spot and pore values to quantitatively evaluate the foundation's coverage and long-lasting effects.

3. Results

Centrifugation Results Based on Pigment Concentration

To evaluate the physical stability of the W/O emulsion formulations containing 15%, 20%, and 25% pigment concentrations, centrifugation was performed at 4,000 rpm for 10 minutes using a centrifuge (Fleta 4). As shown in Figure 1, no clear phase separation was observed in any of the three formulations, and all formulations generally maintained a stable dispersion state.

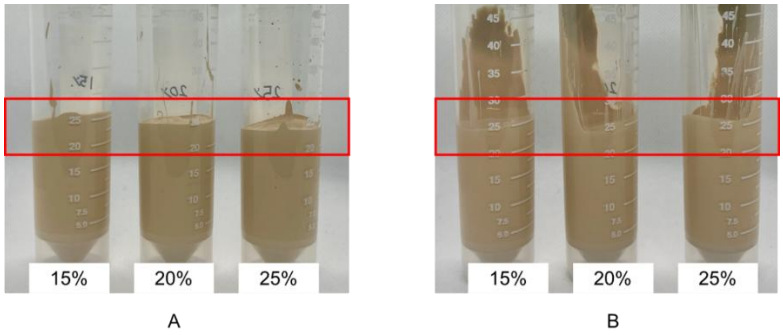

Figure 1. Stability Evaluation Using Centrifugation (4,000rpm, 10min). A) Formulation before Centrifugation / B) Formulation Immediately After Centrifugation.

Evaluation of Formulation Stability Based on Temperature and Storage Period
Each formulation was stored at 25°C, 45°C, 50°C, and 0°C for 4 weeks to evaluate stability and viscosity changes. As a result, no phase separation was observed under any temperature conditions, and the formulations maintained their overall physical stability. In addition, the initial viscosity of the formulations decreased as the pigment content increased. Under all temperature conditions, the viscosity increased over time compared to the initial viscosity and then stabilized.

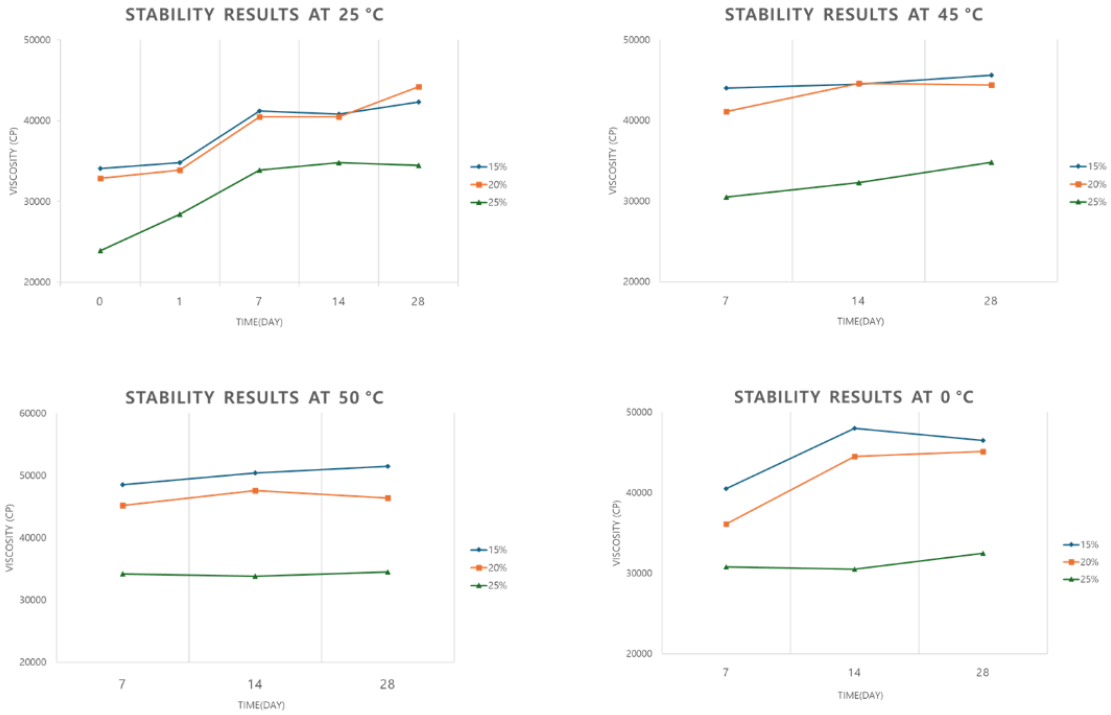

Figure 2. Viscosity Changes of W/O Foundations Containing 15%, 20%, and 25% Pigment.

Comparison of Emulsion Particle Changes
The particle state of the formulations was observed immediately after preparation and after 4 weeks of storage at 25°C using an optical microscope. After 4 weeks, voids between particles were observed in all concentrations. However, the overall physical stability of the formulations was maintained, and the particle distribution remained relatively uniform. Furthermore, the changes in particle morphology with respect to pigment concentration appeared consistent across all formulations.

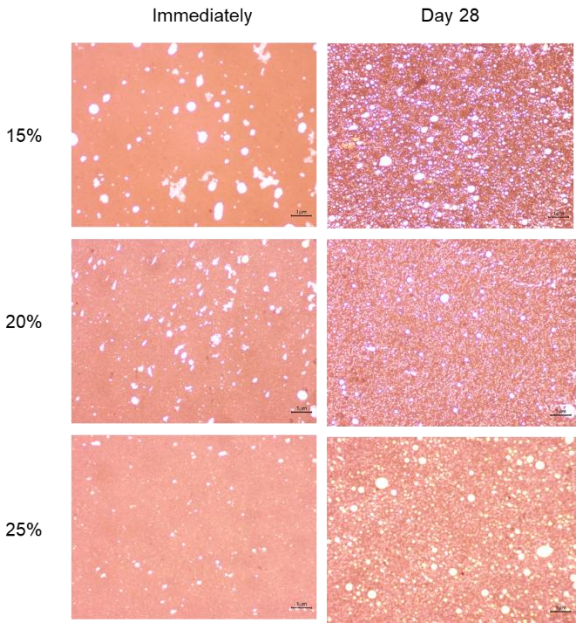

Figure 3. Images of particle state immediately after manufacturing and after 28 days (stored at 25°C) of formulations with powder contents of 15%, 20%, and 25%, captured under an optical microscope (×400).

Usability through Skin Analyzer

The pores and blemishes of five participants were analyzed using the VISIA-CA skin analysis system. Figure 4 shows representative facial images of participants taken at three time points: before application, immediately after application, and 6 hours after application. The images show a noticeable reduction in pores and blemishes immediately after application, and no significant changes were observed after 6 hours, confirming the durability and coverage effect.

The results of analyzing the results of all five participants showed that the number of pores and blemishes was reduced by 67.22% and 55.83%, respectively, immediately after application, showing an immediate coverage effect. After 6 hours, the increase rates were minimal at 10.89% and 5.77%, respectively, compared to immediately after application.

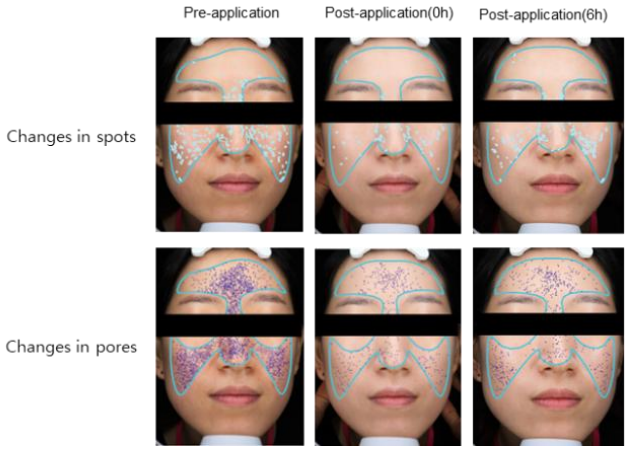

Figure 4. VISIA-CA images of a participant's facial skin showing pore and spot changes before application, immediately after application, and 6 hours post-application.

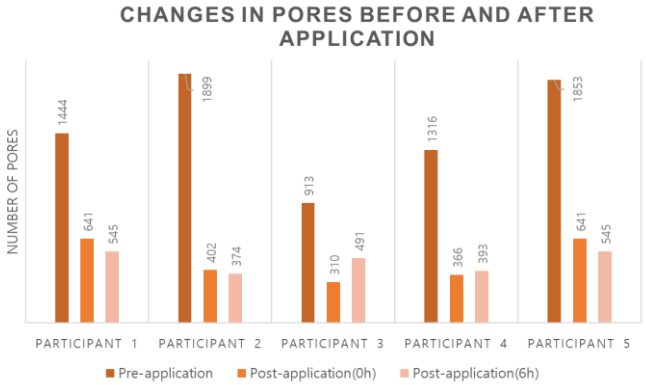

Figure 5. Analysis of pore changes before and after product application, based on VISIA-CA analysis.

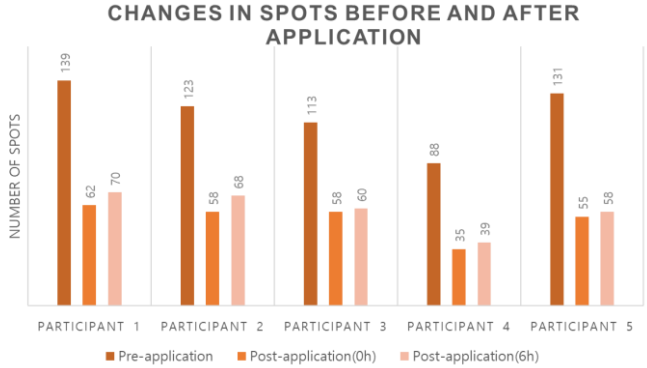

Figure 6. Analysis of spot changes before and after product application, based on VISIA-CA analysis.

4. Discussion

Conventional W/O foundation formulations have typically utilized synthetic ingredients and silicone-based surfactants to ensure adequate pigment dispersion and emulsion stability. In contrast, the present study demonstrates that W/O formulations containing high pigment concentrations can achieve excellent physical stability and dispersion by incorporating naturally derived emulsifiers and polymeric ingredients.

In particular, the clay-based polyglyceryl emulsifier system exhibited characteristics of Pickering emulsions, forming particle-stabilized interfaces that effectively prevented phase separation under external stresses such as centrifugation and temperature fluctuations. These structures are believed to play a significant role in maintaining the structural stability and homogeneity of the formulation.

Furthermore, the combination of pigment pre-treatment via roll milling and the use of natural polymers significantly improved pigment dispersion and skin adherence. This synergy contributed to a more uniform particle distribution in the oil phase, positively influencing both coverage and spreadability, as confirmed through instrumental skin analysis.

However, this study primarily focused on the effect of pigment concentration, without considering variables such as pigment type or surface treatment. Future research should investigate the compatibility of various pigment types and functional ingredients to support the broader application of natural-based cosmetic formulations.

5. Conclusion

This study demonstrated that high dispersion stability, emulsion stability, coverage, and longevity can be achieved in W/O foundation formulations containing 15–25% high concentrations of pigments through the use of naturally derived emulsifiers and polymeric ingredients. The Pickering emulsion system contributed to the enhancement of the physical stability of the formulation, while the introduction of natural polymers improved the dispersion and adhesion of pigments, thereby improving functionality in actual use. This technological approach provides a valuable direction for developing makeup products that pursue both functionality and sustainability without relying on synthetic ingredients, and it can serve as an important foundation for future research in natural-based cosmetic formulations.

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