New Application of Emulsification Technology for the SDGs Era
~Reducing waste through control of emulsification and separating~

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Abstract

Background: Emulsions, the main products of the cosmetics industry, have a large environmental impact during production and disposal. To realize a sustainable society, it is essential to manufacture emulsions using lower energy consumption and recycle them instead of disposing of them.

Therefore, we focused on METHOXY-PEG-23-METHACRYLATE/GLYCERYL-DIISOSTEARATE-METHACRYLATE COPOLYMER (M-polymer), which enables emulsification under non-thermal and only specific concentration conditions, as a sustainable emulsifier.

Method: The emulsification properties of M-polymer were evaluated using electron and Raman microscopy. Next, M-polymer was recovered from the emulsion and quantitatively analyzed by Nuclear Magnetic Resonance (NMR). Then, emulsions were prepared using the recovered M-polymer, and emulsion particle size was evaluated using an optical microscope and sensory evaluation was conducted by a triangle test. Finally, we calculated the reduction of CO_2 emissions when our conventional product was manufactured with M-polymer.

Result: Evaluation of the emulsification properties of M-polymer showed that emulsification and separation could be controlled in a concentration-dependently, and by concentrating the emulsion, a recovered material containing M-polymer could be obtained without oil contamination. Furthermore, we found that the emulsification properties of M-polymer in the recovered material unchanged after recovery. Finally, it was found that CO_2 emissions during production could be reduced by up to 70%.

Conclusion: We found that the characteristics of M-polymer allow production of emulsions using lower energy consumption and recycle emulsions after production. We

would like to spread this concept to all industries that handle emulsions, because designing emulsions that can be recycled will greatly contribute to reducing the environmental impact.

Key words: Sustainability, Separation, Emulsion, Cosmetics-Loss, CO_2 emissions, Recycle

1. Introduction.

To realize a sustainable society, various industries are working toward a "circular economy," a society in which limited resources are used repeatedly. Therefore, the cosmetics industry is promoting recycling, such as the collection and reuse of used containers.

While both emulsions and their containers tend to use naturally derived materials, only the container is currently considered recyclable. This is because to achieve high stability of emulsions, conventional emulsifiers are firmly adsorbed to the oil-water interface through a heating process, which inevitably results in CO_2 emissions during production. Furthermore, the strong adsorption of emulsifiers not only makes it difficult to recycle emulsified products, but also forcing them to be disposed of, and the waste has a negative impact on the environment [1]. Therefore, it is necessary to eliminate the need for a heating process during production, as well as to make it possible to control the separation of emulsions and the recovery of components at any time to eliminate all waste, and to produce emulsions again with the recovered material obtained. On the other hand, there are conventional cosmetic emulsifiers that do not require a heating process. However, none have achieved separation and recovery. In general, as a method of demulsify (separate) emulsion, an addition of third component such as salt [2] or a change in temperature [3] is known. But these methods only promote the merging of emulsified particles. We subsequently, considered it important to control the adsorption force of the emulsifier on the oil-water interface in order to achieve separation and recovery.

Therefore, we used emulsifiers with fine particles to achieve both emulsification without heating and control of the adsorption force of the emulsifier. Emulsification mechanisms using fine particles, such as Pickering emulsions [4], use heteroaggregation [5-7] as an adsorption force to the oil-water interface. Heteroaggregation is a cohesive force that occurs between large and small particles when different types of large particles (oil

droplets) and small particles (emulsifier) are mixed, and thus does not require a heating process during emulsification. However, as long as the emulsifier remains a fine particle, it will continue to adsorb to the oil-water interface through heteroaggregation. To cancel heteroaggregation, we focused on lyotropic liquid crystals formed by amphiphilic polymers [8]. By designing emulsifying fine particles with amphiphilic polymers, we thought that concentration-dependent and reversible structural changes would occur, and that the heteroaggregation caused by the size relationship between particles could be controlled, i.e., the state in which the emulsifier can be adsorbed on the oil droplet (emulsification) and the state in which it cannot (separation).

In this study, we used an amphiphilic random copolymer, METHOXY-PEG-23-METHACRYLATE/GLYCERYL-DIISOSTEARATE-METHACRYLATE COPOLYMER (M-polymer), to investigate whether emulsion recycling by controlling emulsification and separation is possible (Figure 1).

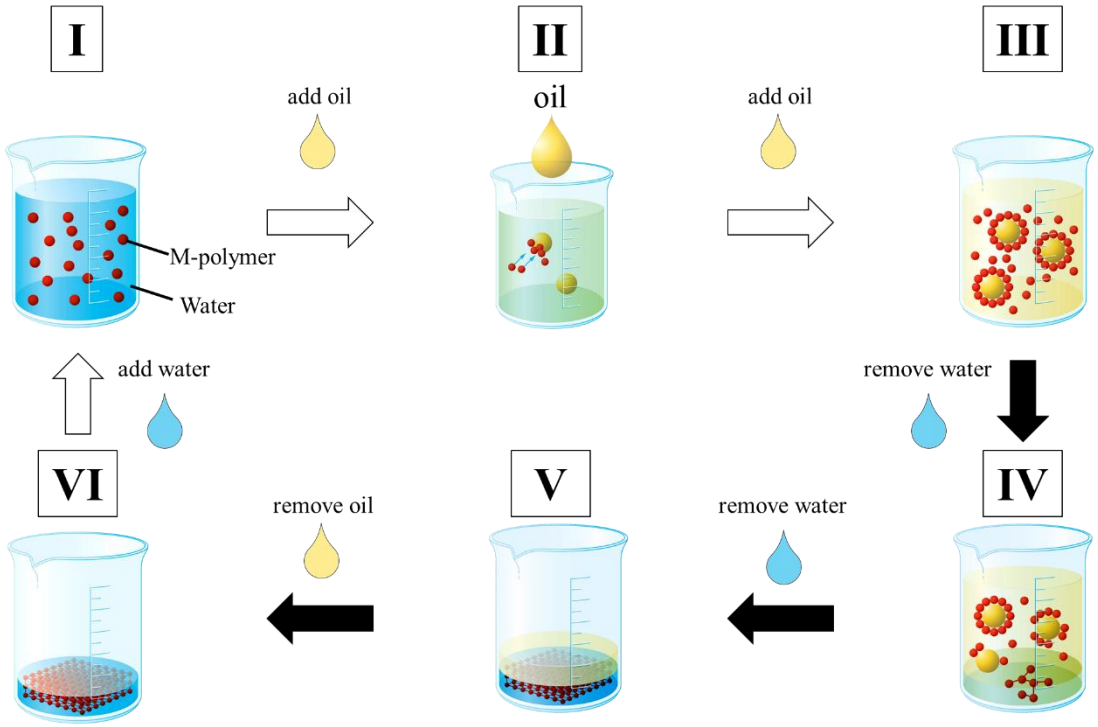

Figure 1. Concept of the recycling emulsion

I: M-polymer form fine particle and disperse in water. II: Large oil droplets are surrounded by fine particles made by M-polymer. III: The oil droplets do not aggregate, sustaining the emulsification. IV: As water removes, M-polymer detaches from oil droplets and self-assembles. V: By complete self-assembly of M-polymer, oil and water are separated. VI: Recover the aqueous phase containing M-polymer.

2. Materials and Methods.

2.1. Materials

METHOXY-PEG-23-METHACRYLATE/GLYCERYL-DIISOSTATE-METHACRYLATE COPOLYMER (M-polymer) was used as an emulsifier, made by Nichiyu Co. As moisturizers, 1,3-butanediol (1,3-BG) from Daicel Corporation and Glycerin from Emery Oleochemicals were used. As viscosity modifiers, corboxyvinyl polymer from 3V Sigma was used. Dimethicone was made by Shin-Etsu Chemical, squalane by Nikko chemicals, and isododecane by Presperse. These samples were used in the experiment without purification. Ion-exchanged water was used.

2.2. Methods

2.2.1. Observation of emulsion particles by M-polymer

To prepare an oil-in-water (O/W) emulsion, dimethicone was added to the aqueous M-polymer solution at room temperature to make the emulsion composition 1 wt% M-polymer, 30 wt% dimethicone, and 69 wt% water, and the mixture was stirred for 15 minutes at a speed of 7,000 rpm using PRIMIX ROBOMIX.

The emulsion particles of the prepared emulsions were observed using Transmission electron microscopy with freeze-fracture technique (FF-TEM). The emulsions were quickly frozen by plunging them into liquid propane (below -170 °C) in a Leica Microsystems quick-freeze sample preparation apparatus (Leica EM CPC). The frozen specimen was then broken with a glass knife using a freeze replica fabricator (FR-7000A) manufactured by Hitachi High-Technologies, and the replica, platinum and carbon, was deposited on the broken surface of the specimens. The replica film was washed with acetone and water, then adhered to a TEM grid for observation and dried. The specimen was then observed using a Hitachi High-Technologies transmission electron microscope (H-7650) at an applied voltage of 100 kV.

2.2.2. Observation of dry film formed by emulsion with M-polymer

The emulsion is mixed with M-polymer and glycerin in an aqueous solution of corboxyvinyl polymer at room temperature so that the composition of the emulsion is 2 wt% M-polymer, 20 wt% Squalane, 20 wt% Glycerin, 0.1 wt% corboxyvinyl polymer, and 57.9 wt% water. After adding glycerin, squalane was added, and an O/W emulsion was prepared by stirring at a speed of 7,000 rpm for 15 minutes using PRIMIX ROBOMIX.

A few drops of the prepared emulsion were dropped onto a Matsunami glass hydrophobic substrate (APS01) that had been washed with a cleanser, applied evenly with a 76.2 m thick Yoshimitsu Seiki doctor blade, and stored at 35°C for 2 hours to evaporate the water. The dried film was measured using a WITec Raman microscope (alpha300), a WITec Spectrometer (UHTS300) for spectroscopy of Raman scattering light, and an ANDOR Spectro Camera (Newton DU970N-BV) for detection. 3D imaging of the cosmetic films was performed by Basis analysis of WITec's software (Project FIVE). Image analysis was based on a fitting algorithm for the Raman spectra of the components, with resolutions of 500 nm/pixel, 500 nm/pixel, and 750 nm/pixel in the x, y, and z directions, respectively.

2.2.3. Recovery of M-polymer from emulsions

An O/W emulsion was prepared with the same procedure as in 2.2.1 with the composition of M-polymer 1 wt%, Isododecane 65 wt%, Glycerin 6 wt%, 1,3-BG 6 wt% and water 22 wt%.

The prepared emulsion was placed in a constant temperature box (DKM600) manufactured by Yamato Science set at 60 °C for 2 weeks and subjected to thermal energy equivalent to 3 years of storage in a 20 °C environment. After this aging, the emulsion was then concentrated using a BUCHI evaporator (R-300) until the weight of the emulsion was equal to the sum of the weight of the M-polymer, glycerin and 1,3-BG. The conditions of concentration are shown in Table 1. The concentrate was subjected to qualitative and quantitative analysis using a Bruker nuclear magnetic resonance system (AVANCE III 600). For the analysis, each component in the emulsion and the concentrate were prepared with deuterated acetone made by Sigma-Aldrich as a solvent at about 20 mass%. The ^{13}C NMR spectra of the prepared samples were measured at an observation frequency of 150.91 MHz, pulse width of 12 μs, and repetition latency of 20 sec. The total number of scans was 1024 for concentrates, M-polymer, and glycerin, and 512 for isododecane and 1,3-BG. The inverse-gated-decoupling procedure was used for quantitative analysis.

Table 1. Evaporator conditions

	Temperature (°C)	Speed (rpm)	Decompression (hPa)	Time (min)
1st Step	50	280	100	30
2nd Step	50	280	70	30
3rd Step	50	200	50	60
4th Step	80	150	20	30

2.3. M-polymer recycling properties - Investigation of recyclability of M-polymer

After the M-polymer solution was prepared by adding 22 wt% water at room temperature to the concentrate obtained in 2.2.3., 65 wt% Isododecane was added and the O/W emulsion was prepared by stirring at a speed of 7,000 rpm for 15 minutes using a PRIMIX ROBOMIX (defined as Recycle Formulation). At the same time, an emulsion with the composition described in 2.2.3 was prepared using new ingredients not used in the recovery experiment (Virgin formulation).

Recycle formulation and virgin formulation were placed at 20 °C for 1 day and at 60 °C for 2 weeks, and then three images were taken at 400x in different fields of view using an Olympus optical microscope (BX63) to evaluate the stability of the emulsion particle size over time. The emulsion particle diameters after 1 day at 20 °C and 2 weeks at 60 °C, 100 emulsion particles were randomly selected per image, and a box plot of the emulsion particle diameter distribution was created using Olympus imaging software (cellSens).

Recycled formulation (R) and virgin formulation (V), which were placed for 2 weeks at 60 °C, were sensory evaluated using the triangle test. The evaluators were 10 in-house expert panelists, and the samples presented were (R, R, V) and (V, V, R). This test was conducted with the approval of the ethical review board of POLA Chemical Industries, Inc. (approval number : 2022-F-039).

2.4. Application of M-polymer for low-energy manufacturing

Using our Product A as an example, we estimated the reduction of CO_2 emissions when this product was manufactured with M-polymer.

Based on the product manufacturing flow, the CO_2 emissions from manufacturing our Product A were calculated, and the CO_2 emissions were calculated if the heating process was no longer required.

The CO_2 emissions were calculated by multiplying Used gas volume (Nm^3) and emission factor determined by the ministry of the Environment, Japan [9].

The used gas volume (Nm^3) was calculated by the value which multiplying steam volume produced in boiler (kg) and latent heat of vaporization at boiler (kJ/kg) divided by the value which multiplying efficiency of boiler and Lower Heating Value (kJ/Nm^3). For this calculation, the boiler efficiency was assumed to be 100 %, and the lower heating value of city gas was used.

The steam volume produced in boiler (kg) was calculated by heating volume (kJ) divided by latent heat of vaporization at emulsification tank (kJ/kg).

The heating value (kJ) was calculated by multiplying volume of emulsification tank (L) and specific heat of emulsion (kJ/kg･K) and Temperature after heating minus temperature before heating (K).
The above latent heat of vaporization was calculated using actual boiler and emulsifying tank pressures and temperatures based on steam table [10].

3. Results.

3.1. Emulsification properties of M-polymer

3.1.1. Emulsification characteristics of M-polymer in the low concentration range

Figure 2 shows the FF-TEM image of the emulsion prepared using M-polymer. The oil phase was observed at the bottom of the image, and the water phase at the top of the image, confirming the existence of a layer at the interface between the two. If we focus on this layer structure, we can observe fine particles of about 10~20 nm in size, which are thought to be M-polymer. Although the results are not shown, dynamic light scattering measurement revealed that M-polymer forms aggregates with a particle diameter of 10 nm in the concentration range up to 50 wt%.

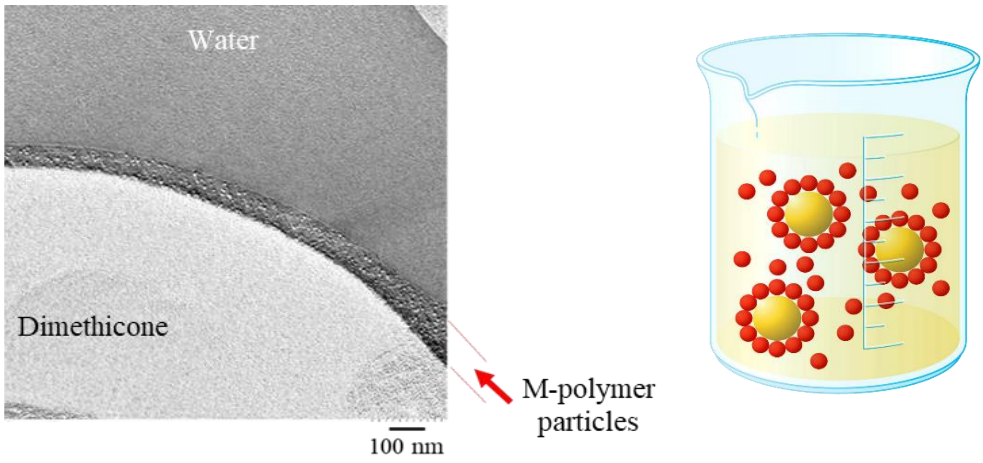

Figure 2. Transmission electron microscopy with freeze-fracture technique (FF-TEM) image of emulsion by M-polymer
An emulsion was prepared with M-polymer at 1 wt%, Dimethicone 30 wt%, water 69wt%, replica film of the freeze-fractured sample was observed using FF-TEM. There were M-polymer particles (10~20 nm) between dimethicone and water.

3.1.2. Emulsification characteristics of M-polymer in the high concentration range

Figure 3(a~d) shows Raman microscopy images of the dried emulsions.

Figure 3(a) shows squalane in yellow, Figure 3(b) shows glycerin in green, and Figure 3(c) shows M-polymer in red. Figure 3(d) shows a merged imaging image of squalane and M-polymer.

It was confirmed that each ingredient existed spread out on a flat plane, and that oil agent, squalane and M-polymer were separated into two layers. In particular, squalane was not distributed as oil droplets, indicating that demulsification occurred under the condition of high concentration of M-polymer.

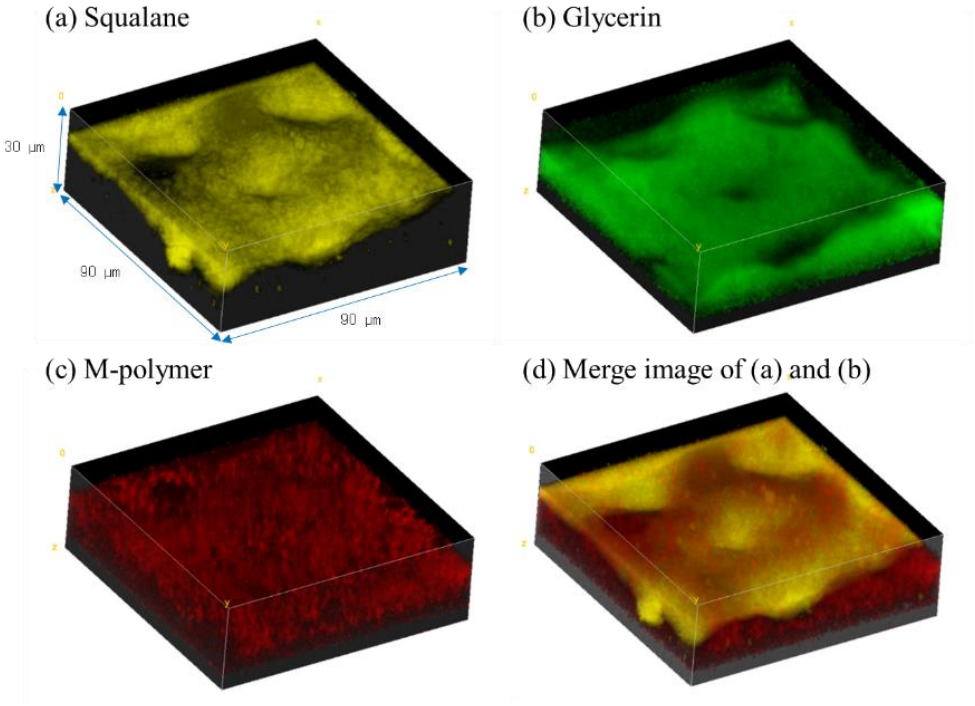

Figure 3. Raman-spectroscopy images of the 3D mapping of cosmetic membrane

The emulsion was prepared with M-polymer 2 wt%, squalane 20 wt%, glycerin 20 wt%, corboxyvinyl polymer 0.1 wt%, water 57.9 wt%, After drying, the cosmetic membrane structure of the emulsion was observed. The cosmetic membrane showed that squalane and M-polymer were separated into two layers.

3.1.3. Recovery of M-polymer from emulsions

Figure 4(a~d) shows the NMR spectrum of each component in the emulsion. Figure 4(e) shows the NMR spectrum of the recovered material obtained from the emulsion using an evaporator. Table 2 shows the results of quantitative analysis of recovered material.

From the results of Figure 4(a~d), a signal derived from polyethylene glycol (PEG), which is a part of M-polymer, was confirmed around δ=70 ppm, and no spectral overlap with the other components was observed. We used this chemical shift value for quantitative analysis of M-polymer in the recovered material (δ = 73.4 ppm for glycerin, and δ = 42.1 ppm for 1,3-BG). As a result of quantitative analysis, no oil was found in the recovered material, and mixture of M-polymer and the water-soluble components (glycerin, 1-3BG), were confirmed. In other words, M-polymer and water-soluble components were recovered from the emulsion without oil contamination.

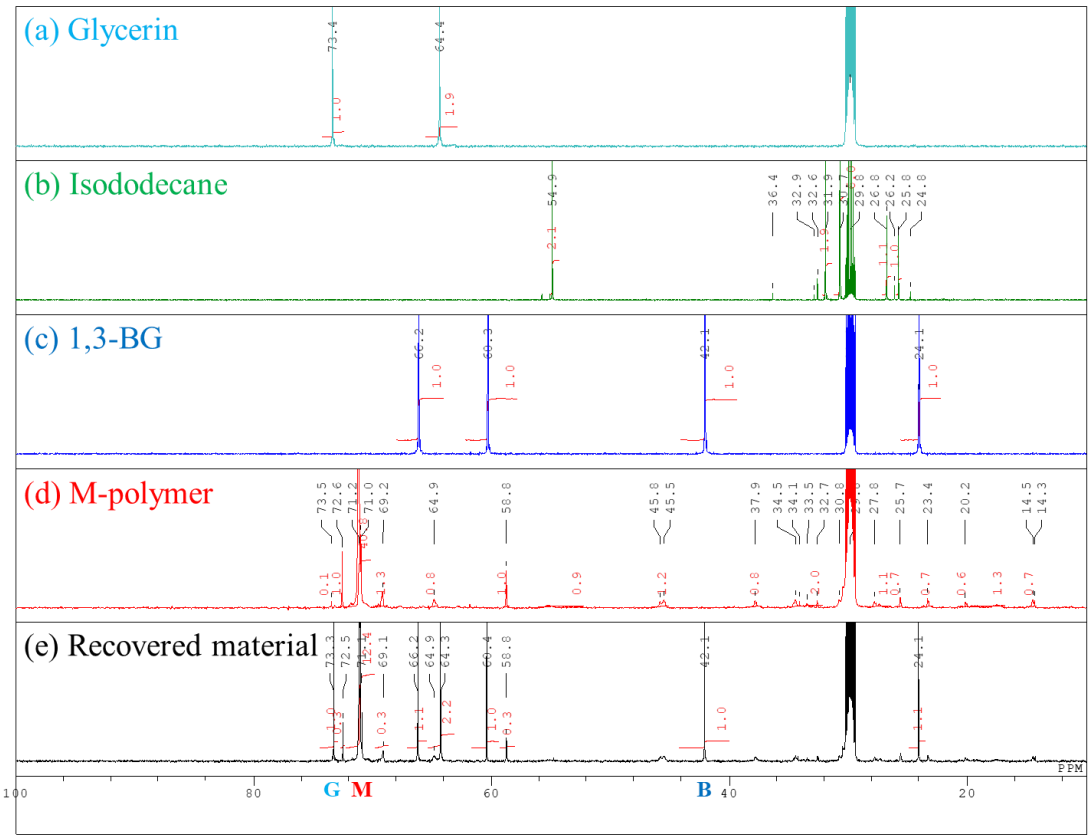

Figure 4. Nuclear Magnetic Resonance measurement of each ingredients and recovered material

Each emulsion ingredients and recovered material were dissolved in a deuterated acetone, then NMR measurement was performed. (a~d) M-polymer has a unique spectrum at δ=70 ppm due to PEG chain. (e)NMR measurement of Recovered material showed that recovered material was containing a M-polymer without oil contamination. three letters (G, M, B) means spectrum used to quantitative analysis for glycerin, M-polymer and 1,3-BG, respectively.

Table 2. The results of quantitative analysis of recovered material

Sample / Ingredients	(1) Emulsion (blending ratio)	(2) Expected recovered material (existence ratio)	(3) Actual recovered material (existence ratio)	(4) Recover efficiency (= (3) %/ (2) %)
M-polymer	1 wt%	7.7 wt%	4.1 wt%	53.2%
Isododecane	65 wt%	0 wt%	0 wt%	-
Glycerin	6 wt%	46.15 wt%	52.1 wt%	112.9%
1,3-BG	6 wt%	46.15 wt%	43.8 wt%	94.9%
Water	22 wt%	0 wt%	0 wt%	-
Total	100 %	100 %	100 %	-

3.2. M-polymer recycling properties

3.2.1. Verification of recyclability of M-polymer

Figure 5 shows optical microscope images and box plot of emulsion particle size for emulsions prepared using the recovered material obtained in 3.1.3 (recycle formulation) and for emulsions prepared using new raw materials not used in the recovery experiment (virgin formulation), stored for 1 day at 20 °C and 2 weeks at 60 °C. From box plot, there were not significant difference between emulsion particle size of recycle formulation and virgin formulation. In addition, we also confirmed no emulsification defects (separation of oil) by visual observation (data not shown).

Figure 6(a) shows the result of the triangle test using the recycle formulation (R) and the virgin formulation (V), and Figure 6(b) shows significance level of triangle test. From Figure 3, there were no significant difference between the two. This indicates that the quality of the M-polymer emulsion can be maintained before and after recycling.

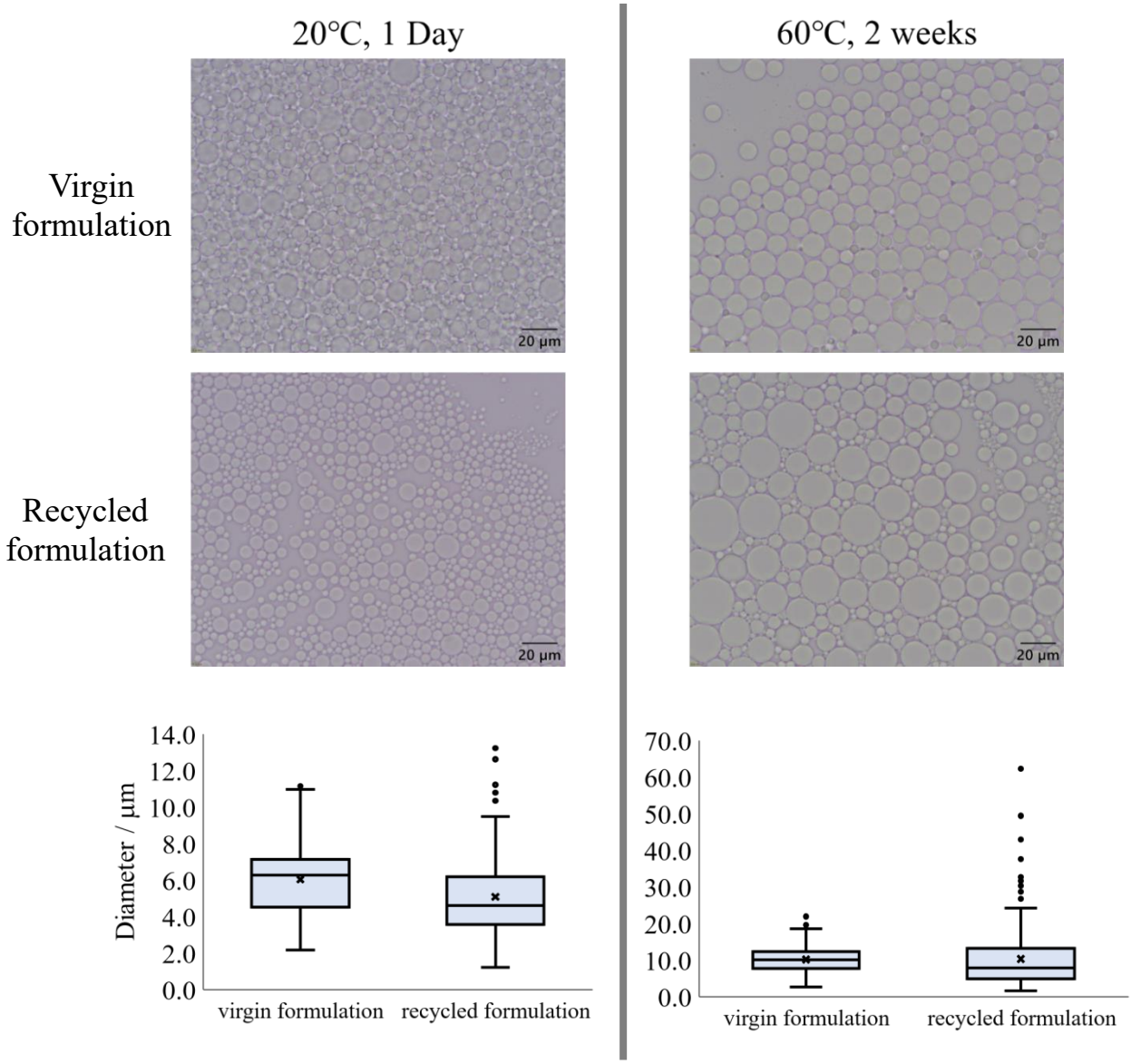

Figure 5. Optical microscope observation and size distribution of the emulsion particle size

Recycle formulation was prepared with recovered material, 22 wt% water, 65 wt% isododecane, and virgin formulation was prepared with new ingredients 1 wt% M-polymer, 6 wt% 1,3-BG, 6 wt% glycerin, 22 wt% water, 65 wt% isododecane. To confirm the difference of emulsion stability between recycle formulation and virgin formulation, each sample was stored at 20 ℃ for 1 day and 60 ℃ for 2 weeks and the emulsion particle size was measured.

In box plot, X means average and bar in the box means median, and emulsion particle size greater than 1.5 times the quartile range were shown as dot as outliers.

The quartile range for virgin and recycle formulation which were stored for 1 day at 20 ℃ were (4.5 μm – 6.2 μm – 7.1 μm), and (3.5 μm – 4.6 μm – 6.1 μm) respectively. The quartile range for virgin and recycle formulation which were stored for 2 weeks at 60 ℃ were (7.6 μm – 10.1 μm – 12.2 μm), and (5.0 μm – 7.8 μm – 13.2 μm) respectively.

(a) Result of triangle test

Combination	Number of answers	Correct answer	Result
(R, R, V)	10	4	Not significant
(V, V, R)	10	3	Not significant
Sum	20	7	Not significant

(b) Significance level of triangle test

	Minimum number of correct answers at each significance level		
Number of answers	5%	1%	0.1%
5	>4	>5	-
10	>7	>8	>9
15	>9	>10	>12
20	>11	>13	>14

Figure 6. Result of triangle test

A triangle test, a sensory test that detect the presence of difference between two samples, was conducted with recycle formulation (R) which was prepared with recovered material and virgin formulation (V) which was prepared with new ingredients that had not undergone recovery operations. Figure 6 (a) show the result of test and Figure 6 (b) is reference table for judging significant difference of triangle test.

3.3. Application of M-polymer for low-energy manufacturing

Figure 7(a) shows the CO_2 emissions generated by the current manufacturing process of Product A. Figure 7(b) shows the CO_2 emissions assumed when the emulsifier of Product A is replaced by M-polymer.

Currently, 24.0 kg of CO_2 is emitted per production run of our product A. All of this CO_2 comes from the heating process. The heating process used in the manufacture of Product A is divided into heating for the purpose of emulsification and heating for the purpose of dissolving ingredients, and the CO_2 emissions for both processes are 17.6 kg and 6.4 kg, respectively. Therefore, by replacing the emulsifier in Product A with M-polymer, we were able to calculate a reduction in CO_2 emissions of 17.6 kg (approximately 70% of the current level).

(a) Product A	Tank1 for emulsification	Tank2 for pre-heating for mixing with Tank1	Tank3 for dissolving ingredients	Sum
Heating volume (MJ)	151	126	100	377
Steam volume (kg)	69	58	46	173
Used gas volume (Nm^3)	4.3	3.6	2.9	10.9
CO_2 emission (Kg)	**9.6**	**8.0**	**6.4**	**24.0**
	⬇	**Reduction** ⬇		⬇
(b) Product A replaced by M-polymer	Tank1	Tank2	Tank3	sum
Heating volume (MJ)	0	0	100	100
Steam volume (kg)	0	0	46	46
Used gas volume (Nm^3)	0	0	2.9	2.9
CO_2 emission (Kg)	**0**	**0**	**6.4**	**6.4**

Figure 7. Calculation of the CO_2 emissions that can be reduced by using M-polymer
(a) CO_2 emissions per one production of our product A. (b) CO_2 emissions per one production of our product A replaced by M-polymer. In production of our product A, about 70 % CO_2 emissions can be reduced by replacing M-polymer.

4. Discussion.

4.1. Emulsification properties of M-polymer

In an emulsion in which M-polymer was applied as an emulsifier, interesting results were obtained: an emulsified state was observed in the low concentration range of M-polymer, while in the high concentration range of M-polymer, the M-polymer and oil were separated into two layers. The reason for this is discussed in terms of the structural properties of the M-polymer. The hydrophobic part of M-polymer is isostearic acid, the hydrophilic part is PEG, and the main chain is methacrylic acid. It has been reported that at low concentrations (50% or less) in aqueous solution, M-polymer forms core-shell type fine particles with an inner hydrophobic part and an outer hydrophilic part, and at high concentrations (50% or more), it forms a discontinuous micelle cubic phase [11].

Therefore, since M-polymer becomes fine particles in emulsions with low M-polymer concentration, heteroaggregation occurs between oil droplets and fine particles, and emulsification is considered to be realized by adsorption of fine M-polymer particles at the oil-water interface.

On the other hand, as the M-polymer concentration increases due to drying of the emulsion, the M-polymer undergoes a phase transition from fine particles to discontinuous micelle cubic, and the cohesive force due to heteroaggregation is lower than the repulsive force generated between the hydrophilic part outside the micelle and the oil-drop interface, so the M-polymer cannot adsorb at the oil-water interface. This is thought to be the cause of demulsification. After demulsification, the oil phase and the aqueous phase are separated, and since M-polymer is a water-soluble ingredient, it is considered to exist in the aqueous phase.

Therefore, by using evaporator concentration, we were able to obtain M-polymer without oil. Even when squalane which is a nonvolatile oil was used, it was visually confirmed that the oil phase and the aqueous phase containing M-polymer could be separated by centrifugation after evaporating (Figure 8). Therefore, we believe that the same mechanism for separation of emulsions using M-polymer is applicable to any oil.

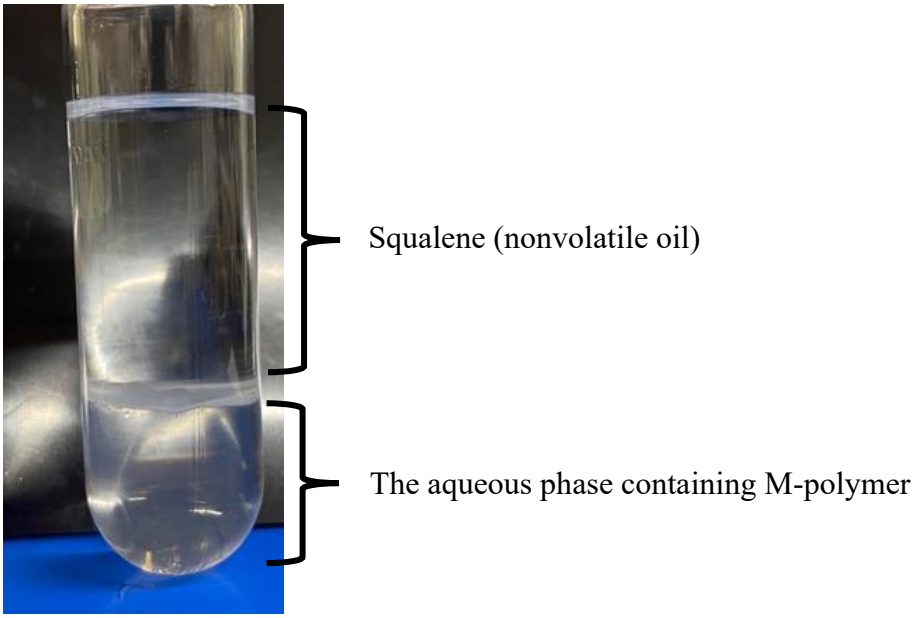

Figure 8. Separation of oil and water phases in emulsion with squalane

Even in emulsions with squalane, a nonvolatile oil, the oil and water phases could be separated by centrifugation after the evaporator. We visually confirmed that squalane in the upper layer and aqueous phase in the lower layer.

4.2. M-polymer recycling properties

The recovered material from the emulsion could be used to prepare the emulsion again. This is thought to be because the addition of water to the recovered material diluted the M-polymer in the recovered material, causing a phase transition from discontinuous micelle cubic to fine particles, and the cohesive force due to heteroaggregation between oil droplets and fine particles was generated again. Thus, separation and re-emulsification of emulsions using M-polymer is based on the lyotropic liquid crystal created by M-polymer, and as long as M-polymer maintains its own molecular structure, separation and re-emulsification can be repeated. In support of this, the recycle formulation showed no significant change compared to the virgin formulation in terms of texture and emulsion particle size. In other words, the characteristics of M-polymer as an emulsifier were considered to be unchanged before and after recycling. An increase of outliers was observed in the evaluation of the emulsion particle size of the recycle formulation, which may be attributed to the insufficient amount of M-polymer in the recycle formulation. Recovered material was used in the preparation of the recycle formulation, and it was assumed that 100% of M-polymer, 1,3-BG, and glycerin would be recovered from this concentrate. However, as shown in Table 2, 100% recovery of M-polymer was not achieved, and only about 50% was recovered. Hence, the amount of M-polymer adsorbed at the oil-water interface in the recycle formulation was lower than in the virgin formulation, and some emulsified particles were thought to have been coalescing.

In addition, in this study, we used an evaporator to recover M-polymer, but the recovery rate was only about 50% and heating was required during the recovery process. To realize truly sustainable recycling, 100% of M-polymer should be recovered from emulsions without heating process.

That is why we are currently working to develop a heatless M-polymer recovery process.

4.3. Application of M-polymer for low-energy manufacturing

Nonionic emulsifiers, which have been widely used in skin care products, as typified by the Phase Inversion Temperature emulsification method [12], optimize the Hydrophilic-Lipophilic Balance of the emulsifier through a heating process, resulting in a significant decrease in interfacial tension, thereby achieving high stability and a variety of sensations. On the other hand, M-polymer, as mentioned above, uses heteroaggregation as an adsorption force to the oil-water interface, thus eliminating the need for a heating process during emulsification. Furthermore, it has been reported that M-polymer has a wide

tolerance range for the types and amounts of oils and moisturizers [11], so it is possible to replace many of our emulsifiers with M-polymer. In other words, many of our skin care products can be manufactured without the need for a heating process. In addition, throughout the entire manufacturing process, the necessary heating process can be divided into the dissolution and emulsification processes of raw materials. Therefore, if the ingredients are all liquid, it is considered possible to manufacture the product without emitting any CO_2.

5. Conclusion.

Cosmetics provide consumers with a variety of values, including not only "beauty" but also unique "feel". In the past, much consideration has been given to the realization of these values, however in recent years, attention has finally focused on the environmental impact that occurs during and after production. We could recycle emulsions using M-polymer, in which emulsification is performed by fine particles. We were able to separate the oil phase and aqueous phase and recover M-polymer, which is indispensable for controlling emulsions. Since the water and oil phase in emulsion could be separated, this suggested the possibility of recycling oil and water-soluble ingredients. While the recovery was incomplete, the recycling of emulsions proposed in this study can reduce required volume of virgin cosmetic ingredients. This means that the low environmental footprint of M-polymer, which does not require a heating process, is considered to be significant. We believe that designing emulsions that can be recycled by utilizing the characteristics of raw materials from the design stage is a major step toward realizing a sustainable society, and we hope to spread this kind of product design widely throughout the emulsification industry.

Conflict of Interest Statement.

NONE.

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