Preparation and Thermal Properties of Fatty Alcohol/Surfactant/Oil/Water Nanoemulsions and Their Cosmetic Applications

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Abstract: Physicochemical properties of oil-in-water (O/W) emulsions containing fatty alcohols and surfactants have been investigated with the aim of developing new formulations that are less viscous and more transparent than conventional milky lotions, as well as for providing greater skin-improving effects. O/W-based creams can be converted to low viscosity milky lotions following their emulsification with a homogenizer at temperatures greater than the transition temperatures of their molecular assemblies (α-gel). The stability of the O/W emulsions evaluated in the current study increased as the transition temperatures of the molecular assemblies formed from their fatty alcohol and surfactant constituents increased. A decrease in the emulsion droplet size led to the formation of a new formulation, which was transparent in appearance and showed a very low viscosity. The absence of a molecular assembly (α-gel) formed by the fatty alcohol and surfactant molecules in the aqueous phase allowed for the formation of a stable transparent and low viscosity nanoemulsion. Furthermore, this decrease in droplet size led to an increase in the interfacial area of the emulsion droplets, with almost all of the fatty alcohol and surfactant molecules being adsorbed on the surfaces of the emulsion droplets. This was found to be important for preparing a stable transparent formulation. Notably, this new formulation exhibited high occlusivity, which was equivalent to that of an ordinary cosmetic milky lotion, and consequently provided high skin hydration. The nanoemulsion was destroyed following its application to the skin, which led to the release of the fatty alcohol and surfactant molecules from the surface of the nanoemulsion into the aqueous phase. These results therefore suggest that the fatty alcohol and surfactant molecules organized the molecular assembly (α-gel) and allowed for the reconstruction of the network structure.

Key words: nanoemulsion, molecular assembly, α-gel, phase transition, stability

1 INTRODUCTION

It is well known that oil-in-water (O/W) creams and milky lotions used in cosmetic skin care products are formulated from water, oils, surfactants and fatty alcohols, and that these products can be used to improve the appearance and condition of the skin. O/W creams can be solidified, and the viscosity of milky lotions can be increased because the fatty alcohol and surfactant molecules contained in these products can form molecular assemblies in the aqueous phase, which can give rise to network structures (α-gel). Molecular assemblies of this type consist of a lamellar structure called an α-gel, where the alkyl chains of the fatty alcohols and surfactants are packed in a hexagonal manner. These assemblies are responsible for the rich and emollient feeling of these products. Furthermore, it has been reported that such types of molecular assemblies give rise to the skin moisturizing effects of O/W creams and milky lotions.

In our previous studies, we investigated the physicochemical properties of O/W emulsions containing fatty alcohols and surfactants with the aim of developing a new cosmetic formulation with low viscosity, transparent appearance and excellent skin-improving effects. The network structures of O/W creams containing fatty alcohols, surfactants, oil and water could be disrupted or even broken up completely by emulsification with a homogenizer at temperatures above the transition temperature of the molecular assembly. This process would therefore allow for the conversion of an O/W cream to a milky lotion with low viscosity. However, the subsequent cooling of these milky lotions would allow the network structures to reform,
which would lead to an increase in the viscosity of these mixtures and their solidification. The results of our previous study revealed that the stability of the viscosity increased as the transition temperature of the molecular assembly (α-gel) formed from the fatty alcohol and surfactant molecules increased. Furthermore, reducing the size of emulsion droplets led to a new formulation that was transparent in appearance and had low viscosity. Although this new formulation was transparent and showed low viscosity, it developed a creamy texture following its application and exhibited excellent skin-improving effects. Furthermore, this new formulation and skincare method were well received by test subjects. Analytical data suggested that these behaviors could be attributed to changes in the structure and state of the molecular assembly (α-gel) in the emulsion.

In this study, we have investigated the mechanisms responsible for the stabilization of nanoemulsions. To enhance our understanding of this process, we have evaluated the impact of changes in the droplet size of these emulsions on the thermal properties of the molecular assembly (α-gel). Furthermore, we have investigated the impact of applying these products into the skin on their cosmetic properties of these products.

2 EXPERIMENTAL PROCEDURES
2.1 Materials

Behenyl (C_{22}OH), stearyl (C_{18}OH), and cetyl (C_{16}OH) alcohols were used as fatty alcohols (Nikkol Chemicals Co., Ltd, Tokyo, Japan). Potassium behenate (C_{22}COOK), potassium stearate (C_{18}COOK), and potassium palmitate (C_{16}COOK) were prepared by treating the corresponding fatty acids with potassium hydroxide. Sodium cetyl sulfate (C_{18}SO_{4}Na; Nikko Chemicals Co., Ltd) and sodium stearoyl glutamate (C_{18GluNa; Ajinomoto Co., Tokyo Japan}) were used as anionic surfactants. Behenyl trimethyl ammonium chloride (BTAC) and stearyl trimethyl ammonium chloride (STAC) were used as cationic surfactants (Nikkol Chemicals Co., Ltd). Glycerol, 1,3-butylene glycol, and petroleum jelly were purchased from Tokyo Chemical Industry Co., Ltd (Tokyo, Japan). Liquid paraffin (LP) and sodium behenate were purchased from Otsuka Electronics Co., Osaka, Japan. Cetyl 2-ethyl-hexanoate was purchased from Nikko Chemicals Co., Ltd. All the other materials were of cosmetic grade and were used without further purification. The water used was deionized and distilled.

2.2 Sample preparation

2.2.1 Fatty alcohol/surfactant/water system (oil free system)

Molecular assemblies (α-gel) consist of three moles of fatty alcohol and one mole of surfactant. Thus, we initially investigated fatty alcohol/surfactant/water systems with a surfactant/fatty alcohol molar ratio of 1/3. The total concentration of the fatty alcohol and surfactant molecules in the test systems was set at 2.5 or 5.0 wt%. The fatty alcohol/surfactant/water systems were prepared as follows. Mixtures of surfactant, fatty alcohol, and water were heated at 80°C, and homogenized with a high-pressure homogenizer (a Microfluidizer, Microfluidics Co., Westwood, MA, USA) at temperatures above the transition temperatures of the molecular assemblies. After the homogenization, the mixtures were rapidly cooled to room temperature.

2.2.2 Emulsion (fatty alcohol/surfactant/oil/water system)

The emulsions were prepared as follows. The fatty alcohol/surfactant/water systems were stirred with an oil phase and emulsified at 80°C with a high-speed mixer. The resulting coarse emulsions were homogenized with a high-pressure homogenizer (Microfluidizer, Microfluidics Co.), which was operated at 20.7–55.2 MPa. The emulsions were subsequently recycled 1–10 times through an interaction chamber of the high-pressure homogenizer at temperatures greater than the transition temperatures of the molecular assemblies contained in the emulsions. After the homogenization process, the mixtures were cooled to room temperature. Nanoemulsions were prepared using the same process. The key feature of this method was the homogenization of coarse emulsions with aqueous phases containing large quantities of water-soluble solvents.

2.3 Sample characterization

The phase transition behaviors of the fatty alcohol/surfactant/water systems and emulsions were determined by differential scanning calorimetry (DSC; SSC-120, Seiko Instrument & Electronics Co., Chiba, Japan). Differential scanning calorimetry is performed by raising the temperature of the insulator from 5 to 100°C at a temperature rise rate of 2°C/min. The mean droplet diameters of the emulsions were determined by dynamic light scattering with a rotational viscometer (Viscomtron rotary viscometer, Shibaura System Co., Tokyo, Japan) at revolutions per minute (rpm) for 3 min and 30°C. In order to attain thermal equilibrium, the sample was kept at 30°C for 30 min before the viscosity measurement. The turbidity of the samples was estimated by measuring the absorbance at 600 nm with a spectrophotometer (U-3410, Hitachi Co., Tokyo, Japan).

2.4 Physiological evaluation

It is well known that the hydration of the skin can be en-
enhanced by increasing the occlusivity of cosmetic creams and milky lotions\(^{18}\). The occlusivity of the formulations prepared in the current study was estimated by reducing their trans-epidermal water loss (TEWL). Ten healthy male and four healthy female participants of 23–33 years of age volunteered in the study. A small area of skin (4 × 2 cm\(^2\)) on the forearm of each participant was used as the measurement site. The TEWL values were measured both before and 2 h after the application of 100 µL (12.5 µL/cm\(^2\)) of each formulation. Although the amount of application of cosmetics was generally 2.5 µL/cm\(^2\), the amount of application was increased five times in order to improve the accuracy of the TEWL measurement.

The occlusivity was calculated with the help of the following equation (Eq. 1):

\[
\text{Occlusivity} = \frac{(\text{TEWL before application} - \text{TEWL after application})}{\text{TEWL before application}}
\]

An occlusivity of 1 therefore indicates that no water evaporated from the skin following its treatment with the formulation. The occlusivity values of the two different formulations were measured at the same time for the same subject.

3 RESULTS and DISCUSSION

3.1 Screening of optimum combination of fatty alcohol and surfactant

Fatty alcohol/surfactant/water systems containing various combinations of fatty alcohols and surfactants were screened in the current study to determine the optimum combination of the fatty alcohol and surfactant. Table 1 shows the transition temperature and stability properties of the different fatty alcohol/surfactant/water systems prepared in the current study. The data marked with an asterisk (i.e., *) in Table 1 have been taken from a previous study\(^ {14}\). All of the systems showed very low viscosity immediately after their preparation. Samples of the different fatty alcohol/surfactant/water systems were analyzed by differential scanning calorimetry (DSC) immediately after their preparation, and the resulting DSC curves revealed a single transition peak for each sample. Notably, the transition temperatures of the mixtures were higher than those of their individual components, which suggested that molecular assemblies (α-gel) had successfully formed in all of the samples\(^ {7}\). The stability of each fatty alcohol/surfactant/water system was found to be dependent on the transition temperature of its molecular assembly and increased with increasing temperature. Systems with a low transition temperature such as C\(_{18}\)OH/C\(_{18}\)E\(_{15}\), C\(_{16}\)OH/C\(_{18}\)E\(_{15}\), C\(_{18}\)OH/

| Amphiphile Surfactant | Transition Temperature (°C) | Stability of fatty alcohol/surfactant/water system | Stability of Emulsion |
|-----------------------|-----------------------------|--------------------------------------------------|-----------------------|
| C\(_{18}\)OH, C\(_{18}\)OH(6:4) C\(_{18}\)E\(_{15}\) | 57* | Solidification* | Solidification* |
| C\(_{22}\)OH, C\(_{18}\)OH(8:2) C\(_{18}\)E\(_{15}\) | 56* | Increase in viscosity* | Increase in viscosity* |
| C\(_{18}\)OH, C\(_{17}\)COOK, C\(_{15}\)COOK(1:1) | 64 | Solidification | Solidification |
| C\(_{18}\)OH, C\(_{16}\)OH(6:4) C\(_{17}\)COOK, C\(_{15}\)COOK(1:1) | 67* | Solidification* | Solidification* |
| C\(_{18}\)OH, C\(_{18}\)OH(6:4) C\(_{17}\)COOK, C\(_{15}\)COOK(1:1) | 69 | Solidification | Solidification |
| C\(_{22}\)OH, C\(_{18}\)OH(8:2) C\(_{16}\)SO\(_{4}\)Na | 74* | Slight increase in viscosity* | Slight increase in viscosity* |
| C\(_{22}\)OH, C\(_{18}\)OH(8:2) C\(_{18}\)N(CH\(_{3}\))\(_{3}\)Cl | 78* | No change in viscosity* | No change in viscosity* |
| C\(_{18}\)OH, C\(_{18}\)OH(6:4) C\(_{18}\)N(CH\(_{3}\))\(_{3}\)Cl | 72 | Slight increase in viscosity | Slight increase in viscosity |
| C\(_{22}\)OH, C\(_{18}\)OH(8:2) C\(_{18}\)N(CH\(_{3}\))\(_{3}\)Cl | 78* | No change in viscosity* | No change in viscosity* |
| C\(_{18}\)OH, C\(_{18}\)OH(8:2) C\(_{18}\)N(CH\(_{3}\))\(_{3}\)Cl | 74* | No change in viscosity* | No change in viscosity* |

Table 1 Screening for the optimum combination of fatty alcohol and surfactant.
C₁₇COOK and C₁₅OH/C₁₆COOK aqueous systems solidified during storage at 50°C, most likely because their network structures could not be reconstructed.

The systems described above were also treated with 5 wt% liquid paraffin as an oil to evaluate its impact on their stability. The resulting mixtures were homogenized under 55.2 MPa of pressure at 80°C. All of the emulsions had droplet sizes in the range of 60–100 nm and very low viscosities of less than 100 mPa·s immediately after their preparation. The stabilities of these mixtures were evaluated following one month of storage at 50°C. Table 1 shows the stability data of these emulsions after they had been stored for one month at 50°C. None of the emulsions solidified during the storage process. The viscosities of the emulsions based on combinations that could form an α-gel with a higher transition temperature, such as the C₂₂, C₁₈OH/C₂₁, C₁₇COOK, C₂₂OH/C₁₈GluNa and C₂₂OH/C₂₂N(CH₃)₃Cl aqueous systems, were unchanged following one month in storage at 50°C.

3.2 Relationship between emulsion stability and phase transition behavior

To determine the optimum conditions for making stable nanoemulsions containing an α-gel structure, we prepared a variety of different nanoemulsions and evaluated their stabilities. The C₂₂, C₁₈OH/C₂₁, and C₁₇COOK/LP aqueous systems were selected as stable nanoemulsion systems.

At first the sample that changed the weight ratio of oil (liquid paraffin) to combined fatty alcohols and surfactants was prepared as shown in Table 2, and their physical properties were investigated. The turbidity of the emulsion increased significantly after it had been stored for one month at 50°C when the weight ratio of oil to combined fatty alcohols and surfactants was extremely small.

Then the sample from which particle size differs by the same composition was prepared as shown in Table 3. The stability of the emulsion increased with decreasing emulsion droplet size.

DSC measurements were carried out to determine the effects of several different factors on the stability of the emulsion. Figure 1 shows the DSC curves of fatty alcohol/surfactant/water system (A) with a ratio of 0 (sample a in Table 2), emulsion (B) with a ratio 0.4 (sample b in Table 2) and emulsion (C) with a ratio of 4 (sample c in Table 2). The DSC curve of (A) contained a single transition peak corresponding to the molecular assembly at 78°C. The DSC curve of (B) contained two transition peaks at 64 and 78°C, which were attributed to a new transition peak and a molecular assembly peak, respectively. The area of the latter peak was small compared with that of the DSC curve of fatty alcohol/surfactant/water system (A). The DSC curve of (C) contained a single transition peak at 64°C, and the peak of the molecular assembly disappeared. These results therefore show that the nanoemulsion that was in the presence of the molecular assemblies (α-gel) in the aqueous phase was unstable.

Figure 2 shows the DSC curves of emulsion (E), with a droplet size of range 1–10 µm (sample e in Table 3);

| Table 2 | Preparation of the test samples and their stability. |
|---------|----------------------------------------------------------|
|         | a            | b            | c            |
| Behenyl alcohol | 1.2          | 1.2          | 1.2          |
| Stearyl alcohol | 0.3          | 0.3          | 0.3          |
| Behenic acid | 0.5          | 0.5          | 0.5          |
| Stearic acid | 0.5          | 0.5          | 0.5          |
| Potassium hydroxide | 0.13 | 0.13 | 0.13 |
| Liquid paraffin | –            | 1            | 10           |
| Water | 97.37 | 96.37 | 87.37 |
| Total | 100          | 100          | 100          |
| Weight ratio of oil to combined amphiphile and surfactant | 0 | 0.4 | 4 |
| Particle size (nm) | 25nm | 30nm | 110nm |
| Turbidity(abs. at 600 nm) and appearance immediately after preparation | Transparent liquid | Transparent liquid | Translucent liquid |
| Turbidity(abs. at 600 nm) after one month at 50°C | 0.26 | 1.29 | 0.47 |
| Stability after one month at 50°C | Increase in turbidity | Increase in turbidity | No change in turbidity |
emulsion (F), with a droplet size of 120 nm (sample f in Table 3); nanoemulsion (G), with a droplet size of 30 nm (sample g in Table 3); and fatty alcohol/surfactant/water system (D), which did not contain oil (sample d in Table 3). All three of these emulsions were prepared with the same composition of materials, as shown in Table 3, but had different emulsion droplet sizes. The DSC curve of emulsion (E) contained a single transition peak at 75°C corresponding to the molecular assembly. The DSC curve of emulsion (F) contained two transition peaks: a peak for the molecular assembly at 75°C and a new peak at 64°C. The area of the peak corresponding to the molecular assembly was smaller than that for the DSC curve of emulsion (E). The DSC curve for emulsion (G) contained a single transition peak at 64°C.

These results clearly demonstrate that small emulsion droplets can be used to stabilize an emulsion, and that the α-gel structure typically found in the aqueous phase of an emulsion is not present in stable fine emulsions. Furthermore, it is noteworthy that the stability of an emulsion increases with decreasing emulsion droplet size and that this process is related to the amount of the α-gel structure in the aqueous phase. To develop a deeper understanding of this behavior, we investigated the relationship between the emulsion droplet size and the stability of the corresponding emulsions, as well as the impact of changes in the emulsion droplet size on the thermal properties of the resulting emulsions. The C22, C18OH/C21, and C17COOK/LP systems showed complex behaviors because of the coexistence of fatty acids in the low pH range. For this reason, we switched to a simple α-gel system using C18N(CH3)3Cl as a surfactant and C18OH as a fatty alcohol. The composition of the resulting emulsion is shown in Table 4. The coarse emulsion resulting from the initial mixing of the different components was converted to a fine emulsion by using a high-pressure emulsifier. Furthermore, it was possible to adjust the emulsion droplet size within the range of 65.4–713.7 nm by simply changing the emulsification pressure of the high-pressure homogenizer or by increasing the number of cycles through the interaction chamber. Viscosity data for the different samples are shown in Fig. 3. The viscosities of the different samples were measured one hour after their preparation. The viscosity of the coarse emulsion (droplet size = 713.7 nm), prepared with a homomixer was 3400 mPa·s and it increased to 6300 mPa·s one month after storage at 50°C. The results revealed that all of these samples had a viscosity of less than or equal to 10 mPa·s However, the viscosities of the emulsions with large

### Table 3  Preparation of emulsions with various particle sizes and their physicochemical properties.

| Sample | Preparation Method | Particle Size (nm) | Viscosity (mPa·s) | Turbidity (abs. at 600 nm) | Appearance Immediately After Preparation |
|--------|--------------------|-------------------|------------------|---------------------------|-----------------------------------------|
|  a     | High speed mixer   | >1000             | 880              | >3.00                     | Milky white                            |
|  b     | High speed mixer   | >1000             | 1020             | >3.00                     | Milky white                            |
|  c     | High pressure homogenizer | 120         | 18               | 0.44                      | Translucent liquid                     |
|  d     | High pressure homogenizer | 30          | 10               | 0.25                      | Transparent liquid                     |
|  e     | High speed mixer   | >1000             | 18               | >3.00                     | Milky white                            |
|  f     | High pressure homogenizer | 120         | 18               | 0.6                       | Translucent liquid                     |
|  g     | High pressure homogenizer | 30          | 10               | 0.26                      | Transparent liquid                     |

**Properties of fatty alcohol/surfactant/oil/water nanoemulsions**

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emulsion droplet sizes increased significantly after one month of storage at 50°C, whereas the viscosities of emulsions with extremely fine droplet sizes did not change.

The DSC curves of these samples are shown in Fig. 4. The DSC curve of the emulsion with a particle size of 713.7 nm was almost identical to that of the gel without oil. As the particle size decreased, we observed the formation of a new peak at a lower temperature to that of the peak corresponding to the α-gel. Furthermore, the area of the peak corresponding to the α-gel at 75°C became smaller as the emulsion droplet size decreased, whilst the area of the low-temperature peak increased. Taken together, these results revealed that the breakdown of the molecular assembly formed from the fatty alcohol and surfactant molecules in the aqueous phase was a key condition for the formation and maintenance of a transparent nanoemulsion. Decreasing the emulsion droplet size led to the formation of an oil/water interface in the emulsion. The fatty alcohol and surfactant molecules required for the formation of the α-gel structure would consequently be adsorbed at the newly generated oil/water interface, which would lead to a reduction in the amount of α-gel in the aqueous phase. These results therefore provided a clear indication that reducing the droplet size leads to an increase in the interfacial area, which is important for the preparation of new formulations.

Changes in the structures of the emulsions resulting from a reduction in their emulsion droplet size are shown in Fig. 5. The fine structure of the fatty alcohol/surfactant/oil/water emulsion prepared using a standard emulsification technique is shown in Fig. 5(A). The fatty alcohol and surfactant molecules in this mixture formed a molecular assembly in the water phase, as well as a network structure between the emulsion particles. The viscosity of the emulsions containing an α-gel structure showed a significant
decrease when they were heated at temperatures above the α-gel transition temperature, as shown in Fig. 5(B).

The molecular assemblies existed in the aqueous phase, where the emulsion droplet size was in the range of 81.1–713.7 nm, and the number of fatty alcohol and surfactant molecules was high. Reducing the particle size led to an increase in the interfacial area, which meant that more of the fatty alcohol and surfactant molecules involved in the molecular assembly could be adsorbed at the droplet interface. The molecular assembly disappeared from the aqueous phase, as shown in Fig. 5(C), which coincided with an increase in the stability. These results therefore show that a reduction in the droplet size can be used to increase the interfacial area, which is an important consideration for the preparation of a new formulation.

3.3 Structural change in the new formulation during application to the skin

Skin hydration is an important function of cosmetic skin-care products. Dry skin can be hydrated using O/W creams and milky lotions with sufficiently high occlusive properties. With this in mind, we evaluated the occlusivity of our new formulation by comparing it with those of a milky lotion and a lotion. The compositions of the different formulations used in this comparison are shown in Table 5 (a), (b) and (c). Conventional lotion and milky lotion were prepared from composition (a) and (b), respectively. The new formulation was prepared from composition (c). The occlusivity of each formulation was estimated based on the difference in its TEWL values before and after its application. Figure 6 shows that the occlusivity of the new formulation was similar to that of the milky lotion, which contained three times as much oil. This result therefore suggested that the new formulation possessed similar appearance and viscosity properties to a lotion and provided high levels of skin hydration.

Our new formulation was transparent following its application and had a low viscosity similar to that of a lotion. However, the initial light lotion-like feeling of this formulation changed to a richer cream-like feeling during its application to the skin. This change in the feel of the formulation was attributed to the breaking down of the emulsion as it was applied to the skin and the evaporation of water, which would result in the release of the adsorbed fatty alcohol and surfactant molecules into the aqueous phase. The changes in the physical properties of the formulation during its application to the skin were investigated by DSC analysis. The DSC curves of the nanoemulsion listed in
The DSC curve of the nanoemulsion (Fig. 7 (A)) before application, contained a single peak at 63°C. However, the single DSC peak was separated into a broad peak at 54°C and a sharp peak at 65°C by its application to the skin. We suspect that the process of applying the nanoemulsion to skin has resulted in the observed structural change.

Figure 7 (D) and (E) shows the DSC curves of the oil-free system (α-gel) listed in Table 5 (d) before and after application to the skin, respectively. The transition temperature of the α-gel decreased from 76 to 66°C following its application to the skin. This decrease in the transition temperature was attributed to an increase in concentration of water soluble components in the aqueous phase following the application process. These results therefore suggested that the new peak detected in the nanoemulsion at 65°C following its application to the skin could be attributed to the formation of an α-gel structure. Furthermore, it is also clear from these results that the structure of the nanoemulsion was destroyed by the application process, which resulted in the release of the fatty alcohol and surfactant molecules from the surface of the nanoemulsion droplets into the aqueous phase. Taken together, these results suggested that the fatty alcohol and surfactant molecules were responsible for the organization of the molecular assembly (α-gel) and the reconstructed network structure. This formulation was therefore easy to spread like a lotion, and subsequently provided a rich cream-like feeling. The high occlusivity of this formulation may have therefore been

![Image](image_url)
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4 CONCLUSIONS

The physicochemical properties of O/W emulsions containing fatty alcohols and surfactants have been investigated with the aim of developing a new cosmetic formulation. The following conclusions can be drawn based on the results obtained:

1. The stability of the viscosity of the fatty alcohol/surfactant/water systems was found to be dependent on the transition temperature of the molecular assembly formed by the fatty alcohol and surfactant molecules. The stability of the viscosity increased with increasing transition temperature. The C_{22}OH, C_{18}OH/C_{21}COOK, C_{17}COOK C_{22}OH/C_{18}GluNa, and C_{22}OH/C_{22}N(CH_{3})_{3}Cl aqueous systems were the most stable of all of the formulations tested in the current study, and maintained a constant low viscosity. The stability of these systems was attributed to the molecular assembly being unable to reconstruct the network structure. A molar ratio of 3:1 for the fatty alcohol and surfactant afforded a high level of stability. The alkyl chains of the fatty alcohol and surfactant molecules in the molecular assembly were packed in a hexagonal manner.

2. Emulsions based on a combination of components capable of forming an α-gel structure with a high transition temperature, including the C_{22}, C_{18}OH/C_{21}, C_{17}COOK, C_{22}OH/C_{18}GluNa, and C_{22}OH/C_{22}N(CH_{3})_{3}Cl aqueous systems, did not solidify or did not change viscosity at temperatures below the transition temperature of the α-gel. Preventing the solidification of an emulsion is an important factor for preventing the reconstruction of the network structure.

3. Reducing the emulsion droplet size afforded a new formulation that was transparent in appearance and possessed very low viscosity. The absence of the molecular assembly (α-gel) formed from the fatty alcohol and surfactant molecules in the aqueous phase stabilized this transparent and low viscosity nanoemulsion. Most of the fatty alcohol and surfactant molecules were adsorbed on the surfaces of the emulsion droplets. Reducing the droplet size led to an increase in the interfacial area, which was important for the preparation of this new formulation.

4. Our new formulation exhibited high occlusivity, which was equivalent to that of a standard cosmetic milky lotion, and therefore provided high skin hydration. The nanoemulsion was destroyed following its application, leading to the release of the fatty alcohol and surfactant molecules from the nanoemulsion surface into the aqueous phase. These results therefore suggested that the fatty alcohol and surfactant molecules effectively organized the molecular assembly (α-gel) and reconstructed the network structure.

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Fig. 7 Phase transition behavior of the new formulation before and after its application. (A) new formulation prior to the application (Table 5(c)), (B) new formulation during the application (Table 5(c)), (C) new formulation after the application (Table 5(c)), (D) oil-free system prior to the application (Table 5(d)) and (E) oil-free system after the application (Table 5(d)).

caused by the high transition temperature of the molecular assembly.
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