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Vibrational Test for Evaluation of Creams. II.[1] Stability of O/W Creams Containing Polyoxyethylene Sorbitan Stearates[2]

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Five O/W creams with different hydrophilic–lipophilic balance (HLB) values were prepared. The stability of these creams was examined by means of a storage stability test for three months and a vertical vibrating test which caused a first-order breakdown of viscoelastic structures formed in the creams at the rates of $K_{\eta'}$ and $K_{G'}$ for dynamic viscosity and dynamic modulus, respectively. Creams that exhibited lower values of $K_{\eta'}$ and $K_{G'}$ were more stable in the storage test. This vibrating test may be useful instead of a prolonged storage test for estimating the stability of creams in comparative screening during development, based on the selection of creams with lower values of $K_{\eta'}$ and $K_{G'}$.

Keywords——stability; vibrational test; O/W cream; viscoelasto recorder; storage test

The estimation of the stability of creams, which are widely used in the field of cosmetics and pharmaceutics, is important to ensure that they have an adequate life span. The final purpose of this series of studies is the establishment of accelerated tests for estimating the storage stability of creams. The time required and the expense of product development can be reduced if an accelerated test requiring only a few weeks can be used to predict the possible shelf life at room temperature. Practically, there are two stages in estimating colloid chemical stability in the development of a cream. First, many samples of creams are examined by means of a comparative screening test, for example, a storage test for a few months at 5 and 40 °C. Second, some creams are then selected and stored at room temperature for a long time to establish the expected life span of the creams.

A centrifuge test[3] and a high-temperature accelerated test[4] have already been reported, though they can not completely estimate the stability.[1] Preliminary studies[1] indicated that vertical vibration imposed on O/W creams caused progressive destruction of viscoelastic structures in the creams according to a first-order representation and accelerated a coalescence of oil globules dispersed in the creams. The purpose of this study was to examine the vertical vibrating test in order to assess whether it can be used to estimate the stability of O/W creams containing polyoxyethylene sorbitan monostearates blended together so as to give hydrophilic–lipophilic balance (HLB) values from 10.2 to 14.3, as a comparative screening test for selecting a HLB value giving maximum stability. The applicability of this vibrating test to O/W and W/O emulsions stabilized with other surfactants will be discussed else-where.

Experimental

Materials——The materials used to prepare O/W creams (as shown in Table I) were as follows. The solid oil was a mixture of ten parts of stearyl alcohol and three parts of cetyl alcohol (both of JP grade). The liquid oil was a mixture of ten parts of squalane and two parts of silicone oil, which were of the Japanese Standards of Cosmetic Ingredients. The 5.5% (w/w) of minor constituents in Table I consisted of 4.5% propylene glycol, 0.5% parabens, and

TABLE I. Composition of the Creams[a)]

Constituents	Sample (g) (O/W type)
Oils	
Solid	13
Liquid	12
Water	65
Emulsifying agents (Polyoxyethylene sorbitan monostearate)	4.5
Minor constituents	5.5

[a)] The following creams were prepared with two kinds of polyoxyethylene sorbitan monostearate, TS-10 and TS-106, from Nikko Chemicals Co., Ltd. The HLB value of these creams were calculated from the ratio of these surfactants. Sample A (HLB 10.2); sample B (HLB 11.4); sample C (HLB 12.5); sample D (HLB 13.7); sample E (HLB 14.3).

0.5% ingredients for pH control (including citric acid and sodium hydroxide), which kept the pH value of these creams at 5.5. Emulsifying agents, polyoxyethylene sorbitan monostearate, were of commercial grade, Nikkol TS-10 (HLB 14.9) and TS-106 (HLB 9.6) from Nikko Chemicals Co., Ltd.

Preparation of Creams——Creams were prepared according to the formulae in Table I by the procedure reported in the previous paper.[1)] The emulsifiers used for these preparations were mixtures of TS-10 and TS-106 blended together so as to give HLB values within the range of 10.2—14.3. The creams were recognized to be of O/W type by using a electroconductometer. They were kept in glass bottles at room temperature (about 20 °C).

Vertical Vibrational Test——Viscoelastic properties of these creams were measured at room temperature (about 20 °C) with the vertical vibrating apparatus at a frequency of 10 Hz and an amplitude of 200 μm. Details of the vibrating apparatus and procedure were reported in the previous paper.[1)]

Appearance of Creams——Creams sandwiched between two glass plates were observed visually.

Centrifuge Test——Creams were examined at 2000 g for 60 min with a centrifugal separator (Sakuma Seisakusho Co., Ltd., Marusan type).

Results and Discussion

Variation of the Viscoelasticity of Creams with Storage Time

Dynamic modulus, G' and dynamic viscosity, η' of the creams were obtained with a recorder on the vibrating apparatus at an amplitude of 200 μm and a frequency of 10 Hz for 30 min. Some of the results are shown in Fig. 1 (sample A) and Fig. 2 (sample D), in which G' and η' are plotted on a log scale against time, t, after the start of oscillatory stress. In Figs. 1 and 2, G' and η' decreased with time in a linear fashion, obeying a first-order representation, from 10 min after the start of stress application, in accordance with the previous results[1)] and the results of Davis.[5)] η' and G' at 15 min after applying oscillatory stress are plotted against storage time up to three months in Figs. 3 and 4, respectively. As regards dynamic viscosity, η' in Fig. 3, samples D (HLB, 13.7) and E (HLB, 14.3) showed maximum viscosities of 16.7 and 15.3 P at the storage time of about two weeks and thereafter these values decreased to 12.3 and 11.9 P over the storage time of three months. On the other hand, samples A (HLB, 10.2) and C (HLB, 12.5) did not show maxima but the viscosities increased monotonically with storage time up to three months. The η' of sample B (HLB, 11.4) decreased slightly on storage for over four weeks. Similar plots for dynamic modulus, G' are given in Fig. 4. None of these five O/W creams showed constant values of η' and G' over three months of strorage, although it was reported that pharmaceutical semisolids such as vaseline showed stable physical properties from one or two weeks after preparation.[6)]

Effect of HLB Values on the Viscoelasticity of Creams

Plots of dynamic viscosity η' and dynamic modulus G' *versus* HLB values of creams are

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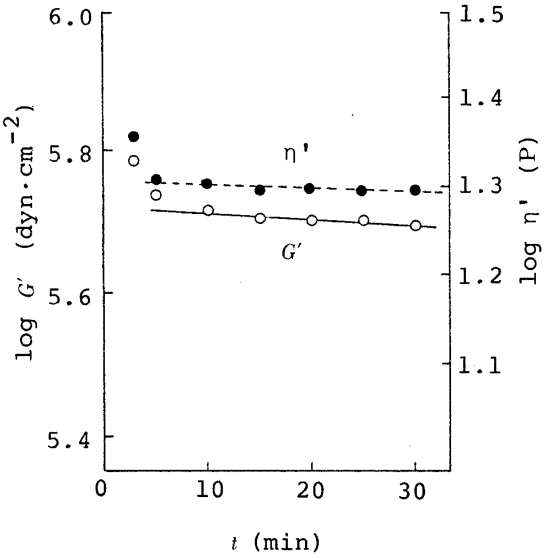

Fig. 1. Dynamic Modulus G' and Dynamic Viscosity η' of Sample A (HLB, 10.2) Stored for One Week

—○—, G'; ---●---, η'.

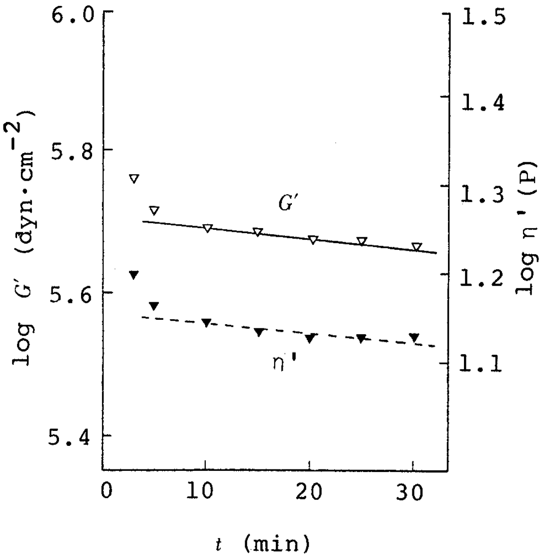

Fig. 2. Dynamic Modulus G' and Dynamic Viscosity η' of Sample D (HLB, 13.7) Stored for One Week

—▽—, G'; ---▼---, η'.

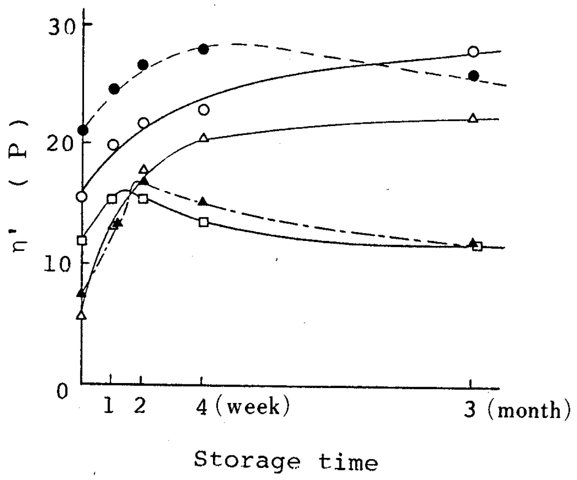

Fig. 3. Dynamic Viscosity η' after 15 min at 10 Hz, *versus* Storage Time

—○—, A (HLB, 10.2); ---●---, B (HLB, 11.4); —△—, C (HLB, 12.5); ---▲---, D (HLB, 13.7); —□—, E (HLB, 14.3).

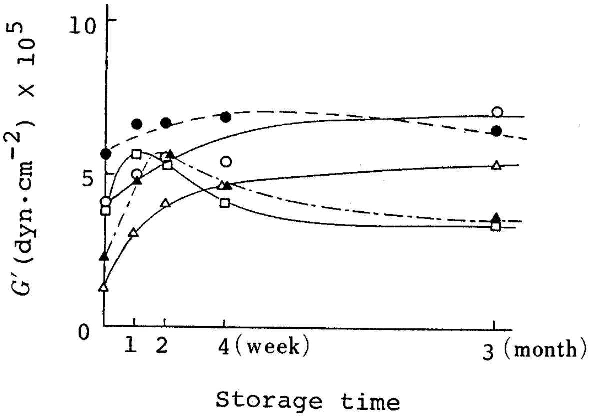

Fig. 4. Dynamic Modulus G' after 15 min at 10 Hz, *versus* Storage Time

—○—, A (HLB, 10.2); ---●---, B (HLB, 11.4); —△—, C (HLB, 12.5); ---▲---, D (HLB, 13.7); —□—, E (HLB, 14.3).

shown in Figs. 5 and 6 at the storage time of three months. HLB value was calculated from the ratio of the two kinds of surfactants used to prepare the creams. It was found that η' and G' of the creams decreased similarly with increasing HLB values.

The variations of η' and G' with storage time as a function of HLB value are shown in Figs. 3 and 4, respectively. For η' and G', as discussed above, the creams of above 13 in HLB value gave maxima at the storage time of one or two weeks. The viscoelastic properties subsequently deteriorated. On the other hand, the creams of below 13 in HLB became firmer during one to three months of storage.

Effect of Storage Time on the Rate of Breakdown of Viscoelastic Structures in Creams under Osillatory Stress

It was recognized in the previous paper[1] that vertical vibration imposed on O/W creams

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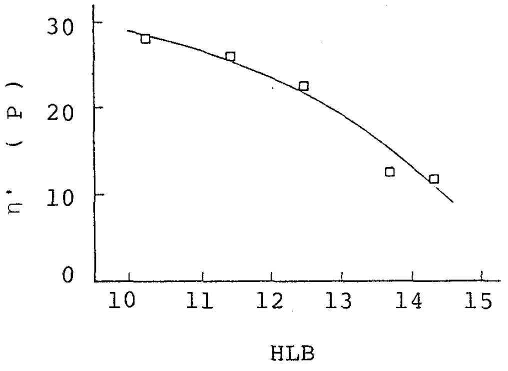

Fig. 5. Plots of Dynamic Viscosity η' after Storage for Three Months *versus* HLB Value of Creams

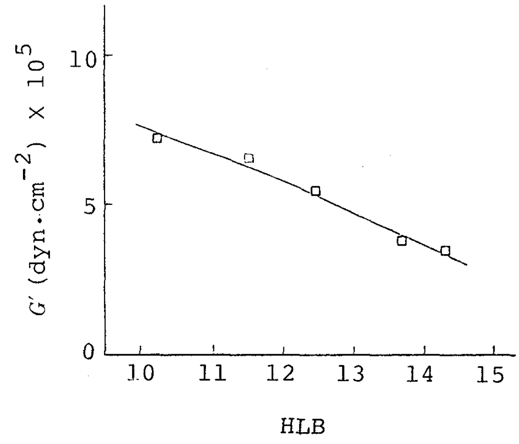

Fig. 6. Plots of Dynamic Modulus G' after Storage for Three Months *versus* HLB Value of Creams

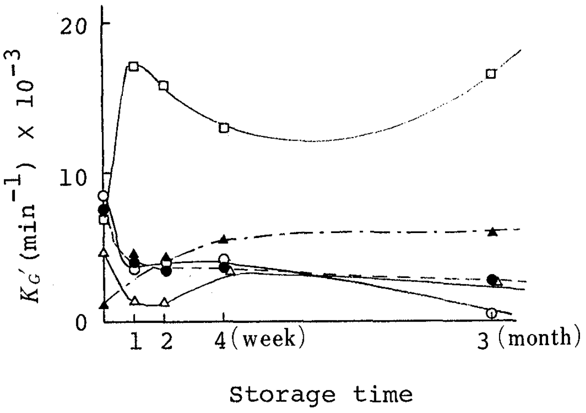

Fig. 7. The Variation of Rate Constant $K_{G'}$ with Storage Time

—○—, A (HLB, 10.2); ---●---, B (HLB, 11.4); —△—, C (HLB, 12.5); ---▲---, D (HLB, 13.7); —□—, E (HLB, 14.3).

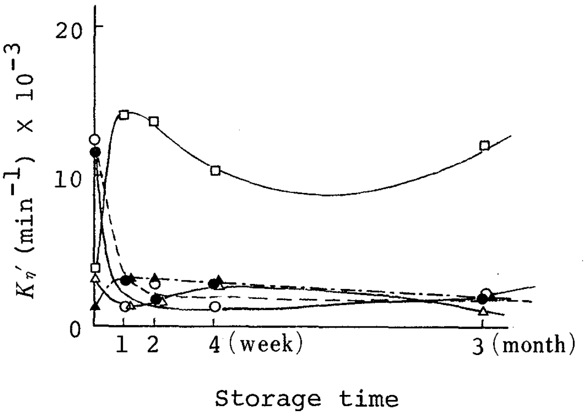

Fig. 8. The Variation of Rate Constant $K_{\eta'}$ with Storage Time

—○—, A (HLB, 10.2); ---●---, B (HLB, 11.4); —△—, C (HLB, 12.5); ---▲---, D (HLB, 13.7); —□—, E (HLB, 14.3).

caused the destruction of viscoelastic structures in the creams with time according to a first-order representation$^{5)}$ and accelerated the coalescence of the oil globules dispersed in the creams. In Figs. 1 and 2, G' and η' decreased similarly. The rate constants, $K_{G'}$ and $K_{\eta'}$ obtained from the slopes of plots of G' and η' *versus* vibration time (*e.g.* Figs. 1 and 2), are shown in Figs. 7 and 8 for various storage times. Samples A and B (HLB $<$ 12) gave maxima in $K_{G'}$ and $K_{\eta'}$ immediately after preparation, then these values decreased monotonically with storage time up to three months. Immediately after preparation, the viscoelastic structures of these creams were susceptible to vibration, but after storage for one week the structures became more stable. On the other hand, samples D and E (HLB $>$ 13) gave higher values of $K_{G'}$ and $K_{\eta'}$ after one week of storage than immediately after preparation, when these creams showed the lowest values of G' (Fig. 4) and η' (Fig. 3). Sample C (HLB, 12.5) showed the most stable values of $K_{G'}$ and $K_{\eta'}$ among the five samples during storage for three months.

Effect of HLB Values on the Rate of Breakdown of Viscoelastic Structures in Creams under Oscillatory Stress

The effects of storage time on the rheological properties, η' and G', are shown in Figs. 3 and 4. Up to two weeks after preparation, these properties were more changeable than they

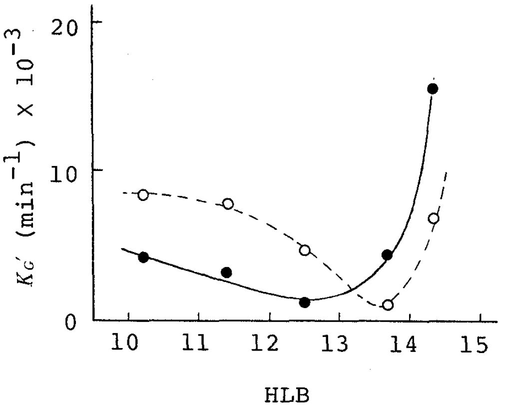

Fig. 9. Plots of Rate Constant $K_{G'}$ *versus* HLB Value of Creams after Storage for Two Weeks (——) and Immediately after Preparation (----)

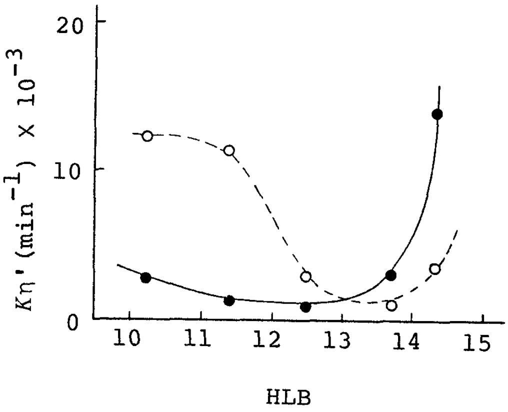

Fig. 10. Plots of Rate Constant $K_{\eta'}$ *versus* HLB Value of Creams after Storage for Two Weeks (——) and Immediately after Preparation (----)

Table II. Effect of HLB Value on the Rate Constant for Breakdown of Viscoelastic Structure in O/W Creams after Storage for Two Weeks by Vertical Vibration

Sample	HLB	Rate constant $k_{G'}$ (min^{-1})	Rate constant $k_{\eta'}$ (min^{-1})
A	10.2	4.1 ($\times 10^{-3}$)	2.5 ($\times 10^{-3}$)
B	11.4	3.6	1.6
C	12.5	1.3	1.0
D	13.7	4.1	3.1
E	14.3	15.4	13.7

were on further storage. Plots of $K_{G'}$ and $K_{\eta'}$ *versus* HLB values for creams after storage for two weeks and immediately after preparation, as discussed above, are shown in Figs. 9 and 10, respectively. Samples A, B, and C (HLB < 13) were found to be more stable after two weeks of storage than immediately after preparation under oscillatory stress. On the other hand, samples D and E (HLB > 13) were found to be weaker after two weeks of storage. It is interesting to note that there is a boundary at around HLB 13 where maximum rheological stability of creams is observed.

After two weeks of storage, sample C (HLB, 12.5) gave the lowest values of $K_{G'}$ and $K_{\eta'}$ as shown in Table II. In addition, these values were found to decrease in the order to samples E, D, A, B, and C.

The viscoelastic properties of pharmaceutical semisolids were studied with a horizontal oscillation rheometer over the frequency ranges of 2.5×10^{-4}—25 Hz by Davis[5] and 3×10^{-4}—7.5×10^{-2} Hz by Kobayashi *et al.*[7] Compared with these studies, the frequency of 10 Hz applied in this study is in a relatively high frequency region. The elastic elements were more easily broken down, as discussed in the previous paper,[1] than the viscous elements by vertical vibration, so that the $K_{G'}$ value was higher than the $K_{\eta'}$ value, as shown in Table II.

Comparison of the Results of the Storage Test and the Rate of Breakdown of Viscoelastic Structures by Vibration

The appearance of samples and the results of the centrifuge test are shown in Table III at one week and three months of storage. Each sample of these five creams at one week was a white semisolid showing a uniform consistency. On storage for three months, samples A and B (HLB < 12) showed a white shiny surface appearance and uneven consistency. Coagulated

TABLE III. The Results of Storage Tests

Sample	HLB	Appearance		Centrifuge test	
		One week	Three months	One week	Three months
A	10.2	[a]	White shiny coagulated	Unseparated	Separated (10%)
B	11.4	[a]	White shiny coagulated	Unseparated	Separated (10%)
C	12.5	[a]	Unchanged	Unseparated	Separated (4%)
D	13.7	[a]	Heterogeneous with light and dark parts	Unseparated	Unseparated
E	14.3	[a]	Heterogeneous with light and dark parts	Unseparated	Unseparated

a) White semisolid with a uniform consistency.

parts were observed in these samples sandwiched between two glass plates. The coagulates were accumulated in the upper layer in the centrifuge test. There is a discrepancy between the viscoelastic values determined by the static method and the dynamic method.[1] Samples D and E (HLB$>$13), gave comparatively low values of η' (Fig. 5) and G' (Fig. 6), and although they exhibited no separation in the centrifuge test, their appearance changed from uniform to rough with light and darker parts in samples stored in a glass tube for three months.

Sample C (HLB, 12.5), which showed the lowest values of $K_{\eta'}$ and $K_{G'}$ among the five samples at the storage time of two weeks (Figs. 9 and 10), was unchanged in appearance, although only 4% (v/v) was separated by the centrifuge test. It was found that this sample C was the most stable among the five samples in both the vertical vibration test and the storage test. It was recognized that the lower the values of the rate constants $K_{\eta'}$ and $K_{G'}$ at the storage time of two weeks, the more stable the creams were in the storage test at three months. Although this vibrating test has not been sufficiently investigated with other preparations, these results suggest that this test can be used for to evaluate the stability of creams during comparative screening development, as an accelerated tests instead of a storage stability test for several months. A suitable procedure is as follows: 1) test creams are stored for at least two weeks to avoid the aging effect as shown in Figs. 3 and 4; 2) the creams are subjected to vertical vibration by a viscoelasto recorder, and the changes of dynamic viscosity η' and dynamic modulus G' are observed; 3) the rate constants $K_{\eta'}$ and $K_{G'}$ are obtained from the semilogarithmic plots of η' and G' as a function of time; 4) the cream showing the lowest values of $K_{\eta'}$ and $K_{G'}$ is selected.

Conclusion

Five O/W creams with different HLB values from 10.2 to 14.3 were prepared. Vertical vibration was imposed on these creams, and the viscoelastic properties were examined. On the other hand, the storage stability of these creams was observed for three months. The following results were obtained.

1) Dynamic viscosity, η', and dynamic modulus, G', decreased with time according to a first-order representation similar to that descrived in the previous paper.[1]

2) The lower the values of the rate constants, $K_{\eta'}$ and $K_{G'}$, after storage for two weeks, the more stable the cream was in the three-month storage test.

3) This accelerated vibration test is useful to evaluate the stability of creams for comparative screenings during development in place of a storage stability test taking several months. It is easy to obtain $K_{\eta'}$ and $K_{G'}$ and to select the cream showing the lowest values on the vertical vibrating viscoelasto recorder.

This vibrating test should be widely applicable to other preparations. Further studies are necessary to confirm its general usefulness.

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