

Structure and rheology of cetomacrogol creams: the influence of alcohol chain length and homologue composition

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Liquid paraffin-in-water emulsions prepared with cetomacrogol 1000 and alcohols cetostearyl (A), cetyl (B), stearyl (C) and myristyl (D) were examined by microscopical, particle size analytical and rheological (continuous shear, small strain creep and oscillation) techniques at 25° as they aged over 30 days. The particle sizes of the emulsions were similar and did not increase significantly with age. Thus the rheological stabilities were not correlated with particle size distributions, but rather with viscoelastic networks formed in the continuous phases when the non-ionic mixed emulsifiers interacted with water. The rheological properties of emulsions B and D differed from those of emulsion C. Emulsion A, of mixed homologue composition, showed some properties similar to each of the pure alcohol emulsions. Emulsions B and D were semi-solid immediately after preparation whereas emulsion C was so mobile initially that small strain data were not derived. On ageing, the consistencies of B and D changed slightly initially, and then remained essentially constant. In contrast, the consistency of emulsion C increased on ageing, especially over the first few days when there was a change from mobile liquid to semisolid. Emulsion A was a semisolid initially but like emulsion C increased in consistency especially over the first 24 h. Continuous shear data indicated that this emulsion was the most resistant to structure breakdown. Microscopical examinations supported the view that the networks formed in emulsion A were the most extensive and that stearyl alcohol networks in C formed comparatively slowly. Although the cetomacrogol/pure alcohol networks were diffuse and sometimes crystallized, they did not rapidly disintegrate on storage as did the ionic surfactant/pure alcohol networks examined previously.

In the preparation of semisolid oil-in-water emulsions of pharmaceutical or cosmetic interest, wide use is made of mixed emulsifiers of the surfactant-long chain alcohol type (see for example B.P.C., 1973; Pickthall, 1962). In the past it was often thought unnecessary to discriminate between cetyl or stearyl alcohols or commercial admixtures of these such as cetostearyl alcohol B.P. as their modes of action were assumed to be essentially the same. However, it was reported recently (Barry, 1970; Eccleston, 1976) that alcohol chain length and homologue composition markedly affected both the appearances and the stabilities of emulsions prepared with the ionic surfactants sodium dodecyl sulphate or cetrimide. For example, when cetrimide emulsions were prepared using pure cetyl or stearyl alcohols they were unstable and rapidly broke down to form mobile liquids; when cetostearyl alcohol was used, a stable emulsion formed (Eccleston, 1976).

The present paper extends this work to investigate the effect of alcohol chain length and homologue composition on the rheological properties of

similar oil-in-water emulsions prepared with a non-ionic surfactant, cetomacrogol 1000. This surfactant is often used in semisolid medicinal and cosmetic creams.

MATERIALS AND METHODS

Materials. Water, liquid paraffin, cetomacrogol 1000, cetostearyl alcohol B.P. and the alcohols cetyl (hexadecanol) and stearyl (octadecanol) were as used previously (Barry & Saunders, 1970, 1972a; Eccleston, 1976). Myristyl alcohol (tetradecanol) of nominal purity 99% was obtained from BDH Chemicals Ltd. (Poole, U.K.). The purity was checked and shown to be better than 99% by g.l.c. analyses (Barry & Saunders, 1971).

Penetration experiments. High and low (25°) temperature penetration experiments were made to investigate the interaction between each long chain alcohol and cetomacrogol solution using a Kofler micro hot stage (Reichert, Austria) and a polarizing (Vickers Instrument, U.K.) microscope (Barry & Eccleston, 1973a).

Preparation of the emulsions. Liquid paraffin-in-water emulsions formulated with cetomacrogol and alcohols A-cetostearyl, B-cetyl, C-stearyl and D-myristyl were prepared according to the formulas in Table 1 by a standardized procedure that involved mixing the hot ingredients at 70° and then rapidly cooling to 25° (Barry & Saunders, 1970). The concentrations of mixed emulsifier in Table 1 (approximately 12%) were chosen to produce creams of the soft semisolid consistency widely used in commerce. The emulsions were stored at 25° throughout the 30 day test.

Table 1. *Composition of the emulsions (g).*

	A	B	C	D
Liquid paraffin	100	100	100	100
Water	300	300	300	300
Cetomacrogol 1000	4.8	4.8	4.8	4.8
Cetostearyl alcohol	43.2	—	—	—
Myristyl alcohol	—	—	—	43.2
Cetyl alcohol	—	43.2	—	—
Stearyl alcohol	—	—	43.2	—

Microscopy. The emulsions were examined using the Vickers polarising microscope, soon after preparation and frequently during the 30 day storage and testing period.

Particle size analyses. Emulsions A, B and D were diluted and particle size analyses were performed using a Timbrell double image micrometer and analyser type 526 (Fleming Instruments, U.K.). Freshly prepared emulsion C did not require dilution. The data from each count were plotted on log probability paper (Barry & Saunders, 1970).

Creep experiments. These were performed throughout the 30 day test at 25° using a concentric cylinder reaction air turbine viscometer (Barry & Saunders, 1969; Barry & Grace, 1970). Approximate linearity checks were made at short times, and each creep curve was recorded in the linear viscoelastic region unless otherwise stated (Eccleston, 1976).

Oscillatory experiments. The behaviour of the emulsions in forced oscillation was investigated using an R16 Weissenberg rheogoniometer fitted with parallel plates coupled to a Solartron digital transfer function analyser and a mechanical reference synchronizer. Initial tests for linearity were performed, and the emulsions were examined whenever possible in their linear viscoelastic regions by applying sinusoidally varying shear strains at frequencies ranging from 2.5×10^{-2}

–25 Hz. At each frequency, the amplitude ratio and phase shift were determined and were used to calculate the storage modulus, G' , and the dynamic viscosity, η' , using the Walters and Kemp equations for parallel plate geometry (Walters & Kemp, 1968; Walters, 1968). Further details of the apparatus and experimental techniques were given previously (Barry & Eccleston, 1973b, c). Experiments were performed initially and throughout the 30 days test.

Continuous shear experiments. The emulsions were examined at $25 \pm 0.1^\circ$ using a Ferranti-Shirley cone and plate viscometer in conjunction with an automatic flow recorder unit designed to produce a standardized shear procedure, and an X-Y plotter. The viscometer was fitted with a 600 g cm torque spring, the large cone (3.5 cm diameter) and the manufacturer's anti-evaporation unit. The emulsions were examined initially and throughout the next 30 days using a maximum shear rate of 1671 s^{-1} and a sweep time of 600 s.

RESULTS

Penetration experiments. Crystalline cetostearyl, myristyl and cetyl alcohols interacted slowly with aqueous cetomacrogol solution at 25°. As soon as the surfactant solution touched the alcohol, the edges became less sharp. As interaction proceeded, the alcohol crystals on the slide broke up and spread so that after 24 h the anisotropic penetration product covered the field of view.

Attempts to obtain T_{pen} , identified by the penetration mechanisms described previously (Barry & Eccleston, 1973a), i.e. the sudden appearance of liquid crystalline structures at a specific temperature, were unsuccessful. Although there was a temperature at which penetration accelerated and mobile liquid crystals formed, the structures by which this temperature is identified were too small to be readily visible with the magnifications available. Both high and low temperature penetration were extremely slow for octadecanol.

Appearance of the emulsions. Emulsions A, B and D were white shiny semisolids immediately after preparation; emulsion C was a white, mobile liquid. On storage, emulsions B and D did not change visibly, emulsion A changed to a firmer, less shiny semisolid and emulsion C changed from a mobile liquid to a semisolid of a similar appearance to the other emulsions.

Microscopy. For clarity, the appearance of emulsion A will be discussed first and then compared

with the appearances of emulsions B and D. Emulsion C will be discussed separately.

The oil globules in emulsion A were mainly spherical. In the freshly prepared emulsion a diffuse anisotropic matrix surrounding the larger oil droplets (Barry & Saunders, 1970) together with masses of unreacted cetostearyl alcohol were visible. The matrix was extensive after 30 days storage, by which time the alcohol masses had disappeared. Large, anisotropic crystals (see below) were not observed in emulsion A, even when re-examined after 2 years storage.

In emulsions B and D, the mainly spherical oil droplets were also surrounded by anisotropic matrices, although they were diffuse and difficult to observe initially, especially in B. The matrices were more easily identified after 30 days storage. Unreacted alcohol masses were not observed in emulsion D, either initially or on storage. They were sometimes observed in freshly prepared emulsion B, but were not apparent after a few days storage. It is significant that hexagonal or diamond shaped anisotropic crystals formed in both these pure alcohol emulsions on storage. Crystallization, although not extensive, was readily apparent in emulsion B after 30 days, and increased on further ageing. Crystals were visible occasionally in D after 30 days. These also had increased in number when the emulsion was re-examined after further storage at 25°.

The microscopical appearance of emulsion C differed from that of the other emulsions. Spherical oil globules and large numbers of unreacted stearyl alcohol masses were observed in the fresh, mobile emulsion. On storage, as the emulsion slowly changed to a semisolid, a diffuse anisotropic matrix appeared surrounding many large oil globules and there were corresponding marked decreases in the amounts of unreacted stearyl alcohol. The matrix consolidated on further storage so that after 30 days it was similar to that observed in the other pure alcohol emulsions. Crystallization as described above was not apparent in this emulsion.

Particle size analyses. The apparent geometric mean diameters (μm) defined as the size corresponding to 50% on the log probability axes after 4 days and 30 days (in parenthesis) were as follows: emulsion A-1.8 (1.8); emulsion B-1.4 (1.5); emulsion C-2.0 (2.3) and emulsion D-1.6 (1.6).

The particle size analyses were difficult to perform. This was because the usual method is to dilute the emulsion so that there are approximately 500 oil globules in the field of view and then to

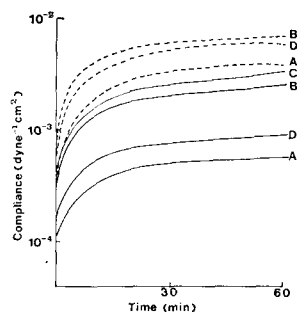


Fig. 1. Creep curves obtained after 1 (---) and 14 (—) days storage. A—cetostearyl alcohol emulsion. B—cetyl alcohol emulsion. C—stearyl alcohol emulsion. D—myristyl alcohol emulsion.

rapidly size and count these (in less than 10 min). It is important that counts are made rapidly, as on dilution the gel networks are destroyed thereby encouraging globule coalescence. In the pure alcohol emulsions, counts were inaccurate because on dilution the crystalline and network debris was often difficult to distinguish from small oil globules. The particle diameters corresponding to 50% on the log probability axes above, however, do confirm the visual observation that oil globule diameters in these non-ionic emulsions, although generally larger than those obtained for the ionics examined previously, do not change significantly when emulsions age (c.f. Barry & Saunders, 1970; Eccleston, 1976).

Creep. Typical creep curves obtained after 1 and 14 days storage are shown in Fig. 1. A 1 day curve was not obtained for emulsion C as the mobile sample was non-linear viscoelastic. Plots of J_T , the total compliance after 50 min creep versus storage time for emulsions A, B and D are given in Fig. 2.

Oscillation. Plots were obtained for the variation of storage modulus and dynamic viscosity with frequency after 24 h and 10 days storage (not shown).

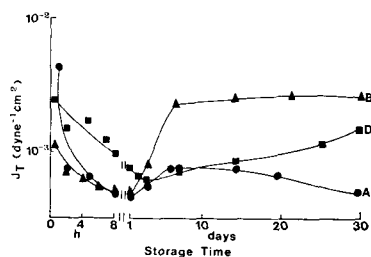


Fig. 2. Creep compliance after 50 min, J_T ($\text{dyne}^{-1} \text{cm}^2$), versus storage time. A—cetostearyl alcohol emulsion. B—cetyl alcohol emulsion. D—myristyl alcohol emulsion.

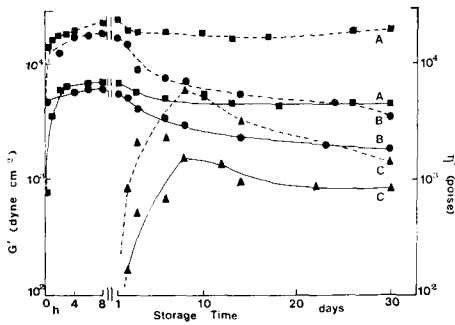


FIG. 3. The variation of storage modulus, G' (dyne cm^{-2}) (—) and dynamic viscosity, η' (poise) (---) at a representative frequency (0.025 Hz) with storage time. A—cetostearyl alcohol emulsion. B—cetyl alcohol emulsion. C—stearyl alcohol emulsion.

Emulsion C was non linear viscoelastic thus 24 h data were not obtained. For each emulsion storage moduli rose and dynamic viscosities decreased monotonically with increase in frequency. In addition, G' and η' values at each frequency decreased in emulsion order A, D, B, C.

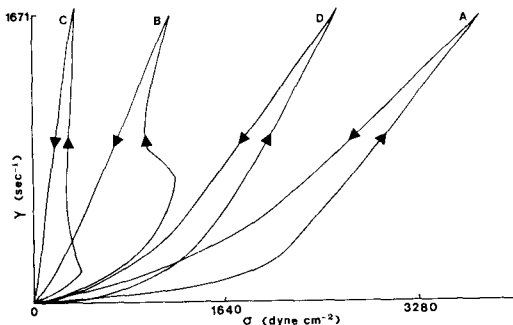


FIG. 4. Ferranti-Shirley viscometer. Flow curves after 24 h storage, of shear rate, $\dot{\gamma}$ (s^{-1}), versus shear stress, σ (dyne cm^{-2}). A—cetostearyl alcohol emulsion. B—cetyl alcohol emulsion. C—stearyl alcohol emulsion. D—myristyl alcohol emulsion.

The variation of storage modulus and dynamic viscosity at a representative frequency of 0.025 Hz with storage time for emulsions A, B and C are shown in Fig. 3. Similar plots for emulsion D are given in Fig. 6.

Continuous shear. Continuous shear flow curves for each emulsion were in the form of anticlockwise hysteresis loops. Typical curves after 24 h storage are shown in Fig. 4. The variations of apparent viscosity, derived at the apex of each loop, η_{app} , with storage time are plotted in Fig. 5.

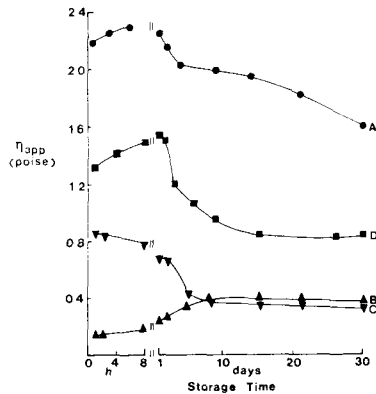


FIG. 5. The variation of apparent viscosity, η_{app} (poise), derived at 1671 s^{-1} with storage time. A—cetostearyl alcohol emulsion. B—cetyl alcohol emulsion. C—stearyl alcohol emulsion. D—myristyl alcohol emulsion.

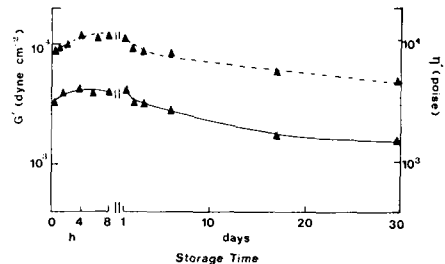


FIG. 6. Emulsion D. The variation of storage modulus, G' (dyne cm^{-2}) (—) and dynamic viscosity, η' (poise) (---) at a representative frequency (0.025 Hz) with storage time.

DISCUSSION

The rheological properties of cetyl alcohol emulsion B differed over the first few days from those of stearyl alcohol emulsion C. Emulsion B was a white, shiny semisolid immediately after preparation. The initial small strain experiments revealed that it was linear viscoelastic. The shape of the 24 h creep curve (Fig. 1) and the oscillatory trends whereby the storage moduli increased and the dynamic viscosities decreased with increase in frequency were also shown initially and are characteristic of those obtained for linear viscoelastic liquids (Barry & Eccleston, 1973b, c; Eccleston, Barry & Davis, 1973; Eccleston, 1976). On ageing, emulsion consistency changed only slightly. There were maxima in G' and η' and minima in J_T values after approximately 24 h and thereafter only slight changes in these parameters (Figs 2, 3).

Stearyl alcohol emulsion C differed. It was so mobile after preparation that initial creep and

oscillatory data were not derived. The 24 h anti-clockwise hysteresis loops obtained in continuous shear did however indicate that some structure was present, although the initial apparent viscosities were much lower than those of emulsion B (Figs 4, 5). On ageing, emulsion C exhibited consistency increases, particularly over the first few days when the system changed from a mobile liquid to a linear viscoelastic semisolid of a slightly lower consistency than B. Thus G' , η' and η_{app} values increased markedly until after approximately 10 days they were similar to those of B. On further ageing, consistencies did not change markedly in either emulsion, thus the rheological parameter values reduced only slightly during the remainder of the time (Figs 3, 5).

Emulsion A, containing cetostearyl alcohol, showed some properties of each of the pure cetyl and stearyl alcohol emulsions discussed above. It was a linear, viscoelastic semisolid immediately after preparation as was emulsion B, showing the same trends in creep and oscillation (c.f. oscillatory and creep data for emulsions A and B). However, the marked consistency increases exhibited by this emulsion, especially over the first 24 h, were similar to those exhibited by C (Figs 2, 3, 5). As for the pure alcohol emulsions, the changes exhibited after approximately 10 days were slight; in emulsion A G' and η' increased and J_T and η_{app} decreased slightly on further storage (Figs 2, 3, 5).

The particle sizes of the emulsions were similar and did not increase significantly with age, thus the appearances and rheological properties of the emulsions were not correlated with particle size distributions, but rather with the formation of viscoelastic networks in the continuous phases when aqueous cetomacrogol solution interacted with long chain alcohols.

As with the cetrimide/long chain alcohol emulsions examined previously (Eccleston, 1976) the concentrations of mixed emulsifier present in each emulsion were in excess of those required to form complex, condensed monomolecular films at the o/w interfaces. At the high temperatures of preparation, excess cetomacrogol solution interacted with molten alcohol to form liquid crystalline structures similar to those visible microscopically during penetration experiments. A small amount of liquid paraffin was also solubilized. No attempts were made during the standardized preparation procedure to ensure equilibrium, and as the system cooled to below T_{pen} , interaction reduced and the liquid crystals, together with unreacted alcohol,

precipitated. The precipitated smectic phase probably possessed a structure intermediate to the crystalline and mesomorphous states, with partially stiff hydrocarbon chains and relatively loose packing. This phase was stable at low temperatures, thus on storage at 25°, cetomacrogol continued to penetrate slowly into any unreacted alcohol to form additional ternary phase (Barry & Eccleston, 1973a).

When the results of this work are compared with the data derived for ionic cetrimide systems (Eccleston, 1976) a major difference emerges. This is that viscoelastic gel networks form in each cetomacrogol emulsion, even those prepared with the pure long chain alcohols. This is in marked contrast to the cetrimide/pure alcohol systems. In these, although viscoelastic networks were present immediately after the heating and cooling cycle of preparation, they were metastable and disintegrated on storage at 25°, causing instability of cetrimide emulsions. The greater stability of the non-ionic networks was due to the bulky nature of the cetomacrogol molecule which lowered transition temperatures sufficiently to ensure that in each emulsion the viscoelastic ternary continuous phase was essentially stable at 25°.

This work also provides further information about the high and low temperature mechanisms involved in the formation of viscoelastic continuous phases. It was observed in this and previous work (Barry & Saunders, 1972b; Barry & Eccleston, 1973a) that low temperature mechanisms are important in cetomacrogol emulsions containing cetostearyl alcohol; networks are only partially constructed at the high temperatures of preparation, but consolidate in time at the lower storage temperature. Thus emulsion A exhibited consistency increases on storage, especially over the initial 24 h. In contrast, high temperature interaction is the major mechanism involved when cetostearyl alcohol and an ionic surfactant (cetrimide, sodium dodecyl sulphate) is used. The viscoelastic continuous phases are essentially complete when ionic emulsions cool to the storage temperature so that these emulsions do not exhibit marked consistency increases on storage. However, when the initial rheological data in Figs 1, 3-5 are compared and contrasted, it is apparent that the mechanisms involved in network formation are not only a function of the surfactant, but also of the alcohol chain length.

The cetyl alcohol emulsion B was semisolid immediately after preparation, and exhibited only

slight consistency increases on storage over the first few days. This indicated that high temperature interaction was the major mechanism involved in the formation of the viscoelastic continuous phase and that low temperature mechanisms played a minor role. In contrast, penetration processes were slower in emulsion C, as the longer chain length stearyl alcohol contained more hydrophobic bonds to be disrupted, and low temperature interaction was important. Thus emulsion C was a mobile liquid initially, but became semisolid on storage at 25°.

In order to confirm that the rate of interaction between cetomacrogol and fatty alcohol is a function of alcohol chain length, a fourth emulsion (D) was prepared using the shorter chain homologue tetradecanol (myristyl alcohol). From the proposed theory, it was predicted that high temperature interaction would be the major mechanism involved in the formation of D, as there were fewer hydrophobic bonds present. The results in Figs 1-6 confirm this. Emulsion D was a white shiny semisolid immediately after preparation, showing the usual trends for linear viscoelastic liquids when examined initially in creep and oscillation. There were minor consistency increases during the first few days of storage, shown by the decreasing total compliances and increasing storage moduli and dynamic and apparent viscosities. Thereafter, as in the other pure alcohol emulsions, the consistency of emulsion D decreased slightly and the plots of each rheological parameter against storage time changed only slightly (Figs 2,3,5,6).

The penetration experiments and microscopical observations support the conclusions reached so far. In emulsions A and C, where low temperature mechanisms are postulated to play a major role, masses of unreacted alcohol were visible initially. These had disappeared (emulsion A) or reduced in number considerably (emulsion C) at the end of the 30 day test, as would be expected if low temperature interaction occurred during this time to form additional viscoelastic networks. Unpenetrated alcohol was not apparent in emulsion D, and only occasionally in emulsion B, confirming that high temperature interaction played a major part in forming these viscoelastic continuous phases.

Although it is emphasized again that apparently stable viscoelastic networks form in each cetomacrogol emulsion whether a pure alcohol or admixture was used, it is significant that the results indicate that the cetostearyl alcohol emulsion A exhibits greater long term stability. Emulsion A was of a higher consistency than the other emulsions and there were slight consistency increases (as opposed to the decreases exhibited by the pure alcohol emulsions) throughout the latter part of the 30 day test. In continuous shear, the emulsion was more resistant to structure breakdown at high shear rates so that apparent viscosities for emulsion A were considerably greater than those of the pure alcohol emulsions (Figs 4, 5). In addition, the crystallization observed in the pure myristyl or cetyl alcohol emulsions implying possible long term instability was not apparent in the cetostearyl alcohol emulsion, even after 2 years storage.

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