Rheological and droplet size analysis of W/O/W multiple emulsions containing low concentrations of polymeric emulsifiers

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Abstract: Multiple emulsions are complex dispersion systems which have many potential applications in pharmaceutics, cosmetics and the food industry. In practice, however, significant problems may arise because of their thermodynamic instability. In this study, W/O/W multiple emulsion systems containing low concentration levels of lipophilic polymeric primary emulsifiers cetyl dimethicone copolyol and PEG–30 dipolyhydroxystearate were evaluated. The concentrations of the primary emulsifiers were set at 1.6 and 2.4 % w/w in the final emulsions. Rheological and droplet size analysis of the investigated samples showed that the type and concentration of the primary lipophilic polymeric emulsifier markedly affected the characteristics of the multiple emulsions. The multiple emulsion prepared with 2.4 % w/w PEG–30 dipolyhydroxystearate as the primary emulsifier exhibited the highest apparent viscosity, yield stress and elastic modulus values, as well as the smallest droplet size. Furthermore, these parameters remained relatively constant over the study period, confirming the high stability of the investigated sample. The results obtained indicate that the changes observed in the investigated samples over time could be attributed to the swelling/breakdown mechanism of the multiple droplets. Such changes could be adequately monitored by rheological and droplet size analysis.

Keywords: W/O/W emulsions; polymeric emulsifiers; rheology; droplet size analysis.

INTRODUCTION

Multiple emulsions are complex dispersion systems, known also as "emulsions of emulsions". The most common multiple emulsions are of the W/O/W type, although, for some specific applications O/W/O emulsions can also be prepared.

In W/O/W emulsions, oil globules containing small droplets of water, are dispersed in an aqueous continuous phase. Relatively high entrapment capacity for hydrophilic compounds, protection of the encapsulated substances from degradation, the ability to introduce incompatible substances into the same system and sustained active substance release are some of the advantages of these types of emulsion systems that make them potentially interesting for application in pharmaceutics, cosmetics and the food industry.[1–5] In practice, however, significant problems may arise because of their thermodynamic instability and strong tendency for coalescence, flocculation and creaming. The stability of W/O/W emulsions may be affected by a number of factors, including the method of preparation, the osmotic balance between the internal and external water phase, the phase volumes ratio and the type and concentration of the emulsifier.

Most literature data relates to multiple emulsions based on conventional non--ionic surfactants. However, most of these surfactant systems were reported to produce multiple emulsions with a limited shelf-life. Polymeric surfactants were shown to be superior to the conventional non-ionic surfactants in maintaining the physical stability of multiple emulsions.[6] According to Tadros,[7] to prepare a stable W/O/W multiple emulsion, the following criteria should be fulfilled: a) two emulsifiers (*i.e.*, one with a low and another with a high HLB value) should be used: one to produce the primary W/O emulsion and the other for the W/O/W multiple emulsion; b) polymeric emulsifiers that provide steric stabilization are necessary to maintain long-term physical stability; c) an optimum osmotic balance between the internal water droplets and the outer continuous phase should be accomplished.

The most often used primary lipophilic polymeric emulsifiers for the preparation of W/O/W emulsions are cetyl dimethicone copolyol (INCI name: cetyl PEG/PPG-10/1 dimethicone, CDC) and PEG 30-dipolyhydroxystearate (PHDS).[1–4,8–12] CDC is polymeric silicone surfactant composed of hydrophilic polyether groups, oriented into the inner water phase, and lipophilic polyalkyl groups, oriented into the oil phase. The polysiloxane backbone strengthens the whole molecule at the interface. The silicone surfactant contributes to distinct physical stability of W/O systems by steric stabilization and reduction of interfacial tension.[13] With CDC, it is possible to prepare W/O emulsions using different emulsifying procedures: hot/hot, hot/cold and cold/cold. PHDS is a triblock copolymer of polyhydroxystearic acid (PHS) / poly(ethylene oxide) (PEO) / / polyhydroxystearic acid. The PEO chain dissolves in water droplets and provides a strong "anchor" to the interface, whereas the PHS chains are highly soluble in most hydrocarbon solvents as well as in some polar ones. These PHS chains provide a strong repulsion upon approach of water droplets. PHS/PEO/ /PHS molecules also lower the interfacial tension of the W/O interface to very low values and, hence, the emulsification of water in oil is very efficient, al-

lowing the preparation of highly concentrated W/O emulsions having a low viscosity.[6] The film formed by CDC and PHDS at the W/O interface was described as reversibly expandable and compressible, while irreversibly adsorbed, which enables the formation of stable W/O/W multiple emulsions.[9,10] These emulsifiers are used in W/O/W emulsions usually at a concentration of about 4 % (in the primary W/O emulsions formulation), however the use of higher concentrations (*i.e.*, 5–15 %) has also been reported.[8] Low emulsifier concentrations are advantageous and preferred in pharmaceutical and cosmetic applications with respect to relevant toxicological, economic and environmental issues.

The objective of this study was to formulate, characterize and compare W/O/W emulsions, based on two different primary polymeric emulsifiers (cetyl dimethicone copolyol and PEG 30–dipolyhydroxystearate) at low concentration levels. The concentrations of the primary emulsifiers were set to 2.0 and 3.0 % w/w in the W/O emulsions, *i.e.*, to 1.6 and 2.4 % w/w in the final emulsions. The prepared sample formulations were characterized by dynamic and oscillatory rheological measurements and microscopic analysis and the obtained results were employed to evaluate the stability of the samples.

EXPERIMENTAL

Materials

The oil phase consisted of medium chain triglycerides (Myritol® 318, Fina, Belgium); two lipophilic polymeric surfactants were used: cetyl dimethicone copolyol (Abil® EM 90, Degussa-Goldschmidt, now Evonik, Germany) and PHS/PEO/PHS block copolymer (PEG 30-dipolyhydroxystearate, Arlacel® P135, ICI, now Croda, Belgium). Ethoxylated propylene oxide copolymer (2-methyloxirane; oxirane; INCI name: Poloxamer 407, Lutrol® PE/F127, BASF, Germany) was used as the hydrophilic surfactant. The other substances used were magnesium sulfate heptahydrate (Zorka Šabac, Serbia) and purified water.

Sample preparation

Both the primary and multiple emulsions were prepared with a high content of inner phase ($\Phi_1 = \Phi_2 = 0.80$). The compositions of the primary emulsions (PE 1 and PE 1a; PE 2 and PE 2a) are given in Table I.

TABLE I. Composition of the primary emulsions (% w/w)

Component	Emulsion			
	PE 1	PE 1a	PE 2	PE 2a
Cetyl dimethicone copolyol	2.0	3.0	–	–
PEG 30-dipolyhydroxystearate	–	–	2.0	3.0
Medium chain triglycerides	18	17	18	17
Magnesium sulfate, heptahydrate	0.70	0.70	0.70	0.70
Purified water to:	100	100	100	100

The general formulation of the multiple emulsions was as follows: primary emulsion: 80.0 g; poloxamer 407: 0.80 g; preservative q.s.; purified water: q.s. to 100.0 g.

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A two-step procedure was used for the sample preparation. The first step consisted of the preparation of the primary emulsion; the second step entailed dispersing a given amount of primary emulsion in the external phase containing the secondary emulsifier.

Preparation of the primary emulsions

The primary W/O emulsions containing CDC (samples PE 1 and PE 1a) were prepared by slowly adding the aqueous phase at room temperature (22±2 °C) to the oil phase (containing the lipophilic surfactant) at the same temperature. Stirring was performed using a mechanical stirrer (Heidolph RZR 2020, Heidolph Elektro GmbH & Co. KG, Germany) at 500 rpm (6 min), 1000 rpm (1 min) and 1500 rpm (1 min).

The primary W/O emulsions containing PHDS (samples PE 2 and PE 2a) were prepared by slowly adding the aqueous phase preheated to 80±2 °C to the oil phase (containing the lipophilic surfactant) preheated to the same temperature. Stirring was performed using a mechanical stirrer (Heidolph RZR 2020, Heidolph Elektro GmbH & Co. KG, Germany) at 1000 and 1500 rpm until cooling to approximately 25 °C.

Preparation of the W/O/W emulsions

In the second step, the primary emulsion was added slowly to the aqueous phase containing the hydrophilic surfactant, while the system was stirred at 500 rpm at room temperature. After complete introduction of the primary emulsion, the stirring was continued for 20 min. The prepared multiple emulsions were designated as ME 1 and 1a and ME 2 and 2a, analogous to the designation of the primary emulsions.

Microscopic analysis

Microscopic analysis of the investigated samples was conducted in order to gain information about the multiple character of the prepared emulsions and their droplet size. An optical microscope (Olympus® BX 50, Olympus Optical Co., Tokyo, Japan) with a camera (DXC-151 Single Chip Sony CCD Camera, Sony Corporation, Tokyo, Japan) was used throughout the study. Measurements of 300 droplets per sample were performed (software Microimage, version 4.0; Olympus, Japan). For the selected samples, the measurements were repeated after different storage times. The mean droplet diameter and standard deviation were calculated for each sample.

Stability studies

The emulsions were observed for consistency, color, homogeneity and eventually phase separation during storage at room temperature (22±2 °C). Centrifugation was performed with 5 g of the samples at 1500 rpm using a laboratory centrifuge (LC 320, Tehnica, Zelezniki, Slovenia). The testing was replicated at predetermined time intervals (*i.e.*, 24 and 48 h and 7, 15 and 30 days). After 30 min of centrifugation, the samples were inspected for eventual phase separation.

Conductometric analysis was performed on selected samples to examine the release of the electrolyte initially entrapped in the internal water phase. The specific conductivity of the emulsions was measured directly using a Conductivity Meter CDM 230 (Radiometer, Copenhagen, Denmark) at 22±2 °C.

Rheological measurements

Rheological measurements were performed using a rheometer Rheolab MC 120 (Paar Physica, Stuttgart, Germany) coupled with a cone and plate measuring device MK 22 (diameter 50 mm, cone angle 1° with a 50 μm gap in the middle of the cone) for rotational and a

MK 24 (diameter 75 mm, cone angle 1° and a 50 μm gap) for oscillatory measurements, at 20±0.2 °C. The rheological measurements were performed in triplicate.

In the steady-state measurements, the shear stress was measured as a function of the shear rate. The shear rate was changed from 0 to 200 s^{-1}, and then from 200 to 0 s^{-1}. The values of the apparent viscosities (at the shear rates 10.5 and 200 s^{-1}) were used for an analysis of the samples flow.

Oscillatory measurements were performed in order to determine the linear viscoelastic region of the samples (amplitude sweep). After the linear viscoelastic region had been determined, the frequency sweep procedure was performed at a constant strain within the frequency range 0.10–10 Hz. The values of the storage modulus (G'), loss modulus (G'') and loss tangent or damping factor (tan δ) were used for sample characterization.

The relationship between G', G'' and tan δ is given by Eq. 1:

$$\tan \delta = G''/G' \tag{1}$$

RESULTS AND DISCUSSION

Immediately after preparation, the multiple emulsions were apparently white and homogenous creams. Samples ME 1 and 1a, prepared with Abil® EM 90 were notably softer than those prepared with Arlacel® P135 (samples ME 2 and 2a) at the same concentration level. The samples did not show any change in appearance and homogeneity over the investigated time period. Centrifugation testing revealed certain phase separation only in the case of sample ME 1, containing the lipophilic emulsifier Abil® EM 90 at the lower concentration level (Table II). It may be assumed that the applied emulsifier concentration was insufficient to efficiently stabilize the W/O/W emulsion.

TABLE II. Separated phase volume after centrifugation test

Samples	Volume, ml				
	24 h	48 h	7 days	15 days	30 days
ME 1	0.20	0.20	0.20	0.20	0.30
ME 1a	0.0	0.0	0.0	0.0	0.0
ME 2	0.0	0.0	0.0	0.0	0.0
ME 2a	0.0	0.0	0.0	0.0	0.0

Microscopic analysis revealed that the investigated W/O/W emulsions contained droplets with a large number of small internal droplets, *i.e.*, the samples belonged to type C multiple emulsions, as described by Florence and Whitehill.[14] The photomicrographs of the multiple emulsions ME 1a and ME 2a 48 h after preparation are shown in Fig. 1.

Rheological measurements

Steady-state rheological measurements. Rheological analysis represents the most important tool for the evaluation of multiple emulsions. These analyses have allowed, by their great versatility and power, the behavior of multiple emulsions to be characterize, changes in them induced by ageing, shear and tempe-

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rature to be followed and their stability to be predicted. Moreover, the rheological properties allow the disruption mechanisms of the oily globules, which occur either by osmotic swelling or simple shear flow to be described and controlled.[15,16]

The results of the steady-state rheological measurements have shown that all the investigated samples exhibited non-Newtonian plastic flow behavior, as demonstrated by the stress-shear rate curves given in Figs. 2 and 3. Such flow behavior is typical of very concentrated emulsions, with a volume fraction $\Phi > 0.74$.[16] All the samples showed shear-thinning behavior: the apparent viscosity decreased with increase in shear rate.
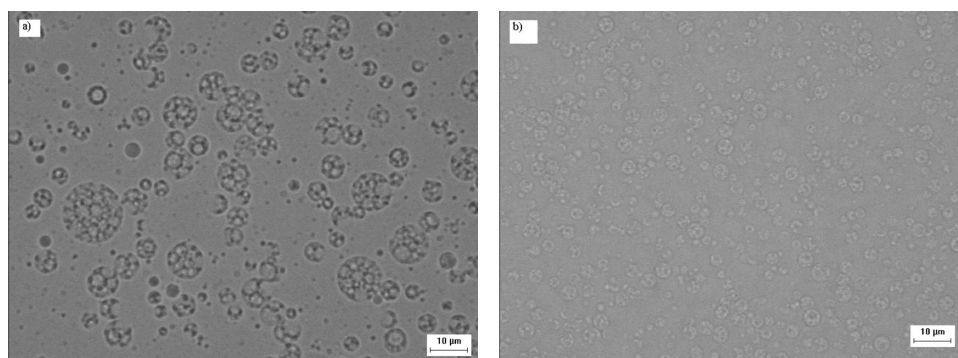

Fig. 1. Photomicrographs of the multiple emulsions, 48 h after preparation (magnification 1000×): a) ME 1a and b) ME 2a.
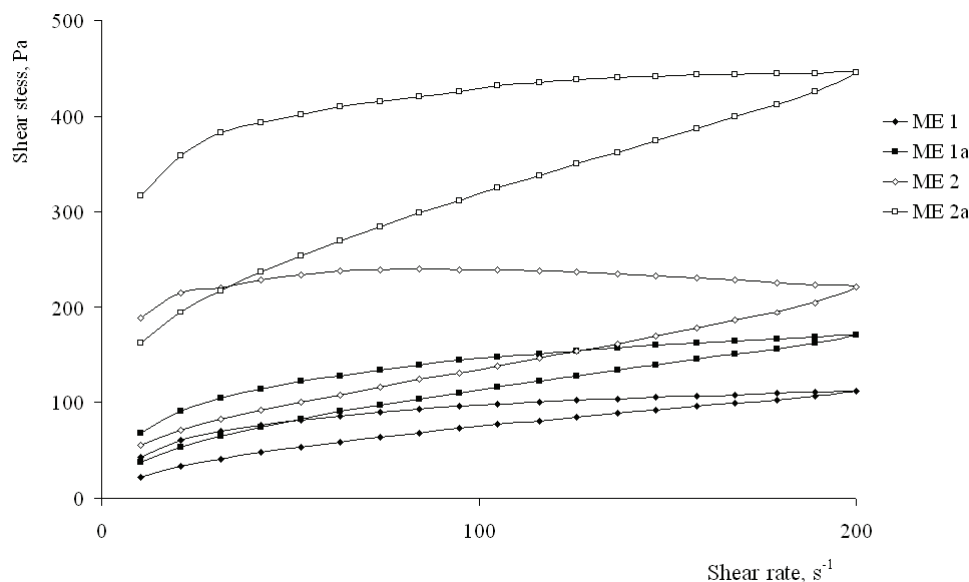

Fig. 2. Flow curves of the multiple emulsion samples, 24 h after preparation.
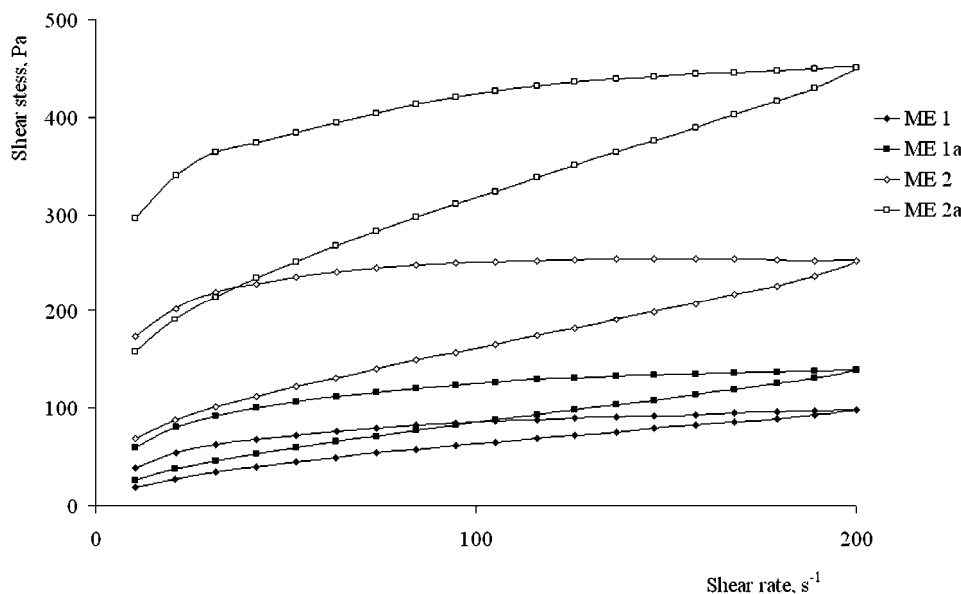
Fig. 3. Flow curves of the multiple emulsion samples, 30 days after preparation.

It can be observed that the download curve is below the upward curve, indicating thixotropy in the system. In such a case, the shear stress induces structural changes, *i.e.*, a break of multiple droplets – the maximum shear produces a decrease in the volume fraction, which results in a decrease in the viscosity.[16]

The upward curves were analyzed by applying different mathematical models using data analysis software (US 200, Paar Physica, Stuttgart, Germany). The best fit ($R > 0.99$) was obtained by the 3rd order polynomial:

$$\tau = a + b\gamma + c\gamma^2 + d\gamma^3 \tag{2}$$

where τ is the shear stress, γ is shear rate, and *a*, *b*, *c* and *d* are coefficients of the 0th, 1st, 2nd and 3rd order, respectively. The 0th order coefficient represents the yield stress (yield point or yield value) which can be used to detect the maturation process of emulsions.[17,18]

The values of the yield stress calculated according to the mathematical model described above and the apparent viscosity values extrapolated from the flow curves are given Table III.

The apparent viscosities and yield stress values of the investigated W/O/W emulsions were markedly influenced by the type and concentration of the lipophilic emulsifier. For both the investigated emulsifiers, higher apparent viscosity and yield stress values were obtained for the W/O/W emulsion prepared with the higher emulsifier concentration. At the same concentration level, the W/O/W emulsions prepared with PHDS exhibited a significantly higher apparent visco-

sity and yield stress values. As can be seen from Table III, there was a general trend towards a decrease of the apparent viscosity and yield stress values of the samples with time. This could be attributed to the coalescence of the internal water droplets with the external water phase, as discussed by Jiao and Burgess.[19] The subsequent increase in the volume of the external water phase of the W/O/W emulsions may lead to a decrease of the apparent viscosities and yield stresses. This phenomenon was less pronounced at the higher concentration level for both the investigated emulsifiers. The constancy of the apparent viscosity and yield stress values was the highest for the sample ME 2a.. Therefore, samples prepared with 2.4 % w/w primary emulsifier were selected for further comparative characterization.

TABLE III. Apparent viscosities (η_{app}) and yield value (τ_0) of the W/O/W emulsions during storage

Time	η_{app}^a / Pa s (at 10.5 s^{-1})	η_{app}^a / Pa s (at 200.0 s^{-1})	τ_0^a / Pa
Sample ME 1			
24 h	4.1 (0.30)	0.56 (0.020)	31 (2.9)
48 h	4.0 (0.06)	0.57 (0.010)	29 (1.1)
7 days	4.1 (0.21)	0.53 (0.032)	32 (1.4)
15 days	3.9 (0.06)	0.52 (0.052)	31 (1.3)
30 days	3.6 (0.06)	0.48 (0.020)	27 (0.9)
Sample ME 1a			
24 h	6.5 (0.21)	0.85 (0.006)	52 (2.8)
48 h	6.6 (0.46)	0.83 (0.035)	54 (5.1)
7 days	6.3 (0.51)	0.80 (0.061)	50 (1.0)
15 days	6.0 (0.11)	0.78 (0.025)	51 (6.1)
30 days	6.1 (0.20)	0.79 (0.076)	50 (1.9)
Sample ME 2			
24 h	17.9 (0.65)	1.11 (0.110)	177 (7.8)
48 h	17.9 (0.25)	1.32 (0.035)	174 (2.7)
7 days	17.3 (0.72)	1.10 (0.154)	172 (2.3)
15 days	17.3 (0.68)	1.21 (0.157)	167 (3.3)
30 days	16.5 (0.72)	1.26 (0.139)	158 (3.4)
Sample ME 2a			
24 h	30.1 (0.80)	2.23 (0.011)	299 (9.0)
48 h	30.0 (0.76)	2.10 (0.100)	296 (3.4)
7 days	30.4 (0.64)	2.24 (0.216)	301 (3.1)
15 days	29.2 (0.91)	2.15 (0.334)	292 (3.9)
30 days	29.4 (1.65)	2.25 (0.196)	294 (20.4)

$^a\pm SD$ ($n = 3$)

Oscillatory rheological measurements. The storage modulus (G') and loss angle (δ) provide quantitative characterization of the balance between the viscous and elastic properties of multiple emulsions.[16] The loss angle (δ) is a very precise

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indicator of this balance, the lower the δ value, the more pronounced is the elastic character, and *vice versa*.

The values of the basic viscoelastic parameters of the investigated samples ME 1a and ME 2a are given in Table IV.

TABLE IV. Storage modulus (G'), loss modulus (G'') and tan δ of the samples ME 1a and ME 2a during storage (at 1 Hz)

Time	G'^{a} / Pa	G''^{a} / Pa	tan δ^{a}
	Sample ME 1a		
24 h	740 (96.0)	232 (26.2)	0.31 (0.032)
48 h	642 (22.3)	268 (28.0)	0.42 (0.035)
7 days	581 (31.7)	203 (16.0)	0.35 (0.035)
30 days	692 (51.6)	240 (14.4)	0.35 (0.014)
90 days	463 (51.1)	252 (12.5)	0.55 (0.074)
	Sample ME 2a		
24 h	1220 (66.6)	290 (40.6)	0.24 (0,020)
48 h	1320 (32.1)	440 (64.2)	0.33 (0.055)
7 days	1380 (122.9)	503 (12.6)	0.36 (0.020)
30 days	1260 (68.0)	440 (21.8)	0.35 (0.040)
90 days	1120 (17.3)	370 (10.1)	0.33 (0.010)

$^{a}\pm SD$ ($n = 3$)

The storage (G') and loss (G'') moduli values of the multiple emulsion systems are presented as a function of frequency for the samples evaluated 24 h, 48 h and 90 days after the preparation are shown in Figs. 4–6, respectively. When a stable sample is stressed in the linear viscoelastic range, the storage modulus (G') predominates and is larger than the loss modulus (G''). For stable samples, the curves for both moduli are nearly parallel over the entire measured frequency range.[17]
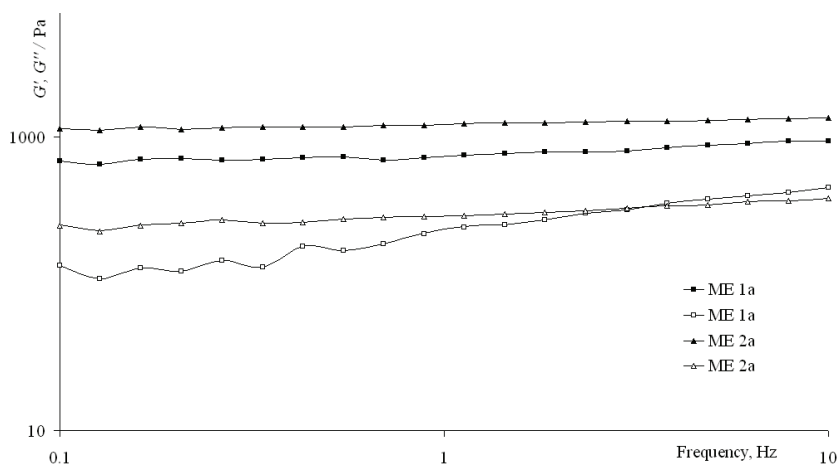

Fig. 4. Storage moduli (G') (filled symbols) and loss moduli (G'') (open symbols) of the multiple emulsion samples, 24 h after preparation.
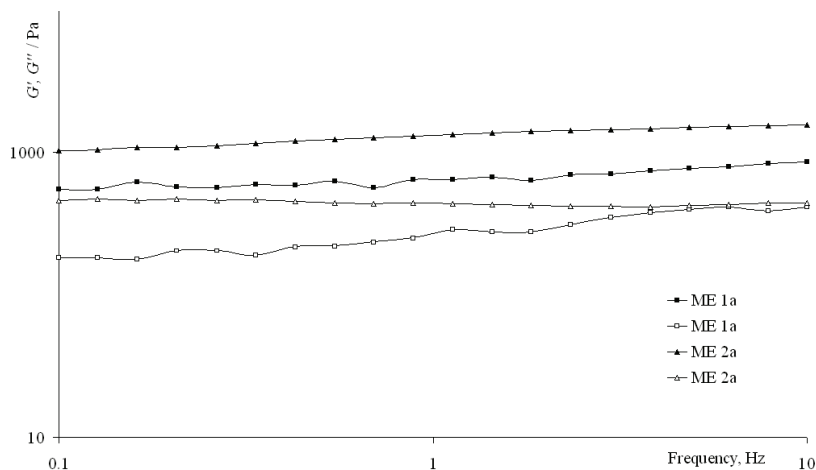
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Fig. 5. Storage moduli (*G'*) (filled symbols) and loss moduli (*G''*) (open symbols) of the multiple emulsion samples, 48 h after preparation.
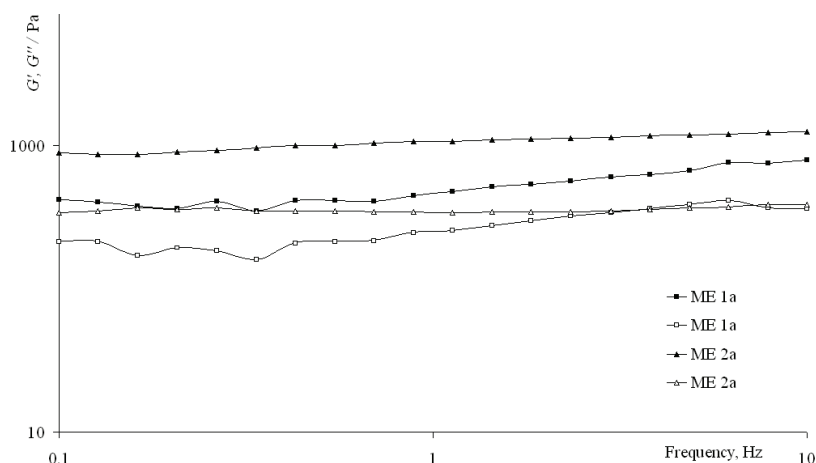

Fig. 6. Storage moduli (*G'*) (filled symbols) and loss moduli (*G''*) (open symbols) of the multiple emulsion samples, 90 days after preparation.

The high elasticity of these systems is a result of the high volume fraction of the multiple emulsions (0.80) and hence droplet interactions are significant, resulting in predominantly elastic systems.[20]

The type of the primary emulsifier had a significant impact on the oscillatory parameters of the investigated samples. At the same concentration of lipophilic polymeric emulsifier, the formulation with PHDS showed a markedly higher elasticity. The formulation ME 2a was highly viscoelastic or "solid-like", as indicated by the considerably higher *G'* values and lower tan δ values.

The observed higher value of the storage modulus of the sample ME 2a was accompanied by smaller droplet sizes in this sample (Table V). It was reported that, the smaller the diameter of the multiple emulsion droplets, the greater the number of contact points between them, which leads to an increase in storage modulus values.[21]

TABLE V. Droplet size of the samples ME 1a and ME 2a during storage

Time	Droplet size[a], μm
Sample ME 1a	
48 h	7.7 (1.29)
30 days	8.9 (2.09)
90 days	10.6 (1.94)
Sample ME 2a	
48 h	4.6 (0.70)
30 days	4.6 (0.82)
90 days	4.9 (1.19)

[a]±S.D. ($n = 300$)

As may be seen from Table IV, there were relatively large changes in the oscillatory characteristics of the investigated samples during the first 48 h after preparation. Such changes describe a classical "ripening step" of emulsions.[16] Following this initial period, the sample ME 1a exhibited acceptable stability only during the first month, while in the case of the sample ME 2a, the changes observed were negligible over the whole storage time evaluated.

When analyzing the droplet size (Table V) and the oscillatory rheological parameter values (Table IV) for the sample ME 1a, it is noticeable that the droplet size increases both 30 and 90 days after preparation, while the elasticity initially increases and then decreases. Water may penetrate from the outer water phase into the inner one by virtue of the osmotic pressure difference. The resulting water flow produces an increase in the internal water droplets size. Consequently, the oil globules swell, until a critical size is reached. Beyond this critical size, the multiple globules may split by breakdown of the oily membrane, as described by Grossiord and Seiller[16] and Geiger *et al.*[22] It may be assumed that the swelling of the multiple globules observed 30 days after preparation leads to an increase in the elasticity of the system, due to the decrease in the volume of the external water phase volume.

Ninety days after preparation, the increase in the droplet size was still pronounced, the storage modulus was markedly reduced and tan δ was higher. The observed elasticity reduction may be explained by the breakup of the oily membrane and expulsion of the internal water droplets into the continuous medium, which results in a decrease in the volume fraction of the multiple emulsion and increase in the external aqueous phase.[21] Although a continuous increase in the

multiple droplets size with time was evident, it may be postulated that the observed discrepancy in the elastic characteristics of the samples 30 and 90 days after preparation is the consequence of the reduced number of multiple droplets per unit volume. In the case of sample ME 2a, the changes in its elastic characteristics with time were less pronounced.

Conductometric analysis

The stability of sample ME 2a during storage was also confirmed by conductometric analysis (Table VI).

TABLE VI. Specific conductivity values (μS/cm) of the samples ME 1a and ME 2a during storage

Sample	Storage time				
	24 h	48 h	7 days	30 days	90 days
ME 1a	115.2	116.6	127.0	130.6	141.0
ME 2a	19.1	20.6	21.4	22.2	23.2

At the same level of the preservative concentration, differences in the specific conductivity of the samples occurred as a consequence of magnesium sulfate heptahydrate release from the inner water phase in which it was initially incorporated. Rupture of some multiple droplets, which could occur in the second phase of the emulsification process, could lead to mixing of the outer water phase with some amount of the inner water phase. Probably, it may be assumed that this phenomenon is more likely to occur in sample ME 1a, prepared with the lipophilic emulsifier CDC, and that this is the reason for the high initial conductivity values recorded in this sample (Table VI). During storage, the specific conductivity values of the samples increased slightly. Such observations could be attributed to the further rupture of multiple droplets with time. The degree of change observed was lower in the case of the multiple emulsion ME 2a, indicating its superior stability.

Droplet size analysis

The results of droplet size analysis of the investigated samples are given in Table V and Fig. 7.

Particle size analysis gives useful information about the stability of multiple emulsions. It also enables the observation of the growth process of particles dispersed in multiple emulsions; accordingly, the evolution of their dimension with time.[23] It may be observed (Table V) that the type of lipophilic polymeric emulsifies had a significant influence on the droplet size of the investigated W/O/W emulsions. The average particle diameters in samples ME 1a and ME 2a 48 h after preparation were 7.7 and 4.6 μm, respectively. At the same concentration level, in the case of the PHDS-based emulsions, both the inner water droplets and
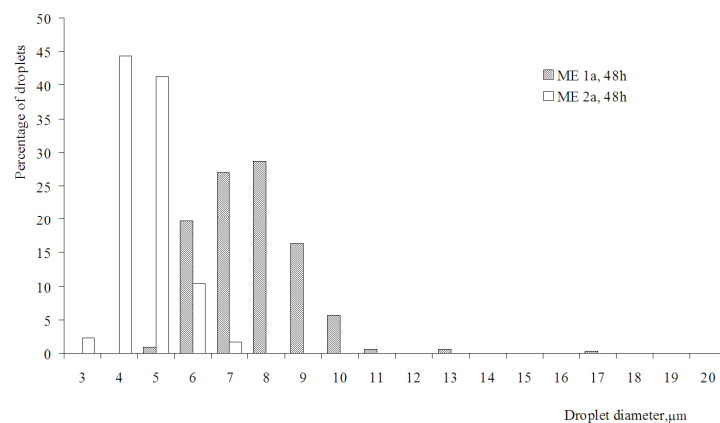
(a)
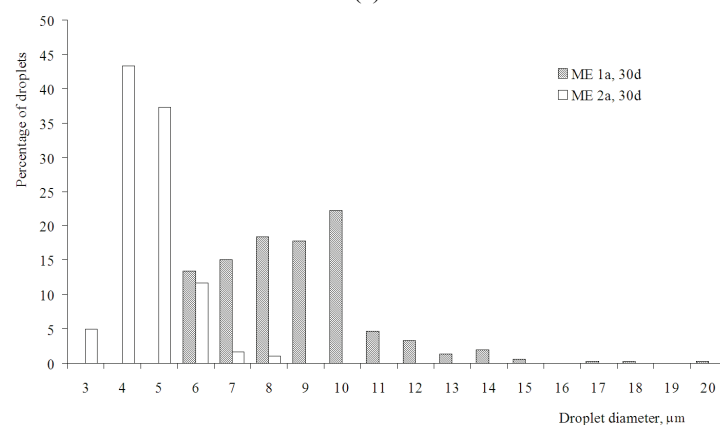
(b)
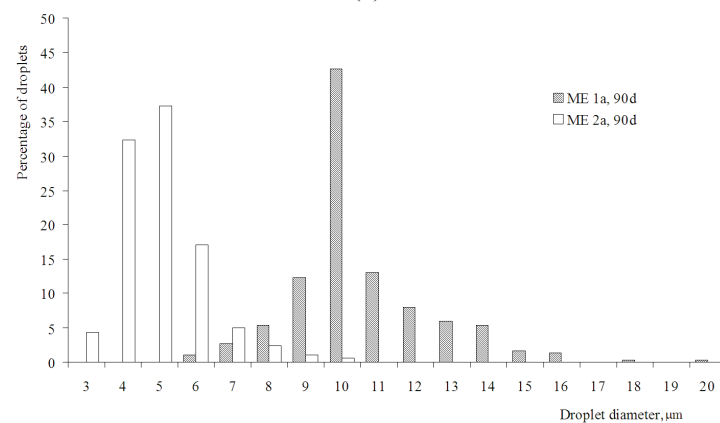
(c)

Fig. 7. Distribution histograms of the multiple droplet size for emulsion ME 1a and ME 2a:
48 h (a), 30 days (b) and 90 days (c) after preparation.

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multiple droplets size were smaller compared to the CDC-based emulsions. The inner water droplets size was about 1.5 and 0.70 µm for samples ME 1a and ME 2a, respectively, although the size of the droplets that were in contact could not be determined accurately. It may be noticed that the range order of the estimated droplet size correlated with the apparent viscosity of the primary emulsions, as the apparent viscosity values were 16.0 and 2.80 Pa s (at 10.5 s^{-1}) for samples PE 1a and PE 2a, respectively. The less viscous primary emulsion (PE 2a) was also easier to re-emulsify compared to the semi-solid primary emulsion PE 1a.

As discussed above, a continuous increase in droplet size with time was observed in the case of sample ME 1a, while the droplet size remained almost constant for sample ME 2a. A certain increase in droplet size, observed 90 days after preparation, may be attributed to droplet swelling. It appears that PHDS more efficiently prevents multiple droplets swelling than CDC used at the same concentration level.

The distribution histograms of the multiple droplet size for ME 1a and ME 2a are presented in Fig. 7. In the case of sample ME 1a, 48 h after preparation, about 55 % of the droplets had a diameter between 7 and 8 µm. However, their increase with time resulted in more than 40 % of the droplets having a diameter of 10 µm 90 days after preparation. In the case of sample ME 2a, more than 85 % of the droplets had a diameter between 4 and 5 µm 48 h after preparation. The droplet size distribution remained almost unchanged with time.

CONCLUSIONS

W/O/W multiple emulsions containing low concentrations (1.6 and 2.4 %) of the primary polymeric emulsifier (cetyl dimethicone copolyol or PEG–30 dipoly-hydroxystearate) were prepared and characterized with respect to their droplet size and rheological behavior. The type and concentration of the applied lipophi-lic polymeric emulsifier markedly affected the characteristics of the W/O/W multiple emulsions. CDC used at the lower concentration level was found insuffi-cient to efficiently stabilize the W/O/W emulsion. The sample containing 2.4 % PHDS exhibited consistent storage and loss moduli values and droplet size over a 90-day time span, indicating the favorable long-term stability of the resulting emulsion. The results obtained indicate that this semi-solid W/O/W emulsion of-fers potential advantages as a vehicle for dermopharmaceutical and cosmetic pre-paration development and merits further investigation.

ИЗВОД

ОДРЕЂИВАЊЕ РЕОЛОШКИХ КАРАКТЕРИСТИКА И ВЕЛИЧИНЕ КАПИ W/O/W ВИШЕСТРУКИХ ЕМУЛЗИЈА ДОБИЈЕНИХ ПРИ НИСКОЈ КОНЦЕНТРАЦИЈИ ПОЛИМЕРНИХ ЕМУЛГАТОРА

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Вишеструке емулзије су сложени дисперзни системи, са великим могућностима примене у фармацији, козметици и прехрамбеној индустрији. Међутим, у пракси се јављају значајни проблеми због њихове изражене термодинамичке нестабилности. У овом раду су испитиване W/O/W вишеструке емулзије које садрже ниску концентрацију липофилних полимерних емулгатора цетил диметикон кополиола и PEG-30 диполихидроксистеарата. Концентрације наведених емулгатора у W/O/W емулзијама су износиле 1,6 и 2,4 mas %. Врста и концентрација липофилног полимерног емулгатора веома утиче на реолошке карактеристике и величину капи испитиваних емулзија. Вишеструка емулзија добијена при 2,4 mas % PEG-30 диполихидроксистеарата има највеће вредности испитиваних реолошких параметара (привидна вискозност, напон попуштања, еластични модул) и најмању величину капи. Наведени параметри се током испитиваног временског периода незнатно мењају, што указује на добру стабилност W/O/W емулзије са 2,4 mas % PEG-30 диполихидроксистеарата. Такође, добијени резултати указују да се промене, које се дешавају током времена у испитиваним вишеструким емулзијама, могу приписати механизму бубрења/пуцања сложених капи, што је праћено одређивањем реолошких карактеристика и величине капи.

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