



Surfactant solubility and aggregate orientation in hydrofluoroalkanes

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Received 9 September 2004; received in revised form 17 January 2005; accepted 20 January 2005

Available online 16 March 2005

Abstract

Purpose: To find surfactants soluble in the two hydrofluoroalkane (HFA) propellants, HFA-134a and HFA-227ea; to compare surfactant solubility in the two propellants with those in 2*H*,3*H*-decafluoropentane (DFP) in order to assess latter's suitability as a liquid model propellant and to investigate surfactant aggregation and aggregate orientation in HFAs.

Methods: To assess surfactant solubility, HFA was added to a known amount of surfactant until dissolution was visibly apparent. An iodine solubilization method was used to determine surfactant aggregation behaviour in DFP. Fluorescence spectroscopic investigations on the surfactant orientation in aggregates were carried out in HFAs using a microviscosity sensitive fluorescent probe (1,3-dipyrenylpropane). The aim was to assess viscosity changes in the microenvironment of this lipophilic probe upon incorporation into surfactant aggregates.

Results: Soluble surfactants could be found among the polyoxyethylene-ethers and POE–PPO-block copolymer surfactants. Solubility in DFP appears to correlate with solubility in HFA-134a, but not HFA-227ea. Iodine solubilization indicates micellization of Brij 30 in DFP at a cmc (type II association behaviour). L-44 in DFP, on the other hand, does not exhibit a well defined cmc, but shows continuous surfactant aggregation (type I association behaviour). The fluorescence spectroscopic studies showed evidence for probe incorporation into surfactant aggregates in HFAs.

Conclusions: DFP proved to be a good model for HFA-134a only. An L₁-aggregate orientation was shown for surfactants in HFAs and is in marked contrast to the chlorofluorocarbon propellant where a L₂-aggregate orientation exists.

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Keywords: HFA propellant; Model propellant; Surfactant orientation; Surfactant solubility; Fluorescence spectroscopy

1. Introduction

Non-ozone depleting hydrofluoroalkanes (HFA) are now replacing the ozone depleting chlorofluorocarbon (CFC) propellants in pressurized metered dose inhalers (pMDI). Among them, 1,1,1,2-tetrafluoroethane

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Table 1
Physico-chemical properties of HFAs and CFCs (adapted from Byron et al., 1994)

Compound	Vapour pressure (bar, at 21 °C)	Boiling point (C°)	Heat of vaporization at boiling point (kcal/mol)	Dipole moment <i>D</i> (debye)	Dielectric constant (ϵ)	Polarizability 10^{-24} cm ³ /molecule (vapour)	Density (kg/l at 20 °C)
CFC-11	0.91 ^a	23.8	5.99	0.46	2.3	9.5	1.49
CFC-12	5.77 ^a	-29.8	4.78	0.51	2.13	7.9	1.33
CFC-114	1.88 ^a	3.6	5.62	0.5	2.26	8.5	1.47
HFA-134a	5.83 ^b	-25.8	5.28	2.06	9.51	5.4	1.23
HFA-227ea	4.06 ^b	-17.3	3.2	0.93	4.07	-	1.41
DFP ^c	0.30	53.6	-	-	15.05	-	1.58

^a Sirand et al. (1992).

^b Blondino and Byron (1998).

^c Rogueda (2003).

(HFA-134a) and 1,1,1,2,3,3,3-heptafluoropropane (HFA-227ea) are considered as the most suitable MDI propellants (Whitham and Eagle, 1994; McDonald and Martin, 2000). However, due to different physical properties, e.g. higher polarity and vapour pressure, HFAs are clearly no “drop-in” replacements for CFCs (Table 1). Of particular concern is the higher polarity of HFA propellants compared to CFC propellants resulting in different solvency behaviour. For instance, commonly used surfactants in CFC-formulations, i.e. Span 85, oleic acid and lecithin, are only poorly soluble in the HFA propellants (Byron et al., 1994). Improving solubility by using a cosolvent such as ethanol, however, may lead to partial drug dissolution in suspension formulations with the risk of subsequent crystal growth (Dalby and Byron, 1988; Blondino and Byron, 1998; Williams and Liu, 1998b). Hence, new surfactants soluble in HFAs are required. The higher polarity of the HFAs compared to the CFCs might also influence the surfactant aggregate orientation. In HFAs surfactant orientation has not been defined, whereas in CFCs a reverse micelle orientation (L_2) has been reported (Evans et al., 1988, 1989; Vervae and Byron, 1999). Detailed investigations on surfactant behaviour in HFA propellants have been impeded to date due to the lack of a low volatility model propellant that is liquid at room temperature and atmospheric pressure, such as P-113 which was used as a model for the CFCs. Dickinson et al. (2000) assessed perfluorohexane, 1H-perfluorohexane and 2,2,2-trifluoroethanol as potential model propellants by comparing solute solubility. Only 1H-perfluorohexane showed a linear relationship between solubilities in HFA propellants and the model. However, solubilities in 1H-perfluorohexane

were only approximately 11% and 26% of those in HFA-134a and HFA-227ea, respectively. The introduction of the hydrogen-atom, thus the ability of hydrogen-bonding appears to have a crucial influence on solvency properties. 2*H*,3*H*-decafluoropentane (DFP), consisting of one carbon less and one additional hydrogen atom may therefore be preferable as model propellant. Its physical properties have been characterized and compared to HFA-134a and HFA-227ea by Rogueda (2003) (Table 1). In this study surfactant solubility tests were made in HFA-134a, HFA-227ea and DFP in order to find HFA-soluble surfactants. The surfactant solubility data in the three HFAs were compared in order to assess the suitability of DFP as a liquid model propellant, which will be used as a reference for pMDI formulation properties. Furthermore, investigations on surfactant aggregation behaviour utilising iodine solubilization and its orientation in aggregates by employing a viscosity sensitive fluorescence spectroscopic method were carried out in HFAs.

2. Materials and methods

2.1. Materials

Brij 30, Brij 35, Brij 97, polyoxyethylene(10) laurylether (POE10-C12), Tween 80, Tween 20, polyoxyethylenes (POE) and iodine were purchased from Sigma–Aldrich (Steinheim, Germany). Brij 56, Brij 76, Tween 60 and Span 20 were purchased from Fluka Chemie GmbH (Buchs, Switzerland). Poly(ethylene oxide)–poly(propylene oxide) block

copolymer (POE–PPO block copolymer) surfactants (Pluronic F-127, F-68, L-64, L-44 NF, L-43, 25-R4, 17-R2, 17-R4, 10-R5) were a generous gift from BASF Corporation (New Jersey, USA) and Synperonic PE L-101 and L-62 from Uniqema (Eversberg, Belgium). The hydrofluoroalkane propellants 1,1,1,2-tetrafluoroethane (Solkane[®] 134a pharma) and 1,1,1,2,3,3,3-heptafluoropropane (Solkane[®] 227ea pharma) were supplied by Solvay Fluor und Deriyate GmbH (Hannover, Germany) (the first supply was a free sample). The liquid model propellant 2*H*,3*H*-decafluoropentane (DFP) was obtained from Apollo Scientific Ltd. (Derbyshire, UK). 3,3-dipyrenylpropane was purchased from Molecular Probes (Oregon, USA). All chemicals were used as received.

2.2. Methods

2.2.1. Surfactant solubility

For the determination of surfactant solubility in liquefied gases and the model propellant, a commonly described method was used (Brown and George, 1997; Blondino and Byron, 1998; Williams and Liu, 1998a). HFAs were added by weight to a known amount of surfactant until dissolution was visibly apparent. Surfactant was considered as dissolved when one clear phase was apparent. Solubility was determined between 0.01% and 50% (w/w) surfactant in HFA at ambient temperature (~23–25 °C). For the solubility determination in the two propellants HFA-134a and HFA-227ea, surfactant was filled into a plastic-coated glass bottle (Wheaton, USA), a continuous spray valve (Valois, France) was then crimped (manual bottle crimper, model 3000-B, Aero-Tech Laboratory Equipment Company, Maryland, USA) onto the bottle and propellant filled through the valve via a pressure burette (Aero-Tech Laboratory Equipment Company, Maryland, USA). After each propellant addition, the bottle was sonicated (XB6 Grant Instruments Ltd.) for 20 s. In order to keep the propellant in the liquid state, pressure within the burette was held between 4 and 6 bar with addition of nitrogen. Surfactant solubility in the liquid model propellant was carried out in screw cap glass squat vials (Scientific Laboratory Supplies Limited, Nottingham, UK) with DFP added by weight using a Pasteur pipette.

2.2.2. Surfactant aggregation

An iodine solubilization method was used to investigate surfactant aggregation behaviour in HFAs (Ross and Oliver, 1959; Ross and Baldwin, 1966). Blondino and Byron (1998) previously used a modified method to determine by visual observation the potential of surfactants to solubilize iodine in HFAs. However, the use of a liquid model propellant allows the use of spectrometric analysis and therefore a more precise determination of the surfactant aggregation behaviour. A 10^{-4} M iodine stock solution in DFP (solution A) was prepared as well as a surfactant stock solution (solution B) by dissolving surfactant in solution A. By diluting solution B with solution A, solutions of different surfactant concentration in a constant iodine concentration could be obtained. As upon surfactant aggregation, a transition from the iodine absorbance maximum at 520–355 nm of the solubilized iodine is expected, the absorbance at 355 nm of the solutions was measured using a Cary 3E Varian UV–vis spectrometer. Solution A was used as standard for 0% absorbance.

2.2.3. Surfactant orientation

Fluorescence spectroscopic investigations into surfactant orientation in aggregates were carried out using a microviscosity sensitive fluorescent probe, i.e. 1,3-dipyrenylpropane. The fluorescence spectroscopic investigations were carried out in the model propellant (DFP) as well as in HFA-134a and HFA-227ea. For the investigations in the model propellant, 1% (w/w) surfactant solutions in DFP were prepared. An appropriate amount of fluorescent probe stock solution in tetrahydrofuran was added to the surfactant solution to achieve a concentration of 1 μ M. The volume of the stock solution did not exceed 0.5% of the volume of the solution in order to avoid effects on the microenvironment (Zana, 1999). The solutions were sonicated for 30 s and then kept for 3 days protected from light to allow probe solubilization. Fluorescence emission intensities were measured using a Perkin-Elmer LS50-B fluorescence spectrometer and a fluorescence cell with 1 cm path-length. 1,3-Dipyrenylpropane was excited at 346 nm. Excitation and emission slit widths were 5 and 2.5 nm, respectively. Accordingly, investigations on the surfactant orientation in the actual propellants were carried out. For the preparation of 1% surfactant solutions containing 3 μ M fluorescent probe, the required amount of surfactant and probe stock solution were filled into

a plastic-coated glass bottle (Wheaton, USA), a continuous spray valve was then crimped (manual bottle crimper, model 3000-B, Aero-Tech Laboratory Equipment Company, Maryland, USA) onto the bottle and the required volume of propellant filled through the valve using a pressure burette (Aero-Tech Laboratory Equipment Company, Maryland, USA). After sonication for 30 s the solutions were kept for 3 days protected from light and then transferred into a fluorescence pressure cell (Hellma quartz Suprasil Cell[®], Germany) with a pathlength of 0.3 cm. The smaller pathlength required an increased probe concentration of 3 μM in the propellant solution in order to obtain sufficient fluorescence emission. The propellant was transferred through the continuous valve into an inline check valve (Upchurch Scientific, USA) that was connected with a polymer tubing (inlet) to the pressure cell. The propellant solution could be released through a micro metering valve (Upchurch Scientific, USA) that was connected to the outlet line of the cell.

3. Results

3.1. Surfactant solubility

Visual assessment of surfactant solubility in HFAs was chosen due to the experimental difficulty of quantitative surfactant analysis in pressurized systems. This method, however, only allows the determinations of approximate solubility values.

Solubility studies were made on the following surfactant groups: polyoxyethylene-ethers (Brijs), poly-

oxyethylene (20)-sorbitan fatty acid-ester (Tweens), sorbitan fatty acid-ester (Spans), POE–PPO–POE triblock copolymer (Poloxamer) and PPO–POE–PPO triblock copolymer (reverse-Poloxamer) surfactants. In Tables 2 and 3, the apparent surfactant solubility in the two propellants HFA-134a and HFA-227ea as well as in the liquid model propellant 2*H*,3*H*-decafluoropentane (DFP) are presented. Furthermore, the solubility of various molecular weight POEs was determined and results are presented in Table 4.

Poloxamer and reverse Poloxamer (R-Poloxamer) solubility in the three HFAs is listed in Table 3. The first letter describes their physical form. “L” for liquid, “P” for paste and “F” for solid. The following digit (two digits in a three-digit number) multiplied by 300, indicates the approximate molecular weight (M_n) of the hydrophobe. The last digit multiplied by 10 indicates the approximate ethylene oxide content in weight percent. For reverse Poloxamers, the digits preceding the “R” multiplied by 100 indicates the approximate M_n of the PPO-block. The number following the “R” multiplied by 10 indicates the approximate weight percent POE in the molecule.

In order to assess the suitability of DFP as a liquid model propellant, solubility data in HFA-134a and HFA-227ea, respectively, are plotted against those in DFP (Figs. 1 and 2). Solubility values of 21 surfactants are plotted, some data points are superimposed). Since solubility was only determined up to 50% (w/w), a 50% (w/w) solubility value was plotted for surfactants which were >50% (w/w) soluble. A significant correlation exists only between surfactant solubility in HFA-134a and

Table 2
Apparent surfactant solubility (% w/w) in HFAs

	HFA-134a	HFA-227ea	DFP
POE10-C12 (polyoxyethylene (10) laurylether)	≈4	≈31	≈30
Birij 97 polyoxethylene (10) oleylether (HLB: 12.4)	≈1	≈50	≈2
Brij56 polyoxyethylene (10) cetylether (HLB: 12.9)	≈0.7–1	≈0.2	≈0.3
Brij76 polyoxyethylene (10) stearylether (HLB: 12.4)	≈0.7	≈0.3	≈0.2
Brij35 polyoxyethylene (23) laurylether (HLB: 16.9)	≈0.08	≈0.03	≈0.05
Brij30 polyoxyethylene (4) laurylether (HLB: 9.7)	≈0.2	>50	≈3
Tween 20 polyoxyethylene (20) sorbitan-monolaurate (HLB: 16.7)	≈0.2	≈50	≈0.2
Tween 60 polyoxyethylene (20) sorbitan-monostearate (HLB: 14.9)	≈0.1	≈0.1	≈0.2
Tween 80 polyoxyethylene (20) sorbitan-monooleate (HLB: 15.0)	≈0.1	≈0.1	≈0.2
Span 20 sorbitan-monolaurate (HLB: 8.6)	<0.01	<0.01	<0.01

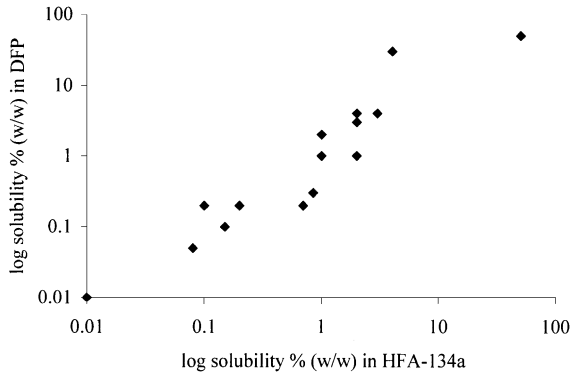


Fig. 1. Log surfactant solubility (% w/w) in HFA-134a vs. DFP.

DFP with a slope of 0.978 and a correlation coefficient of 0.9499.

3.2. Surfactant aggregation

Since highest HFA solubility was found among the Brij and Poloxamer surfactants, Brij 30 and Pluronic L-44 NF were chosen for the investigation on surfactant aggregation behaviour in DFP. Both surfactants showed similar solubility in HFAs. The addition of iodine to both surfactant solutions resulted in a colour change of iodine from violet to yellow with an absorbance maximum at 355 nm. In Fig. 3, the log surfactant concentration (% w/w) in DFP is plotted against the absorbance at 355 nm, hence it shows the extent of aggregation with the increase of surfactant concentration. In both surfactant solutions an absorbance increase with increasing the surfactant concentration is shown. At a surfactant

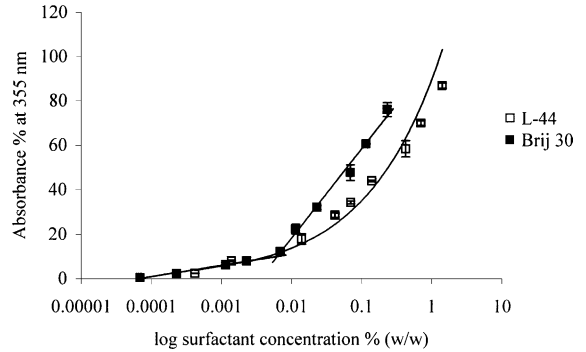


Fig. 3. Log surfactant concentration (% w/w) vs. iodine absorbance (%) at 355 nm.

Table 3

Apparent Poloxamer/R-Poloxamer solubility (% w/w) in HFAs

Poloxamer	HFA-134a	HFA-227ea	DFP
Pluronic F-127	<0.01	<0.01	<0.01
Pluronic F-68	<0.01	<0.01	<0.01
Synperonic PE L-101	≈0.1–0.2	>50	≈0.1
Synperonic PE L-62	≈2	>50	≈1
Pluronic L-64	≈1	>50	≈1
Pluronic L-44NF	≈2	>50	≈4
Pluronic L-43	≈3	>50	≈4
R-Pluronic 25-R4	≈2	≈42	≈4
R-Pluronic 17-R4	>50	>50	>50
R-Pluronic 17-R2	>50	>50	>50
R-Pluronic 10-R5	>50	>50	>50

concentration of 0.0062% (w/w), a sharp transition to a steep absorbance increase can be observed in the Brij 30 solution. For Pluronic L-44, however, a rather gradual absorbance increase is shown with increasing the surfactant concentration.

3.3. Surfactant orientation

The aim of the fluorescence spectroscopic investigations into surfactant orientation was to assess

Table 4

POE/PPO solubility (% w/w) in HFAs

	HPA-134a	HFA-227ea	DFP
POE 300	≈4	>50	≈4.5
POE 600	≈4	>50	>50
POE 1000	≈2	≈2	≈0.7
POE 2000	<0.01	<0.01	<0.01
PPO 2000	≈2	>50	≈0.7

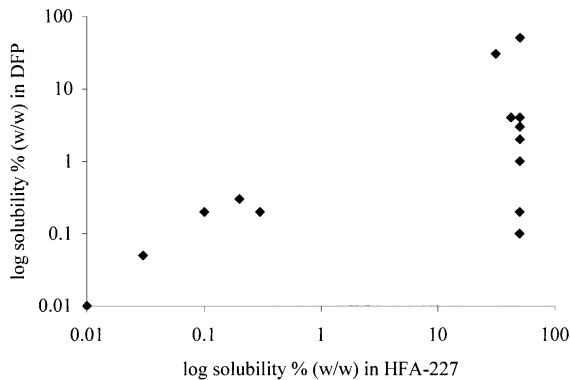


Fig. 2. Log surfactant solubility (% w/w) in HFA-227ea vs. DFP.

viscosity changes in the microenvironment of 1,3-dipyrenylpropane upon its incorporation into surfactant aggregates. Since this probe is a lipophilic molecule, incorporation into surfactant aggregates with subsequent changes of the viscosity in the microenvironment of this probe is only expected for a L_1 -orientation, where the hydrophobic moiety orientates towards the centre of the aggregate and the hydrophilic moiety toward the bulk solvent. The viscosity sensitive property of 1,3-dipyrenylpropane lies in the ability of intramolecular excimer formation (Zachariasse, 1978; Winnik et al., 1991). Excimers are formed, if the two pyrene groups in 1,3-dipyrenylpropane act cooperatively to emit a photon (Turro, 1991). Excimer fluorescence can be seen in the emission spectrum as a broad structureless band, which is red shifted with respect to the “normal” fluorescence of the molecule (Winnik et al., 1990; Binks, 1999). The extent of excimer formation depends on the ability of conformational changes and thus on molecular motion. Low viscosity with high molecular motion for instance results in high excimer emission intensity (I_E : 485 nm) and low monomer emission intensity (I_M : 376–395 nm). Hence, I_M/I_E ratios can be exploited to measure changes in the microviscosity of 1,3-dipyrenylpropane. A viscosity increase shows as an increase in the I_M/I_E ratio. The corresponding wavelength for I_M was the first band at 376 nm. HFA-soluble Brij 97 which consists of a lipophilic oleyl-chain, thus capable of forming a lipophilic aggregate core, was chose for the assessment of surfactant aggregate orientation in HFAs.

In Fig. 4 fluorescence spectra are shown for 1,3-dipyrenylpropane in the absence and presence of Brij 97 in DFP, HFA-134a and HFA-227ea. The small lines show the fluorescence spectrum of the fluorescent probe in the HFA, whereas the bold black lines are spectra of the probe in HFA with the addition of 1% Brij 97. Surfactant addition results in 1,3-dipyrenylpropane spectra exhibiting increased monomer to excimer emission intensity ratios in all three HFAs.

4. Discussion

4.1. Surfactant solubility

The investigations into surfactant solubility showed that HFA-soluble surfactants could mainly be found

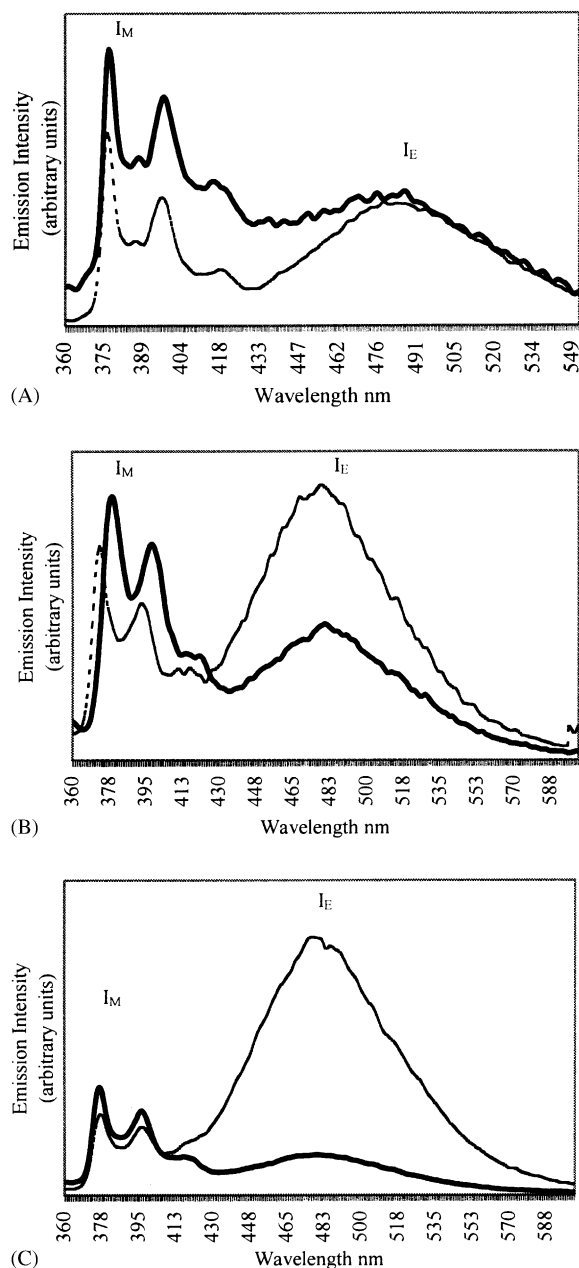


Fig. 4. Comparison of 1,3-dipyrenylpropane spectra in the presence (—) and absence (—) of Brij 97 in (A) DFP; (B) HFA-134a; and (C) HFA-227ea.

among the Brij and POE–PPO block copolymer surfactants. Tween surfactants generally show little HFA solubility and Span 20 is insoluble in all three HFAs. Among the liquid-pasty Brij, i.e.

polyoxyethylene(10)-laurylether (POE10-C12), Brij 30, Brij 97, and the liquid POE–PPO block copolymer surfactants, solubility is significantly higher in HFA-227ea than in HFA-134a and DFP, whereas solid Brijis, i.e. Brij 56, Brij 76 and Brij 35 as well as the solid POE–PPO block copolymers exhibit low solubility in all three HFAs.

Since the physical state of POE-based non-ionic surfactants is mainly determined by the length of the POE-chain, it appears that the hydrophilic POE moiety significantly influences HFA-solubility. POE is liquid at room temperature up to a molecular weight (M_n) of approximately 600 (approximately 10 POE units), further polymerisation results in a waxy-solid state. POE 1000–20,000 has a crystallinity of around 90% (Salamone, 1996). In HFAs, POE solubility decreases with increasing the M_n (Table 4) and becomes insoluble with $M_n > 1000$. Similarly, Brij and POE–PPO block copolymer surfactant solubility decreases with increasing the POE chain length to more than approximately 10 POE units, as seen for example when comparing the solubility of the POE-laurylethers Brij 30, POE10-C12 and Brij 35, consisting of 4, 10 and 23 POE units, respectively. HFA solubility increases with increasing the POE moiety from 4 to 10 units, but a further increase to 23 units results in decreased HFA solubility in all three HFAs. POE changes its configuration from a “zigzag” configuration to a meander configuration with increasing the degree of polymerisation to >10 –12 units in aqueous solution and to >20 –40 units in bulk. However, with POE-based surfactants the change in configuration starts at a degree of polymerisation of 15–20 (Rosch, 1967; Bailey and Koleske, 1967). The meander configuration maximizes hydrogen bonding while minimizing the number of exposed hydrophobic groups resulting in increased polarity and H-bonding capability. The significant reduction of POE solubility in HFAs may be explained by a similar change in configuration with increasing the degree of polymerisation. The strong electron withdrawing effect of the fluorine atoms in HFAs, leaving a partial positive charge on the hydrogen substituents, allows a considerable charge separation and hence the possibility of H-bonding (Byron et al., 1994). However, possible configurational changes of POE in HFAs which may lead to increased polarity as in water may affect the interaction between the POE molecule and HFAs.

Furthermore, the introduction of a hydrophilic polyol structure such as sorbitan in Span 20 results in HFA insolubility. HFA insolubility of Span 85 has previously been reported (Byron et al., 1994; Blondino and Byron, 1998). Moreover, glucoside and thioglucoside surfactants were found to be insoluble or only slightly soluble in HFAs (Brown and George, 1997; Williams and Liu, 1998a, b).

All liquid POE–PPO block copolymers exhibit high solubility in HFA-227ea, whereas in HFA-134a and DFP only reverse Pluronic show solubility $>50\%$ (w/w). One explanation could be the confined middle position of the POE block in the triblock that might inhibit conformational changes. Pluronic 25-R4, however, shows significantly lower solubility compared to the other reverse Pluronic. This may be explained by the fact that Pluronic 25-R4 possesses the longest POE chain with a M_n of 1440.

In conclusion, the investigations into surfactant solubility behaviour in HFAs suggests a strong influence of the hydrophilic moiety on surfactant solubility. However, a correlation between the hydrophile–hydrophobe balance does not exist (Table 2). Generally, non-ionic surfactants show higher solubility in HFA-227ea than compared to HFA-134a and DFP, which suggests stronger interactions between the surfactant and HFA-227ea, e.g. H-bonding interactions and dispersion forces. As a result, surfactant solubility in DFP does only correlate with those in HFA-134a, hence, DFP appears to be a good model for HFA-134a and not for HFA-227ea. Soluble surfactants could mainly be found among the Brij and POE–PPO block copolymer surfactants and may therefore be considered as potential alternative to the HFA-insoluble surfactants commonly used in pMDI formulations. However, toxicity profiles with respect to pulmonary delivery still need to be investigated.

4.2. Surfactant aggregation

The iodine solubilization experiment shows an absorbance increase at 355 nm with increasing the concentration of both surfactants, i.e. Brij 30 and Pluronic L-44, thus surfactant aggregation is evident in both surfactant solutions (Fig. 3). Muller (1978) distinguishes two types of self-association behaviour in non-aqueous solvents, i.e. type I and type II association. Type I is characterized by: (1) small average aggregation num-

bers; (2) not exhibiting a well defined critical micelle concentration (cmc); (3) a progressively increase of aggregation numbers without reaching a limiting constant value; and (4) a stepwise sequential multiple equilibrium model, i.e. reorganisation of small preaggregates to spherical aggregates at higher concentrations (Christen and Eike, 1974; Eike et al., 1975; Eike, 1977). On the other hand, type II association is characterized by: (1) a moderately defined cmc; (2) relatively large aggregation numbers which reach a constant value at higher surfactant concentrations; and (3) aggregation can be described as a monomer-*n*-mer model for micellization as in water. The sharp transition to a steep absorbance increase at a Brij 30 concentration of 0.0062% (w/w) in DFP, reminiscent to the cmc in water, shows good agreement with type II association, L-44 in DFP, however, appears to associate according to type I association characterized by continuous surfactant aggregation in contrast to a sudden micellization at a cmc. Surfactant aggregation behaviour in the HFA propellants itself has still to be established. However, because of the structural similarity between DFP, HFA-134a and HFA-227ea, a similar surfactant aggregation behaviour in the actual propellants is likely.

4.3. Surfactant orientation

Addition of Brij 97 to all three HFAs (DFP, HFA-134a, HFA-227ea) in the presence of 1,3-dipyrenylpropane results in an increased monomer to excimer emission intensity ratio (I_M/I_E). An increased I_M/I_E ratio indicates an increased viscosity in the microenvironment of the probe after Brij 97 addition, which gives evidence for the incorporation of the fluorescent probe into a constricted interior of a surfactant aggregate. Since 1,3-dipyrenylpropane is a lipophilic molecule incorporation is only likely to occur into a L_1 -orientated surfactant aggregate, where the lipophilic moiety of the surfactant is directed towards the aggregate core and the hydrophilic moiety towards the bulk solvent. In conclusion, the fluorescence spectroscopic investigations provide evidence for a different surfactant orientation in HFA propellants than in CFC propellants, where a reverse surfactant (L_2 -) orientation has been reported. The higher polarity of HFA propellants compared to CFC propellants has therefore not only impact on the solvent properties, but also on the surfactant orientation behaviour.

Acknowledgements

This study was sponsored by GlaxoSmithKline, Ware, UK and The School of Pharmacy, University of London, UK.

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