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Synthesis and Surface-Active Properties of 1,3-Bis-[2-(acylamino)ethyltrimethylammonio]-2-hydroxypropane Dichloride

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Abstract : Novel bis[quaternary amidoammonium] salts were easily prepared by reactions of 2-(acylamino)ethyltrimethylamine with epichlorohydrin and should prove chemically hydrolyzable due to amido groups in the lipophilic chains. Surface-active properties were determined and compared with those of 2-(acylamino)ethyltrimethylammonium chloride, and mono- and bis[quaternary alkylammonium] salts. Bis[quaternary amidoammonium] salts each possessing 10 to 14 carbon atoms in the acyl chain showed good water solubility. Cmc of 1,3-bis[2-(dodecanoylamino)ethyltrimethylammonio]-2-hydroxypropane dichloride was smaller by about one order of magnitude than that of 2-(dodecanoylamino)ethyltrimethylammonium chloride with the same acyl chain length, and smaller by about two orders than that of conventional dodecyltrimethylammonium chloride. The bis[quaternary amidoammonium] salts showed lower surface tension at cmc (γ_{cmc}) than other mono- and bis[quaternary alkylammonium] salts. Foaming ability and foam stability of bis[quaternary amidoammonium] salts having dodecanoyl or tetradecanoyl group in the lipophilic chain were quite high.

Key words : amido group, bis[quaternary ammonium] salts, hydrolysis, surface-active properties.

1 Introduction

As antistatic agent, textile softener, germicide, corrosion inhibitor, and petroleum additive, cationic surfactants have been widely and characteristically used¹⁾. Dialkyldimethylammonium compounds (DDAC) have been used mainly for the cationic surfactants. But they are claimed recently by their poor biodegradability under the conditions of rivers or practical sewage plants.

There are three directions to solve this problem. The first is to find the raw materials that are more quickly biodegraded than DDAC, the second is to break the compounds having the destructible group to the biodegradable ones, and the third is to decrease the using amount of cationic surfactants.

Concerning the second point, cationic surfactants having the destructible groups, such as an acetal group^{2),3)} and siloxy group⁴⁾ have been reported to be chemically hydrolyzable. For the third one, the development of cationic amphiphilic compounds having a higher performance is the case. Recently, ionic amphiphilic compounds having two alkyl chains and two hydrophilic groups in a molecule were reported to show the excellent surface-active properties than the conventional ones having one alkyl chain and one hydrophilic group^{5),6)}. Especially, bis[quaternary ammonium] salts with two alkyl chains and two ammonio groups have been reported to show good water solubility, much lower critical micelle concentration (cmc) values, lower surface tension of aqueous solutions⁷⁾, high foaming ability, and high foam stability⁸⁾.

In this work, in order to develop novel quaternary ammonium salts which not only meet ecological demands but also show excellent surface-active properties, a series of bis[quaternary ammonium] salts having amido groups in the lipophilic chains, that is 1,3-bis[2-(acylamino)ethyl]dimethyl ammonio]-2-hydroxypropane dichlorides (**2**), were prepared by the reaction of 2-(acylamino)ethyl]dimethylamine (**1**) with epichlorohydrin. Cationic compounds **2** are expected to be more easily hydrolyzable due to the presence of the amido groups in their lipophilic chains. Furthermore, hydrolyzed fragments are also expected to be easily biodegraded.

In this paper, the synthesis and surface-active properties of **2** are described. And their surface-active properties are compared with those of 2-(dodecanoylamino)ethyltrimethylammonium chloride (**3b**) and mono- and bis[quaternary alkylammonium] salts (**4b-d**) shown in the previous paper⁸⁾.

2 Experimental

2.1 Materials and Methods

Reagents and solvents used were all purchased from commercial sources unless otherwise stated. **1** as a raw material and **2** were prepared as shown in **Scheme 1**. The structures of the prepared compounds were confirmed by their ¹H nuclear magnetic resonance (NMR ; 600 MHz, AM-600, Bruker, Fallanden, Switzerland) and mass spectra (JMS-DX 303, JEOL Co., Ltd., Tokyo, Japan), and elemental analysis (CHN-Corder, Yanagimoto mfg. Co., Ltd., Kyoto, Japan). The Krafft point was measured by the naked eye for each 1 wt% aqueous solution of the compound. The surface tension of the aqueous solution of quaternary ammonium salts was measured with a Wilhelmy tensiometer (Surface Tensometer ST-1, glass plate, Shimadzu Co., Ltd., Kyoto, Japan) at 20°C. The critical micelle concentration (cmc) and the surface tension at the cmc (γ_{cmc}) were determined from the break point of each surface tension *vs.* concentration plots (the semilogarithmic scale). The foaming properties were measured by the semimicro TK method with a 0.1 wt% aqueous solution at 20°C⁹⁾.

Scheme 1

2.2 2-(Acylamino)ethyl]dimethylamines (**1**).

As a typical procedure, the preparation of 2-(dodecanoylamino)ethyl]dimethylamine (**1b**) is as follows : A mixture of methyl dodecanoate (42.9 g, 0.2 mol) and 2-aminoethyl]dimethyl-

amine (88.4 g, 1.0 mol) was heated to reflux until the ester had been consumed, which took 24 h. The complete consumption of the ester in the reaction system was checked by thin-layer chromatography (TLC, silica-gel plate) eluted with a mixture of acetone/29% aqueous ammonia (30 : 1, vol/vol). After evaporation of excess 2-aminoethyldimethylamine under reduced pressure, amidoamine **1b** was isolated as a waxy material. By recrystallization of the waxy material from hexane afforded a white solid (44.4 g, 82% yield). The synthetic results of these compounds are summarized in **Table 1** along with elemental analysis.

Table 1 Characterization of 2-(Acylamino) ethyldimethylamine (**1**).

Compound	R	Yield (%)	mp (°C)	Mass (CI) (m/e , relative intensity)	Anal. Found (Calcd), %	^1H NMR (δ , ppm)
1 a	C ₉ H ₁₉	78	<30	243 [(M+1) ⁺ , 100]	C: 69.58 (69.37) H: 12.35 (12.27) N: 11.65 (11.56)	0.85 (t, 3H, CH ₃ CH ₂), 1.17–1.38 [m, 12H, CH ₃ (CH ₂) ₆], 1.57–1.67 (m, 2H, CH ₂ CH ₂ C=O), 2.15 (t, 2H, CH ₂ C=O), 2.21 [s, 6H, N(CH ₃) ₂], 2.39 [t, 2H, CH ₂ N(CH ₃) ₂], 3.30 (t, 2H, NHCH ₂), 6.02–6.08 (br, 2H, NH)
1 b	C ₁₁ H ₂₃	82	38~39	271 [(M+1) ⁺ , 100]	C: 71.01 (71.06) H: 12.64 (12.67) N: 10.32 (10.36)	0.85 (t, 3H, CH ₃ CH ₂), 1.17–1.38 [m, 16H, CH ₃ (CH ₂) ₈], 1.57–1.67 (m, 2H, CH ₂ CH ₂ C=O), 2.15 (t, 2H, CH ₂ C=O), 2.21 [s, 6H, N(CH ₃) ₂], 2.39 [t, 2H, CH ₂ N(CH ₃) ₂], 3.30 (t, 2H, NHCH ₂), 6.02–6.08 (br, 2H, NH)
1 c	C ₁₃ H ₂₇	87	54~56	299 [(M+1) ⁺ , 100]	C: 72.20 (72.43) H: 12.86 (12.83) N: 9.36 (9.38)	0.85 (t, 3H, CH ₃ CH ₂), 1.17–1.38 [m, 20H, CH ₃ (CH ₂) ₁₀], 1.57–1.67 (m, 2H, CH ₂ CH ₂ C=O), 2.15 (t, 2H, CH ₂ C=O), 2.21 [s, 6H, N(CH ₃) ₂], 2.39 [t, 2H, CH ₂ N(CH ₃) ₂], 3.30 (t, 2H, NHCH ₂), 6.02–6.08 (br, 2H, NH)
1 d	C ₁₅ H ₃₁	90	64~65	327 [(M+1) ⁺ , 100]	C: 73.41 (73.56) H: 12.84 (12.96) N: 8.59 (8.58)	0.85 (t, 3H, CH ₃ CH ₂), 1.17–1.38 [m, 24H, CH ₃ (CH ₂) ₁₂], 1.57–1.67 (m, 2H, CH ₂ CH ₂ C=O), 2.15 (t, 2H, CH ₂ C=O), 2.21 [s, 6H, N(CH ₃) ₂], 2.39 [t, 2H, CH ₂ N(CH ₃) ₂], 3.30 (t, 2H, NHCH ₂), 6.02–6.08 (br, 2H, NH)
1 e	C ₁₇ H ₃₅	86	71~73	355 [(M+1) ⁺ , 100]	C: 74.31 (74.51) H: 13.01 (13.08) N: 8.02 (7.90)	0.85 (t, 3H, CH ₃ CH ₂), 1.17–1.38 [m, 28H, CH ₃ (CH ₂) ₁₄], 1.57–1.67 (m, 2H, CH ₂ CH ₂ C=O), 2.15 (t, 2H, CH ₂ C=O), 2.21 [s, 6H, N(CH ₃) ₂], 2.39 [t, 2H, CH ₂ N(CH ₃) ₂], 3.30 (t, 2H, NHCH ₂), 6.02–6.08 (br, 2H, NH)

Table 2 Characterization of 1,3-Bis[2-(Acylamino) ethyldimethylammonio]-2-hydroxypropane Dichlorides (2).

Com- pound	R	Yield ^a (%)	mp (°C)	Mass (FAB) (<i>m/e</i> , relative intensity)	Anal. Found ^b (Calcd), %	¹ H NMR (δ , ppm)
2 a	C ₉ H ₁₉	>95	157~158	577 [(M-Cl) ⁺ , 16], 527 [(M-2Cl-CH ₃) ⁺ , 17], 299 [100], 198 [81], 58 [35]	C: 59.58 (59.79) H: 10.58 (10.84) N: 9.00 (9.00) Cl: 11.78 (11.39)	0.87 (t, 6H, CH ₃ CH ₂), 1.21–1.42 [m, 24H, CH ₃ (CH ₂) ₆], 1.55–1.67 (m, 4H, CH ₂ CH ₂ C=O), 2.29 (t, 4H, CH ₂ C=O), 3.50 (s, 6H, N ⁺ CH ₃), 3.51 (s, 6H, N ⁺ CH ₃), 3.70–3.88 [m, 10H, NHCH ₂ , CH ₂ CH ₂ N ⁺ , CH(OH)CH _a N ⁺], 4.22 [d, 2H, CH (OH)CH _b N ⁺], 5.08–5.18 (m, 1H, CHOH), 8.12–8.21 (br, 2H, NH)
2 b	C ₁₁ H ₂₃	>95	184 ^c	633 [(M-Cl) ⁺ , 2], 583 [(M-2Cl-CH ₃) ⁺ , 5], 327 [73], 226 [100], 58 [43]	C: 61.38 (61.11) H: 10.75 (11.14) N: 8.09 (8.14) Cl: 10.29 (10.30)	0.87 (t, 6H, CH ₃ CH ₂), 1.21–1.42 [m, 32H, CH ₃ (CH ₂) ₈], 1.55–1.67 (m, 4H, CH ₂ CH ₂ C=O), 2.29 (t, 4H, CH ₂ C=O), 3.48 (s, 6H, N ⁺ CH ₃), 3.49 (s, 6H, N ⁺ CH ₃), 3.70–3.88 [m, 10H, NHCH ₂ , CH ₂ CH ₂ N ⁺ , CH(OH)CH _a N ⁺], 4.22 [d, 2H, CH (OH)CH _b N ⁺], 5.08–5.18 (m, 1H, CHOH), 8.12–8.21 (br, 2H, NH)
2 c	C ₁₃ H ₂₇	93	210 ^c	689 [(M-Cl) ⁺ , 9], 639 [(M-2Cl-CH ₃) ⁺ , 6], 355 [100], 254 [81], 58 [36]	C: 63.12 (62.96) H: 11.05 (11.38) N: 7.50 (7.53) Cl: 9.79 (9.52)	0.87 (t, 6H, CH ₃ CH ₂), 1.21–1.42 [m, 40H, CH ₃ (CH ₂) ₁₀], 1.55–1.67 (m, 4H, CH ₂ CH ₂ C=O), 2.29 (t, 4H, CH ₂ C=O), 3.45 (s, 6H, N ⁺ CH ₃), 3.46 (s, 6H, N ⁺ CH ₃), 3.70–3.88 [m, 10H, NHCH ₂ , CH ₂ CH ₂ N ⁺ , CH(OH)CH _a N ⁺], 4.22 [d, 2H, CH (OH)CH _b N ⁺], 5.08–5.18 (m, 1H, CHOH), 8.12–8.21 (br, 2H, NH)
2 d	C ₁₅ H ₃₁	94	209 ^c	745 [(M-Cl) ⁺ , 2], 695 [(M-2Cl-CH ₃) ⁺ , 4], 383 [95], 282 [100], 58 [40]	C: 62.28 (62.44) H: 11.40 (11.58) N: 6.70 (6.77) Cl: 8.43 (8.57)	0.87 (t, 6H, CH ₃ CH ₂), 1.21–1.42 [m, 48H, CH ₃ (CH ₂) ₁₂], 1.55–1.67 (m, 4H, CH ₂ CH ₂ C=O), 2.29 (t, 4H, CH ₂ C=O), 3.45 (s, 6H, N ⁺ CH ₃), 3.46 (s, 6H, N ⁺ CH ₃), 3.70–3.88 [m, 10H, NHCH ₂ , CH ₂ CH ₂ N ⁺ , CH(OH)CH _a N ⁺], 4.22 [d, 2H, CH (OH)CH _b N ⁺], 5.08–5.18 (m, 1H, CHOH), 8.12–8.21 (br, 2H, NH)
2 e	C ₁₇ H ₃₅	85	212 ^c	801 [(M-Cl) ⁺ , 2], 751 [(M-2Cl-CH ₃) ⁺ , 4], 411 [92], 310 [100], 58 [50]	C: 64.50 (64.57) H: 11.44 (11.76) N: 6.41 (6.40) Cl: 8.43 (8.57)	0.87 (t, 6H, CH ₃ CH ₂), 1.21–1.42 [m, 56H, CH ₃ (CH ₂) ₁₄], 1.55–1.67 (m, 4H, CH ₂ CH ₂ C=O), 2.29 (t, 4H, CH ₂ C=O), 3.44 (s, 6H, N ⁺ CH ₃), 3.45 (s, 6H, N ⁺ CH ₃), 3.70–3.88 [m, 10H, NHCH ₂ , CH ₂ CH ₂ N ⁺ , CH(OH)CH _a N ⁺], 4.22 [d, 2H, CH (OH)CH _b N ⁺], 5.08–5.18 (m, 1H, CHOH), 8.12–8.21 (br, 2H, NH)

^a Calculated from ¹H NMR.^b Calculated values are based on the assumption that the compound contains bonding water.^c Decomposed.

2.3 1,3-Bis[2-(acylamino)ethyldimethylammonio]-2-hydroxypropane dichlorides (2).

As a typical procedure, the preparation of 1,3-bis[2-(dodecanoylamino)ethyldimethylammonio]-2-hydroxypropane dichloride (**2b**) is as follows: Epichlorohydrin (0.5 g, 5.0 mmol) was added to a mixture of **1b** (4.1 g, 15.0 mmol), its hydrochloride (1.5 g, 5.0 mmol), and ethanol (15 mL). The mixture was heated to reflux for 24 h. The yield of product was determined by $^1\text{H-NMR}$ by utilizing the unreacted excess amidoamine as an internal standard (>95% yield). After the solvent was evaporated under reduced pressure, the resulted waxy material was washed with hexane to afford bis[quaternary amidoammonium] salt **2b**. Bis[quaternary amidoammonium] salt **2b** was purified by recrystallization from the mixture of acetone and 2-propanol (19 : 1, vol/vol) to afford a white solid (2.9 g, 85% yield). The synthetic results of these compounds are summarized in **Table 2** along with elemental analysis.

2.4 2-(Dodecanoylamino)ethyltrimethylammonium chloride (**3b**).

An excess amount of methylchloride was condensed to the ethanol solution (20 mL) in which **1b** (5.4 g, 20.0 mmol) was dissolved. The mixture was stirred at room temperature for 24h in a sealed glass tube. After the solvent and unreacted methylchloride were evaporated under reduced pressure, the resulted waxy material was washed with hexane to afford monoquaternary ammonium salt **3b**. Monoquaternary ammonium salt **3b** was purified by recrystallization from the mixture of acetone and 2-propanol (19 : 1, vol/vol) affording a white solid (6.8 g, 90% yield). mp 43~45°C. $^1\text{H-NMR}$ (CDCl_3): 0.81 (t, 3H, CH_3CH_2), 1.13–1.15 (br, 16H, $\text{CH}_3(\text{CH}_2)_8$), 1.40–1.50 (br, 2H, $\text{CH}_2\text{CH}_2\text{C=O}$), 2.18 (t, 2 H, $\text{CH}_2\text{CH=O}$), 3.35 [s, 9 H, $\text{N}^+(\text{CH}_3)_3$], 3.69 (m, 4 H, CH_2N^+ , $\text{CH}_2\text{NHC=O}$). FAB-MS (m/e , relative intensity): 285 [$(\text{M}-\text{Cl})^+$, 100], 226 [56]. Anal. Found: C, 63.74; H, 11.44; Cl, 10.66; N, 8.73%. Calcd for $\text{C}_{17}\text{H}_{37}\text{ClN}_2\text{O}$: C, 63.62; H, 11.62; Cl, 11.05; N, 8.73%.

3 Results and Discussion

2-(Acylamino)ethyldimethylamines having an amido group in the lipophilic chain(1) were prepared by the reaction of the corresponding fatty acid methyl ester with 2-aminoethyldimethylamine in good yields (**Table 1**).

2 were easily and almost quantitatively obtained from the reaction of **1** and its hydrochloride with epichlorohydrin (**Table 2**).

Longer reaction time (24 h) was needed for the preparation of bis[quaternary amidoammonium] salts (**2**) from **1** with epichlorohydrin, compared with the preparation of bis[quaternary alkylammonium] salts from alkylamines and epichlorohydrin¹⁰⁾ (see Experimental section).

The surface-active properties of bis[quaternary amidoammonium] salts (**2**) at 20°C are summarized in **Table 3**, along with data for monoquaternary amidoammonium salt **3b** and reported data for the conventional monoalkylammonium salts¹¹⁾ and bis[quaternary alkylammonium] salts (**4b–d**) from epichlorohydrin⁸⁾. Bis[quaternary amidoammonium] salts **2a–c** having 10 to 14 carbon atoms in the acyl chain are soluble in water, and their Krafft points are below 0°C. The Krafft points of these compounds increased with an increase of the acyl chain length. Thus, those of bis[quaternary amidoammonium] salt **2d** (with palmitoyl group) and **2e** (with stearoyl group) are 17 and 42°C, respectively. The surface-active properties of bis[quaternary amidoammonium] salt **2e** at 20°C were not measured.

The cmc of bis[quaternary amidoammonium] salt **2b** is smaller by about one order of magnitude than that of monoquaternary amidoammonium salt **3b** with the same acyl chain length, and smaller by about two order than that of the conventional dodecyltrimethylammonium salts. This trend is similar to the case of bis[quaternary dodecylammonium] salt **4b** from dodecylamine and epichlorohydrin. These results show that connection of two conventional quaternary ammonium salts using a spacer is a useful way to prepare the quaternary ammonium salts having quite low cmc¹²⁾.

Table 3 Surface-Active Properties of 1,3-Bis [2-(acylamino)ethyldimethylammonio]-2-hydroxypropane Dichlorides (2) at 20°C.

Compound		R	Krafft point (°C)	cmc (mM)	γ_{cmc} (mN/m)	Foam (mL)	
						0'	10'
2 a	C ₉ H ₁₉	<0	1.2	33	40 (130)	0 (0) ^a
	2 b	C ₁₁ H ₂₃	<0	0.19	33	260	240
	2 c	C ₁₃ H ₂₇	<0	0.010	33	270	260
	2 d	C ₁₅ H ₃₁	17	0.0048	33	80	10
	2 e	C ₁₇ H ₃₅	42	n ^b	n ^b	n ^b	n ^b
3 b	C ₁₁ H ₂₃	<0	6.1	35	20	0
4 b	C ₁₂ H ₂₅	<0	0.78	37	280	270
	4 c	C ₁₄ H ₂₉	<0	0.14	39	270	270
	4 d	C ₁₆ H ₃₃	<0	0.019	42	100	10
C ₁₂ H ₂₅	<0	12	39	20	0
		C ₁₄ H ₂₉	—	4.5	—	—	—

^a At 1 wt% aqueous solution, above cmc of bis[quaternary ammonium] salt **2a**.^b Not evaluated.

The cmc's of bis[quaternary amidoammonium] salts (**2a-c**) decreased with an increase of the acyl chain length as can be expected. It should be noticed that bis[quaternary amidoammonium] salt **2d** shows an extremely low cmc.

The cmc of **3b** is the same order as that of tetradecyltrimethylammonium chloride. The cmc's of bis[quaternary amidoammonium] salts **2a** and **2b** are of the same order as those of bis[quaternary alkylammonium] salts with tetradecyl group (**4c**) and hexadecyl group (**4d**), respectively, meaning that the amido groups in their lipophilic chains have a little effect on the cmc.

The plots of the logarithm of the cmc *vs.* the carbon number in the acyl chain of the compound are shown in **Fig. 1**. The log cmc's of bis[quaternary amidoammonium] salts (**2a-c**) decreased linearly with an increase of the carbon number in the acyl chain, like as the conventional amphiphilic compounds having one alkyl chain and one hydrophilic group.

The γ_{cmc} 's of bis[quaternary amidoammonium] salts (**2a-c** in **Table 3**) do not change with the increase of their acyl chain length, and are almost the same within the compounds synthesized. However, values are smaller than those of mono- and bis[quaternary alkylammonium] salts (**4b-d**). It is reasonable to consider that the inter- or intramolecular hydrogen bonding may possibly work between the amido groups¹³⁾, and the lipophilic chains may pack more closely at the air-water interface.

The foaming ability and foam stability up to 10 min were measured for the prepared bis[quaternary amidoammonium] salts (**2a-c**). The foaming ability of monoquaternary amidoammonium salt **3b** is almost zero similarly to monoquaternary alkylammonium salt. But the foaming ability and foam stability of bis[quaternary amidoammonium] salts (**2b,c**) having dodecanoyl and tetradecanoyl group are extremely high equally to those of bis[quaternary alkylammonium] salts (**4b,c**) with dodecyl and tetradecyl group in the lipophilic

Fig. 1 Plots of cmc vs. Carbon Number in the Hydrophobic Group of 1,3-Bis[2-(acylamino)ethyl]dimethylammonio]-2-hydroxypropane Dichlorides (2a-d).

chains. Although bis[quaternary amidoammonium] salts **2a** and **2d** are the homologous members of bis[quaternary amidoammonium] salts **2b** and **2c**, the foaming ability of those compounds are quite low, meaning that the balance of the hydrophobic and hydrophilic parts may be important and the foam properties are sensitive to this balance.

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日本油化学会誌本号掲載 論文要旨

[報文] 耐硬水および耐塩性設計のためのモデルとしての多官能性カルボン酸型バイオサーファクタント

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スピクリスボール酸塩の耐塩性、沈殿曲線および相図は一塩基酸型界面活性剤と相違した。また、スピクリスボール酸塩は優れた乳化剤であった。このような特性は、化学構造から見てカルボキシル基を三つ持つ多官能性界面活性剤であることに基づくものと考えられた。このためスピクリスボール酸ナトリウム塩は通常のアニオン界面活性剤とくらべて耐塩性と耐硬水性に優れた乳化剤であることが結論づけられた。

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[報文] 二塩化 1,3-ビス [2-(アシルアミノ)エチルジメチルアンモニオ]-2-ヒドロキシプロパンの合成と界面活性

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界面活性剤の疎水鎖にアミド基を導入することにより加水分解が期待されるビス型アミドアンモニウム塩を 2-(アシルアミノ)エチルジメチルアミンとエピクロロヒドリンとの反応から簡便に収率よく合成した。ビス型アミドアンモニウム塩の界面物性を測定し、モノ型アミドアンモニウム塩、モノ型及びビス型アルキルアンモニウム塩と比較・検討した。アシル基の炭素数が 10 から 14 までのビス型アミドアンモニウム塩は良い水溶性を示した。アシル基の炭素数が 12 のビス型アミドアンモニウム塩は、同じアシル基を有するモノ型より一けた程度、またモノ型ドデシルアンモニウム塩より二けた程度小さい臨界ミセル形成濃度を示した。得られたビス型アミドアンモニウム塩はビス型アルキルアンモニウム塩よりもさらに低い表面張力を示した。また、アシル基の炭素数が 12 と 14 のビス型アミドアンモニウム塩は極めて高い起泡力と良好な泡安定性を示した。

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