5th International Conference on Research, Implementation and Education of Mathematics and Science (5th ICRIEMS) 2018

Optimisation of CO_2-philic Surfactant Chemical Structure for Water-in-CO_2 Microemulsions Stabilisation

Azmi Mohamed[1,2] and Tretya Ardyani[1]

[1] Department of Chemistry, [2] Nanotechnology Research Centra Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris Tanjong Malim Perak 35900 **MALAYSIA**

E-mail address: azmi.mohamed@fsmt.upsi.edu.my

Yogyakarta Indonesia May 7 – 8, 2018

Presentation Outline

1. Research Background (Why CO_2?, Supercritical CO_2 Applications, Advantages, What is CO_2-philic surfactant?)
2. Research Aims
3. Research Methodology (Hybrid Surfactant Characterization – NMR, CHNS elemental analysis, air-water surface tension, High-Pressure Phase Behavior)
4. Results and Discussion

   Approach 1 – Effect of Substitution CO_2-philic tails

   Approach 2 – Effect of surfactant head group
5. Conclusions
6. Acknowledgment

CO_2: From Green House Gas to Green Solvent

- Carbon Dioxide Information Analysis Center (2015) CO_2 emissions:

  ~36 billion tones world wide

- **World Economic Forum 2012: Top Emerging Technologies Trends**

  Utilization of carbon dioxide as a resource

- At T = 25°C and P = 1 bar– gas phase with **NON-SOLVENT** properties

- ABOVE T_c = 31.1°C and P_c = 73.6 bar turn to **SUPERCRITICAL CO_2 ($scCO_2$)**.

Mohamed, A.; Eastoe, J., *School Science Review* **2011**, 93, 73

Country	**Annual CO_2 emission (10^3 metric tonnes)**	**% Percentage**
(1) China	10,641,789	29.51
(2) USA	5,172,336	14.34
(3) EU	3,469,671	9.62
(4) India	2,454,968	6.81
ASEAN	1,346,648	3.72

Table 1 : Annual CO_2 emission (selected from Top 4 + ASEAN) 2015

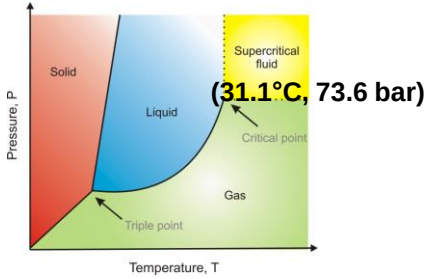


Figure 1: phase diagram for CO_2 showing the critical point (T_c, P_c) and the supercritical fluid region.

scO_2 - Advantages

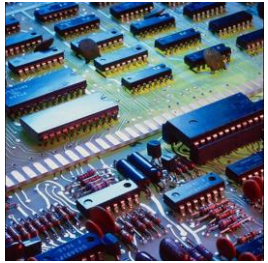
- Accessible Critical Temperature (T_c) and Pressure (P_c)
- Tunable Solvent Properties: Density, Viscosity
- Inert
- Relatively non-toxic
- Recyclable
- Non flammable
- **ABUNDANT** and **CHEAP**.

Solvent	**P_c / bar**	T_c / ºC
CO_2	73.8	31.1
Water	220.5	374.2
Cyclohexane	40.7	280.4
Pentane	33.7	196.6
Toluene	41.0	318.7

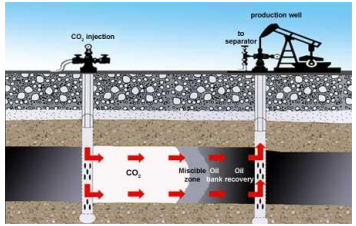
Table 2: Critical pressures and temperatures of some common solvents

$scCO_2$:Applications

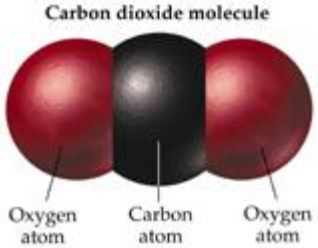
Dry cleaning



Microelectronic industries



Enhanced oil recovery*



Coffee & Tea Extraction

Figure 2: Examples of $scCO_2$ applications

*Xing, D.; Wei, B.; Trickett, K.; Mohamed, A.; Eastoe, J.; Soong, Y. and Enick, R.M. *SPE Journal* **2012** 17 (4), 1172

CO_2-philic surfactant

- **MAJOR HINDRANCE** - high molecular weight **polymers, proteins and polar** mole cules are **insoluble** in $scCO_2$.

- **EFFECTIVE SOLUTION** - use **CO_2-PHILIC SURFACTANTS** to stabilise **water-in-CO_2 microemulsion (w/c microemulsions)**.

- **MOST EFFICIENT:**
  Fully fluorinated (F) surfactants
  e.g. di-CF4

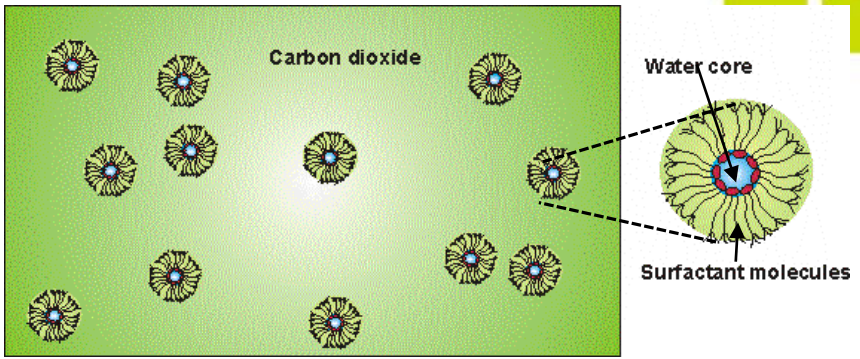


Figure 3: Schematic nanostructure of reverse micelles and water-in-CO_2 (w/c) microemulsions.

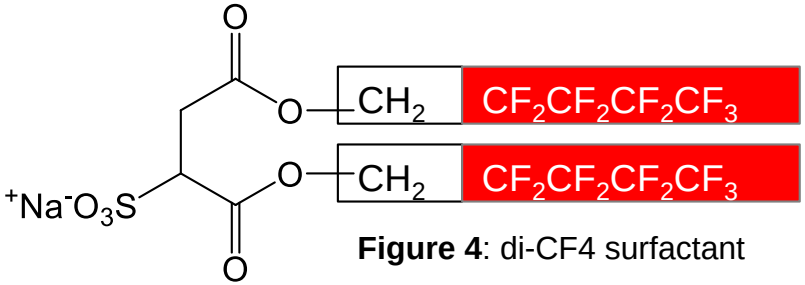


Figure 4: di-CF4 surfactant

Eastoe, J.; Yan, C.; Mohamed, A. *Current Opinion in Colloid & Interface Science*, **2012** *17*, 266

Fluorocarbon (R_F)

❖**Favourable** thermodynamic inter actions with CO_2 (quadrapolar and Lewis acid-base interaction)

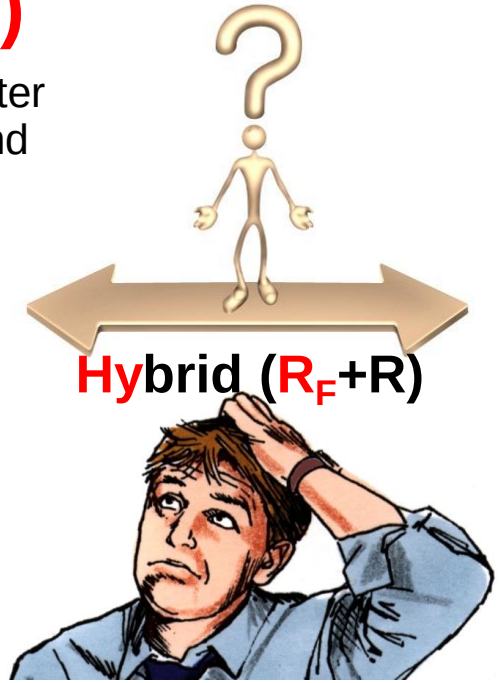
❖**Better performance – Low** cloud point pressure P_{trans}

❖**High solubilising capacity**

❖**Environmental- Biological Persistence & Expensive!**

Surfactant	Cost (US$ g^{-1})	P_{trans} (bar)
AOT (R)	1.0	-
AOT4 (R)	5.0	500
di-CF4 (R_F)	200.0	75
di-CF2 (R_F)	15.0	224

Table 3: Performances and estimated costs of surfactant



Hydrocarbon (R)

❖**Less favorable** (high van der Waals forces)

❖**Limited performance – High** cloud point pressure P_{trans}

❖**Biodegradable** and **more cheaper** for CO_2 applications

(Hollamby, M. J.; Trickett, K.; Mohamed, A.; Eas toe, J. *Angew. Chem. Int. Ed.* **2009,** *48* 4993)

(Mohamed, A.; Sagisaka, M.; Eastoe, J.,. *Langmuir* **2010,** *26* 13861)

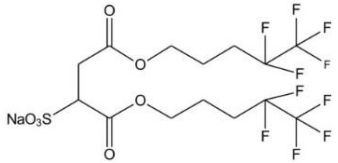
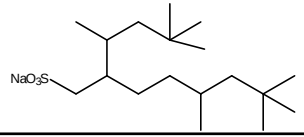
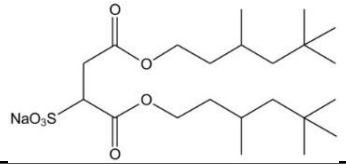
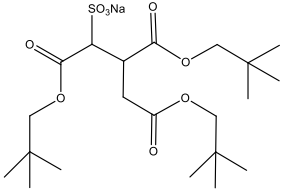
NEW ALTERNATIVE: HYBRID (R_F+R)

❖**MINIMISING R_F and MAXIMISING R whilst retaining acceptable level of surfactant per formance in CO_2**

UNIVERSITI PENDIDIKAN SULTAN IDRIS
www.upsi.edu.my

Current Performance: CO_2-philic surfactants

Table 4: Current Performance of **Fluorocarbon** and Hydrocarbon CO_2-philic surfactants

Surfactant	Surfactant Structure	Chemical Name	P_{trans} / Reference
di-CF2		sodium bis (4*H*,4*H*,5*H*,5*H*,5*H*-pentafluoropentyl)-2-sulfosuccinate	**w = 10 224 bar(0.05M)** Mohamed, *et al Langmuir* **2011**, *27*, 10562
SIS1		Sodium 2-(4,4-dimethylpentan-2-yl)-5,7,7-trimethyloctyl sulfate	**w =0 245 bar (0.0008 M)** Sagisaka et al **2013** *J. Oleo Sci* .62, 481
AOT4		sodium bis(3,5,5-trimethyl-1-hexyl)-2-sulfosuccinate	**w =0 500 bar (0.05 M)** Eastoe, et. al *J. Am. Chem. Soc.* **2001**, *123*, 988.
TC14		sodium 1,4-bis(neopentyloxy)-3-(neopentyloxycarbonyl)-1,4-dioxobutane-2-sulfonate)	**w =0 160 bar (0.04 M)** Hollamby, et. Al *Angew. Chem. Int. Ed.* **2009,** *48* 4993

UNIVERSITI PENDIDIKAN SULTAN IDRIS
www.upsi.edu.my

Research Aims

- To synthesise novel hybrid surfactants with different (1) CO_2-philic tails (2) surfactant headgroup

- To study interfacial behaviour of hybrid surfactants (air- water surface tensions measurements)

- To study phase behavior of hybrid surfactants in stabilising water-in-CO_2 (w/c) microemulsions by using High Pressure (HP) cell

Research Methodology

(1) Surfactants syntheses

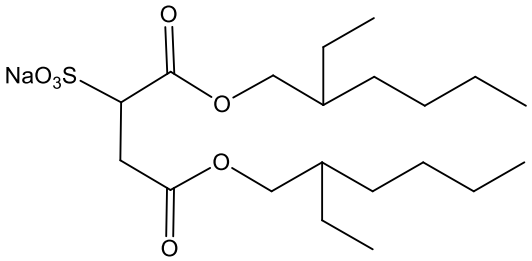


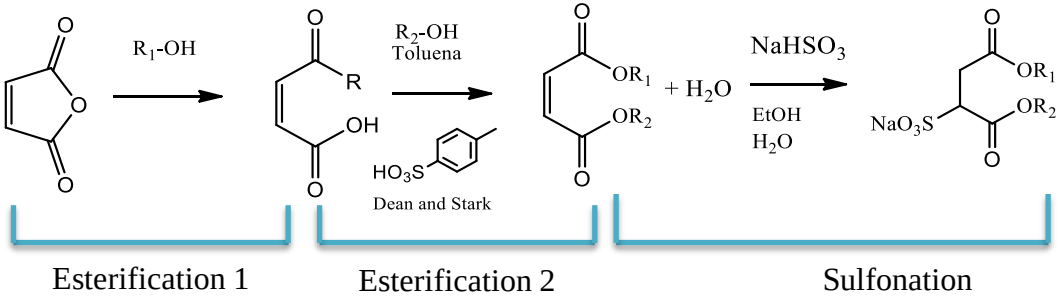
Figure 5: sodium bis (2-ethylhexyl) sulfosuccinate or Aerosol-OT surfactants.

- Aerosol-OT or AOT (sodium bis (2-ethylhexy sulfosuccinate) is commercially available surfactant widely used for microemulsion studies.

- Surfactant is readily prepared in two main step of synthesis:
  (1) esterification and (2) sulfonation

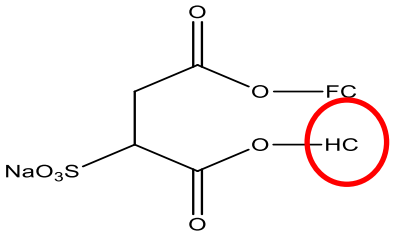
- Unfortunately CO_2 incompatible (inactive/insoluble)

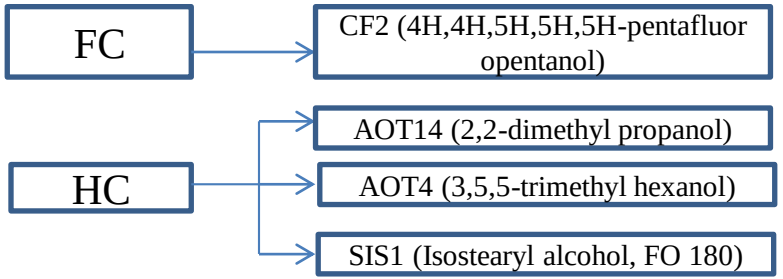
Approach 1 - Synthesis of novel hybrid surfactants with different CO_2-philic tails



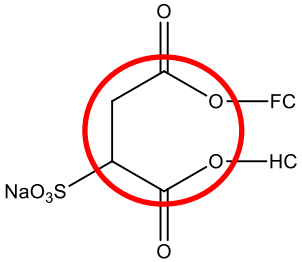
Surfactants were synthesised using AOT template with the modification on:

Hydrocarbon CO_2-philic tail

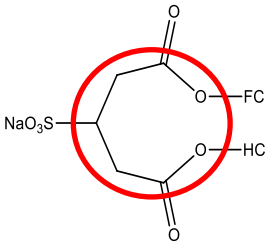




Approach 2 - Synthesis of novel hybrid surfactants with different surfactant headgroup

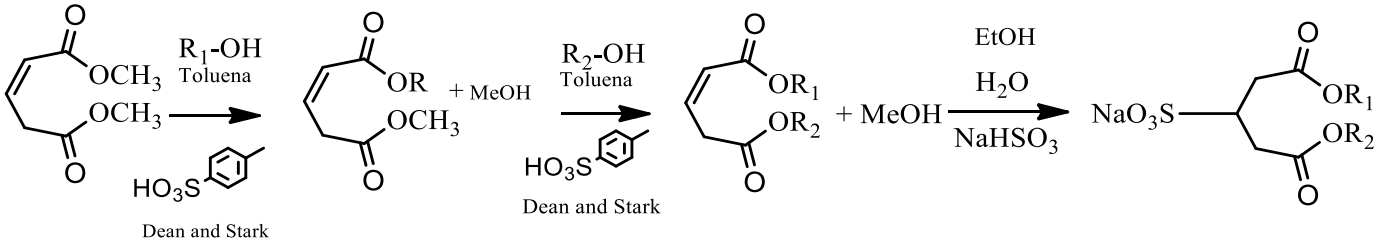


Sulfosuccinate



Sulfoglutaconate (denoted as **GLU)**

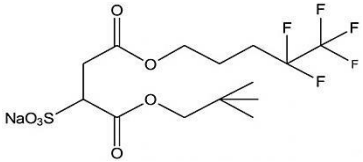
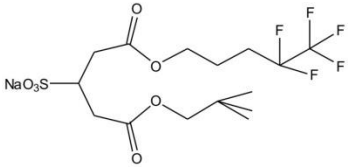
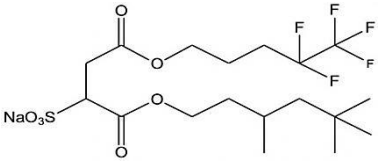
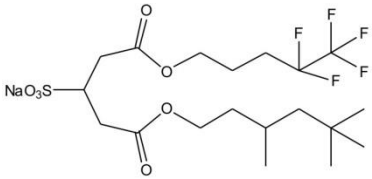
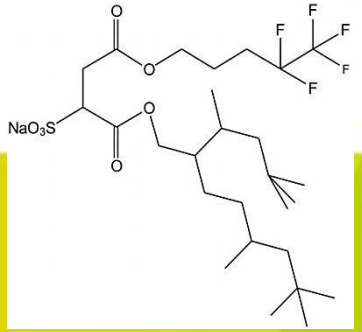
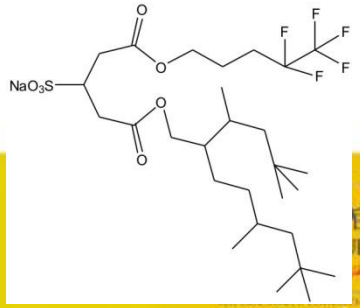
Synthesis route of hybrid sulfoglutaconate surfactants



Esterification 1 Esterification 2 Sulfonation

Designing hybrid surfactants

Table 5: Designing CO_2-philic hybrid surfactants

Approach 1	Chemical structure	Approach 2	Chemical structure
Hybrid CF2/AOT14		Hybrid CF2/AOT14GLU	
Hybrid CF2/AOT4		Hybrid CF2/AOT4GLU	
Hybrid CF2/SIS1		Hybrid CF2/SIS1GLU	

UNIVERSITI PENDIDIKAN SULTAN IDRIS
www.upsi.edu.my

Research Methodology

(2) **Surfactant characterization (NMR and CHNS element analysis)**

(3) **Surface tension measurements -** air-water (a/w) *surface tension measurements*, correlation with CO_2-philicity.

(4) **Phase behavior of hybrid CO_2-philic surfactants in CO_2 - (**High-pressure cell integrated, Hitachi High Technologies) **in Hirosaki University, JAPAN**

Figure 7: K100 surface tension instrument

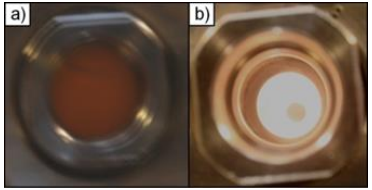


Figure 9: Cloud point pressure, P_{trans} of surfactant. (a) **Pressure < P_{trans} (cloudy – biphasic**), (b) **Pressure > P_{trans} (clear – one phase).**

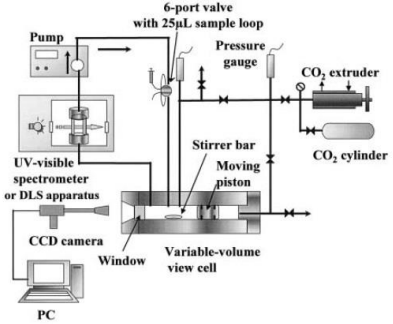


Figure 8: Schematic representation of High-pressure cell integrated with UV-visible spectrometer (Hitachi High Technologies) in Hirosaki University.

Mohamed, A.; Sagisaka, M.; Eastoe, J.*Langmuir* **2012,** *15* 6299
Mohamed, A.; Sagisaka, M.; Eastoe, J.*Langmuir* **2011,** *27* 10562
Mohamed, A.; Sagisaka, M.; Eastoe, J.*Langmuir* **2010,** *26* 13861

Approach 1 - Synthesis of novel hybrid surfactants with different CO_2-philic tails

Molecular fragment	Identified proton	Chemical shift	Relative NMR Integrals	
			experimental	theoretical
Hybrid CF2/AOT14 surfactant				
CH_3*-C-	a	0.90	9.00	9.0
-C-CH_2-CF	b	1.85 -1.96	1.64	2.0
-C-CH_2-C-	c	2.05 -2.20	2.11	2.0
S-C-CH_2-C=O	d	3.12 -3.24	1.86	2.0
O-C-H_2-C-	e	3.69 -3.86	2.19	2.0
O-CH_2-C	f	4.11 -4.30	1.65	2.0
-SO_3-CH-C=O	g	4.32 -4.40	0.89	1.0
Hybrid CF2/AOT4 surfactant				
CH_3-C	a	0.63 – 0.85	12.36	12.0
C-C-H_2*-C	b	0.97 – 1.22	2.00	2.0
C-CH_2-C-	c	1.32 – 1.80	2.94	2.0
C-CH-C-				1.0
-C-C-H_2-CF	d	1.85 – 2.22	3.70	4.0
O=C-CH_2-C-S	e	3.15 – 3.44	1.76	2.0
-O-C-H_2-C	f	4.07 – 4.40	3.90	4.0
O=CH-SO_3-	g	4.48 – 4.67	0.87	1.0
Hybrid CF2/SIS1 surfactant				
CH_3-C	a	0.85 – 0.90	24.24	24.0
-C-CH_2-C-	b	0.97 – 1.29	8.37	8.0
-C-CH-C-	c	1.39 – 1.80	3.28	3.0
-C-CH_2-CF	d	1.83 – 1.99	1.57	2.0
-C-CH_2-C-	e	2.02 – 2.22	1.56	2.0
S-C-CH_2*-C=O	f	3.04 – 3.23	2.00	2.0
O-CH_2-C	g	3.82 – 4.19	3.59	4.0
-SO_3-CH-C=O	h	4.27 – 4.32	1.27	1.0

Table 6. Peak integration for ^{1}H-NMR of hybrid surfactant.

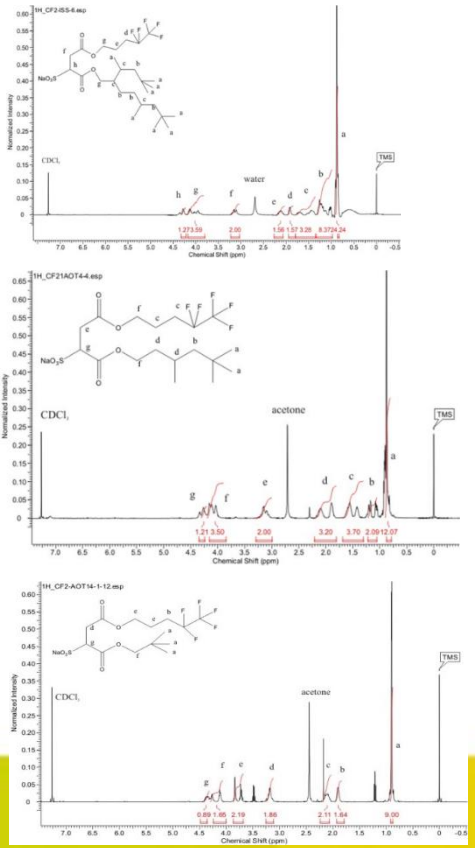


Figure 10. 1H-NMR spectrum for (a) hybrid CF2/SIS(b) hybrid CF2/AOT4 (c) hybrid CF2/AOT14. Solvent = $CDCl_3$

UNIVERSITI PENDIDIKAN SULTAN IDRIS
www.upsi.edu.my

^{1}H NMR & CHNS Elemental Analysis – APPROACH 1

Hybrid CF2/AOT14

^{1}H NMR (500 MHz, $CDCl_3$, TMS), (δ_H/ppm) 0.76-1.00 (a, doublet (d), 9H, *J* = 4.0 Hz), 1.81-1.87 (b, multiplet (m), 2H), 1.99-2.20 (c, m, 2H), 3.07-3.30 (d, m, 2H), 3.64-3.89 (e, m, 2H), 4.04-4.28 (f, triplet (t), 2H, *J* = 6.85), 4.31-4.41 (g, m, 1H). **Elemental analysis: found C, 36.60; H, 5.29; S, 7.89. Calcd C, 37.34; H, 4.48; S, 7.12.**

Hybrid CF2/AOT4

^{1}H NMR (500 MHz, $CDCl_3$, TMS), (δ_H/ppm): 0.77–0.89 (a, m, 12H), 1.17–1.24 (b, m, 2H), 1.40–1 .60 (c, m, 4H), 1.88–2.17 (d, m, 3H), 3.05–3.24 (e, m, 2H), 4.03–4.15 (f, m, 4H), 4.26–4.33 (g, m, 1H). **Elemental analysis: found C, 42.14; H, 6.00; S, 5.28. Calcd C, 42.69; H, 5.57; S, 6.33**

Hybrid CF2/SIS1

^{1}H NMR (500 MHz, $CDCl_3$, TMS), (δ_H/ppm) 0.85 – 0.90 (a, m, 24H), 0.97 – 1.29 (b, m, 8H), 1.39 – 1.80 (c, m, 3H), 1.83 – 1.99 (d, m, 2H), 2.02 – 2.22 (e, m, 2H), 3.04 – 3.23 (f, m, 2H), 3.82 – 4. 19 (g, m 4H), 4.27 – 4.32 (h, m 1H). **Elemental analysis: found C, 52.17; H, 9.03; S, 4.89. Calc d C, 51.26; H, 7.33; S, 5.07.**

Air-Water Surface Tension Measurement – Approach 1

$$\Gamma = -\frac{1}{mRT}\frac{d\gamma}{d\ln c}$$

$$A_{cmc} = \frac{1}{\Gamma N_a}$$

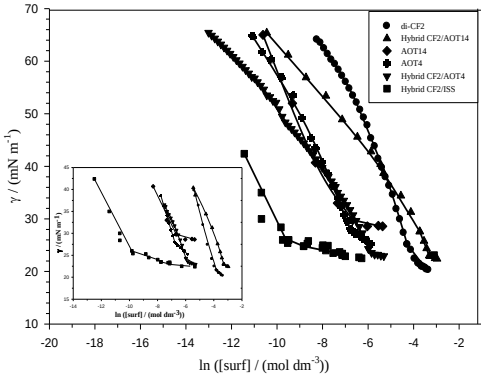


Figure 11. (a) Air – water surface tension γ_{cmc} vs. ln (concentration) f or surfactant at 25°C. The inset shows a close-up of the cmc region.

Table 7. Parameters derived from surface tension

surfactant	fluorine wt%	cmc / (mmol dm^{-3}) ± 0.03	γ_{cmc} / (mN m^{-1}) ±1 (25 °C)	A_{cmc} / Å^2
di-CF2	35.2	19.0	22.4	65
hybrid CF2/AOT14	21.1	46.8	22.5	102
hybrid CF2/AOT4	18.6	1.78	23.8	103
Hybrid CF2/SIS1	15.0	0.05	26.0	112
AOT14	0.0	2.39	28.6	100
AOT4	0.0	1.10	28.0	70
di-SIS1	0.0	-	-	-

High-Pressure Phase Behaviour

Table 8: Phase behaviour surfactant in $scCO_2$.

surfactant	fluorine wt%	P_{trans} / bar w=10 w/c T=55°C
di-CF2	35.2	219
hybrid CF2/AOT14	21.1	383
hybrid CF2/AOT4	18.6	321
Hybrid CF2/SIS1	15.0	215
Equimolar di-CF2:AOT14	21.1	incompatible
Equimolar di-CF2:AOT4	18.6	389
Equimolar di-CF2:di-SIS1	15.0	312
AOT14	0.0	Incompatible
AOT4	0.0	Incompatible
di-SIS1	0.0	compatible

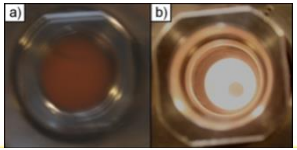


Figure 9: Cloud transition pressure, P_{trans} of surfactant. (a) Pressure < P_{trans} (cloudy – 2Φ biphasic), (b) Pressure > P_{trans} (clear – 1Φ one phase).

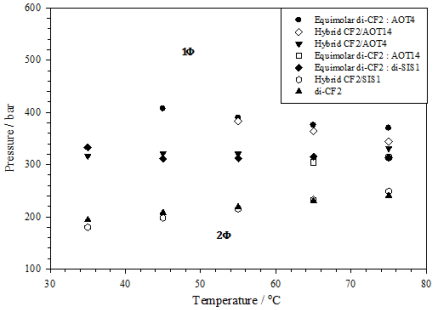


Figure 12: Phase behaviour surfactant in CO_2 at various temperature.[Surf] = 0.05 $moldm^{-3}$ w = 10.

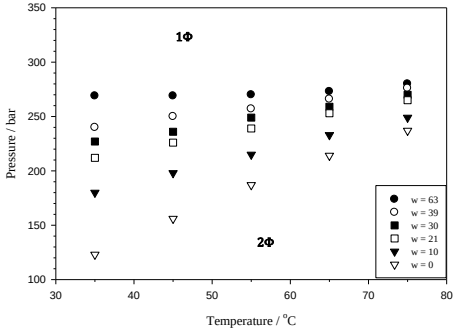
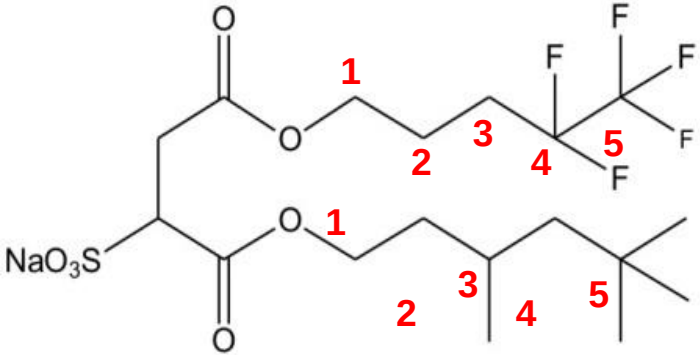


Figure 13: Phase behaviour of hybrid CF2/SIS1 surfactant in CO_2 at various w ratio and temperature.[Surf] = 0.05 $moldm^{-3}$.

UNIVERSITI PENDIDIKAN SULTAN IDRIS
SULTAN IDRIS EDUCATION UNIVERSITY
www.upsi.edu.my

Optimising CO_2-philicity via chain branching



Branching factor (BF)= $\frac{\text{(branch length x branch position)}}{\text{number of carbon}}$

BF for AOT4 chain i.e. 1 methyl in position 3 and 3 methyls on position 5 on a C_6 linear chain

(1 x 1 x 3) + (1 x 3 x 5) / 6 = 3

BF for CF2 chain. Assume F (28.4Å^3) CH_3 (27.4Å^3). Thus,

1 methyl (CH_3) ≡ 1.04 F

(1.04 x 2 x 4) + (1.04 x 3 x 5) / 5) = 4.8

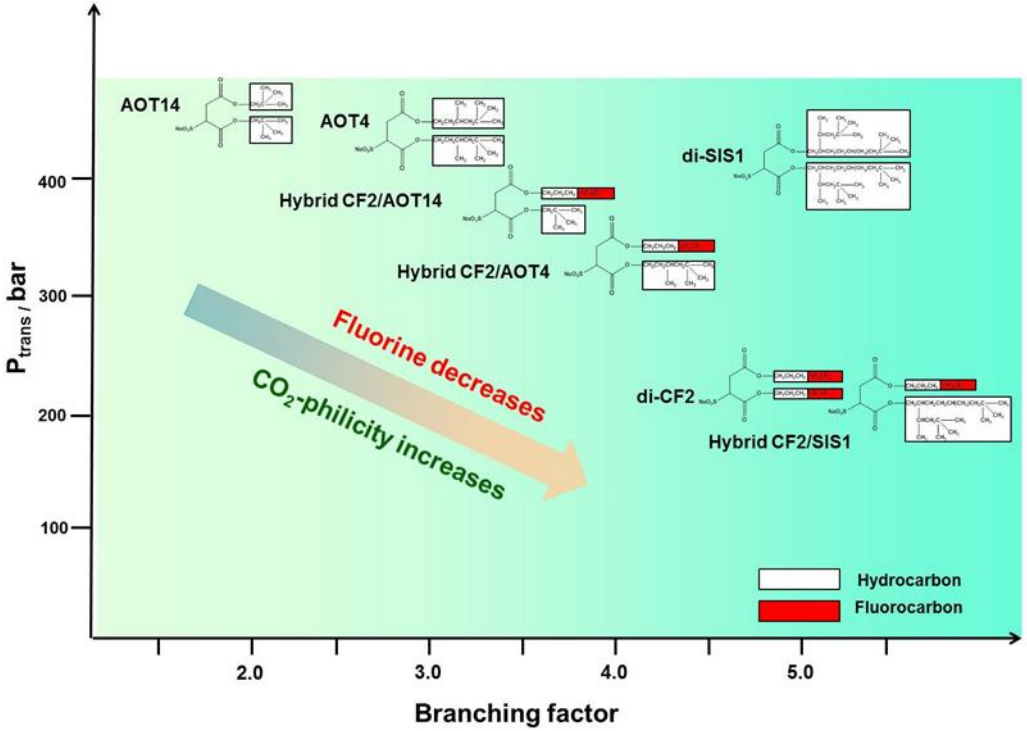
BF for hybrid. BF = (BF hydrocarbon chain + BF fluoro carbon chain) / 2

BF for hybrid CF2/AOT4 = 3 + 4.8 / 2 = 3.9

Table 9: Branching factor vs. surfactant performance

surfactant	Branching factor	P_{trans} / bar w=10 w/c T=55°C
di-CF2	4.8	219
hybrid CF2/AOT14	3.4	383
hybrid CF2/AOT4	3.9	321
Hybrid CF2/SIS1	4.9	215
AOT14	2	Incompatible
AOT4	3	Incompatible
di-SIS1	5	compatible

Tabor, Richard F. et al. *Langmuir* 2006, 22(3) 963-968.


AOT14
AOT4
Hybrid CF2/AOT14
Hybrid CF2/AOT4
di-SIS1
di-CF2
Hybrid CF2/SIS1
Fluorine decreases
CO2-philicity increases
Hydrocarbon
Fluorocarbon
P trans / bar
400
300
200
100
2.0
3.0
4.0
5.0
Branching factor

Approach 1 – Publication (IF 2.991)

J. of Supercritical Fluids 98 (2015) 127–136

Contents lists available at ScienceDirect

The Journal of Supercritical Fluids

journal homepage: www.elsevier.com/locate/supflu

Journal logo

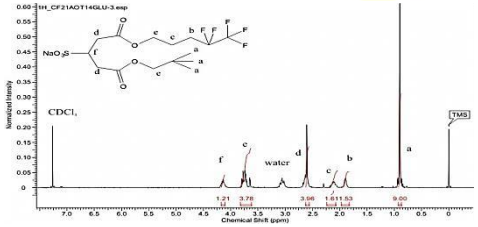
Economical and Efficient Hybrid Surfactant with Low Fluorine Content for the Stabilisation of Water-in-CO_2 Microemulsions

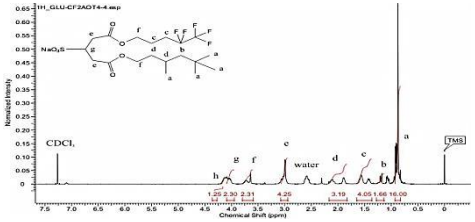
Azmi Mohamed [a,b,*], Tretya Ardyani [a], Masanobu Sagisaka [c], Shinji Ono [c], Tsuyoshi Narumi [c], Makoto Kubota [c], Paul Brown [d], Craig James [c], Julian Eastoe [e], Azlan Kamari [a,b], Norhayati Hashim [a,b], Illyas Md Isa [a,b], Suriani Abu Bakar [b]

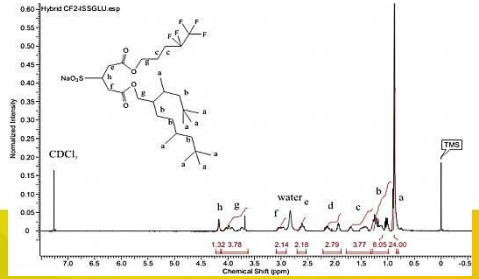
[a] Department of Chemistry, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia
[b] Nanotechnology Research Centre, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia
[c] Department of Frontier Materials Chemistry, Graduate School of Science and Technology, Hirosaki University 1-Bunkyo-cho 3, Hirosaki, Aomori 036-8561, Japan
[d] Department of Chemical Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, United States
[e] School of Chemistry, University of Bristol, Cantock's Close, Bristol, BS8 1TS, United Kingdom

Approach 2 - Synthesis of novel hybrid surfactants with different surfactant headgroup

Molecular fragment	Identified proton	Chemical shift	Relative NMR integrals	
			Experimental	Theoretical
Hybrid CF2/AOT14GLU				
C-CH_3*	a	0.90	9.00	9.00
C-CH_2-CF	b	1.88 – 1.92	1.53	2.00
C-CH_2-C	c	2.06 – 2.18	1.61	2.00
S-C-CH_2-C=O	d	2.60 – 2.63	3.96	2.00
O-CH_2-C	e	3.62 – 3.81	3.78	4.00
-SO_3-CH-C-	f	4.10 – 4.18	1.21	1.00
Hybrid CF2/AOT4GLU				
-C-CH_3*	a	0.82 – 0.94	16.00	16.00
-C-CH_2-C-	b	1.17 – 1.20	1.55	2.00
-C-CH_2-CF	c	1.39 – 1.56	3.74	2.00
-C-CH_2-C-				2.00
-C-CH_2-C-	d	1.88 – 2.17	3.13	2.00
-C-CH-C-				1.00
S-C-CH_2-C=O	e	2.99 – 3.09	4.23	4.00
O-CH_2-C-	f	3.64 – 3.72	2.33	2.00
O-CH_2-C-	g	4.02 – 4.06	1.98	2.00
SO_3-CH-C-	h	4.12 – 4.19	1.07	1.00
Hybrid CF2/SIS1GLU				
C-CH_3*	a	0.88- 0.89	24.00	24.00
C-CH_2-C	b	0.97 – 1.24	8.05	8.00







Approach 2 - Synthesis of novel hybrid surfactants with different surfactant headgroup

Table 11. CHNS Elemental analysis of surfactants used Approach 2 in this study

Surfactant	Percentage by Mass					
	Theoretical			Experimental		
	C	H	S	C	H	S
Hybrid surfactants						
Hybrid CF2/AOT4GLU	48.34	5.81	6.16	43.63	6.03	5.6
Hybrid CF2/AOT14GLU	38.80	4.78	6.90	36.46	5.17	6.30
Hybrid CF2/SIS1GLU	52.00	7.48	4.96	51.34	9.03	4.02

Approach 2 - Synthesis of novel hybrid surfactants with different surfactant headgroup

Air-water (a/w) surface tension study

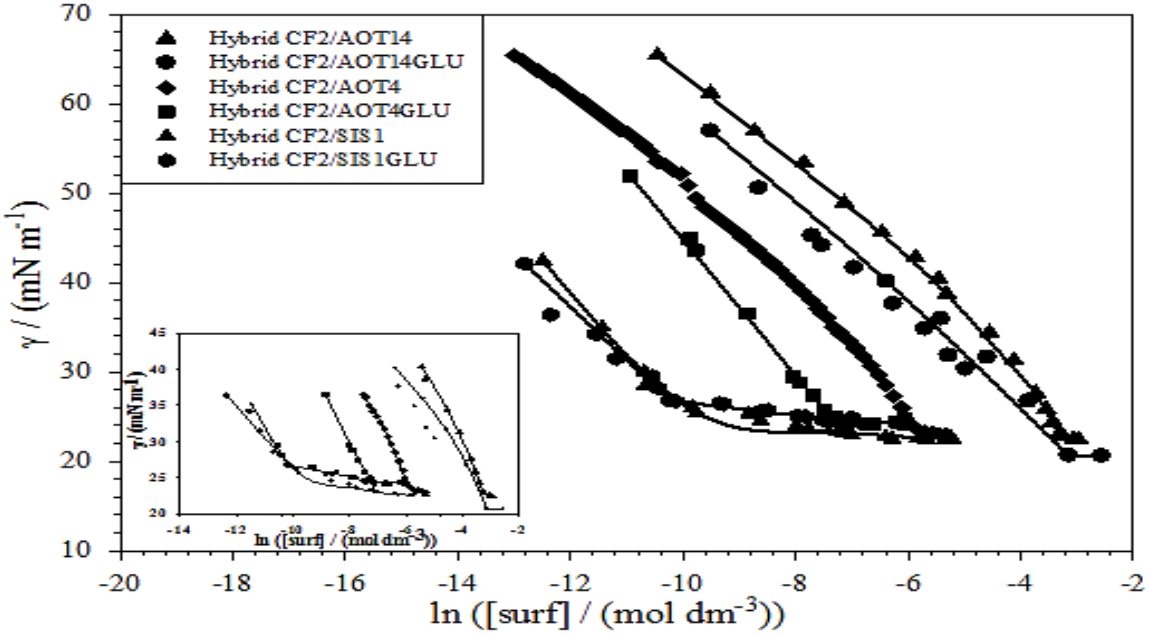


Figure 17. Air-water (a/w) surface tension of hybrid sulfosuccinate and sulfoglutaconate surfactants at 25°C.

Table 12. Hybrid surfactants properties in CO_2 and parameters derived from surface tension measurement at 25°C.

Surfactant	Fluorine / wt %	cmc/ (mmol/dm^3)	γ_{cmc} / mN m^{-1}	A_{cmc} / Å^2	P_{trans} / bar
Hybrid CF2/AOT14	21.09	21.09	22.5	102	383
Hybrid CF2/AOT4	18.76	1.78	23.8	103	321
Hybrid CF2/SIS1	15.01	0.05	26.0	112	215
Hybrid CF2/AOT14GLU	20.46	43.02	20.6	135	232
Hybrid CF2/AOT4GLU	18.25	0.78	24.4	112	Incompatible
Hybrid CF2/SIS1GLU	14.69	0.04	26.8	137	275

High-pressure phase behaviour measurement

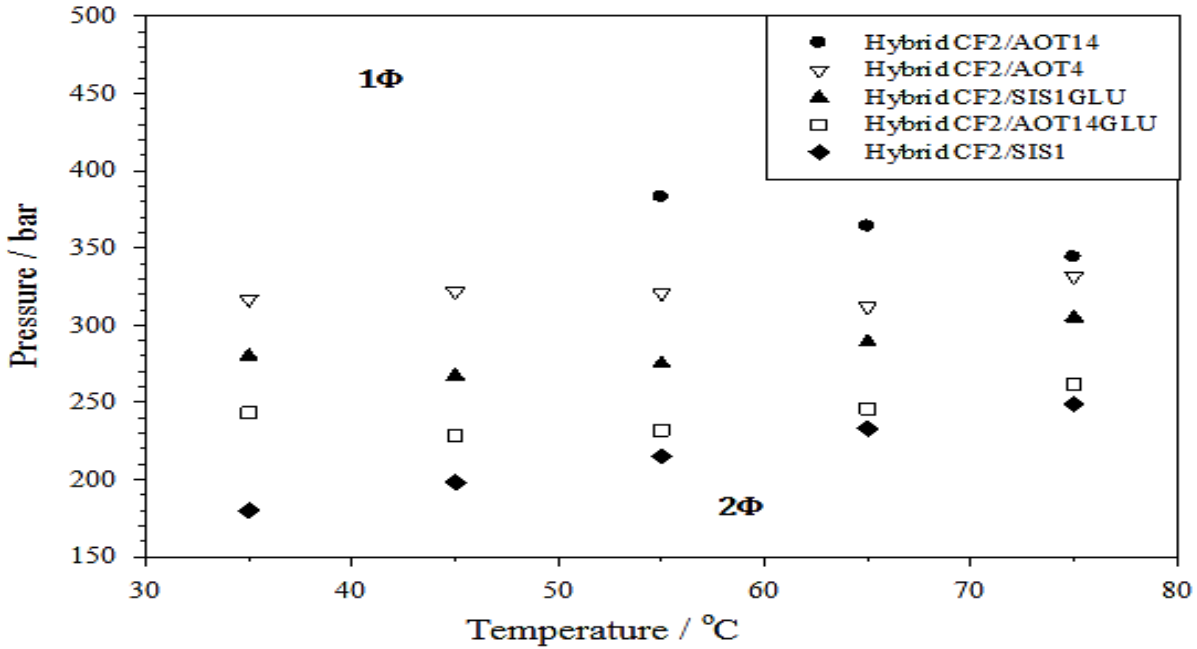
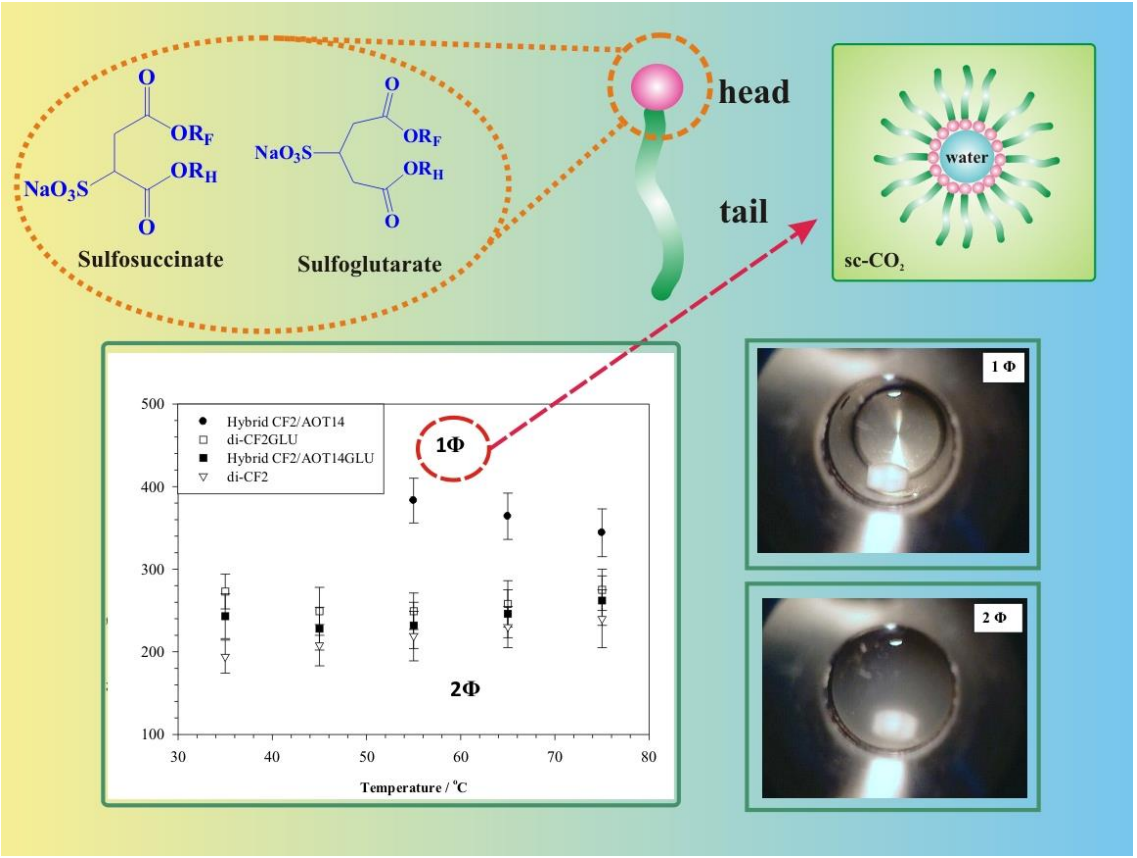


Figure 18. Phase behaviour of hybrid sulfosuccinate and sulfoglutaconate surfactants in CO_2 at various temperature (conditions [surf] = 0.05 mol dm^{-3}; w = 10).

Table 12. Hybrid surfactants properties in CO_2 and parameters derived from surface tension measurement at 25°C.

Surfactant	Fluorine / wt %	cmc/ (mmol/dm^3)	γ_{cmc} / mN m^{-1}	A_{cmc} / Å^2	P_{trans} / bar
Hybrid CF2/AOT14	21.09	21.09	22.5	102	383
Hybrid CF2/AOT4	18.76	1.78	23.8	103	321
Hybrid CF2/SIS1	15.01	0.05	26.0	112	215
Hybrid CF2/AOT14GLU	**20.46**	**43.02**	**20.6**	**135**	**232**
Hybrid CF2/AOT4GLU	18.25	0.78	24.4	112	Incompatible
Hybrid CF2/SIS1GLU	14.69	0.04	26.8	137	275


Sulfosuccinate
Sulfoglutarate
head
tail
water
sc-CO2
Hybrid CF2/AOT14
di-CF2GLU
Hybrid CF2/AOT14GLU
di-CF2
1Φ
2Φ
Temperature / °C
1 Φ
2 Φ

Approach 2 – Publication (IF 2.991)

J. of Supercritical Fluids 116 (2016) 148–154

Contents lists available at ScienceDirect

The Journal of Supercritical Fluids

journal homepage: www.elsevier.com/locate/supflu

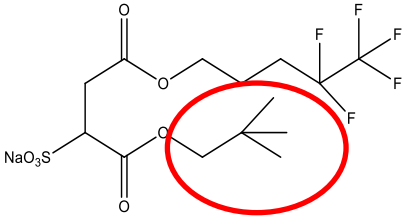
Effect of surfactant headgroup on low-fluorine-content CO_2-philic hybrid surfactants

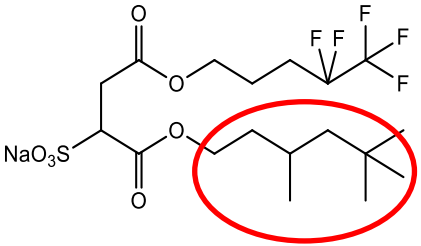
Azmi Mohamed [a,b,*], Tretya Ardyani [a], Suriani Abu Bakar [b], Masanobu Sagisaka [c], Shinji Ono [c], Tsuyoshi Narumi [c], Makoto Kubota [c], Paul Brown [d], Julian Eastoe [e]

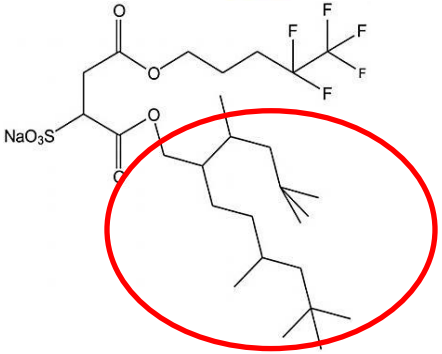
[a] Department of Chemistry, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia
[b] Nanotechnology Research Centre, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia
[c] Department of Frontier Materials Chemistry, Graduate School of Science and Technology, Hirosaki University, Bunkyo-cho 3, Hirosaki, Aomori 036-8561, Japan
[d] Department of Chemical Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, United States
[e] School of Chemistry, University of Bristol, Cantock's Close, Bristol, BS8 1TS, United Kingdom

Conclusions

- The hydrocarbon CO_2-philic tail on surfactant chemical structure play significant role in stabilising w/c microemulsions.







Hybrid CF2/AOT14; P_{trans} = 383 bar (w=10), γ_{cmc} = 22.5 mNm^{-1} , Branching factor = 3.4

Hybrid CF2/AOT4; P_{trans} = 321 bar (w=10), γ_{cmc} = 23.5 mNm^{-1}, Branching factor = 3.9

Hybrid CF2/SIS1; P_{trans} = 215 bar (w=10), γ_{cmc} = 26.0 mNm^{-1}, Branching factor = 4.9

- Surfactant CO_2-philicity was also found to be tuneable on varying surfactant headgroup. Addition of $–CH_2$ group on sulfosuccinate type to be sulfoglutaconate surfactant was found to give a distinct effect to each hybrid surfactants.

Conclusions

❖ Hybrid Sulfosuccinate type Surfactant (Aerosol-OT-analogue) : **ALTERNATIVE** approach for development economic and efficient surfactant via

"MINIMISING R_F and MAXIMISING R whilst optimising acceptable level of surfactant performance for stabilization w/c microemulsion"

❖Branching factor / coverage at interface can be quantified and one of crucial factor affecting CO_2- philicity

Acknowledgement

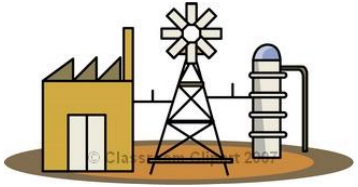
Thanks to:

- Universiti Pendidikan Sultan Idris (UPSI)

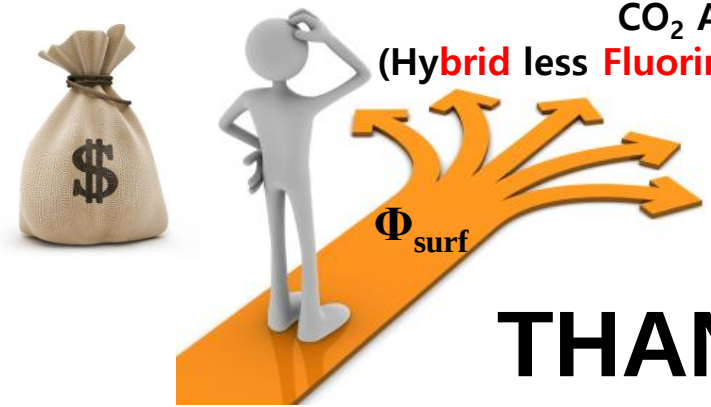
- Masanobu Sagisaka research group

- Julian Eastoe research group

- Paul Brown



CO_2 Application
(Hybrid less Fluorine and more efficient)



THANK YOU

© funmunch.com