Experimental report

21/06/2025

Proposal: 9-10-1840 **Council:** 4/2024

Title: Bile Salt-Driven Innovations: Exploring Deep Eutectic Solvents for Sustainable Solutions

Research area: Soft condensed matter

This proposal is a new proposal

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Samples: Sodium taurocholate solution
Sodium glycocholate solution
Sodium deoxycholate solution

Instrument	Requested days	Allocated days	From	To
D11	1	0		
D22	1	0		
D33	0	1	22/06/2024	23/06/2024

Abstract:

Deep Eutectic Solvents (DESs) are emerging as a potent, cost-effective, and non-toxic alternative to the prevalent volatile organic solvents in both research and industrial applications, offering adjustable physicochemical properties based on their composition. The incorporation of surfactants within DES enhances their adaptability, paving the way for eco-friendly options in the creation of nanostructured materials, non-aqueous responsive materials, and the formulation of gels and detergents. While substantial research has delved into the interactions of conventional head-tail structured surfactants in green solvents like DES, this study seeks to broaden the scope by exploring natural surfactants, specifically bile salts (BSs) - a category of natural surfactants derived from cholesterol, known for their unique facial amphiphilicity.

Bile Salt-Driven Innovations: Exploring Deep Eutectic Solvents for Sustainable Solutions

Introduction

Bile salts (BSs) are natural, biodegradable surfactants renowned for their capacity to emulsify hydrophobic substances. Combining these with Deep Eutectic Solvents (DESs) offers a unique opportunity to harness complementary properties. While BSs provide efficient surfactant capabilities, DESs present a green, tunable solvent platform characterized by low toxicity and sustainability. This synergy has potential applications in drug formulation, enzyme catalysis, nanomaterial synthesis, and separation processes, aligning with modern demands for sustainable, low-toxicity solutions [1].

Although the behaviour of canonical surfactants such as SDS and CTAB in DESs has been reported in the literature [2, 3], from a scientific perspective BSs in DESs provide an opportunity to investigate how amphiphiles with rigid steroid backbones interact with solvents characterized by complex hydrogen-bonding networks and varying polarity. This pairing could reveal novel aggregation morphologies and microemulsion phases. Advanced characterization techniques, such as small-angle scattering (SAS), high-resolution NMR, and molecular dynamics simulations, could elucidate the molecular mechanisms driving BS–DES interactions. However, challenges like high viscosity of DESs and the need for compositional optimization persist.

This study, which follows a previous study on Sodium Cholate (NaC) in DES, focuses on elucidating the aggregation behavior of Sodium Taurocholate (NaTC) and Sodium Glycocholate (NaGC) in reline systems, providing insight into how structural variations influence aggregation and stability.

Experiment

The experiment was conducted on the D33 beamline at the Institut Laue-Langevin (ILL) in Grenoble. The primary goal was to study the aggregation behavior of two bile salts, NaTC and NaGC, in reline systems with varying water content. Reline, a widely used DES, is a 1:2 mixture of choline chloride and urea, known for its high hydrogen-bonding capacity and tunable viscosity.

SANS measurements were performed on samples with varying BS concentrations and solvent compositions, including dry reline and reline/water mixtures. Each BS exhibits structural modifications at the carboxyl end, with NaTC featuring a taurine moiety while NaGC features a glycine moiety, which could influence their hydrophilicity and aggregation properties, allowing for the comparison between the behaviour of these structures with the one of the unconjugated structure of NaC, which features a free carboxylate moiety.

Results

NaTC Aggregation in Reline

Figure 1 presents the SANS data for NaTC in reline systems. The aggregation behavior shows some differences compared to NaC. The average polar radii (R_{polar}) remained stable across all

samples, ranging from 3.4 ± 0.5 Å to 3.8 ± 0.5 Å, with no significant trend linked to water content. Similarly, the equatorial radii ($R_{equatorial}$) and anisotropy ratios showed minimal variation, averaging 4.0 across the dataset. Aggregate volumes were generally larger than those observed for NaC, while the aggregation number hovered around 5, reflecting the larger molecular volume of NaTC.

NaGC Aggregation in Reline

NaGC displays lower solubility in pure reline, which required the study to be carried on mixtures with at least 5% water in them. Aside from this, for NaGC, as shown in Figure 2, the aggregation behavior exhibited a greater degree of isotropy compared to NaC and NaTC. The anisotropy ratio averaged 2.2, indicating less flattened oblate structures. Despite this, both volume and aggregation number values were consistent with those observed for NaC and NaTC.

Comparison and Insights

A comparison of SANS data for NaC, NaTC, and NaGC highlights the influence of structural modifications on aggregation dynamics. NaC aggregates, characterized by pronounced anisotropy, displayed dynamic size and shape changes with increasing water content. In contrast, NaTC and NaGC aggregates showed higher stability and less sensitivity to solvent composition. This stability can be attributed to the presence of hydrophilic conjugates (taurine or glycine), which enhance solvation interactions and stabilize aggregate structures.

Figure 3 illustrates the role of water on intermicellar interactions on these systems. When describing the aggregation of NaTC and NaGC in water, a structure factor is necessary to account for the secondary micelles that are present in solution, for which we used a Hayter-Penfold model. The same systems in DESs show that a structure factor is no longer needed as the ellipsoidal fit is sufficient to describe the experimental data. These findings underscore the influence of DES solvents on the aggregation behaviour of these surfactants.

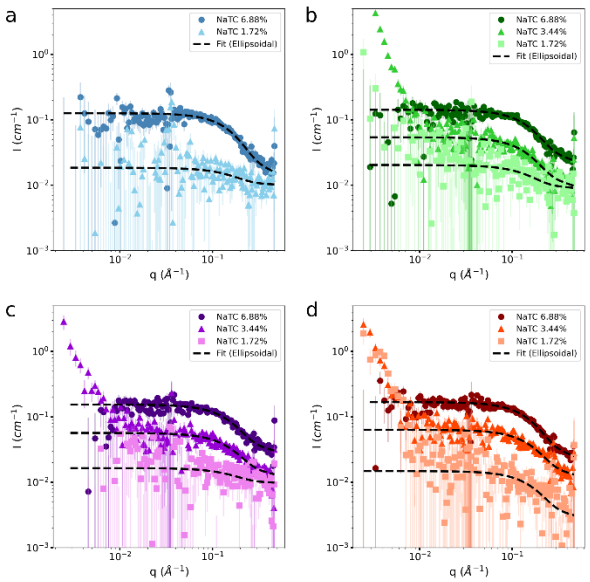

Figure 1: SANS curves for NaTC in reline systems with varying water contents: (a) 0%, (b) 5%, (c) 10%, and (d) 20% water. NaTC concentrations of 6.88% w/w (circles), 3.44% w/w (triangles), and 1.72% w/w (squares) are indicated in the legend. Fits with ellipsoidal model are represented by dashed lines.

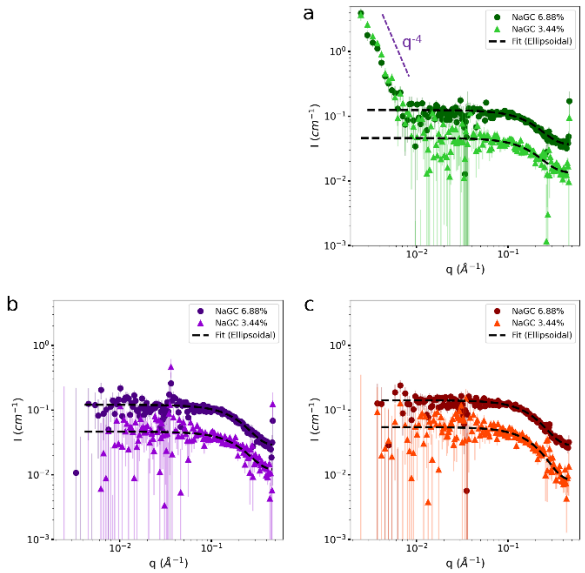

Figure 2: SANS curves for NaGC in reline systems with varying water contents: (a) 5% , (b) 10% and (c) 20% water. NaGC concentrations of 6.88% w/w (circles) and 3.44% w/w (triangles) are indicated in the legend. Fits with ellipsoidal model are represented by dashed lines.

Conclusions

The experiment successfully elucidated the role of BS structural modifications in influencing aggregation behavior in reline systems. NaTC and NaGC formed stable, isotropic aggregates, showing that the conjugation at the carboxyl group stabilizes aggregate morphology under varying solvent conditions. These insights position NaTC and NaGC as promising candidates for applications requiring robust micellar systems.

Future work will focus on expanding the range of DES compositions and exploring functionalized BSs for targeted applications. Additional studies integrating molecular dynamics simulations with experimental techniques will be critical for understanding the mechanistic underpinnings of BS-DES interactions.

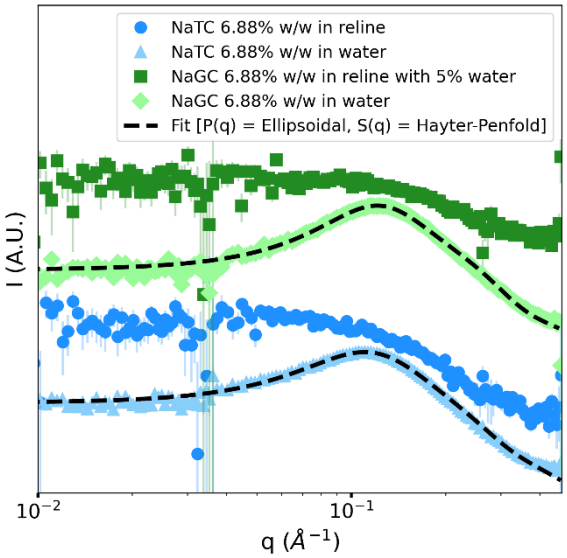

Figure 3: SANS curves for samples of NaTC 6.88% w/w in reline (dark blue) and water (light blue), as well as NaGC 6.88 % w/w in reline with 5% water (dark green) and water (light green). In black dotted lines, the fits for the samples in aqueous systems.

References

[1] Yang Liu, J. Brent Friesen, James B. McAlpine, David C. Lankin, Shao-Nong Chen, and Guido F. Pauli. Natural Deep Eutectic Solvents: Properties, Applications, and Perspectives. Journal of Natural Products, 81(3):679–690,

[2] T. Arnold, A. J. Jackson, A. Sanchez-Fernandez, D. Magnone, A. E. Terry, and K. J.Edler. Surfactant Behavior of Sodium Dodecylsulfate in Deep Eutectic Solvent Choline Chloride/Urea. Langmuir, 31(47):12894–12902, 2015.

[3] R. S. Atri, A. Sanchez-Fernandez, O. S. Hammond, I. Manasi, J. Doutch, J. P. Tellam, and K. J. Edler. Morphology Modulation of Ionic Surfactant Micelles in Ternary Deep Eutectic Solvents. Journal of Physical Chemistry B, 124(28):6004–6014, 2020.