
Chemical Trapping: The Determination of the Aromatic Counterion Distribution Stabilizing the 12-4-12 Surfactant Micelle Transformation

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Abstract: This research includes the use of chemical trapping to quantify the interfacial concentrations of anions which help stabilize the 12-4-12 surfactant micelle structure in solution. Different chemical trapping experiments were run using para-fluorobenzoate salt at different concentrations as the aromatic counterion. Each chemical trapping solution was run on the HPLC using the DAD ($\lambda=220\text{nm}$) and FLD (excite $\lambda=280\text{nm}$, emission= 380nm) as detectors. Chromatographic results display that that bromide ion tends to decrease in concentration due to the benzoate displacement. In parallel, the phenol product concentration tends to decrease with an increase in benzoate salt concentration due to the benzoate binding to the cationic head group leading to the loss of water through tight ion pair formation. The ester product, however, increases minimally due to the increase of benzoate salt and the rearrangement pathway. The individual peaks within each chromatogram is still in the process is being quantified by synthesizing standard products and creating standard curves.

Introduction:

Gemini surfactants have novel properties that are crucial to recent developments in various fields including pharmaceuticals, high efficiency detergents, and mesoporous silica.¹ What differentiates Gemini surfactants structurally from the average surfactant is their M-S-M general shape. Each Gemini carries two M-hydrophobic tails attached to a charged hydrophilic head group which are then attached to one another by an S-hydrocarbon chain (Figure 1). One of

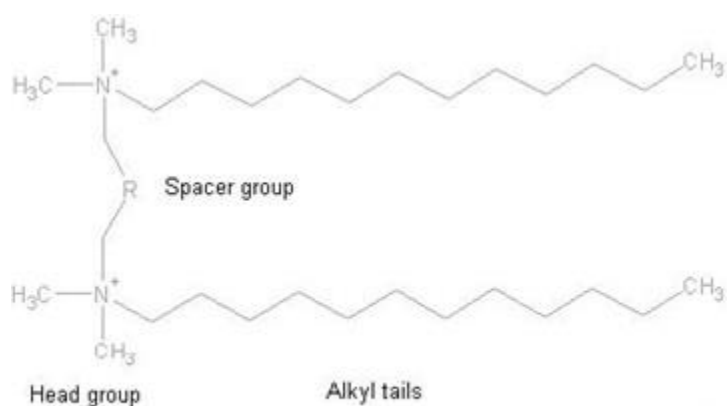
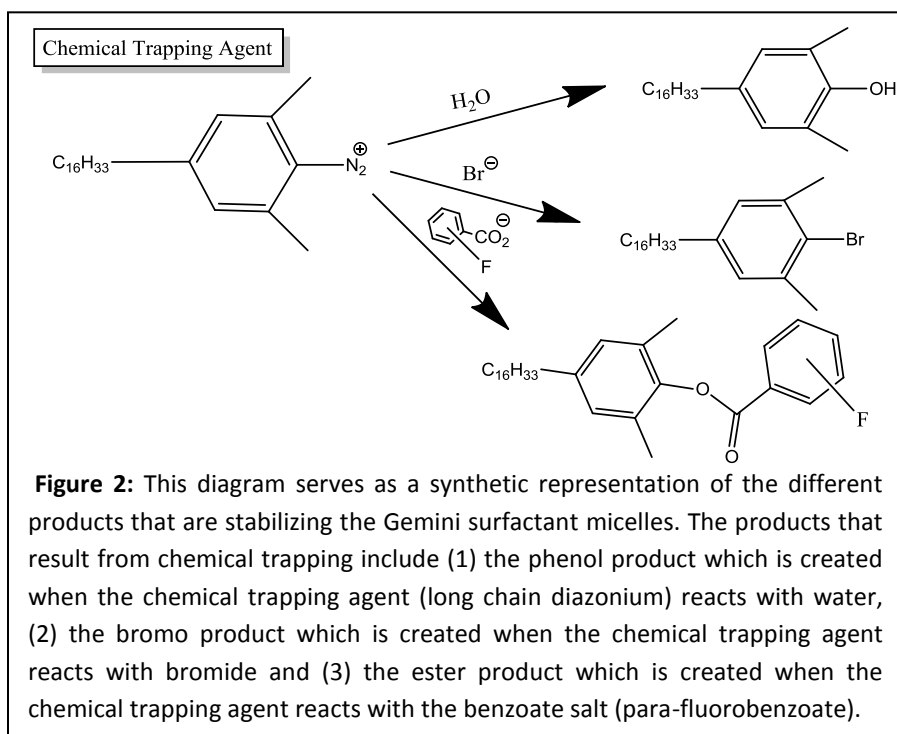


Figure 1: General structure of the m-s-m gemini surfactants.¹

the fundamental properties that make Gemini so special is their ability to change micelle shape from spheres to rods with the help of aromatic counterions. Previous research has indicated that organic ions have induced this sphere to rod transition by incorporating themselves into the structure of the micelle aggregate itself and changing the interfacial interactions.² Although the 12-4-12 bromide Gemini surfactant doesn't readily transform into rods as quickly as other surfactants similar to its structure, it is still vital that we find out what is going on at the interface of its micelles and why it is reacting the way it does. This information can further improve the knowledge on surfactants in order to help the progression of the growing fields that use surfactants within their scientific purpose whether it be cleaning dirty laundry or delivering a critical drug to an infected area of the body.



This research includes the use of chemical trapping to quantify the interfacial concentrations of anions which help stabilize the micelle structure in solution. Plus the interfacial water concentration can be quantified by this method. Chemical trapping experiments entailed the use of a long chain diazonium compound that was created using an aniline precursor. The chemical trapping experiments were

performed at ambient temperature, with the 12-4-12 at either 10mM or 20mM total surfactant concentration. Increments of para-fluorobenzoate salt were added up to a 1:1 ratio to the total surfactant concentration. Once the chemical trapping experiments were ran for 24 hours they were analyzed using the HPLC to determine which products helped stabilize the micelle. In order to discover qualitatively and quantitatively which anions are stabilizing the micelles in solution, each product is in the process of being made separately as a standard. Once each product is made it can be diluted into various concentrations that can be run on the HPLC under the same conditions as the chemical trapping experiments were. The standard chromatograms can then be analyzed and used to create standard curves. Each standard curve will be used to quantify the peaks in the chemical trapping experiments.

Experimental:

Synthesis of 12-4-12 Surfactant

Reflux apparatus was set up using a 250 mL round bottom flask, condenser, rubber tubing, heat mantel and boiling chips (the dark ones). 7.2 mL of 1-Bromodecane was added to 15 mL of acetone with stirring to the 250 mL round bottom flask. 2.27 mL of N,N,N',N'-Tetramethylbutanediamine was then added to the mixture with an additional 5 mL of acetone. The round bottom flask was then placed on a heating mantel where the solution was left to reflux 24hrs. The solid was then recrystallized with acetone three times. 6.4802g of product was weighed after the crystals dried overnight.

The critical micelle concentration of a surfactant is amount of surfactant concentration is needed to cause most of the floating surfactant molecules to aggregate into spherical micelles. In order to determine the CMC, critical micelle concentration, a conductivity test was taken at increasing concentrations of surfactant ranging from 0.2mM to 2mM. These solutions were made using water and surfactant. Before taking each conductivity reading each solution was placed within a conductivity bath for about 10 minutes. Once the readings were recorded this information was used to create a graph which then displays where the CMC is for the surfactant.

Synthesis of 2,6-Difluorobenzoate Salt

In a 700 mL beaker, 5g of 2,6-Difluorobenzoic acid was mixed with 50 mL of deionized water. 336.5 mL of 0.0933 M NaOH was added to the solution in increments in order to reach a pH of about 7. The pH shot up so an additional 0.0225 g of 2,6-Difluorobenzoic acid was added. Once the solid was completely dissolved the pH was at a 7.08 where the solution was then placed on a heating mantel for the water to evaporate.

Synthesis of Long Chain Aniline (4-n-Hexadecyl-2,6-dimethylaniline)

Materials used include: 3-neck round bottom flask, small stir bar, heating mantel, dean-stark trap, thermometer, condenser, two glass stoppers, septa, N₂ gas, Zinc chloride, Hexadecanol, 2,6-Dimethylaniline, aluminum foil and glass wool. 35.2691 g of hexadecanol and 25.6970g of ZnCl was poured into the three-neck round bottom creating 3 layers of hexadecanol and 2 layers of Zinc chloride. The small stir bar was added shortly after the 2,6-Dimethylaniline was added. The system was then flushed with nitrogen gas, the stirrer was turned on, the heat was turned on and the apparatus was then insulated with glass wool and aluminum foil. After stirring for 2 hours the reaction was stopped and the solution was a maroon color which was left to cool and solidify overnight.

The work up of the long chain aniline included removing the product from the 3-neck round bottom flask. A butter knife and hammer were used carefully break the bowling ball of solid product within the flask. The butter knife was held tightly while the hammer was used to hit the knife lightly. Once the knife felt as if it went through the solid it was not allowed to go any further. This process requires a great deal of patience. Once the solid was removed it was ground up as fine as possible. Some of the ground solid was dissolved into to a 1L beaker with H₂SO₄ while the beaker was in an ice bath.

NH₄OH was added to the same beaker until it reached a neutralized pH of 7, the pH was determined using pH strips. The aqueous phase was extracted using three times and the organic phase was dried over NaOH. This procedure was done on all of the ground solid.³

Synthesis of Short Chain Ester Product

Materials used include: 50 mL Erlenmeyer flask, button stir bar, 150 mL beaker and 250 mL beaker for ice bath. A 10% NaOH solution was prepared by mixing 10.4647 g of NaOH pellets and 100 mL of deionized water within a 150 mL beaker. Separately, 0.970 g of mesitol was added to a 50 mL erlenmeyer flask followed by 12 mL of the 10% NaOH solution and 2 mL of 2,6-Difluorobenzoyl chloride. The stirrer was set to stir while a beaker with deionized water was placed on an ice bath. Three hours later the stirring solution was added to the cold water in order to help the crystals fall out of solution. The solid was vacuum filtrated and placed in the freezer for storage.

Synthesis of Short Chain Diazonium (CH₃-ArN₂)

Materials needed: 100 mL 3-neck round bottom flask, dry ice, propanol, ice bath, stir bar, (3) septa, dropping funnel, short chain aniline, THF, BF₃ · O(C₂H₅)₂, pentane, syringes (1-5 mL), needles for each syringe, 500 mL beaker. Glassware was prepared so the dropping funnel was going into the center neck of the round bottom and every other opening was covered with a septum. The apparatus was flushed with nitrogen and checked to make sure seals were tight with vacuum grease. The round bottom was placed into a dry ice and isopropanol bath in order to keep it cold for the additions of THF. 10 mLs of THF was then added to the dropping funnel and was dripped into the round bottom flask to let cool for 10 minutes. 1.4 mLs of BF₃ · O(C₂H₅)₂ was added to the dropping funnel and was also dripped into the round bottom flask which was then stirred for 5 minutes. 9.6 mLs of Short chain aniline and 5 mLs of THF were then added to the dropping funnel and round bottom flask at a slow drip rate. An additional 5 mLs of THF was then added to the dropping funnel and round bottom flask again at a slow drip rate. 1 mL of tert-butyl nitrite and 5 mLs was then mixed and placed in the dropping funnel which was dripped in over a 2 minute period. After 7 hours of mixing under nitrogen the reaction was quenched with 100 mLs of cold pentane in a 500 mL beaker. The product that crashed out was then vacuum filtrated and recrystallized three times using diethyl ether and acetonitrile. This reaction was performed twice during the summer of 2013 using the same procedure with small alterations in volumes of reagents.

Synthesis of Long Chain Diazonium (16-ArN₂)

Materials needed: 100 mL 3-neck round bottom flask, dry ice, propanol, ice bath, stir bar, (3) septa, dropping funnel, long chain aniline, THF, BF₃ · O(C₂H₅)₂, pentane, syringes (1-5 mL), needles for each syringe, 500 mL beaker. Glassware was prepared so the dropping funnel was going into the center neck of the round bottom and every other opening was covered with septa. The apparatus was flushed with nitrogen and checked to make sure seals were tight with vacuum grease. The round bottom was placed into a dry ice and isopropanol bath in order to keep it cold for the additions of the sure seal solutions. 15 mLs of THF was then added to the dropping funnel using a cannula and was dripped into the round bottom flask to let cool for 10 minutes. 3.2 mLs of BF₃ · O(C₂H₅)₂ was added through the side septum by syringe. Shortly after, a solution of 3.004g long chain aniline and 10 mLs of THF was also

syringed through the side septum. 1.3 mLs of tert-butyl nitrite and 10 mLs of THF was added to the dropping funnel and dripped into the round bottom flask over a 2 minute period. A regular ice and salt water bath was switched in for the dry ice and propanol bath an hour into the reaction. After 8 hours of mixing under nitrogen gas the reaction was quenched with 100 mLs of cold pentane (stored in a refrigerator prior to use) in a 500 mL beaker. The product that crashed out was then vacuum filtered and recrystallized three times using cold diethyl ether and cold acetonitrile. When the crystals didn't fall out of solution right away, the rest of the dry ice was used to create a colder environment to help force it out of solution and was quickly isolated. This reaction was performed several times during the summer of 2013 using the same procedure with small alterations in volumes of the reagents used.

Synthesis of Long Chain Phenol Standard Product (16-ArOH)

Materials needed include: a 100 mL 3-neck round bottom flask, a dropping funnel, a glass stopper, septa, THF, long chain diazonium, H₂O, and a stir bar. The glassware was set up so the dropping funnel was placed in the center of the 3-neck round bottom flask and was then flushed with nitrogen. 0.5853g of long chain diazonium mixed with 25 mLs of THF was added into the round bottom flask and stirred 5 minutes. 25mLs of deionized water was then added to the dropping funnel and dropped in slowly 25 minutes later. The solution showed color changes within minutes and was left to stir for 48 hours with expected crystal formation by the morning. Because crystals did not form, NMR of the liquid product was taken. Due to the clear NMR results the THF was stripped off and the solid was collected weighing only 0.2972 g. (Refer to picture B in appendix A for a structural representation of this product)

After questioning the purity and quantity of the phenol made the first time, two more phenol synthesis were done with certain alterations. In the second reaction, every step was performed the same but this time 0.5728 g of long chain diazonium was used. In the third reaction the THF and water were switched. At the time the reaction seemed to be working at a much better rate yet our results and final product weight weren't any better than the first time. After speculating whether or not the product was truly pure, the product was run through a column in order to separate it from any impurities. These impurities were separated by silica gel columns using 60:40 methanol isopropyl alcohol as the mobile phase with collection of each fraction. With the help of the GC-MS each fraction was qualitatively identified in order to find out which fraction contained the highest concentration of phenol product. The fractions with the most amount of phenol product were placed into the roto-vap to strip off the solvent and the solid was considered pure phenol product. This product was used as a standard and was diluted to specific concentrations which were then run on the HPLC in order to compare the results from our chemical trapping experiments. After purification, the third method used to produce phenol product was considered to be the best method because it provided the most amount of product.

Chemical Trapping

To begin, a diazonium stock solution using of 25mg of diazonium product in acetonitrile was made in a 4.0 mL volumetric flask and inverted multiple times to ensure the product was dissolved. Solutions with a constant concentration of surfactant (10 and 20mM) and incrementally increasing concentrations of para-fluorobenzoate salt (4-20mM) were prepared. Using the prepared solutions, with

constant surfactant concentrations and incrementally increasing para-fluorobenzoate concentrations, chemical trapping experiments were prepared in 2mL volumetric flasks. Each volumetric flask included 2mLs of the premade solution and a 25 μ L syringed volume of long chain diazonium product. The chemical trapping experiments were closed and left to sit for 48 hours. After 48 hours each solution was ran on the HPLC at 25 $^{\circ}$ C, a flow rate of 0.6mL/min the solvent composition 64:36 iPrOH:MeOH causes all micelles to disaggregate, and a 40 μ L injection volume under the DAD (λ =220nm) and FLD (excite λ =280nm, emission=380nm) detectors.

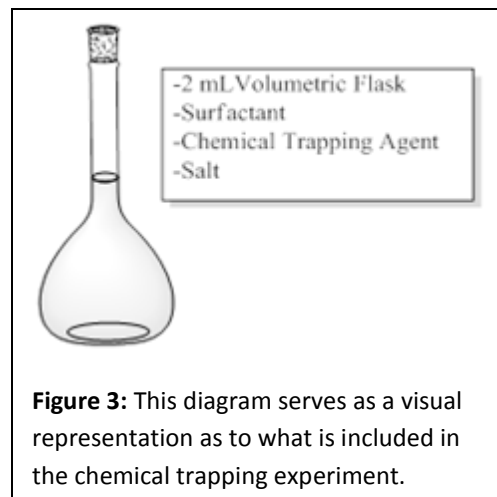


Figure 3: This diagram serves as a visual representation as to what is included in the chemical trapping experiment.

Results:

CMC Results

The graphical representation of conductivity measurements as function of surfactant concentrations is represented in Figure 4. Here the early concentrations tend to have a much steeper positive slope compared to the points at higher concentrations of surfactant. The break in between points 0.8 and 1.0 represents the region where the CMC value lies for the 12-4-12 surfactant. Beyond this point in the graph the solution will always contain micelles and very few free floating surfactant molecules.

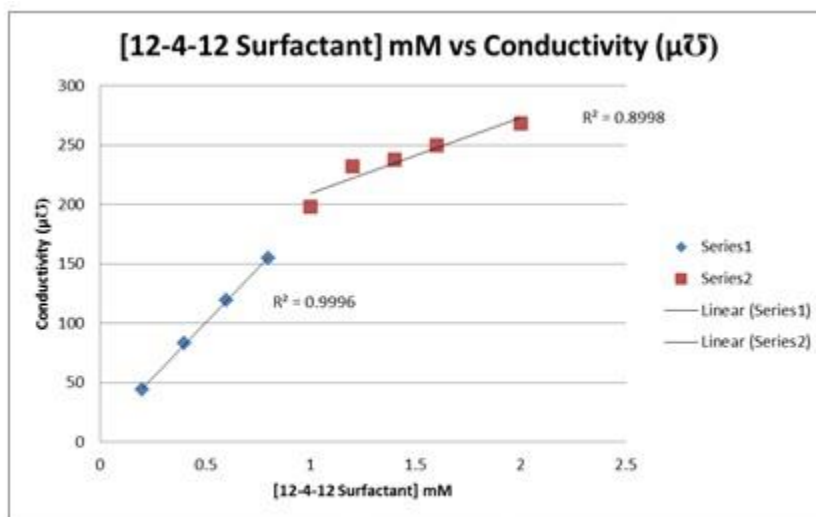


Figure 4: Conductivity Test of 12-4-12 Surfactant at Increasing Concentraions in Determination of CMC

Chemical Trapping Results

Figure 5 below displays the five layered chromatograms for the chemical trapping experiment solutions containing a constant concentration of 10 mM 12-4-12 Gemini surfactant with an increasing concentration of para-fluorobebzoate salt. The 4mM concentration of para-fluorobenzoate is shown in blue at the bottom of the chromatogram and increases to 12mM shown in gold at the top of the chromatogram. There is an abundance of excess salt which comes off the column faster than any of the other products within the four to ten minute range which we will disregard during analysis. Shortly after the first ten minutes, there is a peak that tends to decrease as the concentration of benzoate salt increases which is believed to be the peak responding to the phenol product. Here phenol product

concentration is decreasing due to the benzoate ion binding to the cationic head group leading to the loss of water through tight ion pair formation.

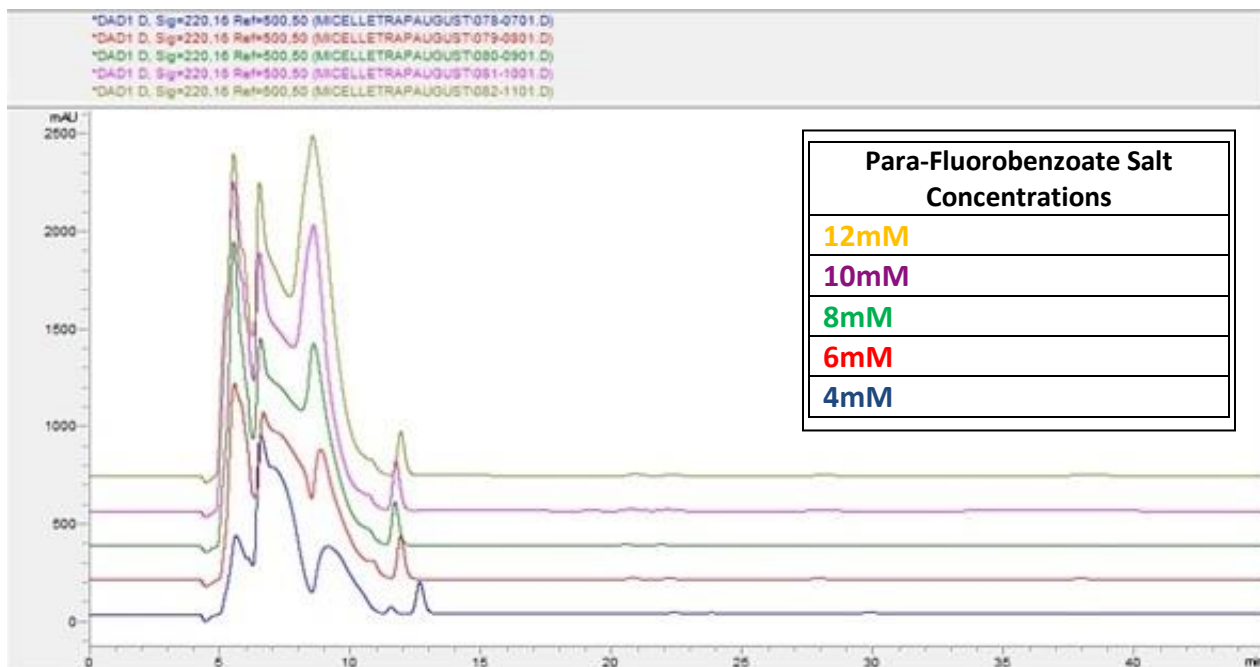


Figure 5: These are the layered chromatograms for the chemical trapping experiment including 10 mM 12-4-12 Gemini surfactant concentration with increasing para-fluorobenzoate concentrations of 4mM, 6mM, 8mM, 10mM and 12mM.

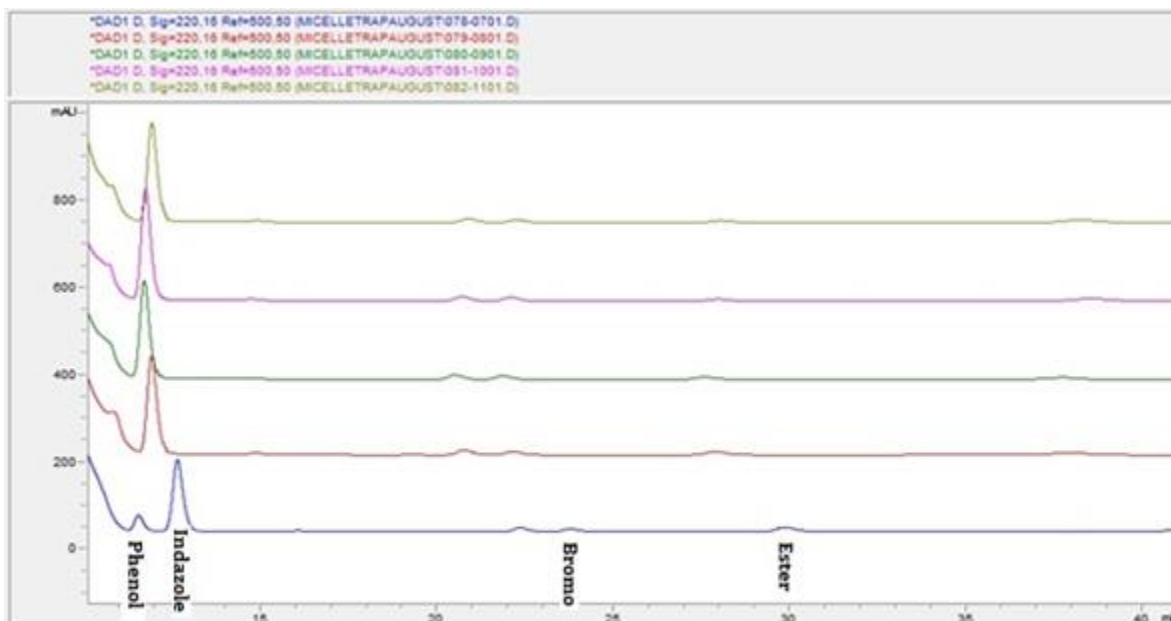


Figure 6: Zoomed in version of the five layered chromatograms for the chemical trapping experiment including 10mM 12-4-12 Gemini surfactant concentration with increasing para-fluorobenzoate concentrations of 4mM, 6mM, 8mM, 10mM, and 12mM.

Figure 6 is an enlarged version of the exact same graph which gives a slightly better representation of the changes in each individual peak. The peak following the phenol in the 14 minute region is believed to be an indazole product, or rearrangement, of the long chain diazonium which appears to be increasing as the concentration of salt increases.⁴ This information is vital when the other important peaks are taken into consideration. The esters peak which occurs around 37 minutes is also increasing as the concentration of benzoate salt increases. Although it is minimal, the increase makes logical sense due to the fact that the benzoate salt is the reactant responsible for making the ester product. Due to their close relationship, one would think both the benzoate salt and ester product would have a 1:1 ratio, meaning

as you increase benzoate salt one would expect the ester product to increase the same amount. That relationship isn't seen within the results which could be due to the fact that so much of the diazonium is rearranging before it can react with the benzoate salt to make the ester product. Bromo product on the other hand, happens to be decreasing in concentration. Similar to the decrease in phenol product, bromo product concentration is also believed to be decreasing

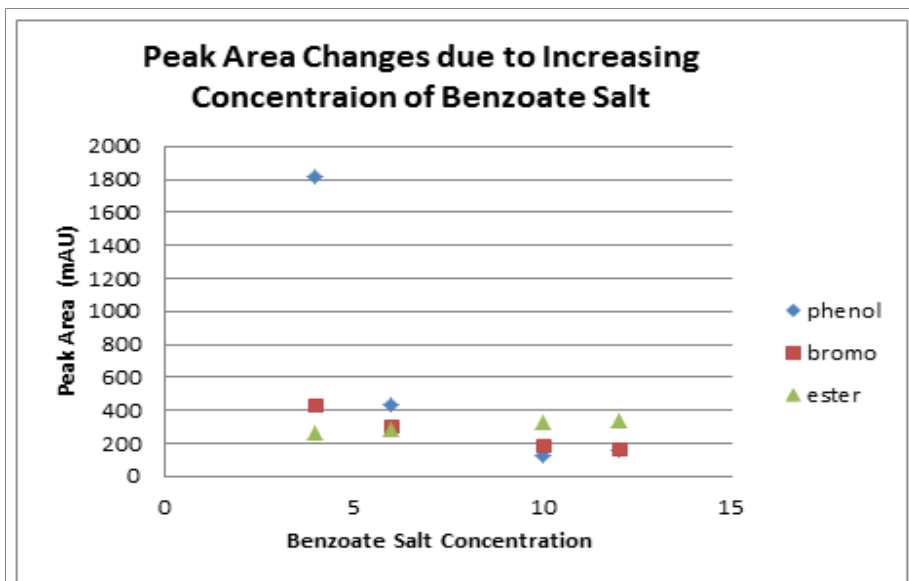


Figure 7: Graphical representation of the peak areas for the phenol product, bromo product and ester product as a function of benzoate concentration.

due to the benzoate ion displacement. Figure 7 is a graphical representation of the peak area for each product as a function of benzoate concentration. This graph makes it much easier to see that phenol product is indeed decreasing, bromo product is decreasing and the ester product is slightly increasing as benzoate salt concentration is increasing.

Figure 8 displays the same type of zoomed in layered chromatograms but for a constant surfactant concentration of 20 mM with an increasing para-fluorobenzoate salt concentration of 4mM, 8mM, 12mM, 16mM and 20mM. This set of chemical trapping experiments displayed the same trends in the phenol, ester and bromo products as the 10mM surfactant chemical trapping experiments.

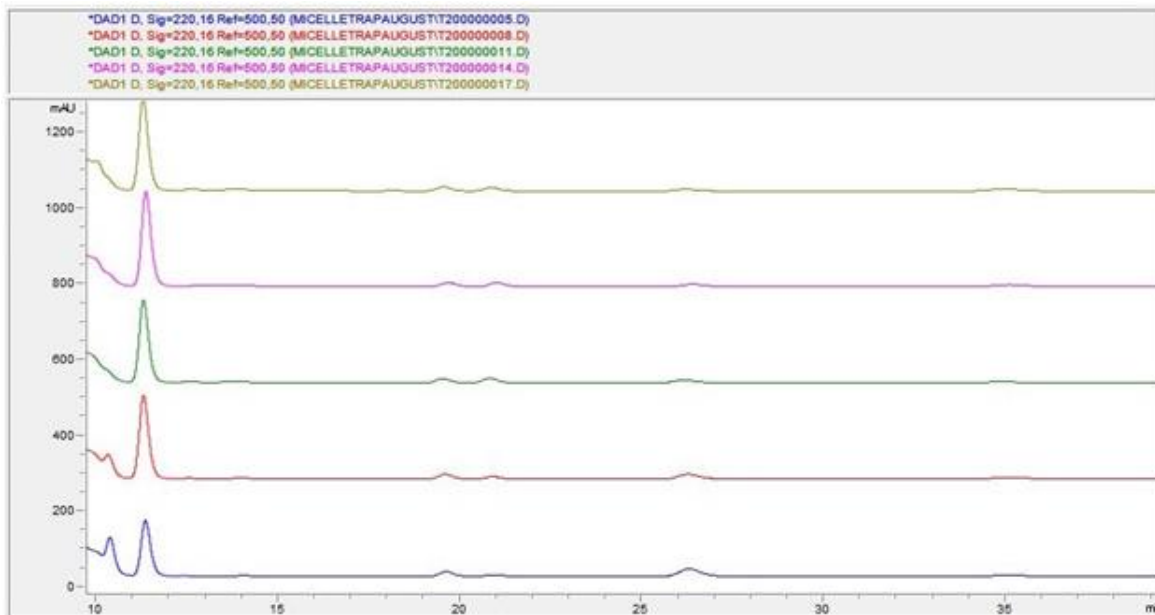


Figure 8: Zoomed in version of the five layered chromatograms for the chemical trapping experiment including 20mM 12-4-12 Gemini surfactant concentration with increasing para-fluorobenzoate salt concentrations of 4mM, 8mM, 12mM, 16mM and 20mM.

Standard Curves

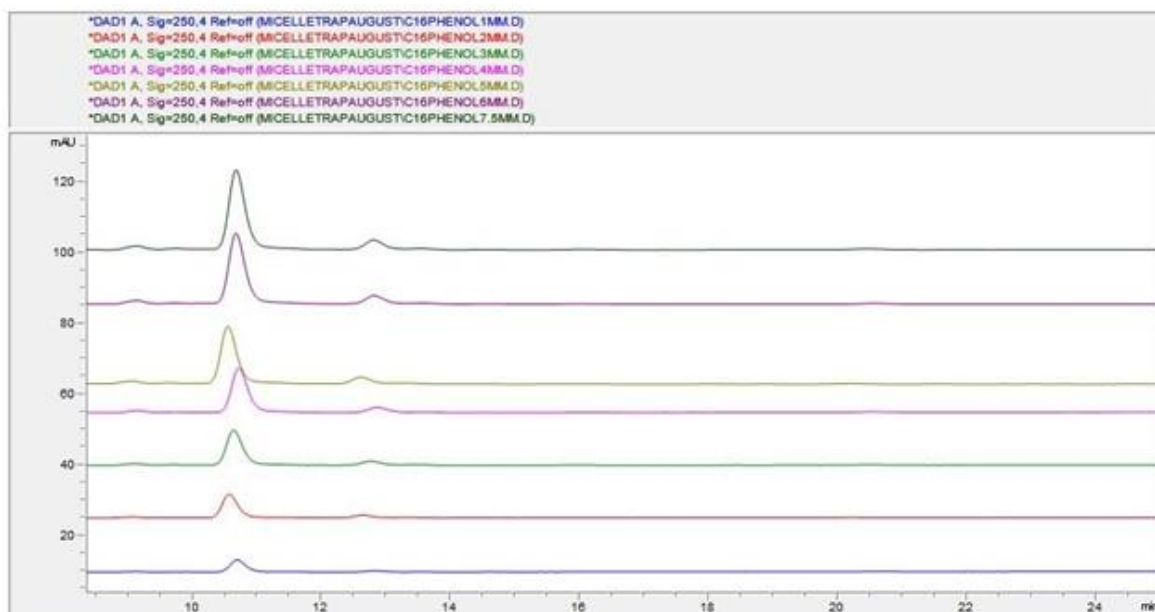


Figure 9: Layered chromatograms for the standard phenol product at 0.1mM (blue), 0.2mM (red), 0.3mM (green), 0.4mM (pink), 0.5mM (gold), 0.6mM (purple) and 0.75mM (black) concentrations.

In order to correctly identify and quantify each product represented in each chromatogram, standard curves are in the process of being produced. The first product that has been standardized with results is the phenol product. Figure 9 displays the phenol standard product's chromatogram results at increasing concentrations from 0.1mM to 0.75mM. Their chromatograms display that the peaks around 10 minutes in each of the chemical trapping experiment chromatograms are in fact the phenol product.

Each phenol peak area was imputed into a graph with its corresponding concentration which produced a standard curve with a linear equation. This equation can now be applied to the peak areas of each phenol peak in the chemical trapping experiments to identify how much phenol product is present.

At this point the rest of the standard products are still in the process of being produced in order to create multiple standard curves which will be used to quantify the product distribution for the chemical trapping experiments.

Conclusion:

Based on the chromatographic results it is evident that the bromo product tends to decrease in concentration due to the benzoate displacement. In the meantime, the ester product increases due to the increase of benzoate salt and the rearrangement pathway. The change in the ester concentration may look minimal based on the chromatogram comparisons but there is a chance that they may become more significant once the chromatographic data is normalized. On the other hand, the phenol product concentration tends to decrease with an increase in benzoate salt concentration due to the benzoate binding to the cationic head group leading to the loss of water through tight ion pair formation.

Compared to the 12-3-12 surfactant, there is believed to be less water loss at the micelle interface during the chemical trapping experiments between the 12-4-12 surfactants and the benzoate salt. When a great deal of water is lost at the interfaces of micelles their shape tends to transform much sooner than those with less water loss. This belief can further explain as to why the 12-4-12 micelles don't transform into rods as readily as the 12-3-12 surfactant micelles do.

Future:

As for future work, there are many things that have yet to be done on this topic of research. When it comes to the 12-4-12 Gemini surfactant that we have worked on during this summer, we have sets of chromatograms that have a number of unknown peaks which may be difficult but helpful to identify. These unknown peaks can tell us a significant amount of information that is going on at the surface of the micelle during the chemical trapping reactions. In order to identify these peaks one needs to identify the possibilities of what the peak could make and create a standard to be run on the HPLC in different concentrations in order to compare retention times and quantify the amount of product based on peak intensity. There are also other chemical trapping experiments, using different concentrations of added benzoate with the surfactant and diazonium compound, which can be done in order to gain more information on the way this surfactant aggregate changes under different conditions. The information gained in the various chemical trapping experiments can add to the general knowledge about this specific surfactant which would help lead into the possibility of it being used in various different fields including pharmaceutical, oil and mesoporous compounds.

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