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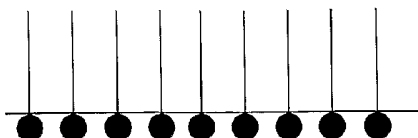
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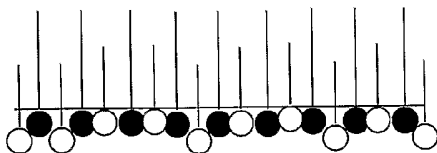
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Initial Solution



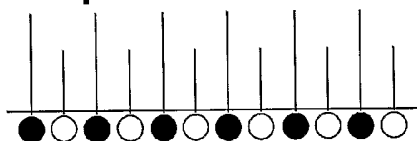
A

Super-saturation of Surface



B

Equilibrated Surface



C

(57) Abstract: A process extracts liquid from a fabric having a first content of liquid through the use of a mechanical extraction means and penetration of a surfactant monolayer created at the air-liquid interface of the first liquid contained in the fabric by a surfactant penetrant.



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Process For Extracting Liquid From a Fabric

*Daniel Larry Carter**Dinesh Ochhavlal Shah**Shulin Larry Zhang*CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/637,318, filed December 17, 2004. The entire disclosure of which is hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates to a process of extracting liquid from a fabric having a first content of liquid through the use of a surfactant monolayer at the air-liquid interface of the liquid in the fabric and a surfactant penetrant.

BACKGROUND OF THE INVENTION

The amount of liquid remaining in fabric at the end of a washing cycle increases the time and energy required to dry the fabric. The reduction in the amount of time and energy in drying the fabric has been of great interest to consumers. It is widely believed that water wicks into fabric due to capillary forces operating between fabric fibers that create capillaries. If capillary forces are indeed the cause of water retention, then the capillary rise in the fabrics should be governed by the LaPlace equation for capillary rise. These forces can be strong or weak depending on the weave of the fabric as well as the composition of the fabric. For example, cotton fibers typically hold about 75-80% of initial water after the spin cycle of a washing machine. Prior attempts to reduce liquid remaining in fabric at the end of a washing cycle have been directed to modification of fabric to be less absorbent or to affect the surface of the fabric by deposition of specified agents. However, modifying a fabric surface often leads to other undesired fabric properties and often fails to achieve the ideal reduction of drying time and energy desired by consumers. Therefore, there is a continuing need to effectively reduce the amount of liquid remaining in fabric such as clothing, linens and the like at the end of a washing cycle.

SUMMARY OF THE INVENTION

The present invention relates to a process of extracting liquid from a fabric having a first content of liquid. The process comprises: creating a surfactant monolayer at an air-liquid

interface of the liquid in the fabric, wherein the monolayer has a first surface tension; penetrating the surfactant monolayer with a surfactant penetrant to reduce the surface tension at the air-liquid interface for a period of time; and subjecting the fabric to mechanical extraction during the period of time to reduce the liquid content of the fabric to a second liquid content. The process of the present invention is advantageous for providing good extraction of liquid from a fabric or other porous materials and may be employed in both consumer and industrial applications. These and additional advantages will be apparent in view of the detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing and distinctly claiming the present invention, it is believed that the same will be better understood from the following description taken in conjunction with the accompanying drawings in which:

Figs. 1A-1C are schematic illustrations of transient surface tension mechanisms of the present invention;

Fig. 2 sets forth surface tension properties of a surfactant system comprising sodium tetradecyl sulfate ($C_{14}SO_4$) penetrated into a solution of hexadecyl trimethyl ammonium bromide ($C_{16}TAB$) according to a first exemplary embodiment of the present invention;

Fig. 3 sets forth surface tension properties of a surfactant system comprising $C_{14}SO_4$ penetrated into a $C_{16}TAB$ monolayer according to a second exemplary embodiment of the present invention;

Figs. 4-7 set forth surface tension properties of exemplary surfactant systems comprising $C_{14}SO_4$ penetrated into various surfactant monolayers according to third, fourth, fifth and sixth, respectively, exemplary embodiments of the present invention;

Fig. 8 sets forth surface tension properties of a surfactant system comprising tetradecyltrimethyl ammonium bromide penetrated into a stearic acid monolayer according to a seventh exemplary embodiment of the present invention;

Fig. 9 sets forth surface tension properties of a surfactant system comprising $C_{14}SO_4$ penetrated into a 1:10 molecular ratio $C_{14}SO_4$:dioctyldecyldimethylammonium bromide (DODAB) monolayer according to an eighth exemplary embodiment of the present invention;

Fig. 10 sets forth surface tension properties of a surfactant system comprising $C_{14}SO_4$ penetrated into a 1:5 molecular ratio $C_{14}SO_4$:dioctyldecyldimethylammonium bromide (DODAB) monolayer according to a ninth exemplary embodiment of the present invention;

Fig. 11 sets forth surface tension properties of a surfactant system comprising $C_{14}SO_4$ penetrated into a 1:3 molecular ratio $C_{14}SO_4$:dioctyldecyldimethylammonium bromide (DODAB) monolayer according to a tenth exemplary embodiment of the present invention;

5 Fig. 12 sets forth surface tension properties of a surfactant system comprising $C_{14}SO_4$ penetrated into a 1:2 molecular ratio $C_{14}SO_4$:dioctyldecyldimethylammonium bromide (DODAB) monolayer according to an eleventh exemplary embodiment of the present invention; and

Fig. 13 sets forth surface tension properties of a surfactant system comprising $C_{14}SO_4$ penetrated into a 1:5 molecular ratio $C_{14}SO_4$:dioctyldecyldimethylammonium bromide (DODAB) monolayer according to a twelfth exemplary embodiment of the present invention.

10 The embodiments set forth in the drawings are illustrative in nature and not intended to be limiting of the invention defined by the claims. Moreover, individual features of the drawings and the invention will be more fully apparent and understood in view of the detailed description.

DETAILED DESCRIPTION OF THE INVENTION

15 Incorporated and included herein, as if expressly written herein, are all ranges of numbers when written in a "from X to Y" or "from about X to about Y" format. It should be understood that every limit given throughout this specification will include every lower, or higher limit, as the case may be, as if such lower or higher limit was expressly written herein. Every range given throughout this specification will include every narrower range that falls within such broader range, as if such narrower ranges were all expressly written herein.

20 The liquid content remaining in fabric, for example clothing, linens or the like, at the end of a washing cycle largely determines the time and energy required to dry consumer bundles of fabrics. The reduction of time and energy in drying laundry has been of great interest to consumers. A real challenge in drying laundry is to achieve the desired reduction in drying time and energy for an average consumer bundle of fabrics, which comprise various fabric types having different water retention properties. For example, an average consumer bundle of fabric may comprise a mixture of cotton towels in the same consumer bundle as synthetic/cotton mixed fabric clothing. Perceived "hard-to-dry" items such as cotton fabrics with thicker weaves often result in the longest drying time and highest energy requirements, even after the use of mechanical drying means such as washing machines with a spin stage. An additional issue facing consumers is the effective distribution of liquid extraction agents added to a washing process. Most consumers desire that one dose added during the washing process be effective in delivering benefit agents for an entire consumer bundle. Without effective distribution, the desired consumer benefit from the added benefit agent is not always obtained. Therefore, an identified

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problem in extracting the liquid content from a fabric to a reduced liquid content held interstitially in a fabric weave or structure such as void spaces is the effective distribution of the benefit agents throughout the consumer bundle during a washing process.

Process

5 The present invention relates to a process of extracting the liquid content from a fabric to a reduced second liquid content through the use of a mechanical extraction means and a surfactant monolayer created at an air-liquid interface in the fabric and a surfactant penetrant capable of reducing the surface tension at the air-liquid interface for a period of time. In one embodiment, the surfactant monolayer and surfactant penetrant are utilized during the washing process, which
10 is commonly accomplished through the use of a washing machine having a mechanical extraction means such as a spin stage. As used herein "a reduced second liquid content" means a liquid content that would be less than that achieved by use of a mechanical extraction means alone.

As used herein "fabric" refers to natural, synthetic, and mixed natural/synthetic materials, including but not limited to silk, wool, cotton, rayon, nylon, polyesters, lycra, and spandex.

15 As used herein "liquid" refers to any aqueous bases material that can have a liquid form at room temperatures (about 0°C to about 60°C) or can comprise a mixture of liquid and vapor phases at ambient temperatures and pressures, e.g., at 25°C and 101 kPa (1 atm) pressure. As used herein "liquid" further refers to a pure liquid, a solution, or a colloid suspension of solids in an aqueous material, such as water.

20 As used herein "liquid content" refers to the liquid held interstitially in a fabric weave or structure such as void spaces. The liquid content may range from saturated to dry. "Dry" as used herein refers to fabric that has no damp feel when touched. "Saturated" as used herein refers to fabric that has the maximum liquid content of the fabric.

As used herein, an "effective amount" refers to an amount of a material or additive that
25 when utilized delivers a perceivable benefit, such as the amount of water extracted from fabric.

The washing process of a typical washing machine comprises the following stages. First the washing machine, after being loaded with the desired fabrics, has a "washing stage," which, as used herein, refers the stage where the washing machine fills with water to a predetermined volume, agitates for a specified period of time, drains the washing liquor, and then the machine
30 spins the fabrics. "Rinse stage" as used herein refers the next stage wherein the washing machine fills with water to a predetermined volume, agitates for a specified period of time, and then drains the water as the machine spins the fabrics. During the washing stage and rinse stage, fabrics become wet with the wash liquor and have a first liquid content. During the spinning and draining portion of the rinse stage, some washing machines have a small amount of water

dropping onto the fabric. "Splash" as used herein refers to water dropped onto the fabrics during the rinse stage, but not retained or held in the washing machine. After the rinse stage, a type of mechanical extraction means to further remove the liquid content from the fabrics may be used. It is intended that the claimed process of the present invention encompass mechanical extraction means separate from a washing machine as well as mechanical extraction means incorporated as part of the washing machine. The "spin stage" as used herein, refers to a stage wherein the washing machine incorporates a mechanical extraction means. A reduced second liquid content may be measured at the end of the spin stage. One exemplary embodiment comprises a washing machine spin cycle for a specified period of time without the addition of water to the washing machine.

The surfactant monolayer utilized in the present process may be created at the air-liquid interface of the liquid content held interstitially in a fabric weave or structure such as void spaces at any time during the washing process. In one exemplary embodiment, the surfactant monolayer is created at the air-liquid interface during the washing stage. In another exemplary embodiment, the surfactant monolayer is created at the air-liquid interface during the rinse stage. In an alternative embodiment, the surfactant monolayer is created at the air-liquid interface immediately prior to any mechanical extraction, such as, immediately prior to the spin stage. In yet another alternative embodiment, the surfactant monolayer is created at the air-liquid interface during the splash portion of the rinse stage. In still yet another embodiment of the present invention, the surfactant monolayer may be created at the air-liquid interface during the spin stage. In one exemplary embodiment, the surfactant monolayer is created by the addition of a one dose form at any of these stages.

Likewise, the surfactant penetrant may be added at any time during the washing process. In one exemplary embodiment, the surfactant penetrant is added after the surfactant monolayer has been created. In another exemplary embodiment, the surfactant penetrant is contacted with the fabric having a first liquid content during the washing stage. In another exemplary embodiment, the surfactant penetrant is contacted with the fabric having a first liquid content during the rinse stage. In an alternative embodiment, the surfactant penetrant is contacted with the fabric having a first liquid content immediately prior to any mechanical extraction, for example in one exemplary embodiment, immediately prior to the spin stage. In yet another alternative embodiment, the surfactant penetrant is contacted with the fabric having a first liquid content during the splash portion of the rinse stage. The surfactant penetrant may be added in a one dose form at any of these stages.

The penetration of the surfactant monolayer with a surfactant penetrant during any of these stages is believed to result in a reduced second liquid content of the fabric when the mechanical extraction means is applied. As one skilled in the art will appreciate, the surfactant penetrant may be located in the liquid content (i.e., the liquid held interstitially in a fabric weave or structure such as void spaces). In an alternative embodiment, the surfactant penetrant is applied onto the fabric during one of the stages of the washing process.

The process can further comprise the step of subjecting the fabric to mechanical drying, air-drying, or a combination thereof. As used herein "air drying" includes indoor or outdoor drying, such as line drying. Exemplary mechanical drying means include vacuum drying or heat drying such as that which occurs in commercial or in-home drying machines.

Without being limited by a theory, it is believed that the role of surface tension at the air-liquid interface is a key aspect in the present process. A reduction in the amount of liquid content during the spin cycle of the washing process is believed to correspond to a reduction in drying time of a fabric. It is believed that by decreasing the surface tension of the air-liquid interface, more liquid content can be removed from the fabric while applying the same centrifugal force in the spin cycles of washing process.

The liquid content is directly proportional to the surface tension at the air-liquid interface of the wash liquor. For traditional surfactant systems, as the concentration of the surfactant is increased, the surface tension at the air-liquid interface is lowered until the solution critical micelle concentration (CMC) is reached. After the CMC is reached, the surface tension at the air-liquid interface typically remains constant. While not intending to be bound by theory, the liquid content should follow this trend (i.e., lower until CMC is reached and then remain constant after the CMC of the surfactant is reached) since it is believed that liquid content typically decreases as surface tension decreases.

As noted above, once the CMC is reached, the surface tension at the air-liquid interface typically remains constant. The lowest equilibrium air-liquid surface tension achieved with fluorosurfactants and/or siloxane surfactants is approximately 15-20 mN/m. For other common typical surfactants, the air-liquid surface tension is higher, typically above 20 mN/m. The present invention comprises a process of extracting liquid from a fabric by creating a surface tension at the air-liquid interface significantly lower than that of these common typical surfactants. Without being limited by theory, it is believed that a decrease in surface tension of the air-liquid interface is achieved by creating a surfactant monolayer and then penetrating the monolayer with a surfactant penetrant.

As used herein a "monolayer" is a one molecule thick adsorbed layer of surfactant at an interface. In the case of a monolayer adsorbed at an air-liquid interface, the surface tension can be significantly altered. In the present invention, the monolayer is at the air-liquid interface of the liquid content.

5 In one exemplary embodiment, the surfactant monolayer is created by dissolving a surfactant in solvent and then spreading the dissolved surfactant over the air-liquid interface of the liquid content. The solvent then evaporates and the surfactant reaches an equilibrium and forms the monolayer (Fig. 1A). As noted by S.Y. Shaiio et al., Advances in Colloid and Interface Science 74 (1998) 1-29, the addition of a surfactant with mismatched chain lengths to a surfactant
10 monolayer, can result in the excess hydrocarbon tails disrupting the molecular packing and creating a supersaturation period which can lead to lower interaction energies and a resulting decrease in surface tension (Fig 1B). As the air-liquid interface equilibrates (Fig 1C), the surface tension increases. Without being limited to a theory, it is believed that due to the surface activity of the surfactants, the air-liquid interface can become super saturated and then equilibrate.

15 In one exemplary embodiment of the present invention, the surface tension of the air-liquid interface is decreased after the surfactant penetrant penetrates the monolayer for a period of time ranging from about 10 seconds to about 3,000 seconds. In an alternative embodiment, the surface tension is decreased by the present process for a period of time comprising at least 300 seconds, alternatively for a period of time comprising at least 900 seconds. In yet another
20 alternative embodiment, the surface tension is decreased for a period of time comprising at least 1,000 seconds.

Surfactant Monolayer

In one embodiment, the surfactant monolayer and surfactant penetrant used in the process of the present invention are capable of reducing the surface tension of the liquid content to a range
25 of from about 20 mN/m to about 1 mN/m; in an alternative embodiment, from about 10 mN/m to about 1mN/m, and in a further exemplary embodiment, from about 5 mN/m to about 1mN/m. Without being limited by theory, it is believed that the reduction in surface tension of the liquid content trapped by capillary forces interstitially in the fabric weave or in void spaces (i.e., liquid content), results in larger volumes of the liquid content being removed from the fabric by the
30 same amount of mechanical extraction. Unlike prior techniques for reducing residual water in fabric, the surfactant monolayer and surfactant penetrant are not required to be deposited or attached to the fabric surface or fiber after the rinse cycle. Therefore, the surfactant monolayer and surfactant penetrant of the present invention encompass benefit agents that are not required to modify the surface properties of the fabric, but rather modify the properties of the liquid in the

fabric fibers (i.e., liquid content). In one exemplary embodiment, the surfactant monolayer and surfactant penetrant do not result in excessive foaming as they are added during the washing process and the fabric does not need to be further contacted with additional liquid to eliminate any foaming that results there from.

5 In one embodiment, selection of a surfactant monolayer optimizes surface tension reduction with the least amount of material added into the laundry process under common consumer conditions. While not being limited to a theory, it is believed that a mixed monolayer may form tighter packing in the monolayer due to electrostatic interactions between headgroups. In one exemplary embodiment, the surfactant monomer is sufficiently dispersible in the
10 predetermined volume of liquid in the washing stage or the rinse stage so that an effective amount of surfactant monolayer is created throughout a consumer bundle of fabric.

In one exemplary embodiment of the present invention, the surfactant monolayer and the surfactant penetrant are oppositely charged. While not be limited to a theory, it is believed that the opposite charges result in tighter packing which leads to lower surface tension at the air-liquid
15 interface.

Surfactants – Exemplary surfactant monolayer and surfactant penetrant components according to the present invention may comprise a surfactant or surfactant system comprising one or more surfactants selected from nonionic, anionic, cationic, ampholytic, zwitterionic, and/or semi-polar nonionic surfactants, other adjuncts such as alkyl alcohols, or mixtures thereof. Non-
20 limiting examples of anionic surfactants include, mid-chain branched alkyl sulfates, modified linear alkyl benzene sulfonates, alkylbenzene sulfonates, linear and branched chain alkyl sulfates, linear and branched chain alkyl alkoxy sulfates, and fatty carboxylates. Non-limiting examples of nonionic surfactants include alkyl ethoxylates, alkylphenol ethoxylates, and alkyl glycosides. Other suitable surfactants include amine oxides, quaternary ammonium surfactants, and
25 amidoamines.

Anionic Surfactants

Nonlimiting examples of anionic surfactants useful herein include: C₈-C₁₈ alkyl benzene sulfonates (LAS); C₈-C₂₂ primary, branched-chain and random alkyl sulfates (AS); C₈-C₂₂ secondary (2,3) alkyl sulfates; C₈-C₂₂ alkyl alkoxy sulfates (AE_xS) wherein x is from 1-30; C₈-C₂₂
30 alkyl alkoxy carboxylates comprising 1-5 ethoxy units; mid-chain branched alkyl sulfates as discussed in US 6,020,303 and US 6,060,443; mid-chain branched alkyl alkoxy sulfates as discussed in US 6,008,181 and US 6,020,303; modified alkylbenzene sulfonate (MLAS) as discussed in WO 99/05243, WO 99/05242 and WO 99/05244; methyl ester sulfonate (MES); and alpha-olefin sulfonate (AOS).

One exemplary anionic surfactant is sodium tetradecyl sulfate ($C_{14}SO_4$).

Nonionic Surfactants

Non-limiting examples of nonionic surfactants include: C_8 - C_{22} alkyl ethoxylates, such as, NEODOL[®] nonionic surfactants from Shell; C_6 - C_{12} alkyl phenol alkoxylates wherein the
5 alkoxylate units are a mixture of ethyleneoxy and propyleneoxy units; C_8 - C_{22} alcohol and C_6 - C_{12} alkyl phenol condensates with ethylene oxide/propylene oxide block alkyl polyamine ethoxylates such as PLURONIC[®] from BASF; C_{14} - C_{22} mid-chain branched alcohols, BA, as discussed in US 6,150,322; C_{14} - C_{22} mid-chain branched alkyl alkoxylates, BAE_x, wherein x 1-30, as discussed in
10 US 6,153,577, US 6,020,303 and US 6,093,856; Alkylpolysaccharides as discussed in U.S. 4,565,647 Llenado, issued January 26, 1986; specifically alkylpolyglycosides as discussed in US 4,483,780 and US 4,483,779; Polyhydroxy fatty acid amides (GS-base) as discussed in US 5,332,528; and ether capped poly(oxyalkylated) alcohol surfactants as discussed in US 6,482,994 and WO 01/42408.

Cationic Surfactants

15 Non-limiting examples of cationic surfactants include: the quaternary ammonium surfactants, which can have up to 26 carbon atoms include: alkoxylate quaternary ammonium (AQA) surfactants as discussed in US 6,136,769; dimethyl hydroxyethyl quaternary ammonium as discussed in 6,004,922; polyamine cationic surfactants as discussed in WO 98/35002, WO 98/35003, WO 98/35004, WO 98/35005, and WO 98/35006; cationic ester surfactants as
20 discussed in US Patents Nos 4,228,042, 4,239,660 4,260,529 and US 6,022,844; and amino surfactants as discussed in US 6,221,825 and WO 00/47708, specifically amido propyldimethyl amine (APA).

Adjunct Materials

25 The surfactant penetrant may further include adjuncts materials to deliver further benefits other than fast drying of the fabrics. The precise nature of these additional components, and levels of incorporation thereof, will depend on the physical form of the surfactant penetrant and the nature for which it is to be used. Suitable adjunct materials include, but are not limited to, chelating agents, dye transfer inhibiting agents, dispersants, enzymes, and enzyme stabilizers,
30 brighteners, suds suppressors, dyes, perfumes, structure elasticizing agents, fabric softeners, anti-abrasion agents, carriers, hydrotropes, processing aids and/or pigments, and other fabric care agents. In addition to the disclosure below, suitable examples of such other adjuncts and levels of use are found in U.S. Patent Nos. 5,576,282, 6,306,812 B1 and 6,326,348 B1.

Surface Tension Adjuncts

It may be desired in the present invention to use surface tension adjuncts which assist in achieving the desired results of the present invention and aid in the performance of the surfactant monolayer and surfactant penetrant system. Without being limited by a theory, such adjuncts can improve the packing of the surfactant penetrant with the surfactant monolayer at the desired interface (e.g., water/air).

Suds Suppressors

It may be desired in the present invention to use suds suppressors to prevent excess foaming. As used herein "excess foaming" refers to the formation of visible foams on clothes at the end of rinse, or the resulted foam (suds) hindering the spinning action of the washer drum, an phenomenon referred as "suds locking". A wide variety of materials may be used as suds suppressors, and suds suppressors are well known to those skilled in the art. See, for example, Kirk Othmer Encyclopedia of Chemical Technology, Third Edition, Volume 7, pages 430-447 (John Wiley & Sons, Inc., 1979). The present invention may also contain non-surfactant suds suppressors. These include, for example: high molecular weight hydrocarbons, N-alkylated amino triazines, monostearyl phosphates, silicone suds suppressors, secondary alcohols (e.g., 2-alkyl alkanols) and mixtures of such alcohols with silicone oils. Hydrocarbon suds suppressors are described, for example, in U.S. Pat. No. 4,265,779, issued May 5, 1981 to Gandolfo et al. Silicone suds suppressors are well known in the art and are, for example, disclosed in U.S. Pat. No. 4,265,779, issued May 5, 1981 to Gandolfo et al and EP 354 016. Mixtures of alcohols and silicone oils are described in U.S. Pat. Nos. 4,798,679, 4,075,118 and EP 150,872. Additional examples of all of the aforementioned suds suppressors may be found in WO00/27958.

In one exemplary embodiment of the present invention, the surfactant monolayer comprises a single surfactant. Exemplary surfactants include hexadecyl trimethyl ammonium bromide ($C_{16}TAB$); didodecyldimethylammonium bromide (DDAB); and dioctyldecyldimethylammonium bromide (DODAB). In another embodiment of the present invention, the surfactant monolayer comprises a mixed surfactant system. Exemplary mixed surfactant monolayers comprise sodium tetradecyl sulfate ($C_{14}SO_4$) with DODAB. In one exemplary embodiment of the present invention, the mixed surfactant monolayer comprises a molecular ratio of the $C_{14}SO_4$:DODAB in the monolayer ranging from about 1:10 to about 10:1. In an alternative embodiment, the molecular ratio of the $C_{14}SO_4$:DODAB in the monolayer ranges from about 1:10 to about 1:3. One specific exemplary molecular ratio of $C_{14}SO_4$:DODAB in the monolayer is about 1:5.

In another embodiment of the present invention, the surfactant penetrant comprises an anionic surfactant. One exemplary anionic surfactant penetrant is sodium tetradecyl sulfate

(C₁₄SO₄). In one exemplary embodiment, the surfactant penetrant comprises a concentration of from about 0.1 mM to about 50 mM C₁₄SO₄; alternatively, the concentration of the surfactant penetrant (C₁₄SO₄) is about 4mM.

5 In one embodiment of the present invention, the amount of surfactant penetrant delivered is from about 0.1 mmol to about 5 mmol for each m² of the total liquid surface area in the fabric; alternatively, the amount of the surfactant penetrant delivered is about 3.3 mmol for each m² of the total liquid surface area in the fabric.

10 In one exemplary embodiment, the surfactant monolayer component(s) are dissolved into one or more solvents. As one skilled in the art will appreciate, any compatible solvents may be utilized in the present invention which allows the surfactant monolayer to be created on the air-liquid interface of the liquid in the fabric. Exemplary solvents include: ethanol, isopropanol, methanol, chloroform, hexane. It is understood that the use of any of these solvents may be limited by compatibility with the device and conditions of the application.

15 In one exemplary embodiment, in a washing machine system, the surfactant penetrant may be present in a laundry detergent, a fabric softener or it can be added as part of the one of the washing stages, such as the rinse or spin stage. In one exemplary embodiment, the surfactant monolayer is sprayed or otherwise delivered onto the fabrics during the spin stage allowing a surfactant monolayer to be created on the air-liquid interface of the liquid content. In another exemplary embodiment, the surfactant monolayer is created during the spin stage.

As will be appreciated by one skilled in the art, the present invention can be useful for removing liquid from surfaces other than fabrics, such as in oil recovery and in drying surfaces of semiconductors, ceramics, metals, glasses, plastics, silicon wafers and laser disks. One exemplary embodiment of the present invention comprises a method of removing liquid from a surface having a first amount of liquid. The method comprises: creating a surfactant monolayer at an air-liquid interface of the liquid on the surface, wherein the surfactant monolayer has a first surface tension and is free of fluorosurfactants or silicone surfactants; penetrating the surfactant monolayer with a surfactant penetrant free of fluorosurfactants or silicone surfactants to reduce the first surface tension at the air-liquid interface for a period of time; and subjecting the surface to mechanical extraction during the period of time to reduce the first amount of liquid to a second amount of liquid.

Another exemplary embodiment of the present invention is a process of reducing the surface tension of a liquid. The process comprises: creating a surfactant monolayer at an air-liquid interface of the liquid, wherein the surfactant monolayer has a first surface tension and is free of fluorosurfactants or silicone surfactants; and penetrating the surfactant monolayer with a

surfactant penetrant free of fluorosurfactants or silicone surfactants to reduce the first surface tension from about 1 mN/m to about 17.5 mN/m at the air-liquid interface for a period of time.

Examples

The following examples demonstrate aspects of the invention.

5 Test Methods

The surface tension measurements of the present invention are made using the Wilhelmy Plate method. The output from a gram-force sensor holding the plate is sent to a transducer and then output to a voltage readout. The system calibrates using two known solutions (water at 72.5 mN/m and acetone at 23 mN/m). The platinum plate is heated using a torch between each reading
10 to clean off any surface impurities. To measure residual moisture content (RMC), a fabric sample is first weighed while dry; and then the fabric sample is soaked for ten minutes in solution and centrifuged for ten minutes. The centrifuge tube has a copper insert. The copper insert has one closed end and one flared end to prevent it from falling into the centrifuge tube. The copper insert has 3/16 inch holes through it to allow water to drain through the insert into the collection tube.
15 After centrifuging the fabric, the weight is taken to determine the Residual Moisture Content (RMC). The surface tension measurements of monolayer penetration are made using the same the Wilhelmy Plate method above, with the exception of collecting the voltage output using a data acquisition card available from DATAQ Instruments, which allows measuring and recording surface tension as a function of time (approximately 40 times per second).

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Example 1

In this experiment, sodium tetradecyl sulfate ($C_{14}SO_4$) penetrates into a solution of hexadecyl trimethyl ammonium bromide ($C_{16}TAB$). A solution of 3.68 mM hexadecyl trimethyl ammonium bromide ($C_{16}TAB$) is prepared. Using 10 mL of the $C_{16}TAB$ solution, different
25 amounts (250 μ L, 500 μ L, 750 μ L and 1000 μ L) of 4 mM $C_{14}SO_4$ are injected beneath the air-liquid interface of the $C_{16}TAB$ solution and the surface tension is measured (approximately 40 times per seconds) as a function of time as set forth in Figure 2. The lowest surface tension achieved is $\sim$ 20 mN/m. While not limited by a theory, it is believed that since the $C_{16}TAB$ is in bulk solution and not a monolayer, any $C_{14}SO_4$ injected into the system immediately interacts with
30 the bulk surfactant instead of partitioning the air-liquid interface.

Example 2

In this experiment, a C_{16} TAB monolayer is created on distilled water and increasing amounts of $C_{14}SO_4$ are injected beneath the monolayer and the surface tension is measured (approximately 40 times per second) as a function of time.

The monolayer is created by first solubilizing 0.1 wt% of C_{16} TAB in a mixture of 3:1:1 volume ratio of hexane to chloroform to methanol. Five μL of the resulting solution is placed on the surface of 5mL of distilled water. The solvent (hexane, chloroform and methanol) is allowed to evaporate, thus leaving a C_{16} TAB monolayer. Increasing amounts (250 μL , 500 μL , 750 μL and 1000 μL) of 4mM $C_{14}SO_4$ are injected beneath the monolayer and the surface tension is measured as a function of time as set forth in Figure 3. A transient low surface tension of 17.5 mN/m is achieved for about 20 seconds using 750 μL of 4 mM $C_{14}SO_4$.

While not limited by a theory, it is believed that once the $C_{14}SO_4$ is injected into the solution, supersaturation of the surface with both C_{16} TAB and $C_{14}SO_4$ causes the surface tension to decrease. Then as the solution equilibrates, the surface tension increases.

Additional surfactant monolayers are also investigated. Figure 4 sets forth the surface tension for $C_{14}SO_4$ penetrating a monolayer of arachidyl alcohol ($C_{20}OH$); Figure 5 sets forth the surface tension for $C_{14}SO_4$ penetrating a cholesterol monolayer; Figure 6 sets forth the surface tension for $C_{14}SO_4$ penetrating a monolayer of didodecyldimethylammonium bromide monolayer (DDAB); and Figure 7 sets forth the surface tension for $C_{14}SO_4$ penetrating a monolayer of dioctyldecyldimethylammonium bromide (DODAB). Figure 8 sets forth the surface tension for tetradecyltrimethyl ammonium bromide (C_{14} TAB) penetrating into a stearic acid monolayer. As shown in these studies, the lowest surface tension occurs with charged surfactants that are essentially insoluble in water. In systems where the monolayer is slightly soluble, the surfactant leaves the air-liquid interface and the surface tension increases. When the monolayer is insoluble, the surfactant stays at the air-liquid interface and attracts the oppositely charged penetrating surfactant and causes a large change in the surface tension (~ 13.5 mN for the $C_{14}SO_4$ & DODAB system).

Example 3

In this experiment, mixed surfactant monolayers are demonstrated and the packing due to electrostatic interactions between the headgroups of the surfactants is observed. A tetradecyl sodium sulfate ($C_{14}SO_4$) with dioctyldecyldimethylammonium bromide (DODAB) is employed. Molecular ratios of 1:10, 1:5, 1:3, and 1:2 of the $C_{14}SO_4$:DODAB monolayers are investigated. The procedures for preparing the monolayers are similar to those described in Example 2.

Figure 9 sets forth the results for the 1:10 molecular ratio of $C_{14}SO_4$:DODAB monolayer injected with $C_{14}SO_4$. As shown, the 1:10 molecular ratio of $C_{14}SO_4$:DODAB monolayer system results in a surface tension as low as 19 mN/m. Figure 10 sets forth the results for the 1:5 molecular ratio of $C_{14}SO_4$:DODAB monolayer injected with $C_{14}SO_4$. As shown, in the 1:5 molecular ratio of $C_{14}SO_4$:DODAB monolayer, the surface tension drops to approximately 8.5 mN/m with 1000 μ L of $C_{14}SO_4$ injected beneath the monolayer.

Tight packing for the $C_{14}SO_4$:DODAB monolayer occurs at a 1:3 molecular ratio. Figure 11 sets forth the results for the 1:3 molecular ratio of $C_{14}SO_4$:DODAB monolayer injected with $C_{14}SO_4$. As shown, the minimal surface tension for the 1:3 molecular ratio $C_{14}SO_4$:DODAB system is not as low as the 1:5 molecular ratio $C_{14}SO_4$:DODAB. While not being limited by theory, it is believed that this is due to the molecular packing trying to achieve the 1:3 molecular ratio. At a lower ratio of $C_{14}SO_4$:DODAB (the 1:5 system) there is somewhat tight packing. This packing can be optimized by the addition of more $C_{14}SO_4$ beneath the monolayer. The addition of the 4 mM $C_{14}SO_4$ results in what is believed to be a 1:3 molecular ratio of $C_{14}SO_4$:DODAB in the monolayer after the addition of the $C_{14}SO_4$ beneath the monolayer. However, when the monolayer is already at its tightest packing at a 1:3 molecular ratio of $C_{14}SO_4$:DODAB, it is believed that there is not sufficient room for more $C_{14}SO_4$ to penetrate the monolayer resulting in a higher surface tension than the 1:5 molecular ratio systems. As shown in Figure 12, when higher ratios (1:2) of $C_{14}SO_4$:DODAB is tested, there is no monolayer present after spreading the universal solvent. Since the $C_{14}SO_4$ is soluble in water, once the monolayer is spread on the distilled water, it is solubilized into solution due to the increased amount of $C_{14}SO_4$ which results in a higher surface tension (approximately the surface tension of water) that reduces with the addition of $C_{14}SO_4$.

Example 4

In this experiment, the 1:5 molecular ratio of $C_{14}SO_4$:DODAB monolayer from Experiment Three is further investigated. Using a 1:5 molecular ratio of $C_{14}SO_4$:DODAB monolayer with 1000 μ L of 4mM $C_{14}SO_4$ as the surfactant penetrant, penetration experiments are performed for longer time periods with five repetitions as set forth in Figure 13. A minimum surface tension of ~8.5 mN/m is achieved for time periods of over 700 seconds (~12 minutes).

All documents cited are, in relevant part, incorporated herein by reference; the citation of any document is not to be construed as an admission that it is prior art with respect to the present invention.

While particular embodiments of the present invention have been illustrated and described, it would be obvious to those skilled in the art that various other changes and modifications can be made without departing from the spirit and scope of the invention. It is therefore intended to cover in the appended claims all such changes and modifications that are

5 within the scope of this invention.

What is claimed is:

1. A process of extracting liquid from a fabric having a first content of liquid, comprising:
creating a surfactant monolayer at an air-liquid interface of the liquid in the fabric,
wherein the surfactant monolayer has a first surface tension;
penetrating the surfactant monolayer with a surfactant penetrant to reduce the surface
tension at the air-liquid interface for a period of time;
subjecting the fabric to mechanical extraction during the period of time to reduce the
liquid content of the fabric to a second liquid content.
2. The process of claim 1, wherein the surfactant monolayer comprises a surfactant selected
from the group consisting of: anionic surfactants, cationic surfactants, nonionic surfactants and
combinations thereof.
3. The process of claim 1, wherein the surfactant monolayer comprises hexadecyl trimethyl
ammonium bromide.
4. The process of claim 1, wherein the surfactant penetrant comprises a surfactant selected
from the group consisting of: anionic surfactants, cationic surfactants, nonionic surfactants and
combinations thereof.
5. The process of claim 1, wherein the surfactant penetrant comprises sodium tetradecyl
sulfate.
6. The process of claim 5, wherein the surfactant penetrant is delivered through a solution
which has a concentration of from about 0.1mM to about 50mM sodium tetradecyl sulfate, and
the amount of the surfactant penetrant delivered is from about 0.1 mmol to about 5 mmol for each
m² of the total liquid surface area in the fabric.
7. The process of claim 5, wherein the surfactant penetrant is delivered through a solution
which has a concentration of about 4mM sodium tetradecyl sulfate, and the amount of the
surfactant penetrant delivered is about 3.3 mmol for each m² of the total liquid surface area in the
fabric.

8. The process of claim 1, wherein the surfactant monolayer comprises dioctyldecyldimethylammonium bromide and sodium tetradecyl sulfate.
9. The process of claim 8, wherein the molecular ratio of the sodium tetradecyl sulfate to the dioctyldecyldimethylammonium bromide in the surfactant monolayer ranges from about 1:10 to about 1:3.
10. The process of claim 1, wherein the surfactant monolayer is oppositely charged from the surfactant penetrant.
11. The process of claim 1, wherein the surfactant monolayer comprises two or more surfactants.
12. A process of extracting liquid from a fabric having a first content of liquid, comprising:
 - creating a surfactant monolayer at an air-liquid interface of the liquid in the fabric, wherein the surfactant monolayer has a first surface tension;
 - penetrating the surfactant monolayer with a surfactant penetrant to reduce the surface tension at the air-liquid interface for a period of time;
 - subjecting the fabric to mechanical extraction during the period of time to reduce the liquid content of the fabric to a second liquid content;
 - wherein the surfactant monolayer comprises sodium tetradecyl sulfate and dioctyldecyldimethylammonium bromide in a molecular ratio of from about 1:10 to about 1:3; and
 - wherein the surfactant penetrant is delivered through a solution which comprises about 1mM to about 5mM sodium tetradecyl sulfate, and the amount of the surfactant penetrant delivered is from 0.1 mmol to about 5 mmol for each m² of the total liquid surface area in the fabric.
13. A process of removing liquid from a surface having a first amount of liquid, comprising:
 - creating a surfactant monolayer at an air-liquid interface of the liquid on the surface, wherein the surfactant monolayer has a first surface tension and is free of fluorosurfactants or silicone surfactants;

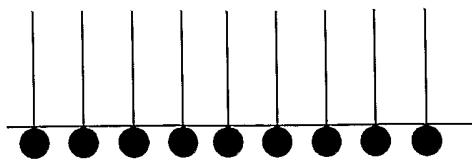
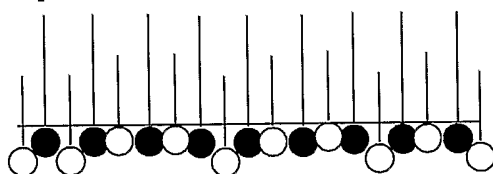
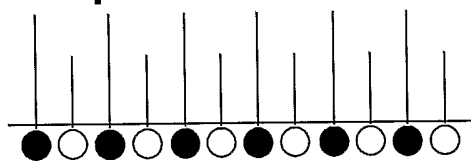
penetrating the surfactant monolayer with a surfactant penetrant free of fluorosurfactants or silicone surfactants to reduce the first surface tension at the air-liquid interface for a period of time; and

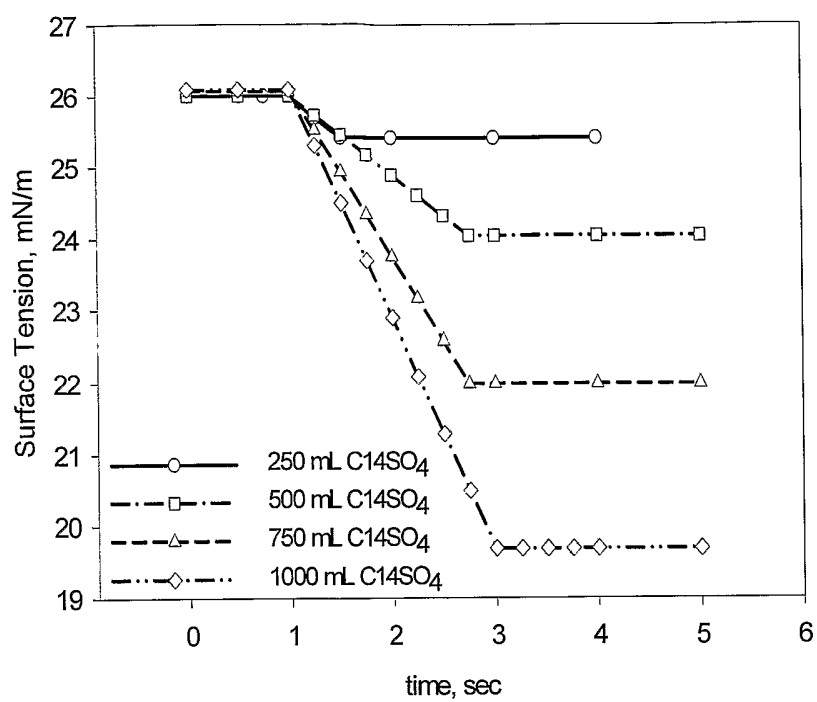
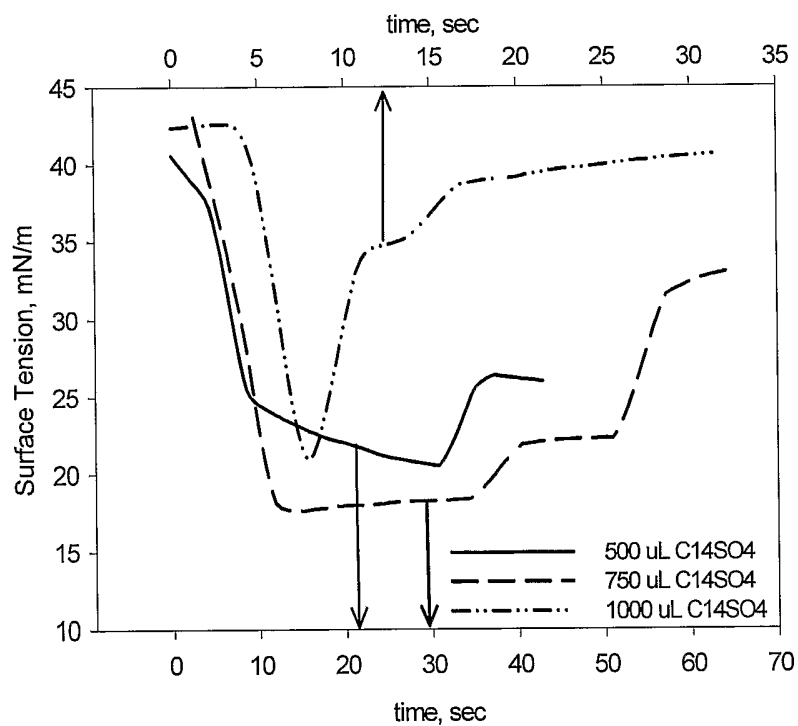
subjecting the surface to mechanical extraction during the period of time to reduce the first amount of liquid to a second amount of liquid.

14. A process of reducing the surface tension of a liquid, comprising:

creating a surfactant monolayer at an air-liquid interface of the liquid, wherein the surfactant monolayer has a first surface tension and is free of fluorosurfactants or silicone surfactants; and

penetrating the surfactant monolayer with a surfactant penetrant free of fluorosurfactants or silicone surfactants to reduce the first surface tension to about 1 mN/m to about 17.5 mN/m at the air-liquid interface for a period of time.

Initial Solution**Figure 1A****Super-saturation of Surface****Figure 1B****Equilibrated Surface****Figure 1C**

**Figure 2****Figure 3**

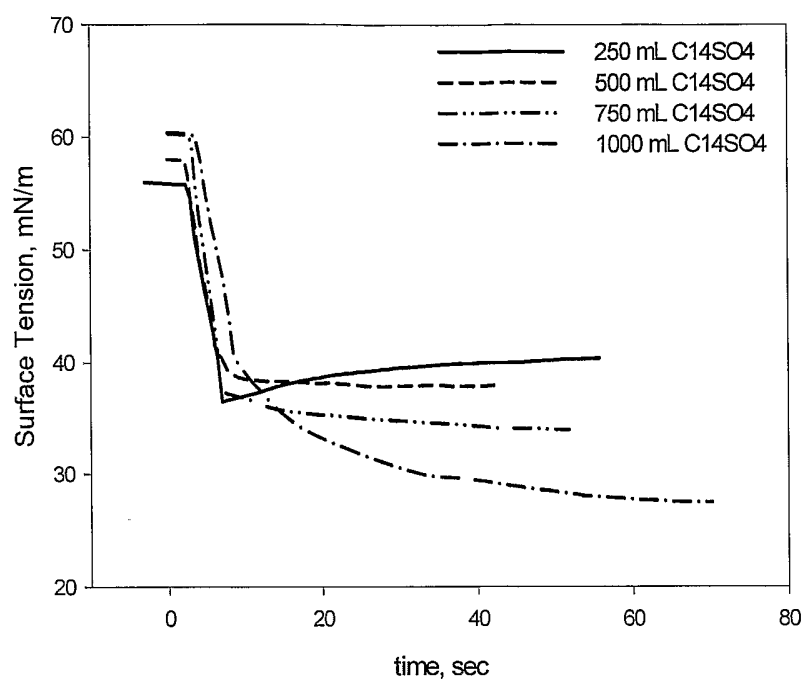


Figure 4

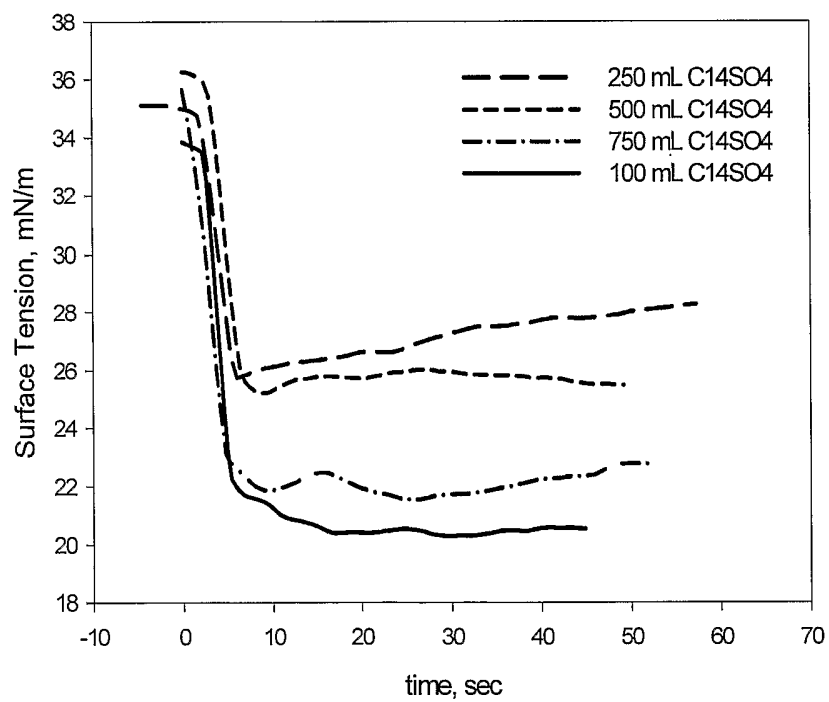


Figure 5

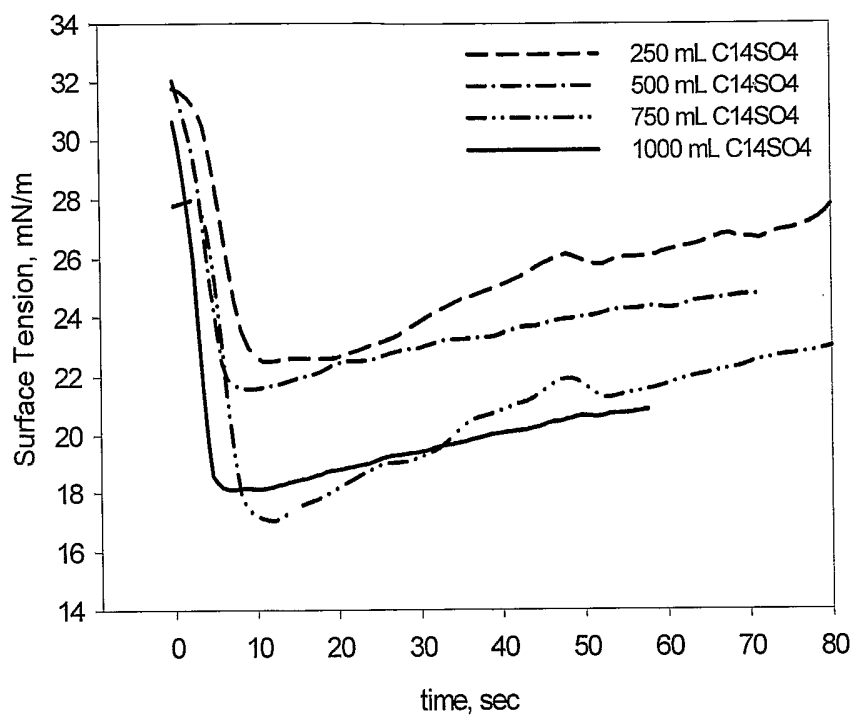


Figure 6

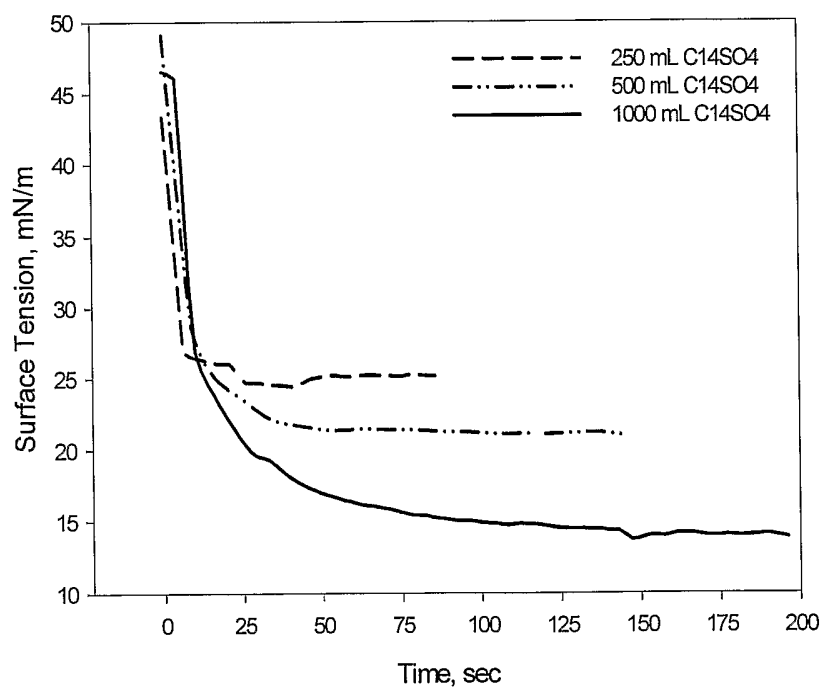
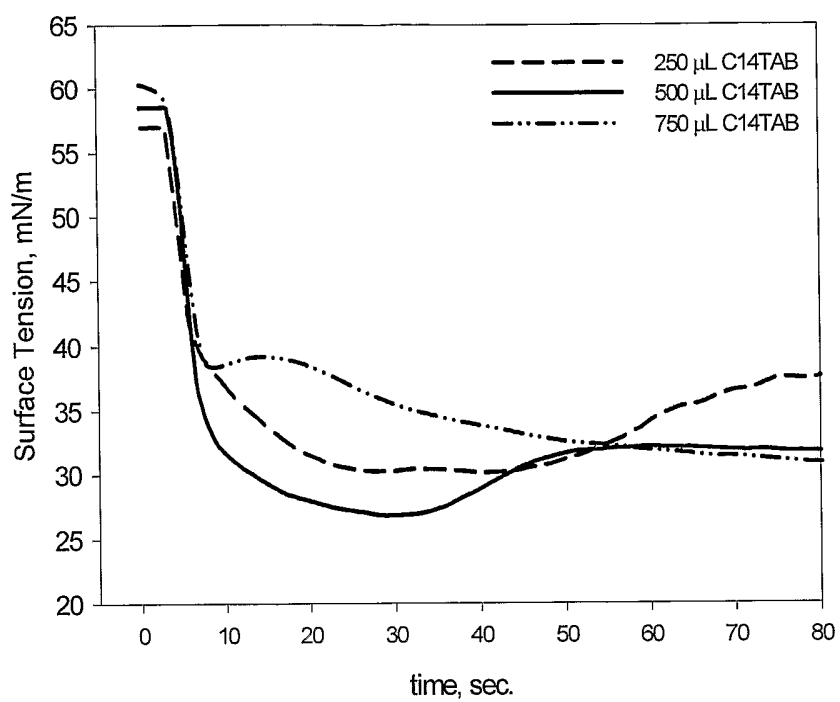
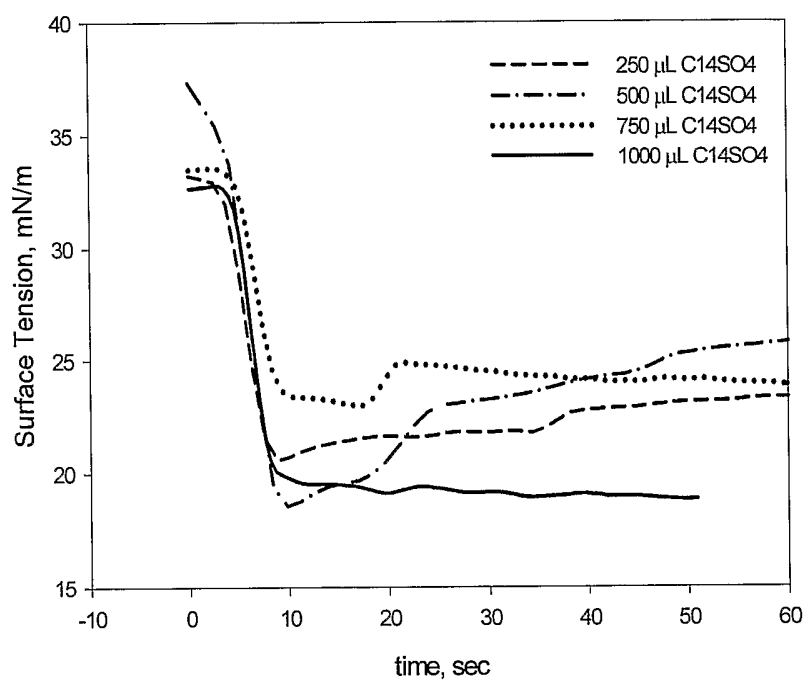
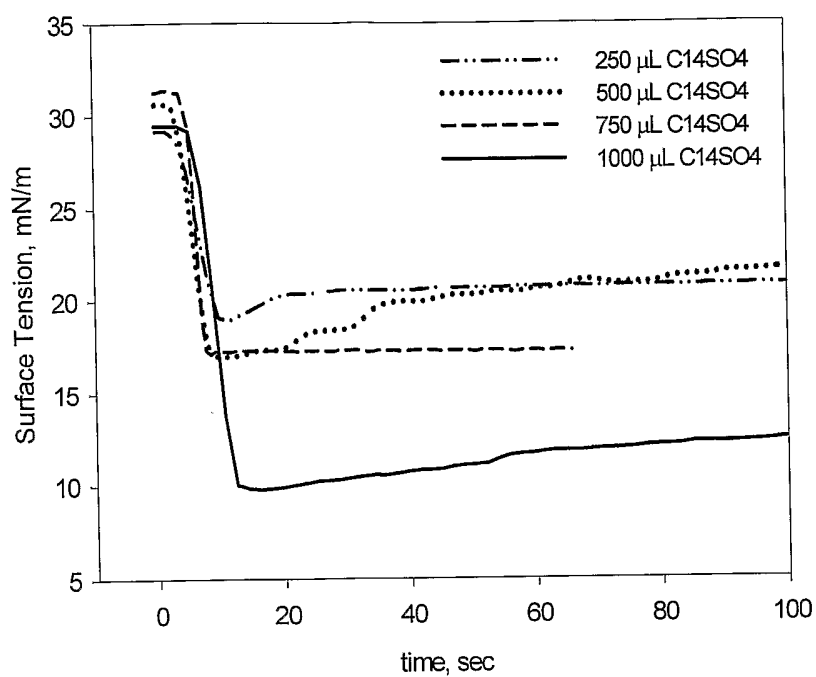
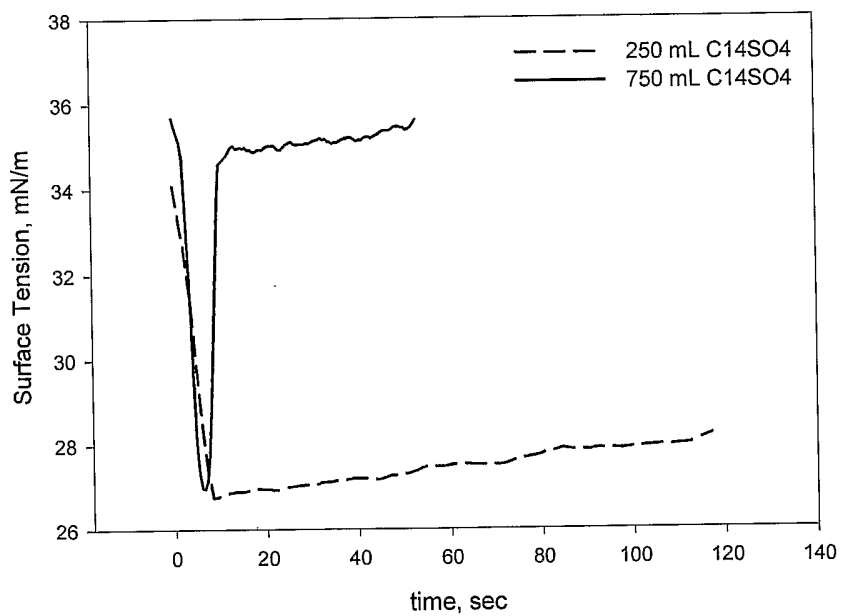
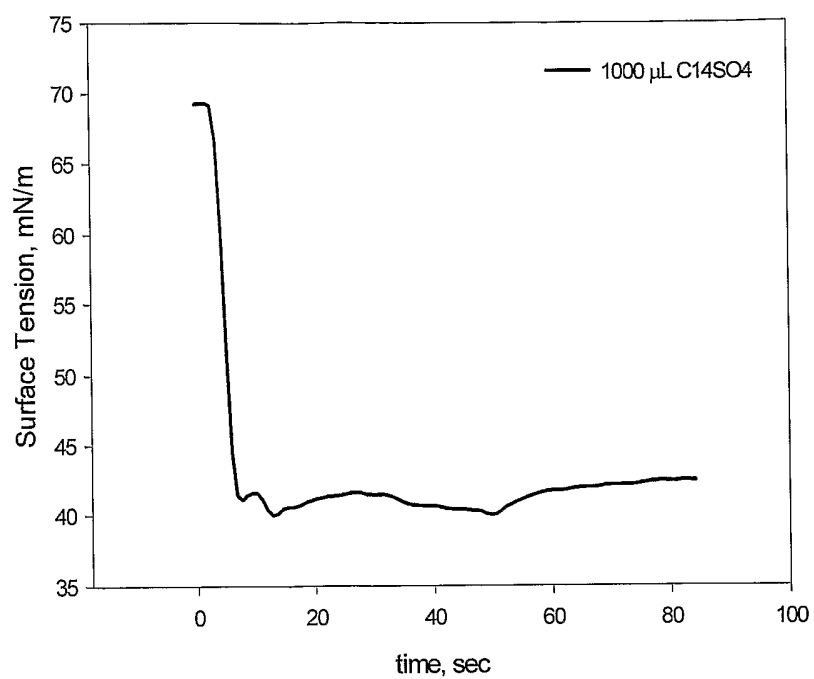
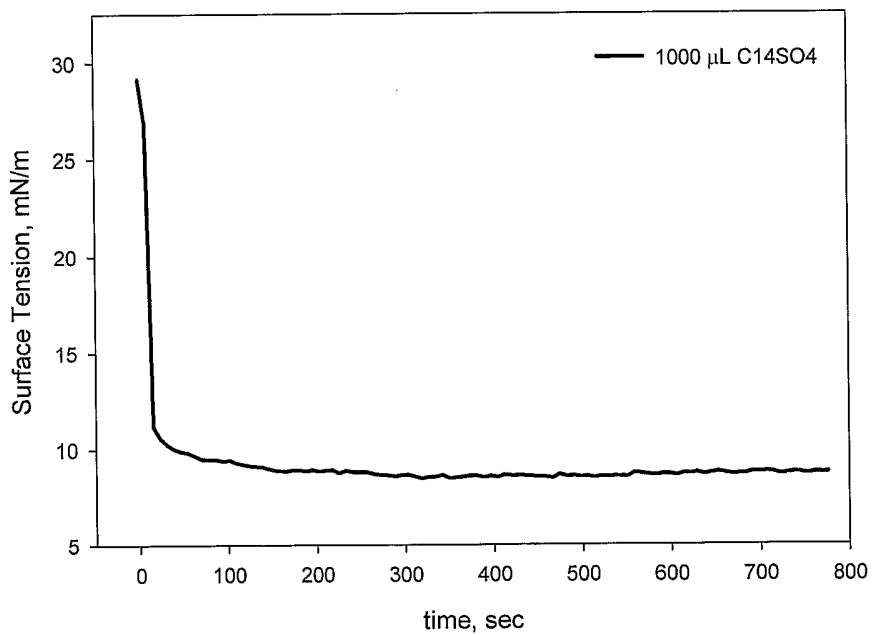


Figure 7

**Figure 8****Figure 9**

**Figure 10****Figure 11**

**Figure 12****Figure 13**