CHAPTER I

I. INTRODUCTION

1.1. Introductory remark:

1.1.1. Surface active agents(1):

The surface active agents (surfactants), literally means active at a surface. In other words, a surfactant is characterized by its tendency to adsorb at surfaces and interfaces.

The term interface denotes a boundary between any two immiscible phases, while the term surface indicates that one of the phases is gas, usually air.

There are five different interfaces exist:

Solid – Vapor, Solid – Liquid, Solid – Solid, Liquid – Vapour and Liquid – Liquid.

The driving force for a surfactant to adsorb at an interface is to lower the free energy of that phase boundary. The interfacial free energy per unit area represents the amount of work required to expand the interface.

The term interfacial tension is often used instead of interfacial free energy per unit area. Thus, the surface tension of water is equivalent to the interfacial free energy per unit area of the boundary between water and the air above it. When that boundary is covered by surfactant molecules, the surface tension (or the amount of work required to expand the interface) is reduced.

The tendency to accumulate at interfaces is a fundamental property of a surfactant. In principle, the stronger the tendency, the better is the surfactant.

The degree of surfactant concentration at a boundary depends on surfactant structure and also on the nature of the two phases that meet at the interface.

Therefore, there is no universally good surfactant suitable for all uses. The choice will depend on the application.

A good surfactant should have low solubility in the bulk phases. Some surfactants are only soluble at the oil-water interface. Such compounds are difficult to handle but are very efficient in reducing the interfacial tension.

There is of course a limit to the surface and interfacial tension lowering effect by the surfactant. In the normal case that limit is reached when micelles start to form in bulk solution.

The many guises of surfactants functional names:

Wetting Agents
Emulsifiers
Demulsifiers
Dispersants
Corrosion Inhibitors
Foam Boosters
Defoamers

Soaps
Detergents
Sanitizers
Tensides
Solubilizers
Antistatic Agents
Plasticizers

1.1.2. Surfactants are Amphiphilic:

The name amphiphile is sometimes used synonymously with surfactant. The word derived from the Greek word amphi, meaning both, and the term relates to the fact that all surfactants molecules consist of at least two parts, one which is soluble in a specific fluid (the Lyophilic part) and one which is insoluble (the Lyophobic part).

When the fluid is water one usually talks about the Hydrophilic and Hydrophobic parts, respectively. The Hydrophilic part is referred to as the head group and the hydrophobic part as the tail, see figure (1).

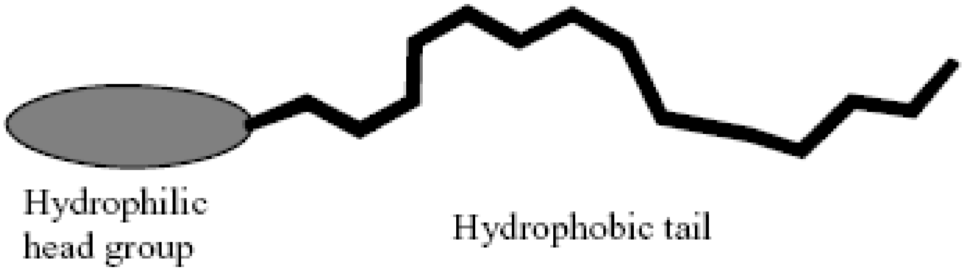


Fig. (1): Schematic illustration of a surfactant

When a surfactant adsorbs from aqueous solution at a hydrophobic surface, it normally orients its hydrophobic group towards the surface and exposes its polar group to the water. The surface has become hydrophilic and as a result the interfacial tension between the surface and water has been reduced.

Adsorption at hydrophilic surfaces often results in more complicated surfactant assemblies.

The hydrophobic part of a surfactant may be branched or linear. The polar head group is usually but not always attached at one end of the alkyl chain. The length of the chain is in the range of 8-18 carbon atoms.

The hydrophobic group is normally hydrocarbon (alkyl or alkylaryl) but may also be polydimethylsiloxane or fluorocarbon. The two latter types of surfactants are particularly effective in non-aqueous systems.

The polar part of the surfactant may be ionic or non-ionic and the choice of polar group determines the properties to a large extent.

A surfactant usually has one polar group. Recently, there has been valuable research in certain dimeric surfactants, containing two hydrophobic tails and two head groups linked together with a short spacer. These species, generally known under the name gemini surfactants, are not yet of commercial importance.

Weakly surface active compounds which accumulate at interfaces but which don't readily form micelles are of interest as additives in many surfactant formulations. They are referred to as hydrotropes. Addition of hydrotropes is a way to prevent the formation of highly viscous liquid crystalline phases which constitutes a well –known problem in surfactant formulation. Xylene sulfonate and cumene sulfonate are typical examples of hydrotropes used.

- Effects of nature of Hydrophobic Group:

a. **Length of hydrophobe:**

Increase in the length of the hydrophoic group leads to:

- Decreases water solubility and increases solubility in organic solvents,
- Increase surface activity

- Causes closer packing of the surfactant tails at an interface,
- Increase sensitivity of surfactant to electrolyte, pH or temperature.

b. Branching and unsaturation:

- Increases solubility in water or organic solvents relative to straight chain
- Causes looser packing at interfaces and inhibits precipitation and liquid crystal formation
- May result in oxidation or colour formation in unsaturated compounds
- May decrease biodegradability for branched chain compounds.

c. Aromatic group:

- Can cause an increase in adsorption on polar surfaces
- Decreases biodegradability relative to a straight chain
- Causes looser packing at interfaces

d. Polyoxypropylene chain:

- Increases adsorption on polar surfaces via the hydrophobe
- Increases solubility in organic solvents.

e. Perfluoroalkyl or Polysiloxene groups:

- Permit lower surface tensions than hydrocarbon surfactants
- Permit better wetting than hydrocarbon surfactant
- Can make surfaces both water repellant and oil repellant.

1.1.3. Classification of surfactants:

The primary classification of surfactants is made on the basis of the charge of the polar head group.

Surfactants divide into the classes Anionics, Cationics, Non-ionics and Zwitterionics surfactant. The latter class contains both an anionic and a cationic charge under normal condition.

An amphoteric surfactant is one that depending on pH can be either cationics, zwitterionics or anionics. Simple aminoacids are well-known examples of amphoteric compounds.

A surfactant that contains a carboxylate group and a quaternary ammonium group is zwitterionics, unless the pH is very low, but is not an amphoteric surfactant.

For the ionic surfactants the choice of counterion plays a role for the physicochemical properties. Most anionic surfactant have Sodium as counterion but other cations, such as Lithium, Potassium, Calcium and protonated amines are used as surfactant counterions for speciality purposes.

The counterion of cationic surfactants is usually a halide or methyl sulfate.

a. Anionic surfactants:

Carboxylate, sulfate, sulfonate and phosphate are the polar groups found in anionic surfactants. Figure (2) shows structures of the more common surfactant types belonging to this class.

Sodium and potassium as a counterions impart water solubility, whereas calcium and magnesium promote oil solubility.

- Important facts about anionic surfactants:

i. They are the largest surfactant class
ii. They are not compatible with cationics
iii. They are sensitive to hard water
iv. A short polyoxypropylene chain between the anionic group and the hydrocarbon improves solubility in organic solvents but may decrease the rate of biodegradation

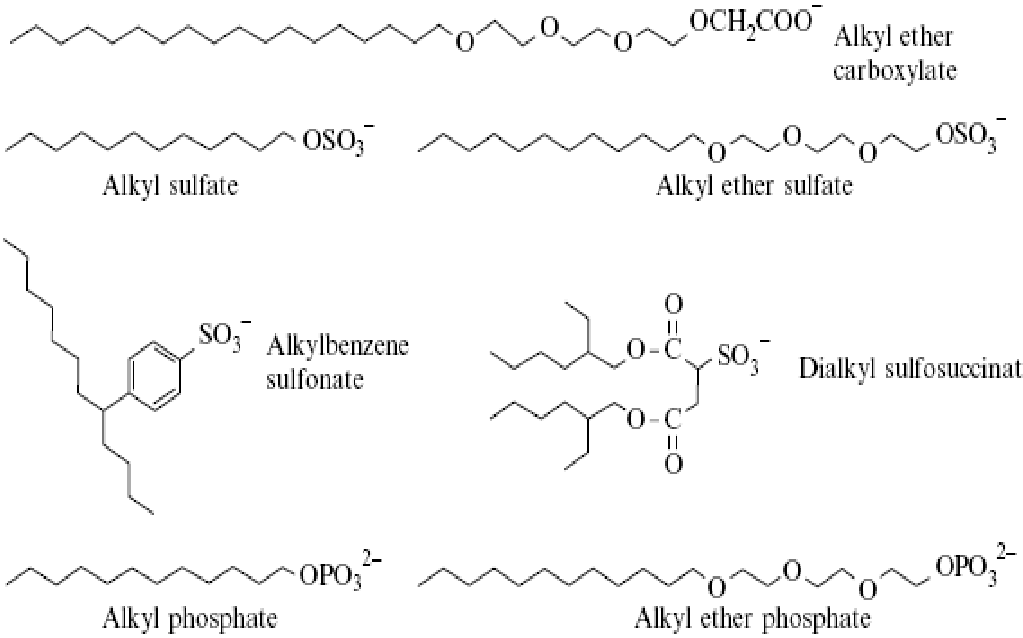


Fig. (2): Structure of some anionic surfactants.

b. Cationic surfactants:

The vast majority of cationic surfactants are based on the nitogen atom carrying the cationic charge. Both amine and quaternary ammonium- based products are common. The amines only function as a surfactant in the protonated state. Therefore, they can't be used at high pH. Quaternary ammonium compounds are not pH sensitive.

Figure (3) shows structures of the more common surfactant types belonging to this class.

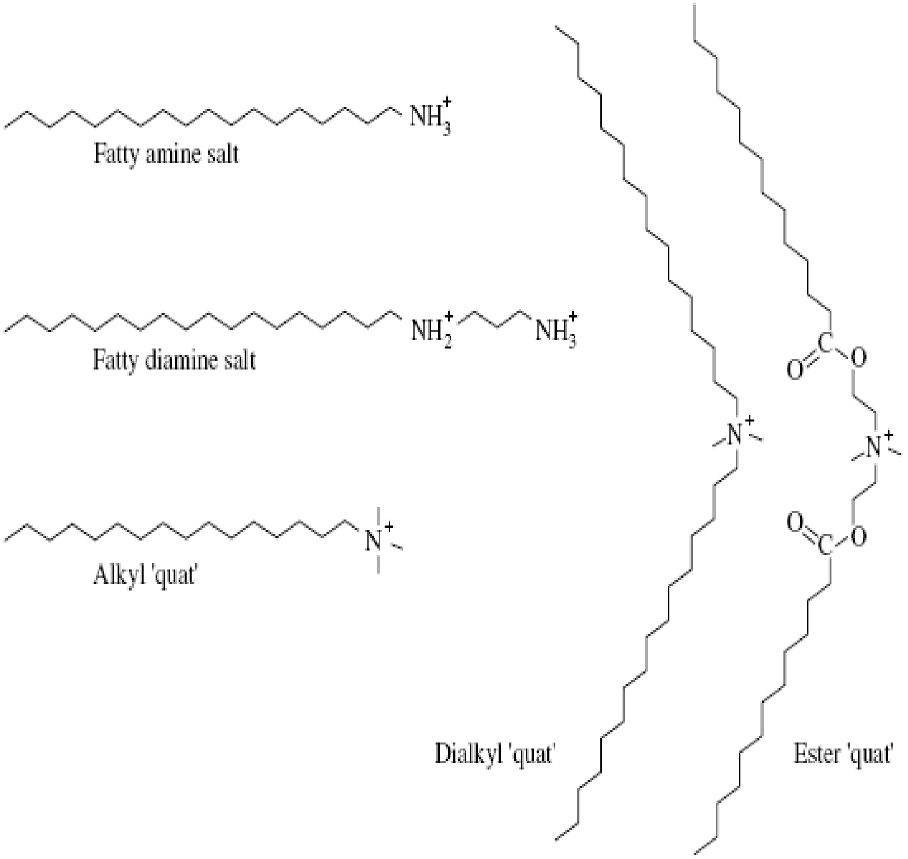


Fig. (3): Structure of some cationic surfactants.

- N-alkyl trimethyl ammonium chlorides are used as emulsifying agents for acidic emulsions or where adsorption of emulsifing agent is desirable (as in insecticide or herbicide formulations).
- Tetra alkyl amonium salts widely used for textile softening.
- Effective Germicides especially the monoalkyls
- Used as hair conditioners and as oral antiseptics as in mouthwashes.

- Important facts about cationic surfactants:

i. They are the third largest surfactant classs
ii. Good compatibility with nonionics and zwitterionics
iii. Poor compatibility with anionics
iv. Adsorbs strongly on most solid surfaces
v. Many are biocides
vi. Generally more expensive than anionics or nonionics
vii. Show poor detergency

The main properties of cationic surfactants are:

1. Biological properties:

One of the most important uses for quaternary ammonium compounds depends on their biological activity(2). Generally, optimum activity of completely aliphatic compound is achieved if the higher aliphatic group contains a normal chain of 16-18 carbon atoms. The bactericidal activity of benzyl quaternary compounds is optimum if the higher aliphatic chain contains 14 carbon atoms. The anion has little influence except on solubility.

The mechanism of the bactericidal action is closely related to the surface activity of the quaternary ammonium compound. Undoubtedly, interaction of the bactericidal agent with the cell wall interferes with the metabolic process of the organism, and this causes the inhibiting or killing action. Results from pharmacological and toxicological studies of certain higher aliphatic quaternary ammonium compounds indicate that these compounds are innocuous in concentrations required for germicidal effectiveness.

In all cases, the biocidal quaternaries are sold as solutions in isopropanol-water or ethanol-water.

2. Toxicity:

Because of their biocidal, algicidal and fungicidal properties, Quaternary ammonium compounds are toxic to some sewage systems(3). However, the organisms in the sewage systems develop so that, unless the quaternary ammonium concentrations are too high, they can biodegradable most compounds.

c. Non ionic surfactants:

Non ionic surfactants have either polyether or polyhydroxyl (polyol-) as the polar group. The polar group is polyether consisting of oxyethylene units, made by polymerization of ethylene oxide. The typical number of oxyethylene units in the polar chain is five to ten. Ethoxylation is usually carried out under alkaline conditions. Any material has an active hydrogen can be ethoxylated.

- Important facts about Non ionic surfactants:

i. They are the second largest surfactant class
ii. Good compatibility with other surfactant types
iii. Soluble in both water and organic solvents
iv. Poor foams and good dispersants
v. Solubility decreases with increasing temperature
vi. Good performance with high electrolyte concentrations.

Figure (4) shows structures of the more common surfactant types belonging to this class.

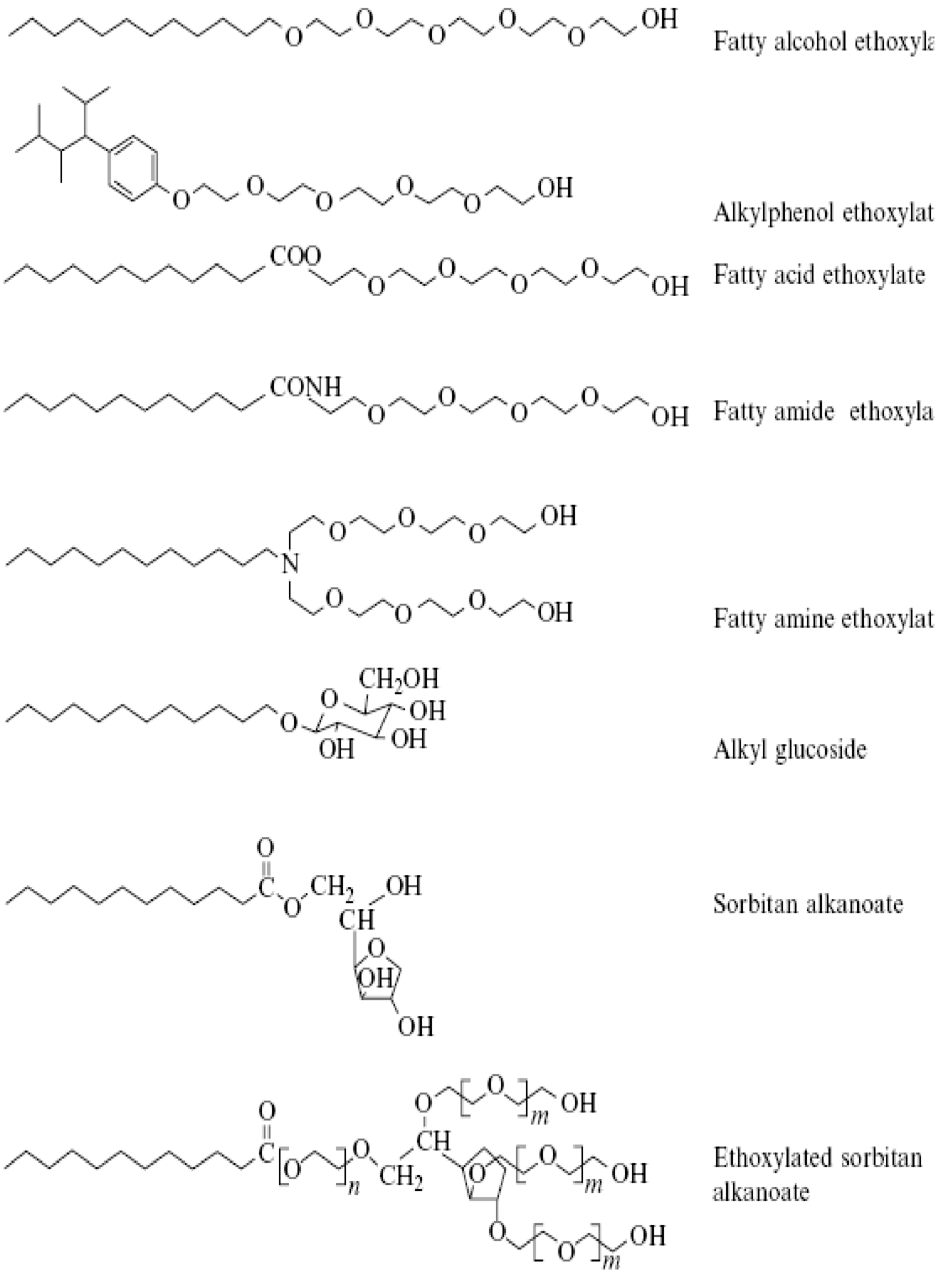


Fig. (4): Structure of some non ionic surfactants.

d. Zwitterionic surfactants:

Zwitterionic surfactants contain two charged groups of different sign. Whereas the positive charge is almost invariably ammonium, the source of negative charge may vary, although carboxylate is by far the most common. Zwitterionics are often referred to as amphoteric, but An amophoteric surfactant is one that changes from net cationic via zwitterionics to net anionic on going from low to high pH. The compound is only zwitterionic over a certain pH range. Zwitterionics exhibit low eye irritation and frequently used in shampoos and other cosmetic products.

- Important facts about Zwitterionic surfactants:

i. They are the smallest surfactant class
ii. They are compatible with all other classes of surfactants
iii. They are generally stable in acids and bases.
iv. Most types show very low eye and skin irritation.

Figure (5) shows structures of some zwitterionic surfactants

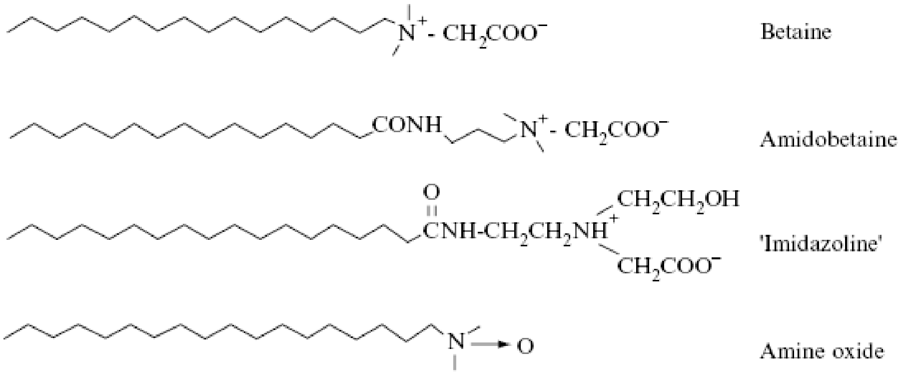


Fig. (5): Structure of some zwitterionic surfactants.

1.2. Adsorption of Surfactants:

Surfactants are characterized by their activity at the different interfaces (air/liquid, liquid/liquid or solid/liquid).

Since, the surface activity depends mainly on the influence of both hydrophobic and hydrophilic moieties towards the environments, solvent, temperature and other conditions of uses, which affect the adsorption of surfactant molecules at various interfaces. The measurements of adsorption at the interfaces are clarifying several variables (4).

1. Surfactant concentrations at the interface since measure how much of the interface has been covered.
2. The orientations of the surfactant molecules at the interface, this determine how the interface will be affected by the adsorption.
3. The energy change in the system ΔG, ΔS and ΔH resulting from adsorption, since these quantities provide information on the type and mechanism of any interaction involving the surfactant at the interface and the efficiency of its operation as surface active agent.

1.2.1. Mechanism of adsorption:

There are several suggestions of adsorption mechanisms as the following

1. Ion exchange, involving replacement of counter ions adsorbed onto the substrate from the solution by similarly charged surfactant ions(5).
2. Ion pairing, adsorption of surfactant ions from the solution onto oppositely charged sites unoccupied by counter ions(6).
3. Hydrogen bonding, adsorption of surfactant molecules at the interface through hydrogen bond formation(7).

4. Adsorption by polarization of Bi-electrons occurred when the surfactant molecules contain Bi-electrons rich moieties as in case of unsaturated hydrocarbons, benzene ring or unsaturated hetero rings(8).

5. Adsorption by dispersion forces occurred via Van-der-waals dispersion forces acting between surfactant molecules and the surface. This type increases by increasing the molecular weight of surfactant molecules(9).

1.2.2. Micelle formation (Micellization):

At sufficiently high concentration in solution, surfactant molecules will nucleate to form aggregates called micelles. The concentration at which this occurs is characteristic of each surfactant and is called critical micelle concentration (CMC)(10-14).

On other words, the CMC is the lowest total surfactant concentration at which micelles are present. There are key factors in micellization like hydrophobic group, hydrophilic moiety, charge-charge repulsion, counter ion binding, steric interactions, dispersion forces and hydrogen bonding. The lower the CMC, the easier the micelle forms(15-19).

Micelles are thermodynamically and geometrically stable phase(20), occurred in the bulk of the solution, which is formed to decrease the polar/nonpolar interaction occurred between the surfactant and aqueous phase molecules.

1.2.3. Characteristics features of CMC:

All of the effects just described help determine the value of the lowest concentrations of surfactants at which micelles can form.

1. The CMC decreases strongly with increasing alkyl chain length of the surfactant. As a general rule the CMC decreases by a factor ca. 2 for ionic surfactants (without added salt) and by a factor of ca. 3 for non-ionic surfactants on adding one methylene group to the alkyl chain. Comparison between different classes of surfactants is best made at a fixed number of carbons in the alkyl chain.

2. The CMCs of non-ionic surfactants are much lower than for ionic surfactants. The relation depends on the alkyl chain length, but two orders of magnitude is a rough starting point.

3. Besides the major difference between ionic surfactants and non-ionic surfactants, the effects of the head group are moderate. Cationics typically have slightly higher CMCs than anionic surfactants. For non-ionic surfactants of the oxyethylene varity, there is moderate increase of the CMC as the polar head becomes larger.

4. Added salts will decrease the CMC of ionic surfactants, but have relatively little effect on nonionic surfactants.

5. The valency of the counterion is significant. While, simple mono valent inorganic counterions give roughly the same CMC, increasing the valency to two gives a reduction of the CMC by roughly a factor of four. Organic counter ions reduce the CMC compared to inorganic ones, the more so the larger the non-polar part.

6. While alkyl chain branching and double bond, aromatic groups or some other polar character in the hydrophobic part reduce produce sizeable changes in the CMC, a dramatic lowering of the CMC (one or

two order of magnitude) result from perfluorination of the alkyl chain. Partial fluorination interestingly may increase the CMC.

1.2.4. Surfactants self-assembly:

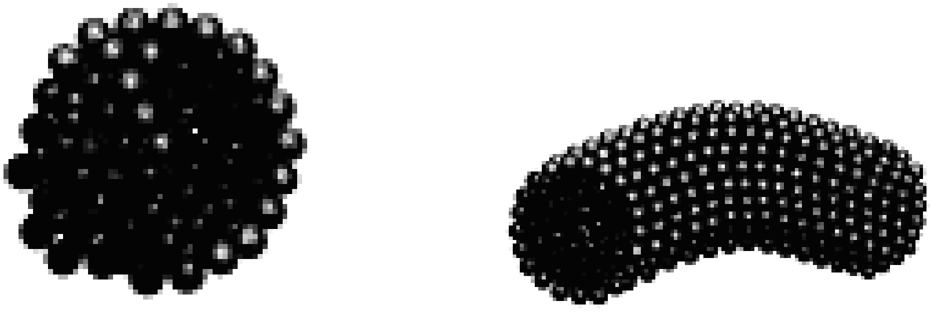
a. Ordered structures of surfactant molecules:

By measuring the different physicochemical properties of aqueous solution of a surfactant or liquid that is enough polar to be water soluble up to relatively high concentrations. At low concentrations, most properties are similar to those of a simple electrolyte. One notable exception is the surface tension which decreases rapidly with surfactant concentration.

At some higher concentrations, which are different for different surfactants, unusual changes are recorded. For example, the surface tension, as also the osmotic pressure, takes on an approximately constant value, while light scattering starts to increase and self diffusion starts to decrease.

All the observations suggest and are consistent with a change-over from a solution containing single molecules or ions, unimers to a situation where the surfactant occurs more and more in a self-assembled or self-associated state.

The concentration for the onset of self-assembly is quite well defined and becomes more so the longer the alkyl chain of the surfactant. The first-formed aggregates are generally approximately spherical in shape. We call the aggregates micelles, and the concentration where they start to form is CMC. An illustration of a micelle's structure is given in fig. (6).



Spherical micelles Cylindrical micelles

Lamellar micelles Reversed or inverted micelles

Vesicles micelles Bi continuous micelles

Fig. (6): An illustration of a micelle's structure

Surfactant self-assembly leads to a range of different structures of which a few are shown:

1. Spherical micelles with an interior composed of the hydrocarbon chains and a surface of the polar head groups (pictured as sphere) facing water. They are characterized by a low surface number (critical packing parameter) and a strongly positive spontaneous curvature. The hydrocarbon core has a radius close to the length of the extended alkyl chain.

2. Cylindrical micelles with an interior composed of the hydrocarbon chains and a surface of the polar head groups facing water. The cross section of the hydrocarbon is similar to that of spherical micelles. The micellar length is highly variable to these micelles are poly disperse.

3. Surfactant bi-layers which build up lamellar liquid crystals have for surfactant-water systems a hydrocarbon core with a thickness of ca. 80% of the length of two extended alkyl chains.

4. Reversed or inverted micelles have a water core surrounded by the surfactant polar head groups, the alkyl chains together with a non-polar solvent make up the continuous medium. Like normal micelles they can grow into cylinders.

5. Bi-continuous structure with the surfactant molecules aggregated into connected film characterized by two curvature of opposite sign. The mean curvature is small (zero for a minimal surface structure).

6. Vesicles are built from bi-layers similar to those of the lamellar phase and are characterized by two distinct water compartments, one

forming the core and one the external medium. Vesicles may have different shapes and there are also reversed- type vesicles(21).

b. Critical Packing Factor (Φ):

$\Phi = V/a_0I_c$	**Aggregate Structure**
< 0.33	Spherical, Ellipsoidal micelles
0.33 – 0.5	Rod –like Micelles
0.5 – 1.0	Vesicles, Bi-layer Structure
1.0	Planar Bi-layers
>1.0	Reverse Micelles

V, Volume occupied by hydrophobic groups in micellar core

a_0, across-sectional are occupied hydrophilic group at the micelle surface

I_c, length of hydrophobic groups.

1.3. Surface Tension:

Surface tension is due to asymmetric cohesive forces at a surface. The surface tension of liquids causes the formation of drops and is related to the attractive forces between molecules, these attractive forces are the source of condensation of vapors into liquids and they originate from dispersion, dipole- dipole and dipole-induced-dipole forces and hydrogen bonding. In the bulk liquid a molecule senses the same attractive forces in all directions, while for a molecule at the surface this attraction is lacking in one direction. This asymmetry is the origin of the surface energy and is manifested in the surface tension. Thus, the surface tension is a reflection of the cohesive forces in a liquid.

A second molecular explanation for the surface tension due to the molecules that close to the surface are at larger separations and hence they have a larger energy.

Surface tension represents the force resisting an increase in the surface area of a liquid. As the surface is extended, more molecules must come to the surface. As a molecule moves through the surface, we must pull to oppose the attractive forces between the emerging molecule and surrounding solvent molecules.

The surface tension is expressed in units of dynes/cm or mN/m. Fortunately the conversion factor is unity in going from one unit to other and hence they can be used interchangeably. Since the surface tension is equivalent to a surface energy, or to be more correct a surface free energy, the surface tension can also be expressed in energy units, erg/cm^2 or mJ/m^2, here also with a conversion factor of unity.

1.4. Interfacial tension:

The interfacial tension is the surface tensions, or the surface free energy, that appears at the interface between two immiscible or partially miscible liquids. The reason for immiscibility is normally to be found in a large difference in cohesion forces between the molecules in the two liquids. The larger this differences in cohesion forces the larger the interfacial tension. If this difference is small enough, however, the two liquids are miscible.

The units of interfacial tension are the same as for surface tension. Besides being dependent on the difference in cohesion forces, the interfacial tension also depend on the specific interaction between the molecules in the two liquids. Water/octane for example has an interfacial tension of 51 mN/m while, water/octanol has an interfacial tension of only 8 mN/m. Clearly the hydroxyl group of octanol faces the aqueous phase and thus reduces the interfacial tension considerably.

1.5. Surfactants for germicidal and fungicidal applications:

a. Introduction:

The use of various surface active compositions for germicidal and disinfectant purposes was well established long before the synthetic surfactants were introduced to commerce. Soap –phenol compositions were among the most popular and versatile of these materials. Soap itself was also recognized as being lethal to some forms of microorganism, although, with regard to sanitation, the cleansing action of soap was held to be more important than its germicidal action. The recognition and study of the powerful germicidal action of certain cationic surfactants, which may be credited largely to the work of Valko and Domagk around 1935, stimulated widespread interest in the possible bactericidal potentials of the whole range of synthetic surfactants. Renewed interest was also aroused in studying the interactions between the well-recognized germicides such as phenols, halogens, heavy metal salts and the surfactants. These studies have led to notable advances in the cleaning, disinfecting and sanitation fields.

Finally, the development of practical and commercially successful germicidal surfactants has stimulated a large amount of fundamental bacteriological work relating to the mechanisms by which surfactants exert their germicidal action(22). At the present time, a survey of the germicidal surfactant field can be conveniently divided into the following broad sections:

i. Effects and utilization of the surfactants themselves. For this purpose, the surfactants can be considered according to their chemical classifications as cationic, anionic, nonionic and ampholytic.
ii. Germicidal-cleansing compositions in which the surfactants (or at least one of the surfactants, if more than one is present) is the major germicidal agent.
iii. Germicidal and germicidal-cleansing compositions in which the surfactant is primarily a cleanser or a carrier and the major germicidal ingredient is not surface active.

Each compound can be considered to have a characteristic germicidal spectrum, being highly toxic to some organisms and relatively innocuous to others, regardless of whether the organisms are bacteria, fungi, protozoa, or the tissue cells of higher plants and animals. The fungicidal are considered separately for the most part because their practical application often differ widely from the practical application of germicides. Thus, fungicides are most widely used in materials such as fabrics and plastics to prevent the growth and the deteriorating effect of fungi on the substrate. Germicides are usually applied not to prevent the deteriorating of an inanimate substrate but to protect human health directly or indirectly.

b. Cationic germicidal surfactants:

Among the various classes of surfactants the cationics, and more particularly the quaternary ammonium compounds, are by far the most effective all around germicides(23). This series includes many compounds which kill or inhibit the growth of both Gram-positive and Gram-negative bacteria, and which are effective over a rather wide pH range. The anionic surfactants, although frequently effective against Gram-positive bacteria, are very rarely effective against the Gram-negative group. Furthermore, their action tends to be much less rapid than that of cationics and is more susceptible to changes in the pH of the system(24). The nonionic surfactants are not generally considered to be germicidal(25).

1. Organisms susceptible to the action of cationic surfactants:

The array of test organisms used by bacteriologists in studying the inhibitory or lethal effect of a germicide is sizable but not exceptionally large. The test organisms are usually selected from the more common and more virulent disease-producing strains. Frequently, however, special organisms are used, corresponding to some specific applications for which the germicide might be considered or proposed. There have been in recent years several reports of the effects of representative cationic surface active germicides on organisms other than those which are usually studied.

The growth of most strains of algae is said to be adequately inhibited by 5 to 15 p.p.m. of several of the better known quaternaries(26). Certain strains of virus are also killed or inhibited by representative cationic surfactants(27). Octimet, a brand of octadecyl dimethyl ethyl ammonium bromide when used at 0.025% concentration is reported(28) to be effective against Candida Albicans, an organism found in the root canal of teeth. Against Tubercle Bacillus, a relatively resistant organism which presents a serious disinfection problem in hospitals, relatively few of the cationics are markedly effective, and even these are much less effective than mercury salts(39).

Considerable evidence has been gathered that certain strains of a single organism may be much more resistant than others to a cationic surfactant, and that these strains can be adapted to withstand as much as 1000 times the normal lethal concentration.

Chaplin(30), Fischer and Larose(31) have studied the adaptation of the organism Serratia Marcescens to benzalkonium chloride. The technique was to expose a colony to a concentration of the germicide high enough to kill all but a few individuals. The rate of adaptation was found to depend on the pH, and the acquired resistance appeared to coincide with an increase lipid content of the cells. The widely studied organism Escherichia coli has also been selectively bred to show greatly increased resistance to quaternaries and the resistant strains differ markedly from the parent strains in their bacteriological reaction(32).

2. **Compatibilities, inactivators and synergists for cationic surfactant:**

The bactericidal activity of the cationic surfactant, like that of most other germicidal compounds, is influenced by the presence of other substances. Relatively few substances appear to potentiate the action of the cationics, but a rather wide variety of inhibiting materials has been described. These inhibitors are of practical importance from two different points of view. First, it is important in disinfecting and sanitizing operations to know if the incidental soil present with the bacteria or the substrate is capable of inhibiting or preventing the germicidal action of the surfactant.

In such cases, the presence of an inhibitor in the system is obviously undesirable. Secondly, the effective inhibitors are needed in assaying the cationics for their germicidal activity. Thus, in determining killing rates it is customary to expose the organisms to a standard concentration of the germicide for a definite time and then to remove the germicide completely and test the organisms for viability. Inhibitors are used to remove or inactivate the cationic germicides. In this latter case, the inhibitor not only must inactivate the cationic completely but also must have no effect on the bacterial metabolism.

Proteins and many of the usual types of food residues encountered on used tableware reduce the germicidal activity of the cationics. Such food residues include starches and fates as well as proteins. There is little if any evidence, however, that quaternaries are more severely inhibited than other commonly used germicides by the presence of these organic substances(33).

It has been noted that the quaternaries cause many microorganisms to clump or agglomerate – a physical effect which may increase the time necessary for total kill(34), and also that at extreme dilution their action is inhibited by relatively low concentrations of organic matter. The tendency of cotton and wool to absorb quaternary ammonium compounds has been studied as a factor influencing their ability to disinfect textiles(35).

Quaternaries can be inactivated and their killing action on bacteria delayed or stopped by a fairly wide range of anionic surfactants and other large organic anion. The higher fatty acids appear to be generally more effective than the sulfonated or sulfated anionic surfactants, although the relative effects of the various inhibitors depend on the test organism and the particular quaternary being used.

There has been considerable investigation of the influence which hard water or, more specifically, the various metallic cations may have on the germicidal action of cationics. There is no doubt that Ca^{++} and Mg^{++} responsible for water hardness reduce the germicidal effectiveness of typical quaternaries on the commonly used test organism. Armbruster and Ridenour(36) found, under their test conditions, that 40 p.p.m. of Ca or Mg hardness or 10 p.p.m. of ferric hardness would reduce the percentage of nonviable organisms from 99.9% to about 50% when the killing agent was 200 p.p.m. of benzalkonium chloride applied at standard temperature and durations of exposure.

Mueller and Seeley examined metallic cations and found that the interfering or inhibiting power of trivalent ions was roughly 10,000 times as great as that of univalent ions and 100 times as great as that of divalent ions. The decreasing order of interfering power of various ions was Fe III, Cu, Zn, Ni, Mn, Ba, Fe II, Mg, and Ca. The univalent ions of Li, and K had little significant interfering power. The pH had much less influence than the nature of the cation on the action of the quaternary germicides(37).

More recently, Klimek and Bailey(38) have presented evidence that Ca^{++} and Mg^{++} even at 450 p.p.m. equivalent hardness have little retarding effect on the bactericidal action of benzalkonium chloride 1:5000. Fe^{+++} and Al^{+++} at 4 p.p.m. similarly have little retarding effect. Certain natural hard water was found by these investigations to lengthen the killing time by a significant factor.

There are relatively few reports of potentiating agents for cationics, i.e., agents which increase their germicidal effectiveness. Sequestering agents which remove the hardness from water would be expected to increase the germicidal effect of quaternaries in hard water. It is claimed that incorporation of alkali metal polyphosphate and carbonate improves the germicidal and cleaning action of detergent containing a quaternary ammonium and nonionic such as $C_6H_5\text{-}(CH_2)_9\text{-}(OC_2H_4)_4\text{-}OH$(39).

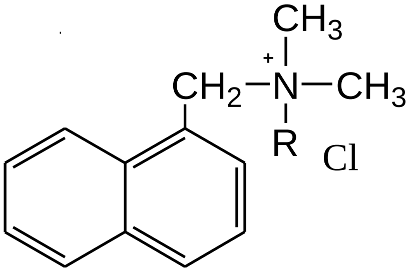
Gershenfeld and Stedman reported that cobaltous salts increase the germicidal effect of several quaternaries. The effect varied with the particular quaternary and the test organism used(40). Dodecylbenzene in minor amounts is said to improve the bactericidal action of quaternary ammonium salts(41).

3. Cationic germicidal compounds:

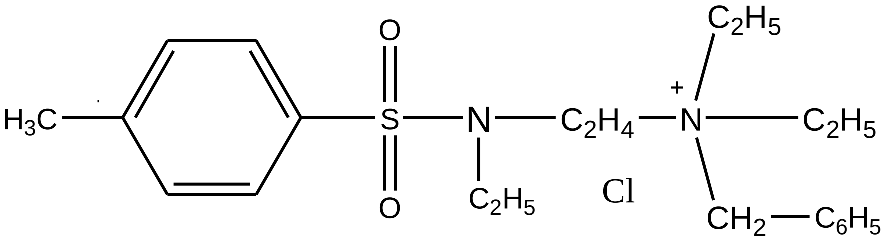
There are a considerable number of cationic surfactants, mostly in the cationic ammonium series, which have been the subject of extensive clinical investigations and which have become relatively well-known commercial items. The best known of these products is coco dimethyl benzyl ammonium chloride, frequently referred to as benzalkonium chloride(42). It is sold at least twenty different trade names in the United States alone, some of the better known brands being Zephiran, Roccal, BTC, Ammonyx T and Bional.

Aside from these older and more thoroughly studied compounds a far great number of cationic compounds have been disclosed as germicides in the patent literature but have had little if any commercial usage. Relatively few of these compounds have been subject to extensive clinical trials. Example of these compounds:

- The naphthalene derivatives containing a quaternary nitrogen(43) where R is a C_8 to C_{12} straight chain alkyl group.

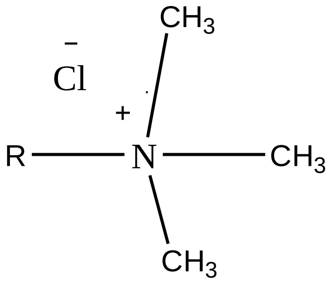


- Sulfonamides containing a quaternary nitrogen, these compounds are said to be surface active and strongly bactericidal despite the face that they have no long chain grouping(44). Analogous compounds containing both a sulfonamide group and a quaternary ammonium group have been studied by Lawrence and co-workers, who attribute their antibacterial action to the quaternary radical(45).The action of sulfonamide is reported to be enhanced by sodium dodecyl sulfate(46).



Tanaka and co-workers(47) have investigated the bactericidal power of several series of quaternary compounds against the standard organisms E. coli., B. typhosa and S. aureus. They found relatively few series which were as potent as the alkyl dimethyl benzyl ammonium salts. Some series such as the amine oxide were found to include many relatively weak germicides. These investigators also measured the surface activity and foaming power of their compounds and found no consistent correlation between these properties and the germicidal action.

Reck and Harwood(48), studying the series against five different organisms, found that the C_{16} to C_{18} derivatives were generally superior to the lower homologs, although no single compound was outstandingly active against all organisms.



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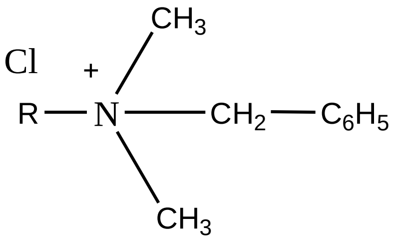

The superiority of the C_{16} derivatives in these series has been established in several other studies(49).

Similar studies, showing generally similar results have been published by Shiels, Powell and Valdez(50) and by Lawrence and co-workers(51).

The latter investigators also measured the surface tension of their compounds in 1% aqueous solution and found no correlation between this property and surface activity. There have been conflicting reports as to the correlation between surface activity and germicidal action, and it is evidence that if a correlation exist it is neither simple nor causal(52).

Burton(53) has pointed out limited correlations between surface activity and germicidal power in certain series. In the series of nuclearly substituted pyridinium alkyl halides(54), the pentadecyl derivatives which is the most powerful germicide also showed a lower surface tension that its neighboring homologs.

Harwood and co-workers have demonstrated that homologs of lower CMC possess higher germicidal effect in any given series of quaternary ammonium surfactants(55). They also have presented strong evidence that the germicidal potency increases with increased charge density around N atom(56).

In several series which have been studied the germicidal power varies inversely with the CMC, although there is some evidence that when the CMC reaches too low a value the germicidal activity starts to diminish(57).

Although the long chain primary, secondary and tertiary amine salts possess considerable germicidal power, they are in most instances less effective than their quaternary analogs(58).

Relatively little bacteriological or clinical work has been done with the phosphonium compounds, but several members of the series are reported to have bactericidal effect comparable with that of the better quaternary ammonium compounds(59).

4. Mechanism of the germicidal action of cationics:

Although a relatively large amount of work has been done in studying the biochemical mechanism by which cationic surfactants exert their germicidal action, no complete theory of this subject has as yet been developed. It appears probably that the surfactant can attack the cell through many different routes and that the particular mechanism which is effective in any single case depends on the organism and the concentration of the surfactant. Simple adsorption, although it occurs in particularly all cases, may be not be sufficiently disturbing to kill unless it seriously upsets the osmotic balance between the organism and the medium(60). Some remarkable parallels between the sorption of quaternaries on wool and their bactericidal action have been pointed out by Fischer and co-workers(61).Some of the mechanism which have been suggested(62) and for which evidence has been brought fourth include:

1. Denaturation of the cell proteins. 2. Combination of the cationic surfactant with the cell lipids. 3. Interference with the enzyme balance within the organism. 4. Interference with the osmotic balance in such a manner as to release vital solute material outward through the cell wall.

c. Fungicidal surfactant compositions:

With few exceptions the only surfactants which possess sufficient fungicidal activity to be used extensively in competition with other fungicides belong to the cationic class. Several members of this group appear to have pronounced activity against the fungi which invade the human skin. The heavy metal salts of carboxylic or sulfonic acid in the surfactant range, such as copper naphthalene and zinc petroleum sulfonated, largely depend for their action on the heavy metal component.

The anionic sulfate and sulfonated surfactants are frequently used as carriers and dispersing agents for water insoluble fungicides such as salicylanilide or the nitophenols, but by themselves they are seldom sufficiently active to be of practical value(63).

Fungicidal activity, like bactericidal activity, tends to be specific with regard to the test organisms. In general, however, the quaternary cationic surfactants have a rather wide fungicidal spectrum, resembling in this respect the compounds of the heavy metals.

Accordingly, the selection of a specific fungicidal compound usually depends on how well the other properties (such as solubility, stability, toxicity) fit in the field conditions. Thus, the simple long chain quaternary compounds which have good substantivity and low toxicity are used in mildew-proofing fabrics(64). Among the more interesting cationic fungicides which can be applied to industrial fabrics is the product made by partial ammonolysis of chlorinated paraffin wax(65). This material is stated to be resistant to leaching and to be effective against wide range of fungi and bacteria.

The long chain alkylolamines such as cetyl diethanol amine are effective fungicides(66) and the long chain quaternary compound which contain an alkyl sulfide group such as C_2H_5-S-C_2H_4- attached to the quaternary nitrogen are also stated to have high fungicidal activity(67).

Aside from phenols and thiol salts, certain water insoluble carboxylic acid salts of the long chain cationic surfactants are said to be better fungicides than either of their components taken separately. Examples of such compounds are the dodecyl amine salt of o-chlorobenzoic acid and the hexadecyl amine salts of salicylic acid(68).

The cationic fungicides are frequently used in synergistic combinations with other fungicidal agents such as mercury compounds, the heavy metal soaps and lower halogenated fatty esters(69).

1.6. Literature survey:

A.M. Badawi, et al.,(70) studied the surface and biocidal activity of some synthesized metallo azobenzene isothiouronium salts. A novel series of azobenzene isothiouronium salts of different alkyl chains (propyl, hexyl and dodecyl) were synthesized by reaction of 4-((4-methylphenyl)azo) phenol with 1,3-dibromopropane, 1,6-dibromohexane and 1,12-dibromododecane, respectively. These salts were reacted with copper (II) halide to give their corresponding metallo complexes. The surface tension measurements for the synthesized compounds show that the metallo complexes have adsorption and micellization better than that of the parent azobenzene isothiouronium salts. The pathogenic Gram-negative bacteria, Gram-positive bacteria, fungi and yeast were used to determine the biocidal activity of these compounds using gradient plate technique. The results indicate that the copper complexes of the synthesized azobenzene isothiouronium salts have a relatively better biocidal activity than the parent salts.

N. A. Negm and Mohamed F. Zaki(71) studied the structural and biological behaviors of some nonionic Schiff-base amphiphiles and their Cu(II) and Fe(III) metal complexes. Novel series of nonionic Schiff bases was synthesized and characterized using microelemental analysis, FTIR and 1H NMR spectra. These Schiff bases and their complexes with Cu and Fe have been evaluated for their antibacterial activity against bacterial species such as *Staphylococcus aureus*, *Pseudomonas aureus*, *Candida albi*, *Bacillus subtilis* and *Escherichia* *coli* and their fungicidal activity against *Aspcrgillus niger* and *Aspcrgillus flavus*. The results of the biocidal activities showed high potent action of the synthesized Schiff bases towards both bacteria and fungi.

Furthermore, complexation of these Schiff bases by Cu(II) and Fe(III) show the metal complexes to be more antibacterial and antifungal than the Schiff bases. The results were correlated to the surface activity and the transition metal type. The mode of action of these complexes was discussed.

N. A. Negm, et al.,(72) studied the biocidal activity of some Mannich base cationic derivatives. A novel series of cationic surfactants was prepared based on Mannich base (produced from the condensation of piperidine and/or morpholine as secondary amine and paraformaldehyde in the presence of 8-hydroxyquinoline). The chemical structures of the synthesized cationic surfactants were confirmed using elemental analyses, FTIR spectroscopy and ^1H NMR. Surface activities of the prepared surfactants were measured including: surface tension (γ) , critical micelle concentration (CMC), effectiveness (π_{CMC}), efficiency (Pc_{20}), maximum surface excess (Γ_{max}), minimum surface area (A_{min}), interfacial tension, emulsification power and foaming power at 25 ^oC. The structural influences on their surface activities and adsorption free energy were discussed. The synthesized cationic surfactants were evaluated for their biocidal activity towards Gram +ve bacteria (Staph. Cocu., Bacillus), Gram -ve bacteria (Salmonella, E. coli), fungi (A. terrus., A. flav.) and yeast (Candida) at

1.0, 2.5 and 5.0 mg/ml, respectively. The target compounds showed good inhibition towards Gram +ve bacteria, Gram -ve bacteria and yeast. Meanwhile, excellent fungicidal results were obtained against the various types of fungi under investigation.

P.C. Griffiths, et al.,(73) studied the metallosurfactants: Interfaces and micelles. Incorporating a metal cation as an integral component of the head group of a surfactant – a metallosurfactant – offers a route to concentrate these ions and their associated functionality at interfaces.

To reduce the lability of the metal, various chelating or macrocyclic ligands may be employed leading to a family of homologous series of related metallosurfactants with a structural diversity that is arguably broader than is inherently possible with conventional surfactants. This review discusses the small number of key papers that are quantifying the physico–chemical properties of metallosurfactants and highlights their “classical” as well as “non-classical” surfactant behavior, providing an insight into the structure of micelles and films formed from these novel materials.

N. A. Negm, et al.,(74) synthesized and studied the characterization and biological Activity of sugar-based gemini cationic amphiphiles. Two series of gemini cationic surfactants were synthesized based on glucose and fructose molecules. Their chemical structures were confirmed using micro-elemental analysis, mass spectral fragmentation and FTIR spectroscopic analysis. The surface activities of these Gemini amphiphiles were measured, including surface tension (γ), critical micelle concentration (CMC), effectiveness (π_{CMC}), efficiency

(Pc_{20}), maximum surface excess (Γ_{max}) and minimum surface area (A_{min}) at 25 ^{o}C. Adsorption and micellization free energies of these amphiphiles in their solutions showed a good tendency towards adsorption at the interfaces. The biological activity of the synthesized gemini amphiphiles showed good inhibition at concentrations of 1, 2.5 and 5 mg/ml. The synthesized amphiphiles showed antimicrobial activity on gram-positive and gram negative bacteria and antifungal activity equal to or comparable to commercially available controls. The discussion rationalized the antimicrobial activities of these amphiphiles with the surface activity and the adsorption parameters. In addition, the effect of sugar nuclei was discussed based on the chemical structure of the bacterial and fungal cell membranes.

A. M. Badawi, et al.,(75) studied the surface and biological activity of some novel cationic surfactants. In this study, steps were taken toward the development of bactericidal and fungicidal synthetic cationic surfactants by reacting decyl, dodecyl or tetradecyl amine with acetic or hydrochloric acid to produce a series of amine salts which consequently converted to copper or cobalt cationic complexes via complexing the first series compounds with copper (II) or cobalt (II) ions. Surface properties such as interfacial tension and emulsifying power of these surfactants were investigated. The surface parameters including critical micelle concentration (CMC), maximum surface excess (Γ_{max}) and minimum surface area (A_{min}) were studied. Free energy of micellization (ΔG^{o}_{mic}) and adsorption (ΔG^{o}_{ads}) were calculated. The antimicrobial activity was determined via the inhibition zone diameter of the prepared compounds, which measured against five strains of a representative group of microorganisms. FTIR spectra, elemental analysis and H^1 NMR spectrum were performed to confirm compound structure and purity.

N. A. Negm and I. A. Aiad(76) synthesized and studied the characterization of multifunctional surfactants in oil-field protection applications. A series of cationic surfactants was prepared using economical raw materials. The chemical structures of the prepared compounds were confirmed using elemental analysis, FTIR and ^1H-NMR spectra, and melting point determination. The synthesized surfactants were evaluated as oil-field protective additives. In this regard, several surface properties of the synthesized surfactants were studied including surface tension (γ), critical micelle concentration (CMC), effectiveness (π_{CMC}), efficiency (PC_{20}), maximum surface excess (Γ_{max}) and minimum surface area (A_{min}). The results obtained from the surface activity measurements were correlated to their chemical structures. The emulsification power measurements for solutions of these surfactants showed their low emulsifying tendency towards paraffin and crude oil. The synthesized surfactants also exhibited high biocidal activity towards gram-positive and gram-negative bacteria and fungi. This activity was increased by increasing the hydrophobic chain length. The corrosion inhibition measurement of these surfactants for mild steel alloys in acidic media using a weight loss technique showed good protection of mild steel alloys against acidic environments. These properties qualify the synthesized compounds as economical oil-field protective additives.

M. C. Murguı´a, et al.,$^{(77)}$ synthesized and studied the surface-active properties and antimicrobial activities of new neutral and cationic trimeric surfactants. Neutral and cationic series of new trimeric ß-hydroxy amino or ammonium surfactants were synthesized via a two-step process involving the Williamson etherification and region selective oxirane ring opening with primary and tertiary amines, which afforded good to excellent yields. The synthesized compounds were obtained in high purity by a simple purification procedure on column chromatography. The critical micelle concentration (CMC), effectiveness of surface tension reduction (γ_{CMC}), surface excess concentration (Γ_{max}), and area per molecule at the interface (A) were determined and values indicate that the cationic series is characterized by good surface-active and self-aggregation properties. The antimicrobial activities are reported for the first time against representative bacteria and fungi for trimeric compounds. The antimicrobial potency was found to be dependent on the target microorganism (Gram-positive bacteria> fungi>Gram-negative bacteria), as well as both the neutral or ionic nature (cationic>neutral) and alkyl chain length (tri-C_{12}>tri-C_{18}>tri-C_8) of the compounds. The tri-C_8 and tri-C_{18} compounds were found to be almost inactive and the tri-C_{12} compounds, the most potent antimicrobial surface-active agents from the synthesized series. The trimeric C_{12} cationic compound was found to be comparable to benzalkonium chloride against Gram-positive bacteria and fungi, in vitro. The antimicrobial effectiveness of this new compound and the facile two-step procedure for synthesizing it with an excellent overall yield (92%) provide a cost effective trimeric gemini surfactant.

R. Barney, et al.,(78) carried out a surfactant studies of quaternary ammonium compounds: critical surfactant concentration. Quaternary ammonium salts (otherwise known as “quats”) commonly form the foundation of formulations in the antimicrobial industry. Although many studies have been conducted on the surfactant and biological aspects of single component systems, there are few studies concerning the surfactant or biological efficacy of these compounds in multiple-component formulations. Preliminary data using simple emulsion studies with decane were determined to be inadequate. Several inexpensive ways to determine critical surfactant concentrations were developed with limited resources.

M. C. Murguı´a, et al.,(79) synthesized and studied the properties of novel antifungal gemini compounds derived from *n*-acetyl diethanolamines. A series of new N-acetylated non-ionic and cationic gemini surfactants (3a–f) having dimeric structures derived from primary and tertiary amines with variably long tails (C_8–C_{12}–C_{18}) were synthesized. In addition, N-acetylated monomeric analogues 6a and 6b were prepared and their antifungal potency and surface properties were also determined. Critical micelle concentration (CMC), effectiveness of surface tension reduction (γ_{CMC}), surface excess concentration (Γ_{max}), and area per molecule at the interface (A) were also determined and the resulting values indicate that the cationic series is characterized by good surface-active and self-aggregation properties. For the first time, all surfactants were tested to valuate their antifungal properties using the method for the broth macrodilution test (M27-A2, NCCLS). Four microbial strains were used to perform the study: Candida parapsilosis (ATCC 22019), C. albicans (ATCC 64548), and a wild-type strain of C. parasilosis and Saccharomyces cerevisiae (ATCC 9763). The antimicrobial activity was measured by yeast growth inhibition expressed as minimum inhibitory concentration (MIC) values. Results were compared to those obtained for their monomeric analogues and for a commercially available reference compound (Fluconazole). Gemini 3b, 3e and 3f were found to be the most potent compounds. The results show S. cerevisiae as the most sensitive strain. In contrast, the wild strain of C. parapsilosis was resistant.

S. Pegiadou-Koemtjopoulou and E. Tsatsaroni(80) synthesized and studied the properties of new cationic surfactants. New pyrimidinium cationic surfactants containing a positively charged nitrogen atom of the pyrimidine ring and a long-chain alkyl group of 6, 8, 10, 12 and 14 carbon atoms were prepared. The structural assignment of these compounds was made on the basis of the elemental analysis and spectroscopic data, infrared, nuclear magnetic resonance and mass spectroscopy. Surface tension and after-treatment of direct dyed cotton fabrics were determined for these surfactants. Antibacterial activities also were examined.

T. Zhao and G. Sun(81) synthesized and studied the characterization of antimicrobial cationic surfactants: aminopyridinium salts. Three antimicrobial 4-aminopyridinium salts were synthesized using two different processes in an effort to develop antimicrobial surface treatment agents for wool fibers. The structures of the salts were fully characterized using Fourier transform infrared, ^{1}H nuclear magnetic resonance (NMR), and ^{13}C NMR analysis. In addition, their thermal stability was determined using differential scanning calorimetry and thermogravimetric analysis. The antimicrobial efficacy of these compounds was evaluated using minimum inhibitory concentration as an indicator. All of the synthesized aminopyridinium salts showed antimicrobial activity against gram-negative bacteria, but in different levels depending on their structures. The salts possessing longer alkyl chains demonstrated better antimicrobial function. The melting points of the salts decreases as the alkyl chain length increases.