A STUDY OF THE EFFECT OF CERTAIN ANIONIC SURFACE ACTIVE AGENTS IN SUSPENSIONS OF SELECTED PHARMACEUTICAL POWDERS

BY

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1. INTRODUCTION

This study was undertaken to investigate the ability of surface active agents to promote the dispersion, in aqueous media, of certain water insoluble powders. The determination of the suspendability of solid powders in liquids is useful in studying the factors responsible for aggregation and deflocculation, the mechanism of dispersion and suspension, and the relationship of the surface active properties of a solution to its ability to deflocculate and suspend solid powders.

Understanding of these phenomena is of basic importance in the preparation of pharmaceutical products. From the standpoint of pharmaceutical technology, the deflocculation of particles into individual units is important in the preparation of suspensions, magmas, emulsions and similar mixtures. Through a detailed study of the factors involving the adsorption of selected anionic surface active agents onto the surface of common pharmaceutical powders it might be possible to establish techniques which would result in the formation of more stable and more elegant pharmaceutical dispersion. By correlating sedimentation data with adsorption data it was felt that an insight might be gained into some of the factors causing instability and flocculation in pharmaceutical suspensions.

2. REVIEW OF THE PAST LITERATURE

Methods of Evaluating the Efficiency of Anionic Surface Active Agents

Although there have been several studies of the ability of surface active agents to disperse pigments and similar materials in organic media (1-3) few studies of a similar nature have been made with respect to dispersion in aqueous media. Those few studies which have appeared in the literature have been primarily concerned with evaluating the efficiency of soaps and synthetic surface active agents as detergents.

Schwartz and Perry (4) state that surface active agents may be classified on the basis of uses to which they are put, on the basis of physical properties, or on the basis of chemical structure. The latter system is the one most commonly employed and using this system surface active agents may be classified as: (1) anionic, (2) cationic and (3) non-ionic. This classification is based on the observation that most surface active agents are characterised by a hydrophilic and a hydrophobic portion in their molecule. If the hydrophobic portion is included in the anion the compound is termed anionic. Cationic surface active agents form a cation containing the hydrophobic portion of the molecule upon ionisation. The non-ionic group are characterized by the presence of many hydrophilic groups in a non-ionizing configuration. Since this study

is concerned with anionic surface active agents as dispersing agents the investigations reported here are related entirely to the behaviour of this group of agents.

In 1909 Spring (5) observed that a solution of "medicinal soap" had the ability to suspend lamp black. This investigator found that there was an optimum effect with a one per cent solution. He also noted that dilute aqueous soap solutions had the power of carrying a certain portion of the lamp black through a filter paper without blackening the paper.

McBain and co-workers (6) by utilising Spring's (5) observations of the effects on filter paper proposed the first quantitative method for measuring the detergent power of soaps. Their investigations showed that only that portion of the carbon black which was stably suspended would be carried through the filter paper. This observation was used to designate a "carbon number" which was employed to designate the efficiency of soaps as detergents. The "carbon number" was stated to be the number of grams of carbon carried through the filter paper by one kilogram of soap solution under standard conditions. They noted in their investigations that there was a sharp maximum "carbon number" at a particular concentration of soap and that higher concentrations of the soap caused a lowering of the "carbon number".

Fall (7) undertook a study of the same problem some-

what later. He criticized McBain's method (6) on the basis that the results were erratic and at the best none too accurate. Fall succeeded in developing a method of measuring the suspending ability of detergents by a study of the extent of stabilization of suspensions of manganese dioxide in soap solutions. The method utilized a specially constructed sedimentation apparatus and consequently was free from many of the disturbing factors encountered by McBain (6). Fall's investigations indicated, as had McBain's, that the stabilising power of any soap increases with increasing concentration up to a maximum. Increasing this concentration was found to cause a loss in stabilizing power. Similar observations were made by Vincent (8) who attempted to correlate the studies of McBain (6) and Fall (7).

Vold and co-workers (9, 10) have carried out an extensive and thorough investigation of the suspension of manganese dioxide in detergent solutions. Their investigations were restricted to synthetic detergents with the exception of sodium oleate and p-toluenesulfonic acid. These investigators found that characteristically the curves of amount suspended versus concentration of dispersing agent passed through a maximum at low concentration of the agent. Griener and Vold (9) also examined the sedimentation volume of manganese dioxide in the various detergent solutions and in water. They observed that the sedimentation volume for manganese dioxide falling through water reached a maximum

and then decreased, whereas the sedimentation volume for the same material falling through an Aerosol OT solution was smaller than that in water but increased steadily with time. They attributed this phenomenon to the fact that the anionic surface active agents aid suspendability by deflocculating the powder particles which are associated with water into secondary aggregates of larger size than the primary particles in the dry powder.

In a more recent investigation Mankowich (11) has continued the examination of the ability of synthetic surface active agents to suspend and disperse insoluble powders in aqueous media. He considered the four hour settling period employed by Griener and Vold (9) prior to the analysis of the suspension to be a serious disadvantage and modified the procedure to employ a two hour settling period. The method also utilized the Andreason sedimentation apparatus instead of the special equipment employed by the previous investigators (9). Mankowich found that at 0.4 per cent concentration alkylaryl sulfonates with alkyl groups greater than C_{10}, and sodium lauryl sulfate were substantially equivalent in their ability to suspend nonpolar carbon powder. He further noted that sulfated alcohols decreased sharply in their suspending ability at 0.2 per cent concentration. At 0.1 per cent concentration all types of anionic surfactants were found to have little carbon suspending power. In the case of manganese dioxide, 0.4

per cent alcohol sulfate and alkylaryl sulfonates with alkyl group greater than C_{10} were also found to possess equal activity.

3. THEORETICAL CONSIDERATIONS

The observation that soaps and synthetic surface active agents of the anionic type are capable of forming stable suspensions of solid particles has led to many investigations in an attempt to gather some insight into the mechanism of this protective action (9-13). In particular investigators have been concerned with the reasons for the suspension maximum which occurs in the use of these materials.

One of the earliest explanations was given by Vincent (8) who concluded that soap solutions will suspend solid material because the solid particles become charged by adsorption of negative ions from solution. He believed that the existence of an optimum value of soap concentration for this stabilization was due to the fact that positive ions are also adsorbed from the solution. Vincent theorized that the soap concentration in which the ions are adsorbed to the same extent as the soap will not produce stabilization. The optimum stabilization, he believed, occurred at that concentration in which there is strong adsorption of the positive ions.

The formation of stable suspensions of solid particles has been attributed by Vold and co-workers (9, 10) to the change in the zeta potential on the insoluble particles. They concluded that even in solutions of colloidal electrolytes the dominant factor in determining the formation of a

stable suspension was the magnitude of the zeta potential on the suspended particles. This change in the zeta potential was theorised as being effected primarily through the adsorption of simple ions from the solution. They concluded on this basis that lyophilic properties or the ability of a dispersing agent to lower surface tension were not essential requirements for the formation of a stable suspension.

Grieneer and Vold (9) further explained the existence of a maximum in the suspension isotherm as being explicable in terms of the initial preferential adsorption of one of the ions. This was considered to be the factor promoting stability of the dispersed particles by increasing their zeta potential. The loss of stability with higher concentrations was considered to be due to the antagonistic effect of the ion of opposite charge to that first adsorbed.

Vold and Koneeny (10) further expanded on this theory by applying the same techniques to the study of an oleophilic powder, carbon. These investigators obtained results which they felt agreed with those obtained by Grieneer and Vold (9) using the hydrophilic powder, manganese dioxide. They felt that these observations confirmed the previously proposed mechanism and also demonstrated the necessity of considering the chemical nature of both the powder and the surfactant. Vold and Koneeny (10) do not feel that there should be an entire reliance on physico-chemical properties and colloidal nature of the solutions as a criteria of effectiveness.

Goette (13) in an extensive investigation of the factors influencing the activity of surface active agents as detergents has supported the theories of Vold et al (9, 10). He attributes the removal of solids from fibers to the action of the surface active agent in simultaneously raising the zeta potential of both the soil and the fiber. Goette reasoned that the fact that cationic surface active agents are not good detergents may be explained on the basis that these materials are not adsorbed by fibers and consequently do not change their zeta potential.

Doscher (12) has taken exception to these explanations of the suspending action of anionic surface active agents. He obtained evidence to show that the suspension isotherm for the positive carbon was similar to that for the negative powder, manganese dioxide. This, Doscher claimed, indicated that the decrease in the suspension isotherm beyond the maximum concentration cannot be attributed to neutralisation of the charge or to any sharp drop in the zeta potential as suggested by Vold and co-workers (9, 10).

Doscher's alternative explanation for the flocculation effects of excess concentrations of dispersing agents is related to the tendency of surface active agents to form micelles above a certain critical concentration. Corrin and co-workers (13) had previously shown that above a certain critical concentration surface active agents are adsorbed on the surface of materials as charged aggregates or micelles and not as simple ions. Since McBain and Ruff (14) had

shown that the charges on these aggregates are distributed rather than being concentrated at a single point, Doscher (12) reasoned that the interaction of the hydrophobic surfaces on one particle with those on another may occur. This, he theorized, would result in the formation of bonds and the consequent re-precipitation of the dispersion.

Adsorption of Surface Active Agents

Powney and Road (15) have stated that the protective action of long chain surface compounds such as soaps, probably arises not only from changes in electrical charges but also from the formation of organized surface films upon the particles. These films are able to modify considerably the adhesional energy at the interface of the solid particles with the fluid medium resulting in a stable suspension. Lomas (16) in a consideration of the functions of dispersing agents has also been led to the conclusion that a stable mono-layer is adsorbed at the solid - liquid interface. The adsorption of surface active material, oleic acid, from solution by titanium dioxide was studied by Harkins and Gans (17). The oleic acid deflocculated the suspension of the powder in benzene, and the quantity required was that amount required to form a unimolecular film at the solid - liquid interface.

An investigation of the role of surface active agents in pigment dispersion was also undertaken by Fischer and Jerome (18). Representative surface active agents were selected from each of the several classes of the commercial

types available. Their results indicated that the quantity of dispersant estimated to form a monomolecular film on the pigment may be considered the minimum to register a decided change in the properties of a dispersion. While these investigators did not refer to any decrease in the degree of dispersion with excess of surface active agent they did comment on the fact that excess concentrations of surface active agents are of little advantage. No explanation for this statement was given.

Mankowich (11) has defined the deflocculating or dispersing power of any agent as a measure of the efficiency with which agglomerates of solid particles are broken up and suspended in a liquid. He stated that deflocculation consists of separating the particles so that the residual forces no longer act between them. This, he concluded, can be made permanent by adsorption of the agent on the surface of the particle to form a monomolecular layer.

It is now generally believed that when insoluble solids are wetted by, or stirred into an aqueous fluid, they either carry no electrostatic charge or are in electrostatic equilibrium. When the solid particles collide they have the tendency to cling together to form flocs. The addition of a dispersing agent to the suspension has been shown (19) to be of assistance in overcoming this tendency. The dispersing agent, on introduction into this suspension, is preferentially adsorbed on the surfaces of the individual particles in the flocs so that the exterior layers of the

adsorbed molecules of the dispersing agent carry the same character of charges, either all positive or all negative. As like charges repel, the flocs are ruptured and broken down into separate, individual particles.

The quantitative measurement of the adsorption of anionic surface active agents from aqueous solutions onto solids has been the subject of but little experimental investigation. Held and Samochevalov (20) measured the adsorption of sodium laurate on barium sulfate. The adsorption of sodium oleate and sodium nonylate upon cinnibar was studied by Held and Khainsky (21). Corrin, Lind, Roginsky and Harkins (22) studied the adsorption of long chain electrolytes from aqueous solution on graphite and polystyrene. With both sodium lauryl sulfate and potassium myristate they got a definite break in the adsorption isotherm. These investigators observed that isotherms at less than the critical micelle concentration for both of these reagents were not of the Freundlich or Langmuir type and could not be represented by equations characteristic of gaseous or condensed surface films. They were unable to advance any explanation for the discontinuity in the sodium lauryl sulfate curve. They postulated, however, that the break in the adsorption isotherm may be indicative of the fact that the nature of the adsorption is altered in the presence of micelles.

A series of investigations on the adsorptions of soaps and synthetic surface active agents has been performed by

Weatherburn and co-workers (23-26). In determinations on adsorption of soaps by carbon black they observed that a marked reduction in the adsorption of soap occurred from an alcoholic solution. They also noted that an excess of free alkali caused a decrease in the adsorption of fatty acid (25).

Weatherburn et al (23) also noted that the adsorption of synthetic surface active agents by carbon black does not conform to the Freundlich adsorption isotherm over the whole of the concentration range they studied. They observed further that with most of the agents studied there was an abrupt change in slope of the curve at concentrations which appeared to correspond to the critical micelle concentrations of the compounds being studied. These investigators further noted that the adsorption of sodium alkyl sulfates increased with increasing chain length of the alkyl group at constant temperature. Adsorption was found to decrease with increasing temperature at constant chain length.

Weatherburn and co-workers (25) also noted that the filtering characteristics of the suspensions depended upon the concentration of the synthetic surface active agent present. Suspensions prepared from solutions below the critical micelle concentration filtered rapidly and gave filtrates which were perfectly clear and free of carbon. At higher concentrations, however, the filtration was much slower, and many of the filtrates were dark colored during the earlier stages of filtration. They concluded that the

surface characteristics of the carbon particles are modified by the adsorption of micelles of the surface active compounds. Under these conditions the finer carbon particles were enabled to pass through the filter paper.

Although this review is primarily concerned with the adsorption of surface active agents from aqueous media on the solid particles it might be interesting at this time to note the similarity between this type of adsorption and the adsorption of surface active agents on to other materials and from other than aqueous media.

Demerell and Urbanic (1) investigated the effects of twenty-four surface active agents upon calcium carbonate-xylene systems and carried out adsorption and sedimentation studies. They obtained data to indicate that the surface active agents were positively adsorbed by the calcium carbonate. These investigators concluded that the surface active agents aided the dispersion by going to the xylene-calcium carbonate interface and forming a protective coating. This was assumed to have an effect on the breaking up of calcium carbonate aggregates by giving the disperse phase a positive charge.

Garner and collaborators (2) have investigated the detergency of carbon black in organic liquid media and have concluded that the detergency of the added surface active agent is correlated with its degree of adsorption on the carbon particles. They also noted that while detergency or dispersion in an organic solution is not related to deter-

gency in an aqueous solution many liquids of high dispersing power may also possess high dielectric constants. In a second investigation (3) they noted that the systems of carbon black dispersed in organic liquids exhibited the phenomenon of electrophoresis, electro-osmosis and sedimentation potential in a manner analagous to an aqueous system. They attributed this to the presence of an electrical double layer at the surface of the particles of the carbon black. This electrical double layer was assumed to be present due to adsorption from solution and was largely responsible for the stability of the dispersion.

In addition to studies on the adsorption of surface active agents from aqueous and organic media onto the surface of solid particles studies have also been made of the adsorption of these agents by textile fabrics. Adams (27) determined the adsorption of several types of soaps and detergents on wool and cotton. Neville and Jeanson (28) measured the adsorption of Gardinol C A and Igepon T on wool. Steinhardt and co-workers (29) measured the combining of wool with lauryl sulfuric and lauryl sulfonic acids. Aicken (30) made a comprehensive study of the adsorption of secondary alkyl sulfates on cotton and wool. Rose and Bayley (31) conducted an extensive investigation of the adsorption of the sodium soaps of several fatty acids on different textile fabrics. They concluded that the adsorption of soap is a complex process involving more or less independent adsorption of neutral soap, hydrolytic

fatty acid or acid soap, and hydrolytic alkali. Weatherburn and co-workers (23) were of the opinion that whereas the adsorption of soap from solution by carbon black is probably due entirely to physical adsorption, in the case of textile fabrics the phenomenon more readily resembles chemical reaction than physical adsorption. Meader and Fries (32) have studied the adsorption of soap on cotton and wool by means of a radio-active tracer technique. They observed discontinuities in the isotherms which agreed very closely with the critical micelle concentrations although the maxima in the curves occurred at considerably higher concentrations. These investigators noted that these breaks were similar to those reported by Harkins and co-workers (17) in the adsorption of sodium dodecyl and potassium myristate on graphite.

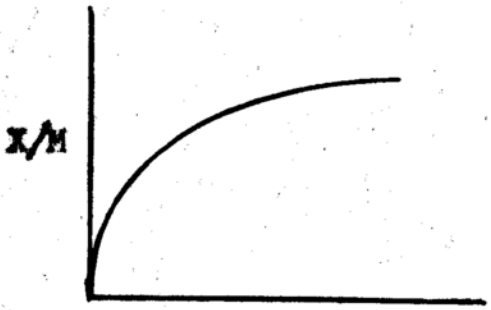
Techniques of Measuring Adsorption

Measurement of adsorption from solution onto a solid surface is usually carried out by observing the difference between the concentration of the solution before the addition of the absorbent and after equilibrium has been established. Cassidy (33) states that this type of indirect measurement involves two assumptions: (1) that the components of the liquid phase do not dissolve in the absorbent; and (2) that the solvent is not adsorbed to an extent which vitiates the measurement.

The data obtained by the procedure outlined may be recorded in various ways but the most common method is in

the form of an adsorption isotherm in which the amount of the substance adsorbed is plotted against the equilibrium concentration of the solution. The term "isotherm" follows from the fact that these data are taken at constant temperature.

Brunauer and co-workers (34) have classified adsorption isotherms obtained in the adsorption of gases or vapors on solids into five types. In the case of surface active agents the Type 1 isotherm shown below is the one commonly obtained (33). Brunauer and collaborators (34) state



that this type isotherm represents adsorption in which the surface of the adsorbent eventually becomes covered with a monomolecular layer of adsorbent. When this point is reached no further adsorption occurs since the surface is covered.

Both Freundlich (35) and Langmuir (36) have developed equations which may be used to interpret the data obtained by means of an adsorption isotherm. The Freundlich equation describes the relationship between the amount of solute adsorbed and its concentrations and may be written as follows:

$$x/m = kc^n$$

where x = the amount of solid adsorbed

m = the weight of the adsorbent in grams

c = the equilibrium concentration

and k and n are constants. The equation may also be written in logarithmic form:

$$\log (x/m) = \log k + n (\log c)$$

If Freundlich's equation is obeyed the plot of log x/m against log C should give a straight line. The intercept is log k and the slope is n.

In general this equation fits the data of an adsorption over a reasonable range, but it does not reduce to a linear equation at very low concentration, nor does it approach a constant value for the adsorption at higher concentrations.

Type 1 isotherms are best represented by Langmuir's equation and for this reason it is sometimes termed a Langmuir isotherm. The equation describes the adsorption of molecules on fixed sites upon a surface and may be written as:

$$x/m = k_1k_2 (1 + k_1c)$$

where x = the amount of solute adsorbed

m = the weight of the adsorbent in grams

c = the equilibrium concentration of the solute

and k_1 and k_2 are constants. At low concentrations the equation reduces to:

$$x/m = k_1k_2c$$

At higher equilibrium concentrations the value of x/m approaches that of the constant k_2 and we can write:

$$x/m = k_2$$

Therefore, the value of the constant k_2 is a good measure of the adsorptive capacity of the particular adsorbent being employed for the adsorbate present in the solution.

If $c/x/m$ is plotted against c, the equilibrium concentration, a straight line should be obtained if Langmuir's equation fits the data obtained. The slope of this line is $1/k_2$ while the intercept is $1/k_1k_2$.

Micelle Formation

Aqueous solutions of most soaps and other surface active agents exhibit a more or less abrupt change in physical properties over a relatively short concentration range. In particular surface tension curves exhibit well defined breaks at certain critical concentrations. Other physical properties of colloidal electrolytes also show similar abrupt changes (37-49). According to Bury and collaborators (38, 39) such breaks probably correspond to a sharp transition in bulk solution from single ions to micelles. The concentrations at which these breaks occur have conveniently been termed "Critical Concentrations for Micelles".

Micelles are colloidal particles formed by the progressive association of surface active ions and ion pairs. Two distinct types have been suggested. Hartley's spherical

micelle (43) is visualized as two ions in diameter, oriented with polar heads outward in water and the long chains forming a hydrophobic interior. McBain (44) has postulated the lamellar micelle, consisting of two layers of surface active molecules arranged side by side, the adjacent long chains forming a hydrophobic layer. Hess (45) proposed a modification of the latter type by combining two or more McBain micelles separated by water layers.

Preston (41) has presented data showing that a great increase in the detergent action of soaps occurs at about the concentration at which micelle formation becomes apparent. As mentioned previously Weatherburn and co-workers (23-26) found most of the adsorption curves of surface active materials on carbon black exhibited a more or less abrupt change in slope at concentrations which appeared to correspond, at least approximately, to the critical micelle concentrations of the compounds. These investigators confirmed their observations on different carbons. While the magnitude of the adsorption of any one surface active compound varied with the different carbons the breaks in the curves occurred at virtually the same equilibrium concentration. This concentration was again found to correspond to the critical micelle concentration. They considered this to be conclusive evidence that a change occurs in the adsorption characteristics at or near the critical micelle concentration. These observations would appear to be related to Preston's (37) findings on detergent

efficiency.

Solubilisation has also been shown to be a property of the micelles in solutions of colloidal electrolyes (50-53). This micellar solubilisation is stated to be the solution of an otherwise insoluble material by adsorption onto or incorporation into micelles (50). The action has been attributed to three types of actions: adsorption onto external polar groups; interlayering within the lamellar micelle between hydrophobic layers; and interpenetration between the molecules of the micelle (44). McBain and Green (54) have obtained data to show that in sufficiently dilute solutions there is no solubilisation. They presumed this was because there are no colloidal micelles in which the insoluble material can be incorporated. These investigators found that as suitable micelles formed in the solution upon increase in concentration, the amount of dye solubilised by each mole of soap rose to a constant value.

McBain and Green (54) also noted that in all concentrations salts greatly increase the amount of solubilisation of a given amount of soap. They found this effect to be particularly striking in the lower concentrations where no solubilization was observed until the salt was added. Their investigations confirmed the observations of Hartley (42) that the first addition of salt has a much greater effect than later additions although the effect continued to increase as more salt was added. Lambert and Busse (56) as well as other workers in this field (57, 58) have also

observed that the solubilisation characteristics of surface active agents are influenced considerably by the presence of electrolytes.

In his investigations Preston (41) further observed that any material which lowers the minimum concentration necessary for micelle formation in a soap solution would then likely decrease the concentrations necessary for good detergency. Weatherburn (24) in addition noted that the addition of sodium sulfate to anionic compounds resulted in an increase in the adsorption of the latter on the surface of carbon black particles.

Although electrolytes do alter the critical micelle concentration Merrill and Getty (57) found that the concentration at which micelle formation occurs is not entirely dependent on the amount of salt added or the total ionic strength of the solutions. These findings have been supported by Corrin and Hawkins (58) who state that the extent of lowering of the critical concentration by a salt exhibits independence of the number of charges on the ion of the salt which has the same sign of charge as the ion aggregate of the micelle.

In addition to noting the effects of electrolytes Klevens (59) observed that the critical concentration for micelle formation increases with increasing temperature. He stated the increase was due to a lesser tendency of the molecules to aggregate at elevated temperatures due to increased thermal agitation of the coalescing units.

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4. PLAN OF STUDY

By performing adsorption studies with certain selected anionic surface agents and several insoluble powders commonly employed in pharmaceutical preparations it would be possible to determine whether adsorption did occur to a measurable extent. Further, it might be determined whether the anomalies reported for the adsorption of this class of agent on carbon black would also occur in the adsorption of these commonly employed pharmaceutical powders. In addition, by determining the suspension isotherms of these insoluble powders it could be observed whether a suspension isotherm peak occurs at one particular concentration of surfactant as is the case with manganese dioxide. The effects of electrolytes on both the adsorption and suspension isotherms would also be of interest considering the effects of these agents on micelle formation of anionic surface active agents. Finally, by correlating all the data obtained it may be that some further insight might be gained into the mechanism by which anionic surface active agents exert their effect as dispersing agents. This study is concerned with these determinations.

The powders chosen in this study were bismuth subcarbonate, calcium carbonate, titanium dioxide, zinc oxide and zirconium oxide. Anionic surface active agents selected were Aerosol OT[1], sodium lauryl sulfate and Duxad 11[2].

The electrolytes investigated were sodium chloride, monosodium citrate, sodium dihydrogen phosphate and sodium sulfate.

The results obtained from these investigations are presented in the form of two papers, immediately following, one presenting the adsorption data and the second the sedimentation data.

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1. Dioctyl sodiumsulfosuccinate - American Cyanamid.
2. A polymerized sodium salt of a sulfonic acid of the alkylaryl type - Dewey and Almay.

ADSORPTION OF SELECTED ANIONIC SURFACE ACTIVE AGENTS BY SOME PHARMACEUTICAL POWDERS*

A. P. Lemberger, L. W. Busse and G. A. Groves*

ABSTRACT

The adsorption of three types of anionic surface active agents on five common pharmaceutical powders has been measured. The effect of electrolytes on the adsorption pattern have been determined. The agreement of the adsorption curves with the Langmuir equation have been determined and the Langmuir constant, k_2, calculated. The data obtained are found to obey the Langmuir equation. The adsorption of the anionic surface active agents is shown to vary widely with the powders investigated and does not appear to be solely related to the surface area of the powder. The addition of electrolytes is found to cause a change in the adsorption pattern in most instances.

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ADSORPTION OF SELECTED ANIONIC SURFACE ACTIVE AGENTS BY SOME PHARMACEUTICAL POWDERS

Insoluble solids when wetted by, or stirred into, an aqueous fluid, either carry no electrostatic charge or are in electrostatic equilibrium. When the solid particles collide they have the tendency to stick together and form flocs. The addition of a dispersing agent, such as an anionic surface active agent, to the suspension will help in overcoming this tendency.

In pharmaceutical suspensions the stability and elegance of the preparation are dependent upon the particle size of the suspended particles. Thus, the addition of an agent which will prevent the tendency towards flocculation should be an accepted procedure in the manufacture of these pharmaceutical preparations.

The adsorption of certain anionic surface active agents by graphite and polystyrene (1) and by carbon black (2) has shown that there is a definite break in the adsorption pattern at a concentration corresponding approximately to the critical micelle concentration of the particular agent employed. It is of interest to determine whether a similar anomaly will occur in the adsorption of three structurally different anionic surface active agents by insoluble pharmaceutical powders.

EXPERIMENTAL

Materials

Aerosol OT[1] in the form of 100 per cent pure pellets was used as received. Sodium lauryl sulfate[2] was a special high purity sample prepared from middle-cut cocoanut alcohols and was also used without further purification. Daxad 11[3], a polymerized sodium salt of a sulfonic acid of the alkylaryl' type, was also used as received.

The insoluble powders used throughout these experiments were bismuth subcarbonate, calcium carbonate, titanium dioxide, zinc oxide and zirconium oxide. All were of analytical grade and were used without further purification.

The electrolytes employed were sodium chloride, monosodium citrate, sodium dihydrogen phosphate and sodium sulfate and were of analytical grade.

Carbon dioxide-free distilled water was used in the preparation of all solutions.

Measurement of Adsorption

Adsorption isotherms were determined at a temperature of 30°C.

Stock solutions of the surface active agents over a concentration range of 0.1 to 10 mg. per ml. were prepared

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1. American Cyanamid
2. Procter and Gamble
3. Dewey and Almay

and the solutions were assayed to determine their exact strength. The alkylaryl derivative was assayed spectrophotometrically using the Beckman Model Du spectrophotometer at a wavelength of 288 mu. A colorimetric method of assay which was a modification of the method of Jones (3) was employed for the sodium lauryl sulfate and the dioctyl sodium sulfosuccinate. The modification consisted essentially of using the methylene blue chloride solution of Epworth (4) which contained anhydrous sodium sulfate, and sulfuric acid instead of the straight 0.1 per cent methylene blue chloride solution as employed by Jones (3). Utilising this solution it was found to be unnecessary to adjust the pH of the solution before extraction as required in the Jones' procedure (3). In addition emulsification of the chloroform and aqueous phases did not occur in the modified procedure. The revised procedure was thus more rapid than the original procedure suggested by Jones (3). The final chloroform extracts were assayed using the Beckman Model Du spectrophotometer at a wavelength of 625 mu.

To determine the amount of adsorption of the surface active agent by the powder a 10 ml. volume of the standard solution was added to a 1 g. sample of the insoluble powder in a 25 ml. Erlenmeyer flask. The contents were then agitated for twenty minutes at 30°C. It was determined initially that adsorption was complete in this time. At the end of the agitation period the contents of the flask were centrifuged until the supernatant fluid was clear.

With the finer powders this was observed to take at least two hours at approximately 3000 rpm. This procedure was adopted for all powders. Following centrifugation a 5 ml. portion of the clear supernatant solution was diluted for analysis. The quantity of surface active agent adsorbed by the powder was calculated by difference.

Solutions containing the electrolytes in addition to the surface active agent were prepared in the manner indicated above. In each solution the concentration of the electrolyte was kept constant at 0.1 N in terms of sodium ion while the amount of surface active agent was varied.

Isotherms were determined for sodium lauryl sulfate with concentrations of surface active agent ranging from 0.1 to 10 mg. per ml. For dioctyl sodium sulfosuccinate the range determined was between 0.1 and 2.5 mg. per ml. and for the alkylaryl derivative between 0.1 and 1 mg. per ml.

Figure 1 to 7 show the isotherms obtained with the surface active agents and with the surface active agent in the presence of electrolytes.

RESULTS AND DISCUSSION

The curves show that the adsorption of the surface active agents by the five insoluble powders follows the general pattern of the Class One Langmuir isotherm. In every isotherm the curves indicate that the adsorption reaches a saturation point at high equilibrium concentrations.

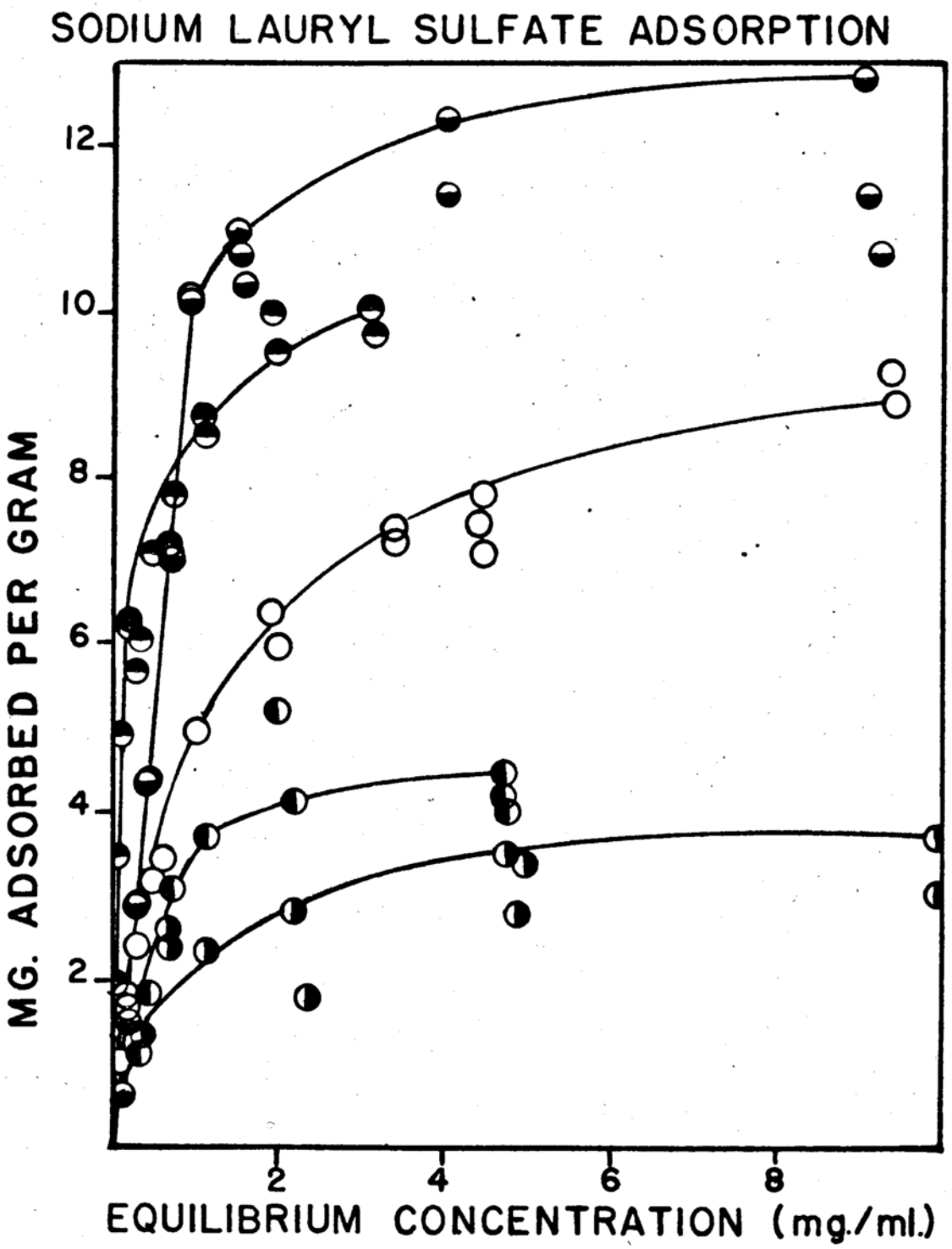


FIGURE I

○ ZINC OXIDE ◒ CALCIUM CARBONATE

◓ BISMUTH SUBCARBONATE

◐ TITANIUM DIOXIDE ◑ ZIRCONIUM OXIDE

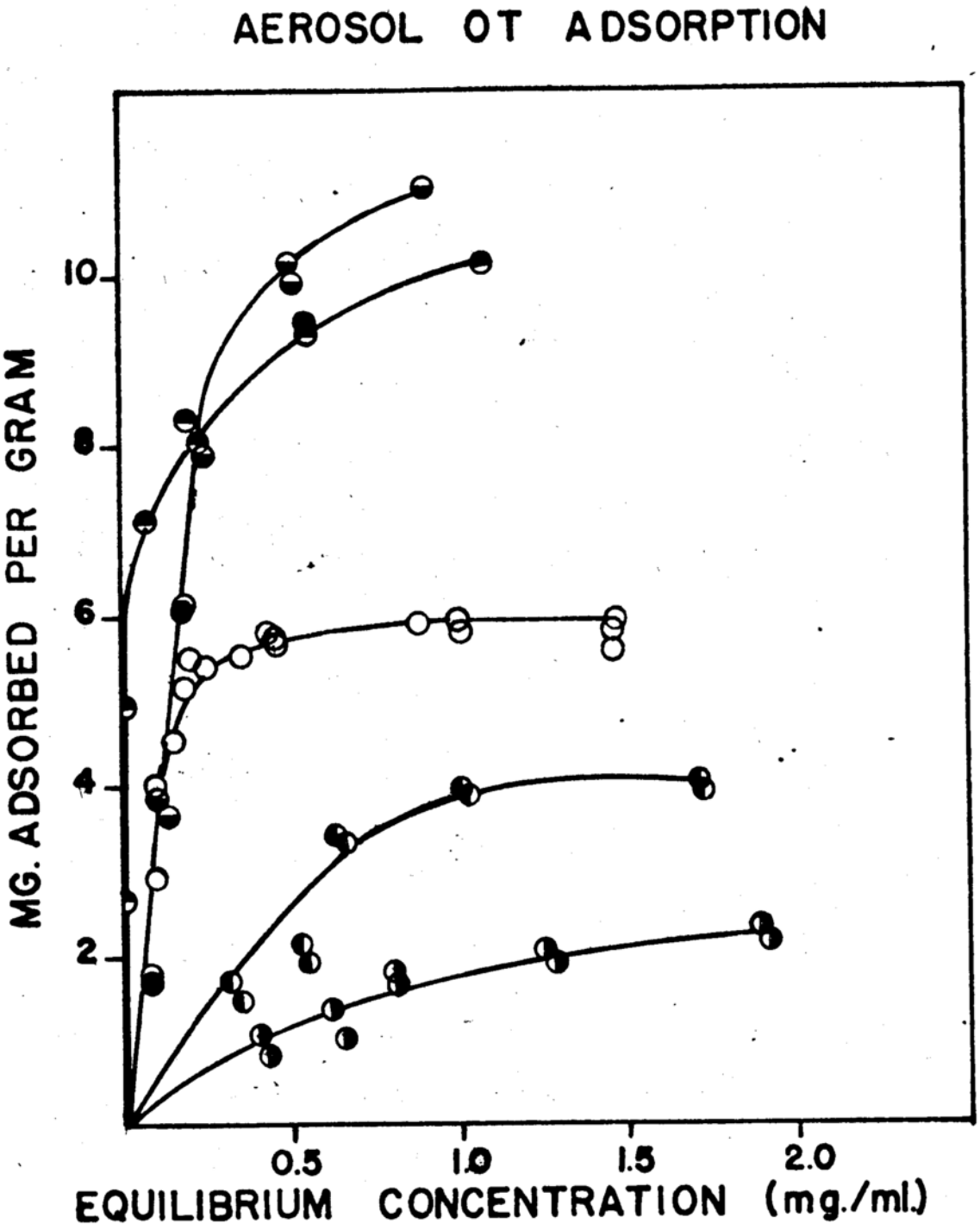


FIGURE 11

○ ZINC OXIDE ◒ CALCIUM CARBONATE

◒ BISMUTH SUBCARBONATE

◐ TITANIUM DIOXIDE ◑ ZIRCONIUM OXIDE

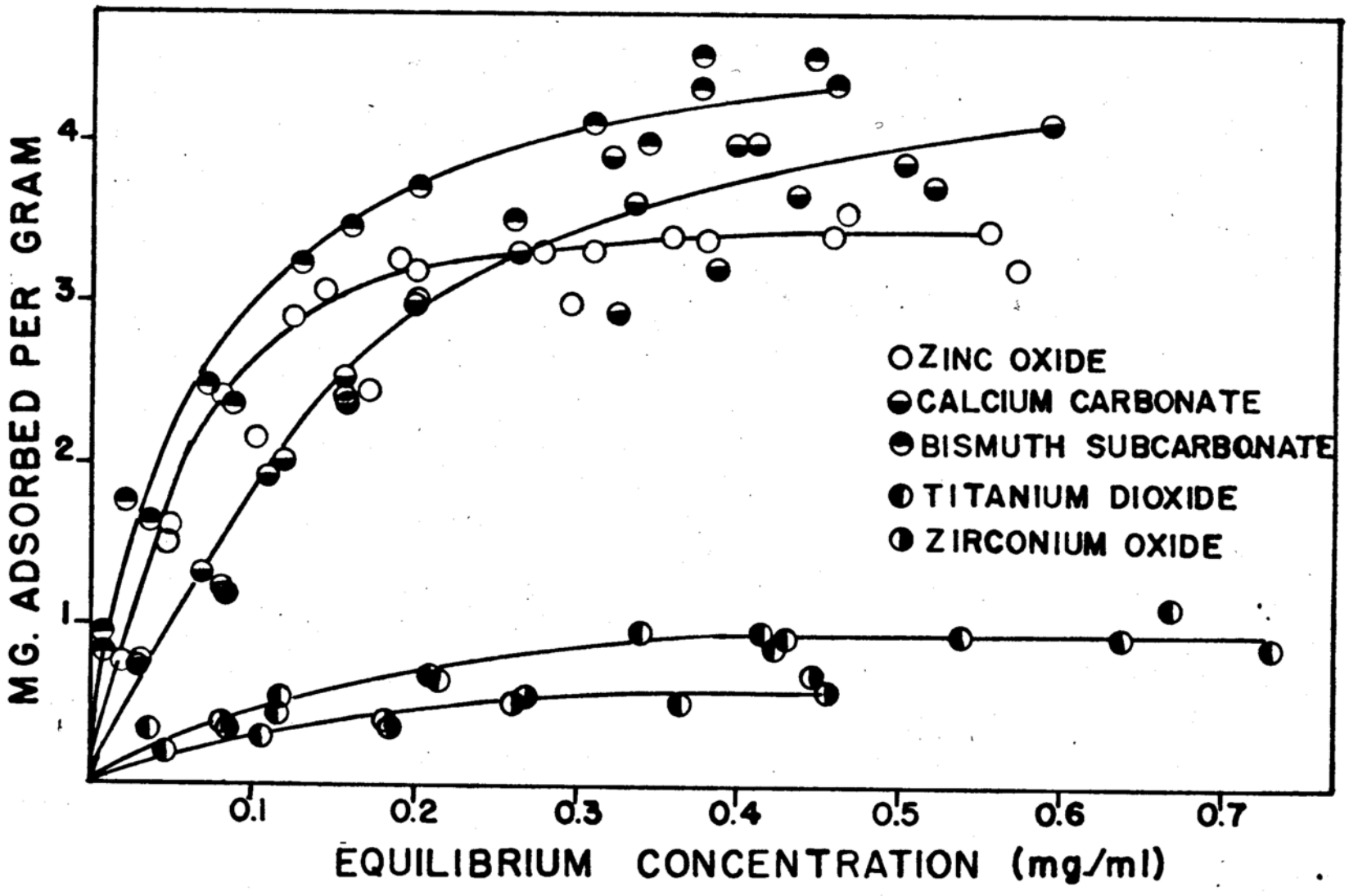

DAXAD 11 ADSORPTION
MG. ADSORBED PER GRAM
1
2
3
4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
EQUILIBRIUM CONCENTRATION (mg./ml)
ZINC OXIDE
CALCIUM CARBONATE
BISMUTH SUBCARBONATE
TITANIUM DIOXIDE
ZIRCONIUM OXIDE

FIGURE III

Further analysis of the adsorption isotherms shows that while the adsorption curve is of the same general pattern with each agent the amount of surfactant adsorbed is not the same on every powder examined. The maximum adsorption obtained on the zinc oxide sample was 8.9 mg. per g. of sodium lauryl sulfate, 5.9 mg. per g. of Aerosol OT and 3.4 mg. per g. of Daxad 11. Two explanations for this occurrence might be given. First, it might be theorized that the difference in the degree of adsorption is due to a difference in the tendency of the surface active agent involved to be adsorbed by the zinc oxide. Thus, Aerosol OT is not so readily adsorbed by the zinc oxide as is sodium lauryl sulfate and again Daxad 11 has less affinity than either of these agents for the surface of the zinc oxide. However, if this were true it would be expected that both Aerosol OT and Daxad 11 would be poorer dispersing agents for zinc oxide than sodium lauryl sulfate. This was not observed during the adsorption studies. In every instance both Aerosol OT and Daxad 11 appeared to more readily disperse the powder than did the sodium lauryl sulfate indicating complete wetting of all the particles. Further, if it were solely a question of affinity to the powder which accounted for the differences in the extent of adsorption it would be expected that some of the powders would show a higher amount of adsorption in some instances for one of the other agents than for sodium lauryl sulfate. This did not occur with any of the powders investigated. On this basis

a second explanation for the different degrees of adsorption by the three surface active agents might be given. It has been established (5) that surface active agents are adsorbed by the surface of insoluble powders in such a manner as to form a monomolecular film. Knowing this it is possible to examine the chemical structure of sodium lauryl sulfate and Aerosol OT for a possible explanation for the different degrees of adsorption. Sodium lauryl sulfate is an aliphatic sulfate with the hydrophilic portion at one end of the chain. Thus, it would be expected that it would occupy less area per molecule than would Aerosol OT where the hydrophilic group is in the center of the molecule giving two branches which may be spread out to cover a given surface area. Consequently it might be theorized that the zinc oxide is able to adsorb more sodium lauryl sulfate than Aerosol OT as it can hold more molecules per given surface area of the powder.

Further support to this theory might be given by considering Langmuir's constants. Since the type of isotherm obtained with all of the powders is of the Class One Langmuir type the isotherm may be represented by Langmuir's equation (6).

$$x/m = k_1 k_2 c/(1 + k_1 c)$$

where x/m = mg. of surface active agent adsorbed per g. of adsorbent

c = equilibrium concentration of surface active agent in mg. per ml.

k_1 and k_2 = constants

At higher concentrations the equation approaches

$$x/m = k_2$$

and thus the value of the constant k_2 is a good indication of the amount of surface active agent which would saturate a unit surface area with a monomolecular film.

The application of the Langmuir equation to the isotherm can be determined by plotting $c/(x/m)$ against c. A straight line will be obtained if the isotherm fits the equation. This line will have a slope of $1/k_2$ and an intercept of $1/k_1k_2$.

A sample plot of $c/(x/m)$ versus C is shown in Figure 4. Similar plots were obtained with all other adsorbent - surface active agent combinations indicating that the isotherms obtained were of the Langmuir type.

The constant k_2 which is an indication of the adsorptive capacity of the powder for the specific surface active agent was calculated for all combinations. These values are shown in Table I. In most instances it will be noted that the saturation level is close to the calculated k_2 value indicating that the surface of the solid is covered with a monomolecular layer of the surface active agent.

In the adsorption studies performed on zinc oxide and bismuth subcarbonate the studies were carried out on powders whose surface areas had previously been determined by the nitrogen adsorption method (7). The surface area of the

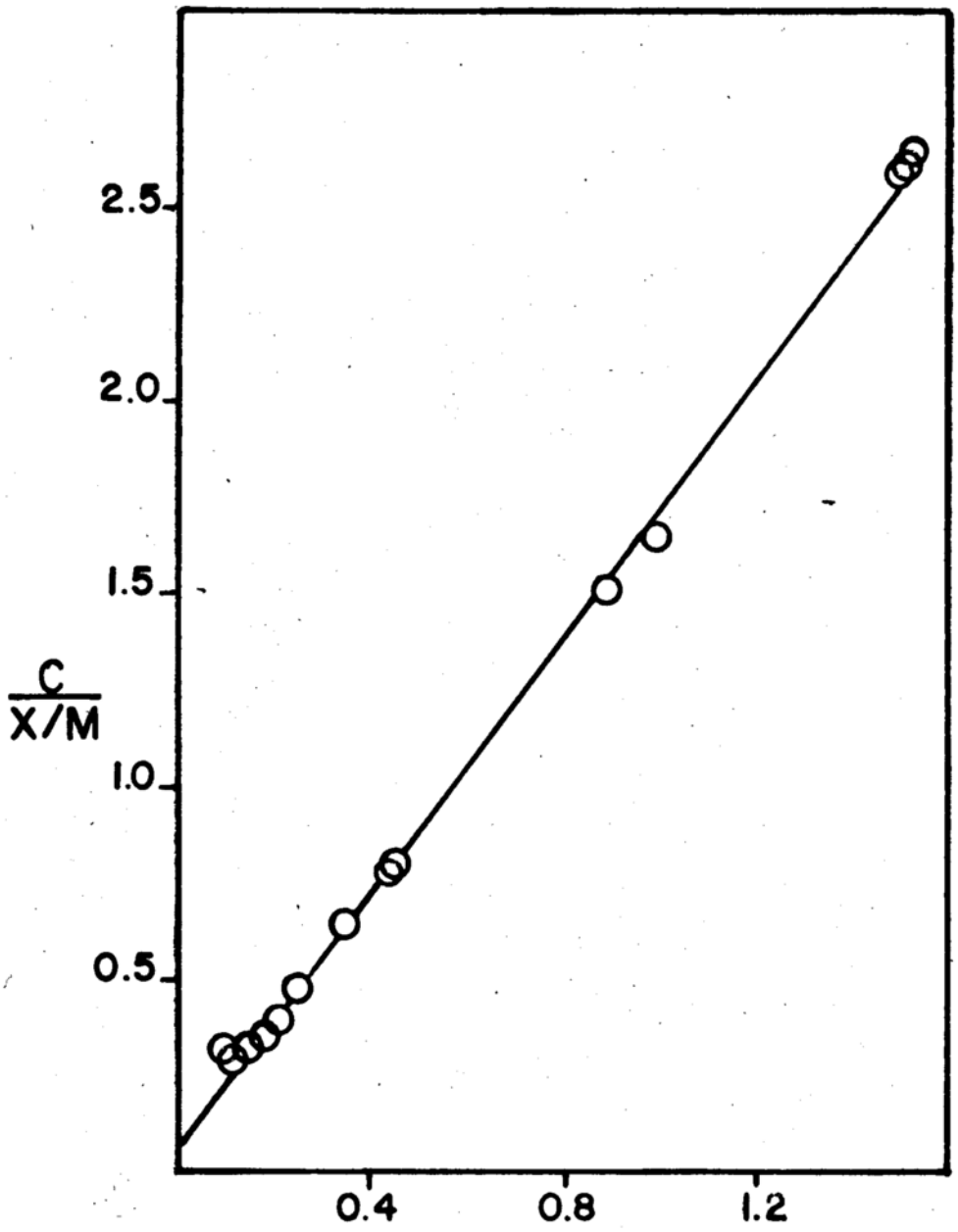


FIGURE IV

Typical plot of the data fitted by the Langmuir isotherm. Plot is the adsorption of Aerosol OT on zinc oxide.

TABLE I

Comparison of Langmuir's Constant and the Saturation Level

Nature of Dispersion	k_2	Saturation Level
Sodium Lauryl Sulfate - Zinc Oxide	10.8	8.9
" " " - Calcium Carbonate	14.7	12.9
" " " - Bismuth Subcarbonate	10.6	10.1
" " " - Titanium Dioxide	5.2	4.6
" " " - Zirconium Oxide	4.1	3.7
" " " - Zinc Oxide-Sodium Chloride	9.1	8.7
" " " - Zinc Oxide-Sodium Sulfate	9.5	8.7
" " " - Zinc Oxide-Sodium Citrate	6.0	5.1
Aerosol OT - Zinc Oxide	6.0	5.9
" " - Calcium Carbonate	14.1	11.1
" " - Bismuth Subcarbonate	9.5	10.1
" " - Titanium Dioxide	5.4	3.9
" " - Zirconium Oxide	4.7	2.0
" " - Zinc Oxide-Sodium Chloride	6.4	6.0
" " - Zinc Oxide-Sodium Sulfate	6.7	6.6
" " - Zinc Oxide-Sodium Citrate	6.6	6.1
Daxad 11 - Zinc Oxide	4.2	3.5
" " - Calcium Carbonate	6.9	4.1
" " - Bismuth Subcarbonate	5.1	4.4
" " - Titanium Dioxide	1.1	0.9
" " - Zirconium Oxide	0.7	0.5
" " - Zinc Oxide-Sodium Chloride	4.7	3.8
" " - Zinc Oxide-Sodium Sulfate	4.4	2.3
" " - Zinc Oxide-Sodium Citrate	3.4	1.9
" " - Zinc Oxide-Sodium Phosphate	-	0.4

The k_2 values and the saturation level are stated in terms of milligrams adsorded per gram of material.

zinc oxide employed was 3.98 square meters per g. and of the bismuth subcarbonate, 4.62 square meters per g. Knowing the surface area of the powders and the k_2 values for the adsorption of the surface active agent it is possible to calculate the area occupied by one molecule of the surface active agent. These values for zinc oxide were found to be 21 square angstroms for sodium lauryl sulfate adsorption and 37 square angstroms for Aerosol OT adsorption. In the case of bismuth subcarbonate these values were calculated to be 18 and 49 square angstroms respectively. In both instances the area occupied by the Aerosol OT is two or more times greater than the area occupied by the sodium lauryl sulfate on the same powder. This indicates further that the presence of the hydrophilic group in the center of the Aerosol OT molecule giving it two side arms enables it to occupy a greater surface area than the sodium lauryl sulfate. Therefore, there is relatively less Aerosol OT adsorbed than of sodium lauryl sulfate on the same powder.

Although the chemical structure of Daxad 11 has not been determined it is known to be a polymerized naphthalene sulfonate with aliphatic side chains (8) and it is logical to assume that a molecule of this type would occupy a much larger surface area than would a molecule of either sodium lauryl sulfate or Aerosol OT. Therefore, the number of molecules per unit area of the monomolecular film would be less with Daxad 11 than with either of the other two surface active agents and therefore its adsorption at the saturation

point would be less.

Further examination of the isotherms will show that the amount of surface active agent adsorbed varies considerably from one powder to another. Calcium carbonate showed the greatest degree of adsorbability for both Aerosol OT and sodium lauryl sulfate. The greatest adsorbability for Daxad was shown by bismuth subcarbonate. With all three surface active agents the least adsorbability was shown by zirconium oxide with not much more being shown by titanium dioxide. In the case of Daxad 11 the amount adsorbed by both zirconium oxide and titanium dioxide was so slight as to be just measurable.

As indicated above isotherms were determined in the case of bismuth subcarbonate and zinc oxide using powders whose surface areas had previously been determined by the nitrogen adsorption method (7). The surface area of the zinc oxide employed was 3.98 m^2 per g. and of the bismuth subcarbonate, 4.62 m^2 per g. With its greater surface area the bismuth subcarbonate would be expected to adsorb more of the surface active agent than the zinc oxide and this was found to occur. However, titanium dioxide which may be expected to have a higher specific surface area than either the zinc oxide or the bismuth subcarbonate showed very little adsorbability for any of the surface active agents. In the case of Daxad 11 titanium dioxide only adsorbed 0.8 mg. per g. at the saturation point as compared to 4.6 mg. per g. for bismuth subcarbonate and 3.6 mg. per g. for zinc oxide.

Therefore, it would appear that there is not necessarily a direct relationship between the surface area of the powder and the degree to which it will adsorb the surface active agent. Factors other than the surface area of the powder appear to be involved in the adsorption phenomenon.

Rose and co-workers (2) in studying the adsorption of synthetic surface active agents by carbon black observed that the adsorption did not conform with the Freundlich equation over the entire concentration range studied. They noted that most of the curves obtained exhibited a change in slope at concentrations which appeared to correspond approximately to the critical micelle concentrations. Rose et al (2) found the portions of the curve above the critical micelle concentration to be linear by Freundlich's equation, while below this concentration the curves for some of the compounds exhibited considerable deviation from lineality.

Comparing the k_2 values calculated with the saturation levels obtained (Table I) for the adsorption of Daxad 11 it can be seen that with the exception of the adsorption on calcium carbonate the two values are practically identical. This would appear to indicate that the adsorption of Daxad 11 by the powders had proceeded according to Langmuir's equation. No explanation can be offered for the exception in the case of calcium carbonate.

Aerosol OT also gave k_2 values very close to the saturation level in the case of zinc oxide. Again, however, in the case of calcium carbonate the saturation level was

considerably lower than the calculated k_2 value. With bismuth subcarbonate a k_2 value was calculated which was lower than the saturation level (9.5 as compared to 10.1). Again there does not appear to be any explanation for this phenomenon. Since the k_2 values and the saturation level for Aerosol OT adsorption on all except calcium carbonate are identical within the range of experimental error it would appear that the adsorption curves obeyed Langmuir's equation.

In the studies with sodium lauryl sulfate it was found that the calculated k_2 values were considerably in excess of the saturation point obtained. This would appear to indicate that some factor had intervened to prevent complete adsorption of the sodium lauryl sulfate to the full capacity of the powders concerned.

Investigations of the effect of electrolytes on the adsorption of surface active agents were conducted for several reasons. These agents are frequent components of pharmaceutical mixtures and might be employed in mixtures in the presence of these surfactants. In addition sodium sulfate is a common contaminant of commercial surfactants and might influence the adsorption.

Results showed that sodium dihydrogen phosphate prevented the adsorption of both Aerosol OT and sodium lauryl sulfate on zinc oxide. With Daxad 11 adsorption was found to occur but was very slight as compared to the

adsorption of Daxad 11 alone (Figure 7).

Monosodium citrate was also observed to lower the amounts of Daxad 11 which could be adsorbed by zinc oxide (Figure 7). A similar result was obtained with sodium lauryl sulfate (Figure 5) but with Aerosol OT no significant difference in the saturation level was observed.

Sodium sulfate also lowered the adsorption of Daxad 11 (Figure 7). The adsorption of Aerosol OT (Figure 6) was again potentiated while there was no significant change in the saturation level for the adsorption of sodium lauryl sulfate by zinc oxide (Figure 5). Rose et al (2) observed that sodium sulfate increased the adsorption of sodium lauryl sulfate by carbon black so these results are not entirely in agreement.

While the lowering of the saturation level was not as great for Daxad 11 in the presence of sodium chloride as with the other electrolytes some lowering did occur (Figure 7). However, the saturation level of Aerosol OT (Figure 6) and sodium lauryl sulfate (Figure 5) were not significantly altered by the presence of the sodium chloride.

An examination of Figures 5 to 7 will show that the electrolytes did have some influence on the shape of the adsorption curve whether or not there were changes in the saturation level. This is particularly noticeable in the case of sodium lauryl sulfate where the saturation level was reached at an equilibrium concentration between 0.25

INFLUENCE OF ELECTROLYTES ON

SODIUM LAURYL SULFATE ADSORPTION

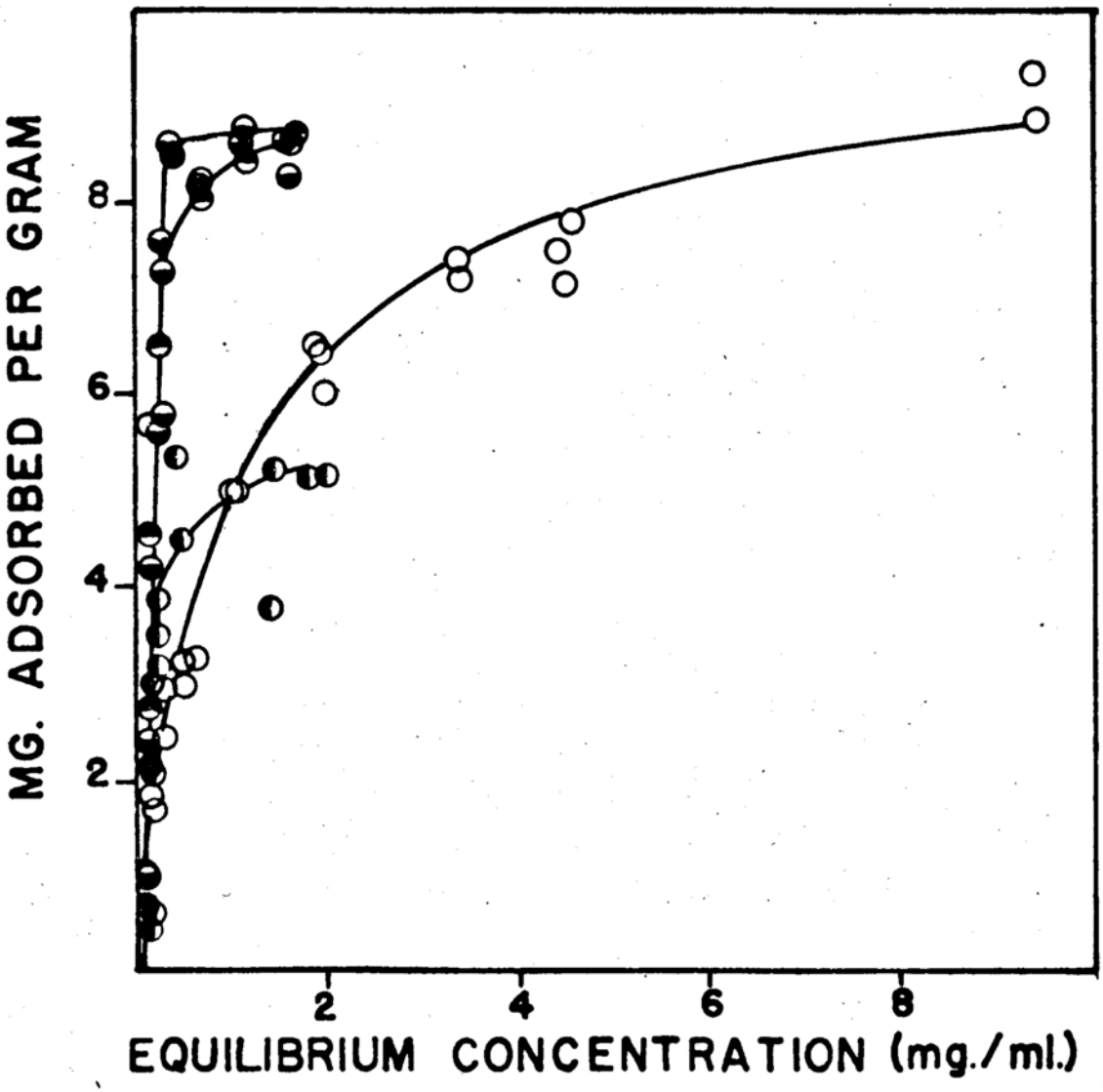
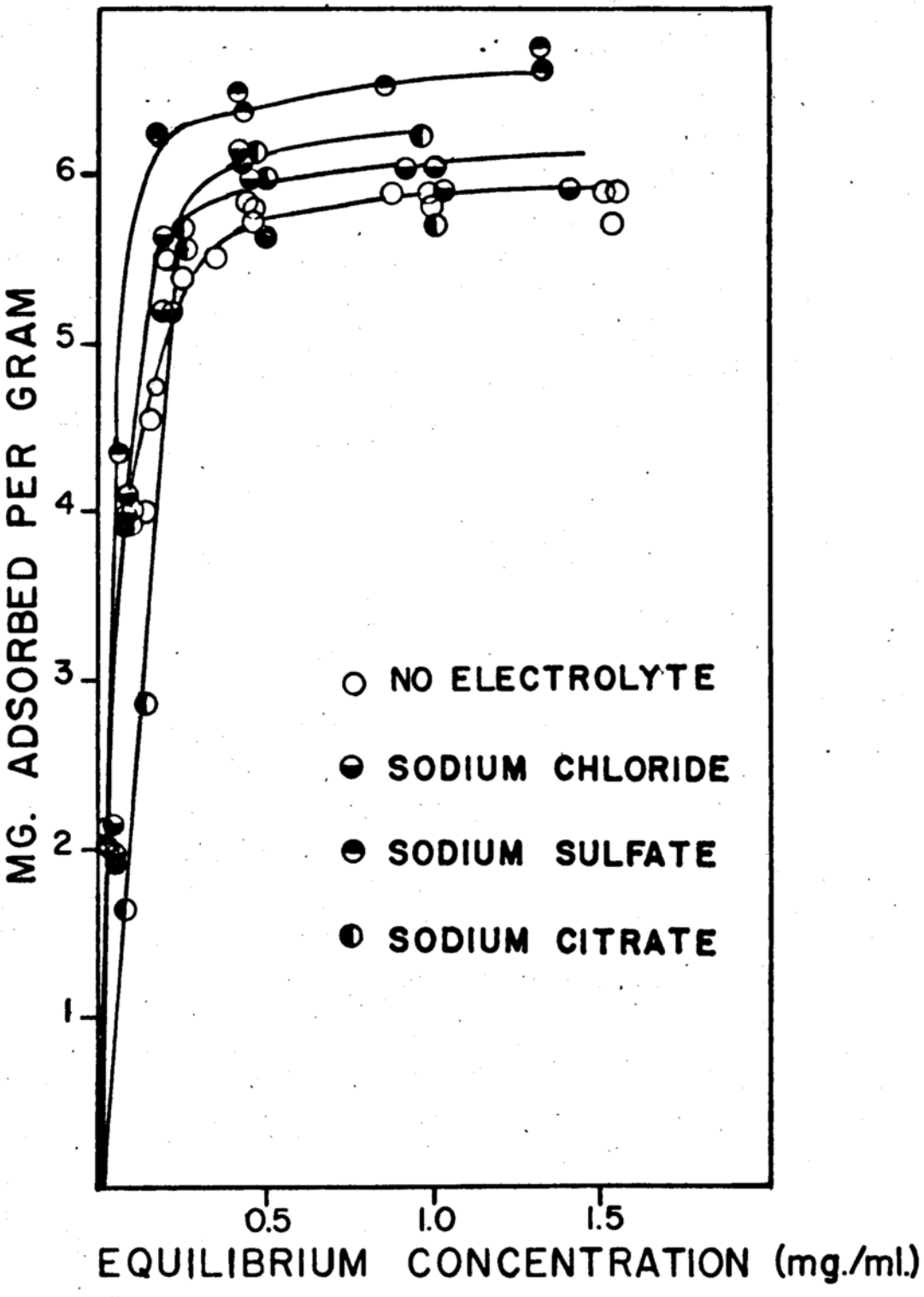


FIGURE V

INFLUENCE OF ELECTROLYTES ON AEROSOL OT ADSORPTION

FIGURE VI



INFLUENCE OF ELECTROLYTES ON DAXAD II ADSORPTION

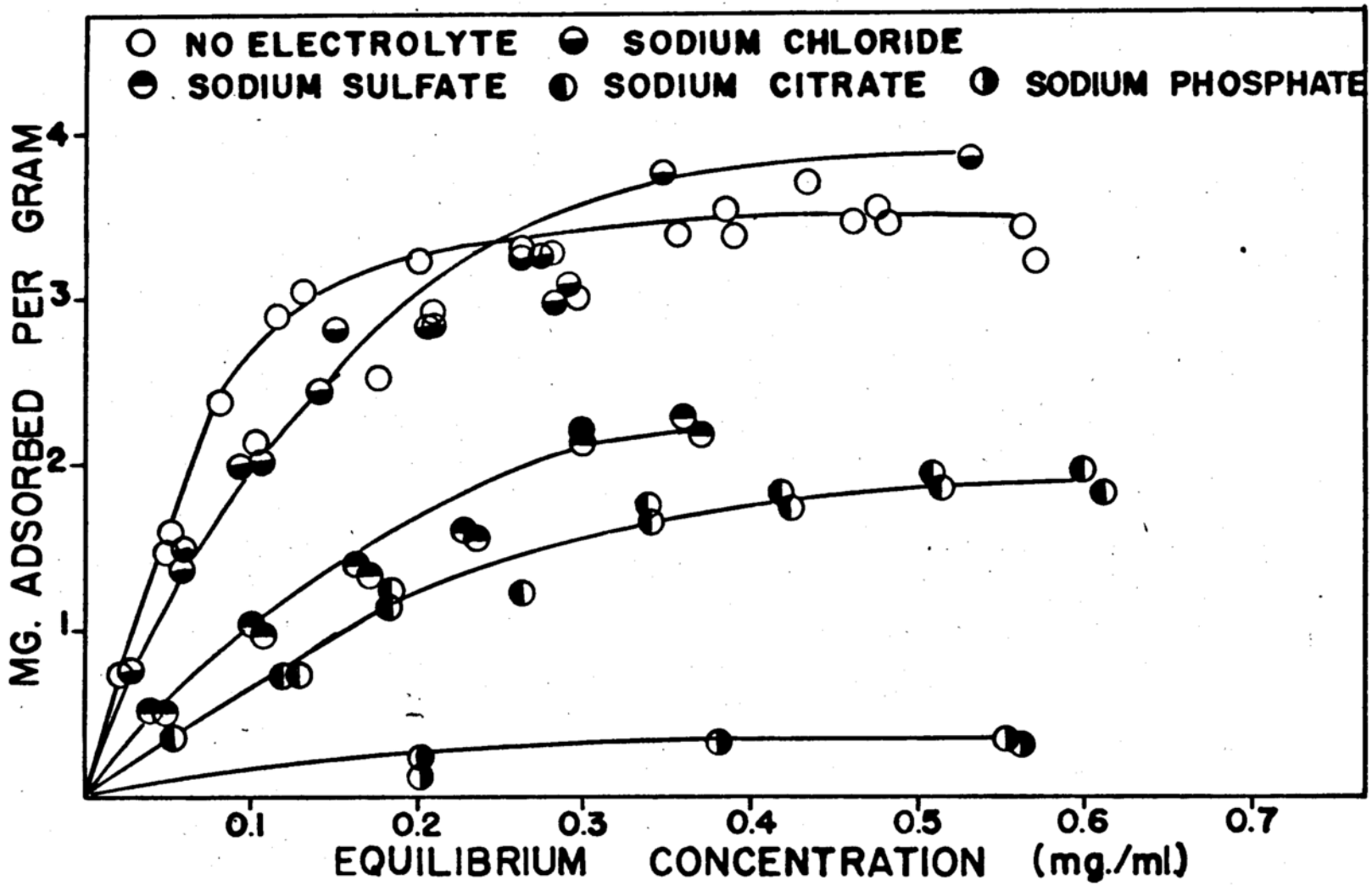


FIGURE VII

and 0.50 mg. per ml. with the electrolytes present as compared to approximately 4 mg. per ml. in the absence of electrolytes.

By comparing the calculated k_2 values with the saturation levels obtained (Table I) it can be seen that there is a much greater variance between the two values than there is in the absence of electrolytes. An exception to this is in the case of the adsorption of Aerosol OT in the presence of sodium chloride and sodium sulfate respectively. This would appear to indicate that, with the exception of the adsorption of Aerosol OT, there was some interference with the adsorption in the presence of the electrolytes.

In the case of Daxad 11 the greater variance might be due to preferential adsorption of the electrolytes in place of the surface active agent. A similar observation might be made with respect to the adsorption of sodium lauryl sulfate. With respect to Aerosol OT where there is little or no variance it would appear that the adsorptive capacity of the Aerosol OT is sufficiently strong to nullify the effects of the electrolytes.

SUMMARY

The three anionic surface active agents investigated all showed an adsorption pattern which corresponded to the normal Langmuir isotherm. Electrolytes were observed to alter the adsorption pattern and also to interfere with the

saturation level of the isotherm with the exception of sodium chloride. Sodium sulfate lowered the saturation level for Daxad 11 but not for Aerosol OT or sodium lauryl sulfate to a significant extent. Sodium citrate lowered the saturation level for Daxad 11 and sodium lauryl sulfate but had little effect on the saturation level of Aerosol OT. Sodium phosphate virtually eliminated the adsorption of all agents.

It would appear that the adsorption of an anionic surface active agent by a pharmaceutical power is specific. The amount of adsorption will depend upon the nature of the surface active agent, the nature of the powder and the presence of other electrolytes in the system.

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A STUDY OF ANIONIC SURFACE ACTIVE AGENTS AS DISPERSING AGENTS IN PHARMACEUTICAL SYSTEMS*

G. A. Groves†, A. P. Lemberger and L. W. Busse

ABSTRACT

An investigation of the suspension of several selected pharmaceutical powders by three anionic surface active agents has shown that the suspension obtained is dependent upon the nature of both the insoluble powder and the surface active agent. In general the amount suspended has been shown to pass through a maximum with a low concentration of the surface active agent. It has been found that to a large extent the suspending ability of the surface active agent is related to its ability to be adsorbed on the surface of the powder concerned. Electrolytes have been found to inhibit the suspending ability of the surface active agents in the majority of cases.

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A STUDY OF ANIONIC SURFACE ACTIVE AGENTS AS DISPERSING AGENTS IN PHARMACEUTICAL SYSTEMS

In the technology of pharmaceutical magmas, suspensions, and similar preparations the size of the dispersed particle is of paramount importance in controlling the stability and elegance of these mixtures. Insoluble particles in the presence of water cling together to form agglomerates or flocs which settle at a much faster rate than would the individual particles if they were kept separate. The addition of a dispersing agent to the system will assist in overcoming this tendency and thus aid in stabilizing the dispersion of the insoluble powders.

Previous investigators (1, 2) in evaluating the efficiency of anionic surface active agents have shown that there is a certain optimum concentration where these agents exhibit a maximum effectiveness. Vold and co-workers (1) have shown that in the dispersion of manganese dioxide in solutions of synthetic surface active agents the curves of amount suspended versus concentration pass through a maximum at low concentrations.

The purpose of this investigation was to determine whether such characteristic curves would be obtained with typical pharmaceutical powders. Data on the adsorption of these agents by the above powders have previously been

presented (3).

Inasmuch as pharmaceutical suspensions commonly contain electrolytes it was thought of interest to determine the effects of electrolytes upon the dispersing ability of the surface active agents.

EXPERIMENTAL

Materials

The insoluble powders, surface active agents and electrolytes were identical with those previously employed in the adsorption studies (3).

Apparatus and Procedure

The method employed in evaluating the dispersing ability of the anionic surface active agents was a modification of the procedure outlined by Griener and Vold (1). Briefly, the suspension after thorough mixing was allowed to stand undisturbed for a two hour period. Following this sedimentation period all the suspension to a depth of 23.5 cm. was withdrawn and analyzed for solid content to determine the amount of powder remaining in suspension.

The apparatus is shown in Figure 1. The surface active agent was dissolved in sufficient water to make 250 ml. of solution. Two hundred ml. of this solution was then placed in the sedimentation chamber which consisted essentially of a twelve inch test tube previously calibrated at

the 50 ml. and 250 ml. levels. The distance between these levels was 23.5 cm. in every instance. A 2 g. sample of the powder to be investigated was added to the solution of surface active agent in the chamber of the stirring apparatus and stirred for exactly two minutes. This suspension was transferred quantitatively to the sedimentation chamber and the volume was adjusted to the 250 ml. level with the balance of the solution of surface active agent. The sedimentation chamber was then stoppered and agitated vigorously for a further eighteen minutes. This brought the total period of agitation to twenty minutes. The suspension was then allowed to stand for two hours undisturbed after which time the suspension down to the 50 ml. mark was withdrawn in such a manner as not to disturb the sediment. This was accomplished by using a withdrawal tube with an upturned tip and a slow rate of withdrawal (25 ml. per minute) as recommended by Griener and Vold (1). The suspension was then assayed to determine the amount of material remaining in suspension.

Zinc oxide was assayed by the U.S.P. XV procedure involving the dissolution of the solid in standard sulfuric acid in the presence of ammonium chloride and back titrating with standard sodium hydroxide solution.

Calcium carbonate was assayed by the procedure stated in the B.P., 1932. This procedure consisted of dissolving the carbonate in an excess of standard hydrochloric acid and determining the excess of acid by back titrating with

standard sodium hydroxide solution.

Bismuth subcarbonate, titanium dioxide and zirconium oxide were assayed according to a gravimetric technique. The suspension was centrifuged until the supernatant liquid was clear. This supernatant liquid was then decanted carefully and the residue was collected, dried and weighed.

Suspension isotherms were obtained by plotting the amount of solid remaining in suspension as a function of the concentration of the surface active agent in the dispersion medium.

Suspension isotherms were also obtained in the same manner for surface active agents plus electrolytes. In each instance the concentration of the electrolyte was kept constant at 0.1 gram - ions of sodium ion in the solution and the concentration of the surface active agent only was varied.

RESULTS AND DISCUSSION

The isotherms obtained are shown in Figures 2 to 9.

As is evident in the curves of Figures 2 to 9 the suspending power of the anionic surface active agents varies both in respect to the nature of the agent employed and with the nature of the powder being suspended. In general it appears that there is an optimum concentration of surface active agent at which a maximum in the amount of suspended material is obtained. However, this maximum is not as

pronounced in the case of zirconium oxide (Figure 6).

Data obtained indicate that Daxad 11 is a slightly better overall dispersant than either sodium lauryl sulfate or Aerosol OT. This statement is based upon two observations. First, in most instances the amount of powder suspended by this agent at the optimum concentration is found to be slightly greater than the maximum amount suspended by either sodium lauryl sulfate or Aerosol OT. Secondly, the optimum concentration of Daxad 11 as a dispersant is found to be considerably lower than the optimum concentration for either of the other two agents investigated. This observation is in line with the adsorption data previously obtained (3). It was observed in this study that the saturation level for the adsorption of Daxad 11 by the insoluble powders was reached with a much lower concentration of Daxad 11 than with either sodium lauryl sulfate or Aerosol OT.

Studies on the dispersing ability of sodium lauryl sulfate and Aerosol OT indicate that these agents possess approximately the same degree of effectiveness with respect to the maximum amount of powder remaining in suspension at the end of the sedimentation period. However, it is again observed that the maximum effective concentration of Aerosol OT is, in general, less than the maximum effective concentration of the sodium lauryl sulfate. This again is in agreement with the adsorption data (3) where the maximum adsorptive capacity is reached with a lower concentration

of Aerosol OT than with sodium lauryl sulfate.

Although the relative degree of effectiveness of the three agents investigated is in decreasing order Daxad 11 - Aerosol OT - sodium lauryl sulfate, one exception must be noted. In the suspension of calcium carbonate, Aerosol OT is found to be a better dispersant with respect to the maximum amount suspended than either sodium lauryl sulfate or Daxad 11. This anomaly would appear to indicate the possibility of a specific interaction favoring the adsorption of the Aerosol OT with calcium carbonate.

Addition of electrolytes to the dispersion medium for zinc oxide suspensions is found to inhibit the suspending ability of the three anionic surface active agents in all but one instance.

In particular the addition of sodium dihydrogen phosphate to the solution of the surface active agent completely inhibits the suspending ability of these agents. The zinc oxide was observed to flocculate immediately. In no instance was any powder left in suspension at the end of the two hour period. In these cases it was previously observed (3) that adsorption of the surface agent on the zinc oxide either did not occur or was substantially reduced, possibly through preferential adsorption of the phosphate. Instability of these suspensions would then appear to be due to the failure of the zinc oxide particles to become stabilized through adsorption of the surface active molecule.

Complete inhibition of the suspension is also obtained with monosodium citrate (Figure 9) when Daxad 11 is employed as the dispersant. In the other cases a reduction in the effectiveness of the surface active agents is observed. This is readily seen in Figures 7 and 8. In contrast to the situation where sodium dihydrogen phosphate was added as electrolyte, adsorption studies (3) in the presence of these electrolytes have shown that the adsorption of the surface active agent by the zinc oxide is not greatly reduced. In fact with Aerosol OT the adsorption is enhanced and maximum adsorption is observed at a lower concentration of the surface active agent.

Several theories have been advanced (1, 2, 4, 5) in attempts to explain why one concentration of an anionic surface active agent should produce a maximum dispersion of the insoluble powder. Harkins and Gans (4) have stated that the quantity of dispersant estimated to form a monomolecular film on the pigment particles may be considered to be the minimum required to register a decided change in the properties of the dispersion. It might be stated, therefore, that the ineffectiveness of concentrations of the surface active agents below the maximum effective concentration could be attributed to the lack of sufficient dispersing agent to completely cover all the particles with a monomolecular film. Particles not sufficiently protected would have a tendency to aggregate and form flocs which would settle to the bottom of the sedimentation chamber at

a much faster rate than would the individual unit particles.

Vold and co-workers (1, 2) have theorized that the formation of stable dispersions of insoluble powders may be primarily attributed to a change in the zeta potential on the solid particles caused by the adsorption of simple ions from solution. This, they state, results in a lack of dependence of suspendability on the lyophilic properties of the colloidal solution or its ability to lower surface tension. These investigators state that the existence of a maximum in the suspension curve may be explained in terms of the initial preferential adsorption of one of the ions. This initial preferential adsorption would promote stability by increasing the zeta potential of the insoluble particles. The loss of stability at higher concentrations of the surface active agent would be due to the antagonistic effect of the ion of opposite charge to that first adsorbed.

The results obtained in the suspensions containing the electrolytes (Figures 7 to 9) are in harmony with this theory. In general the inhibitory effect approximately parallels the increase in ionic strength of the solution indicating that the effect is probably related to a reduction of the zeta potential. An anomaly occurred in the suspension of zinc oxide by Aerosol OT in solutions containing sodium chloride. In this case better suspensions of the zinc oxide are obtained than in the absence of the sodium chloride. No explanation can be offered at this time for this exception to the general pattern.

It therefore appears from this study that the influence of electrolytes upon a suspension may be beneficial or detrimental. Where the electrolyte present decreases the stability of the suspensions, it usually does so through its influence on the zeta potential. However, it is also possible that the effect may be caused by inhibition of adsorption at the solid-liquid interface. At the present time it is necessary to investigate each case to determine the exact nature of the effect.

Sedimentation and Dispersion Apparatus (not drawn to scale).

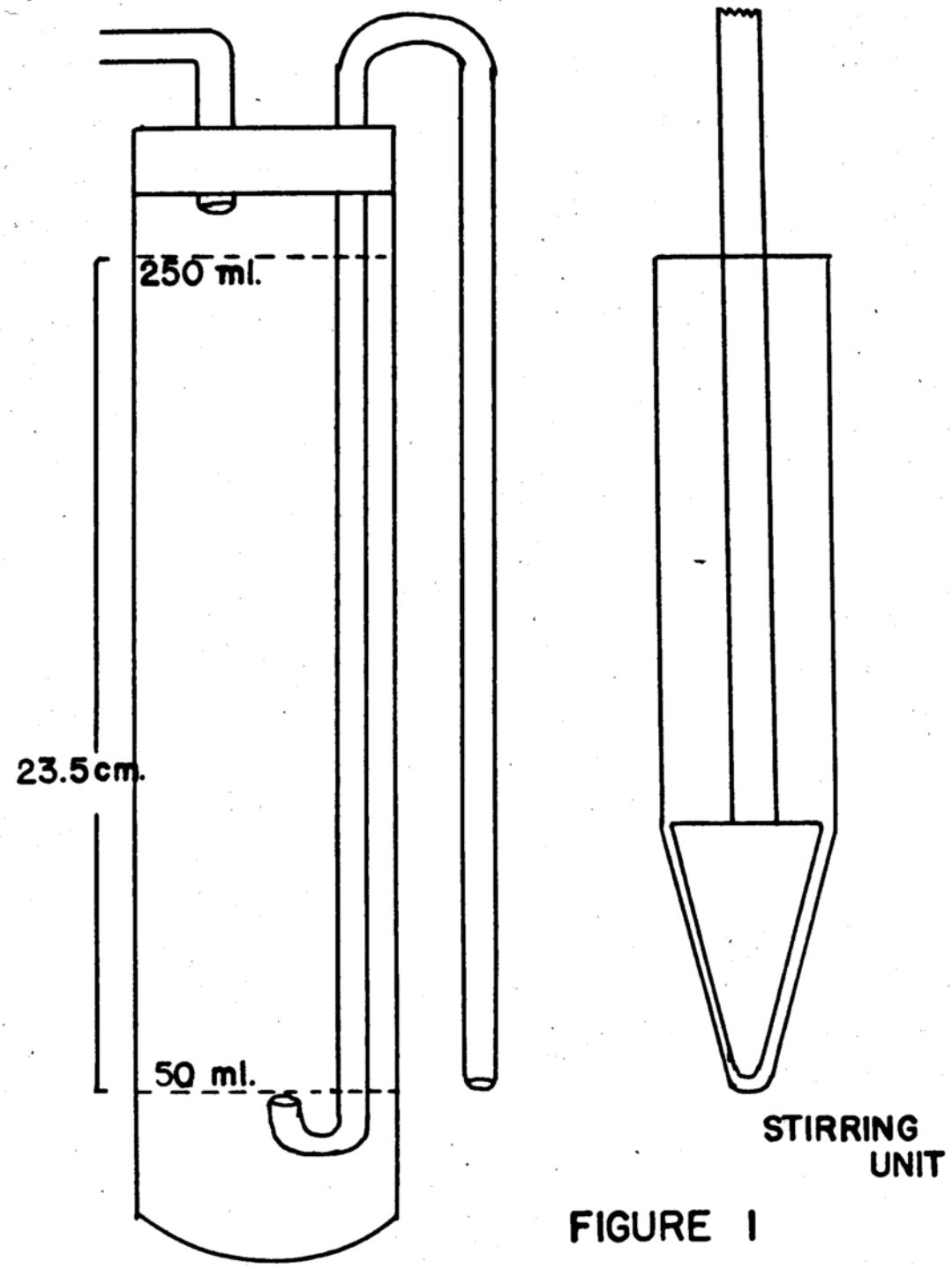

FIGURE 1

Suspension of Zinc Oxide by Anionic Surface Active Agents at 30°C.

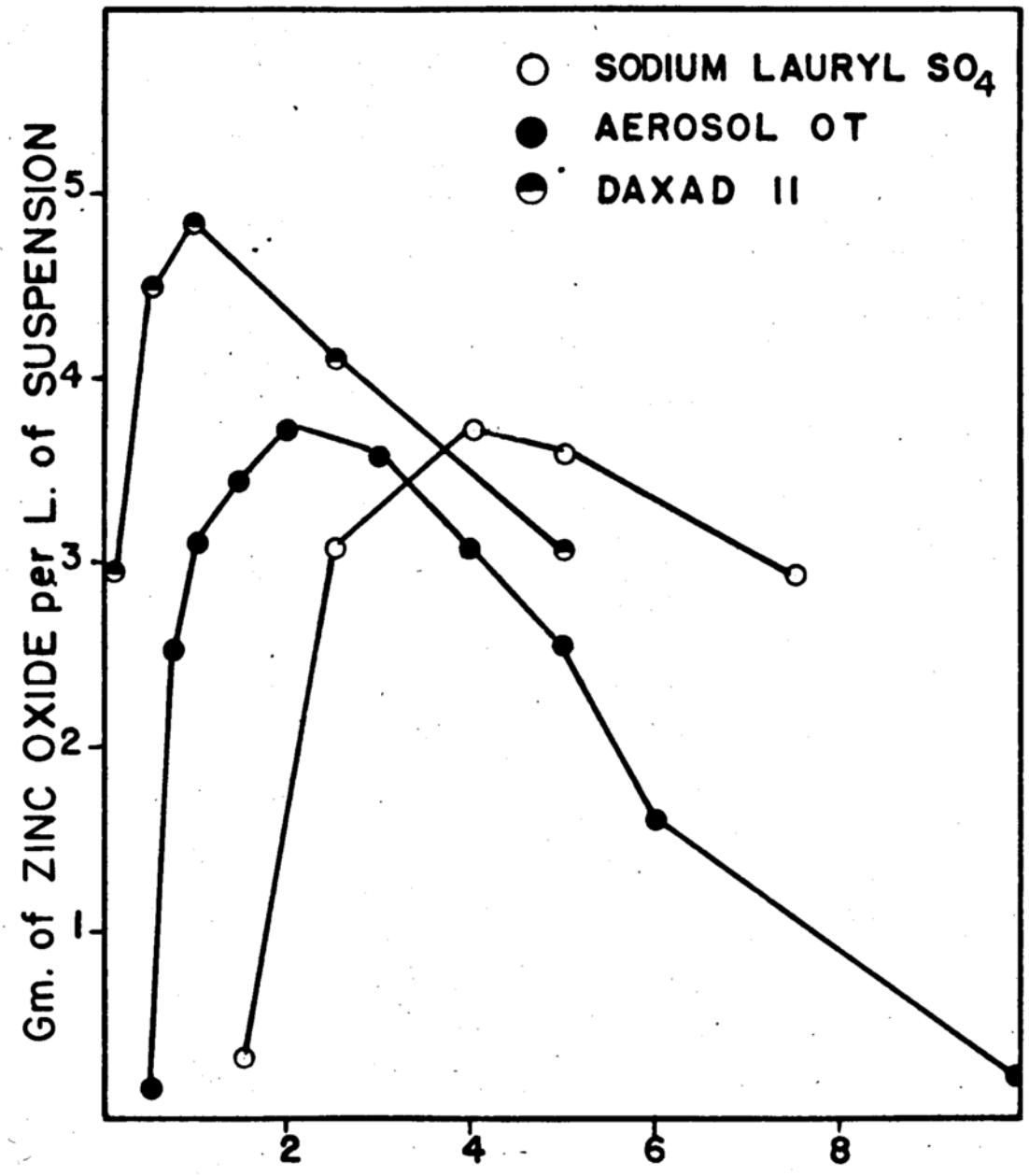

FIGURE 11

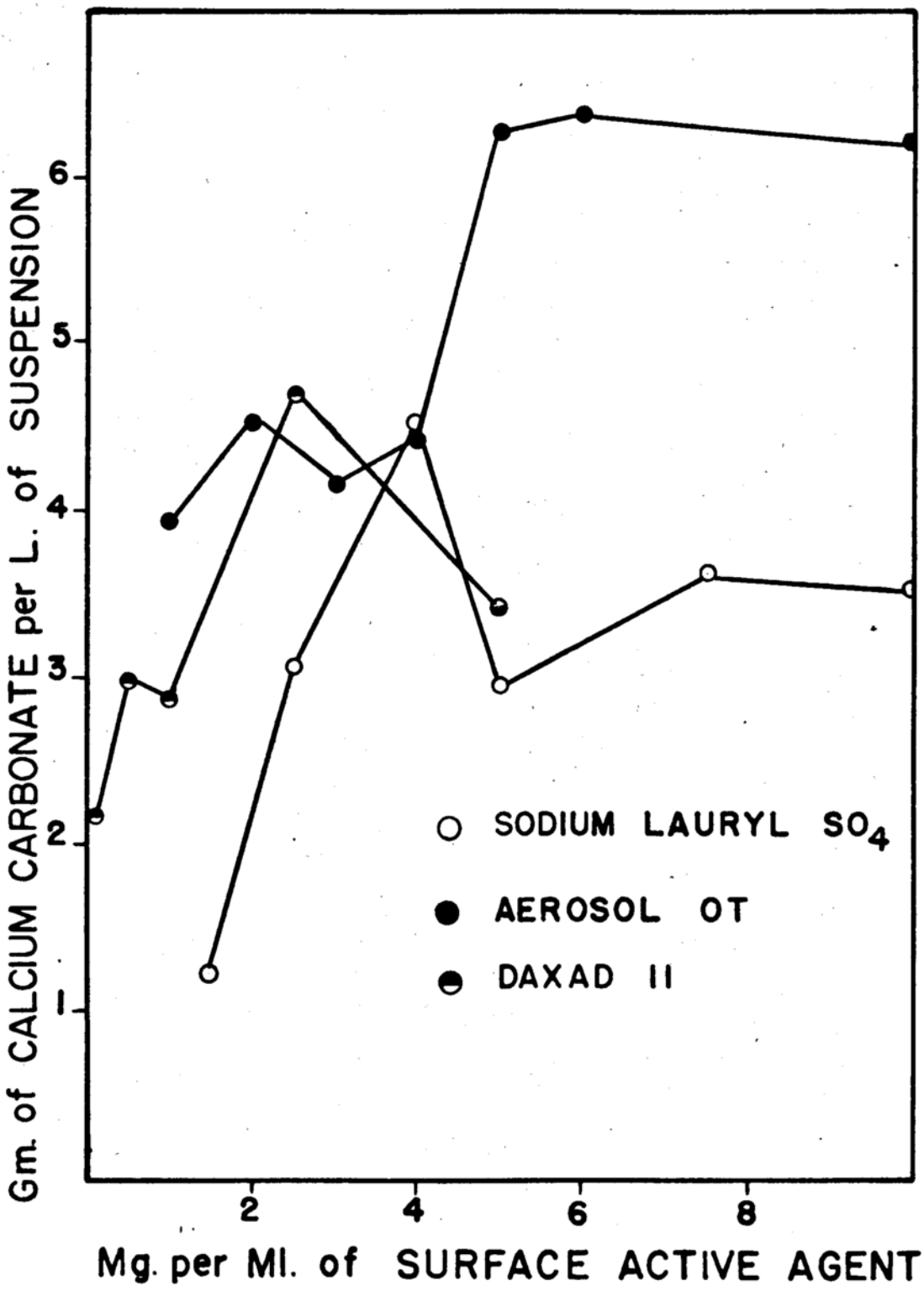

FIGURE III

Suspension of Calcium Carbonate by Anionic Surface Active Agents at 30°C.

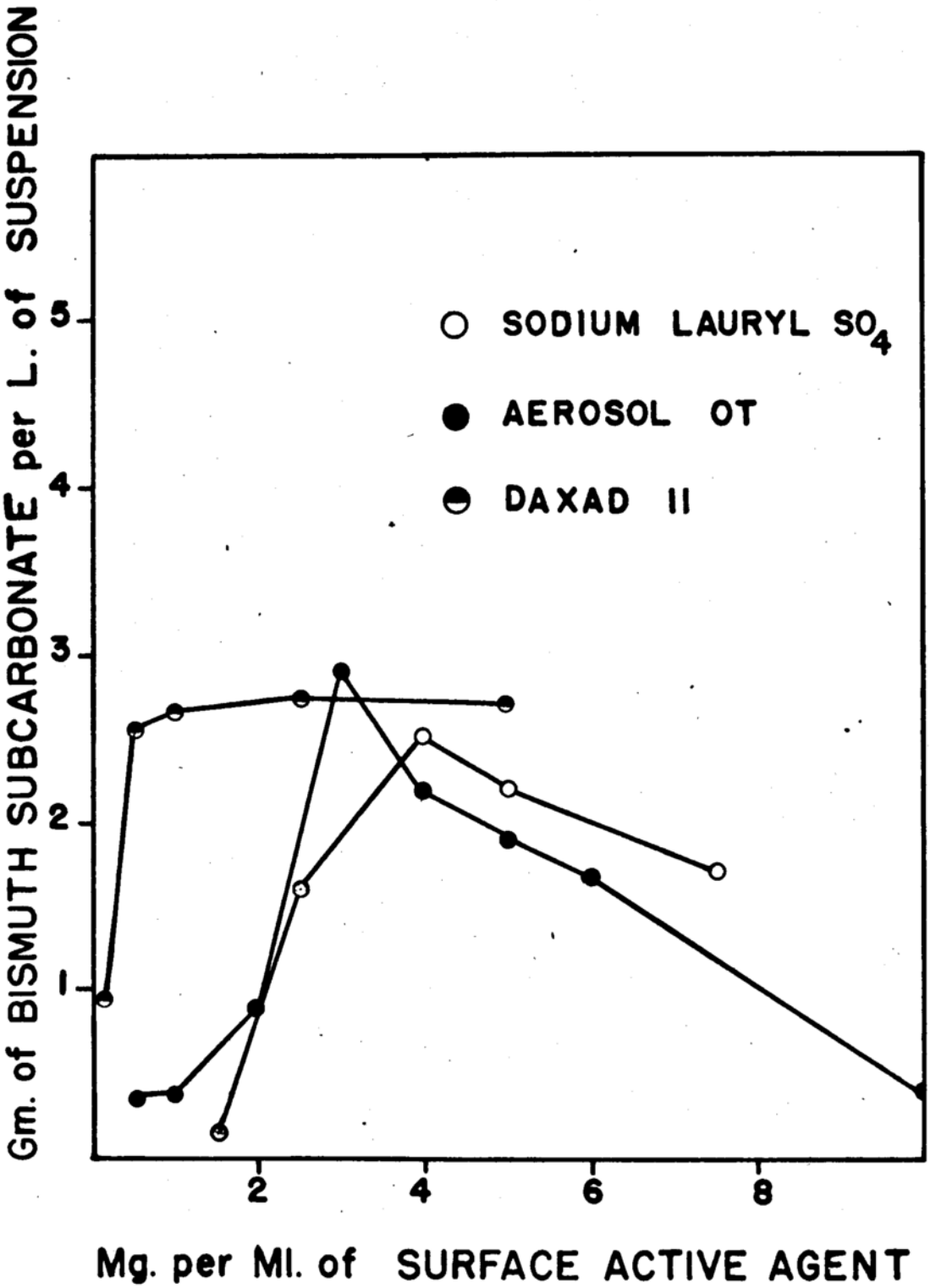

FIGURE IV

Suspension of Bismuth Subcarbonate by Anionic Surface Active Agents at 30°C.

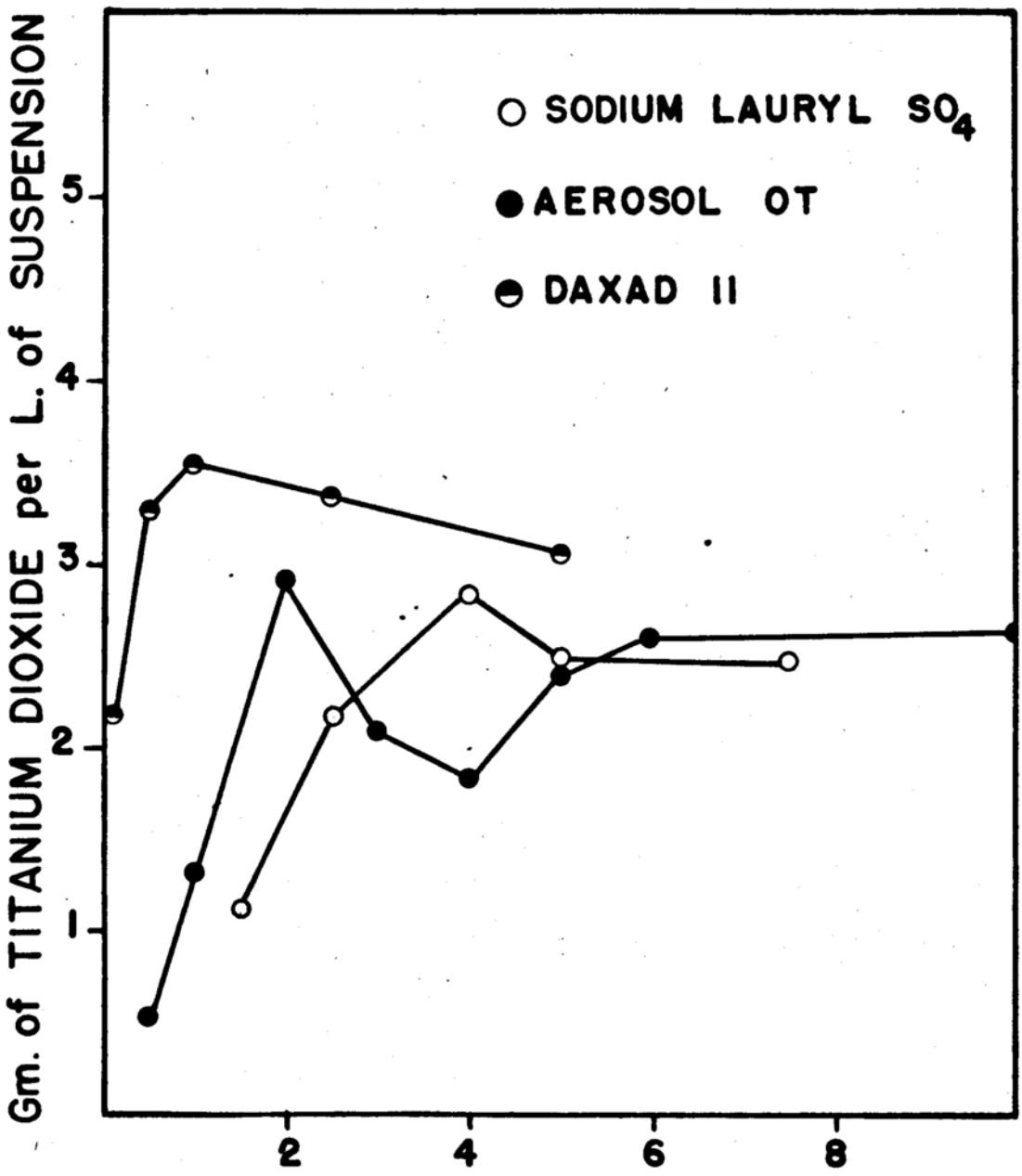

FIGURE V

Suspension of Titanium Dioxide Sulfate by Anionic Surface Active Agents at 30°C.

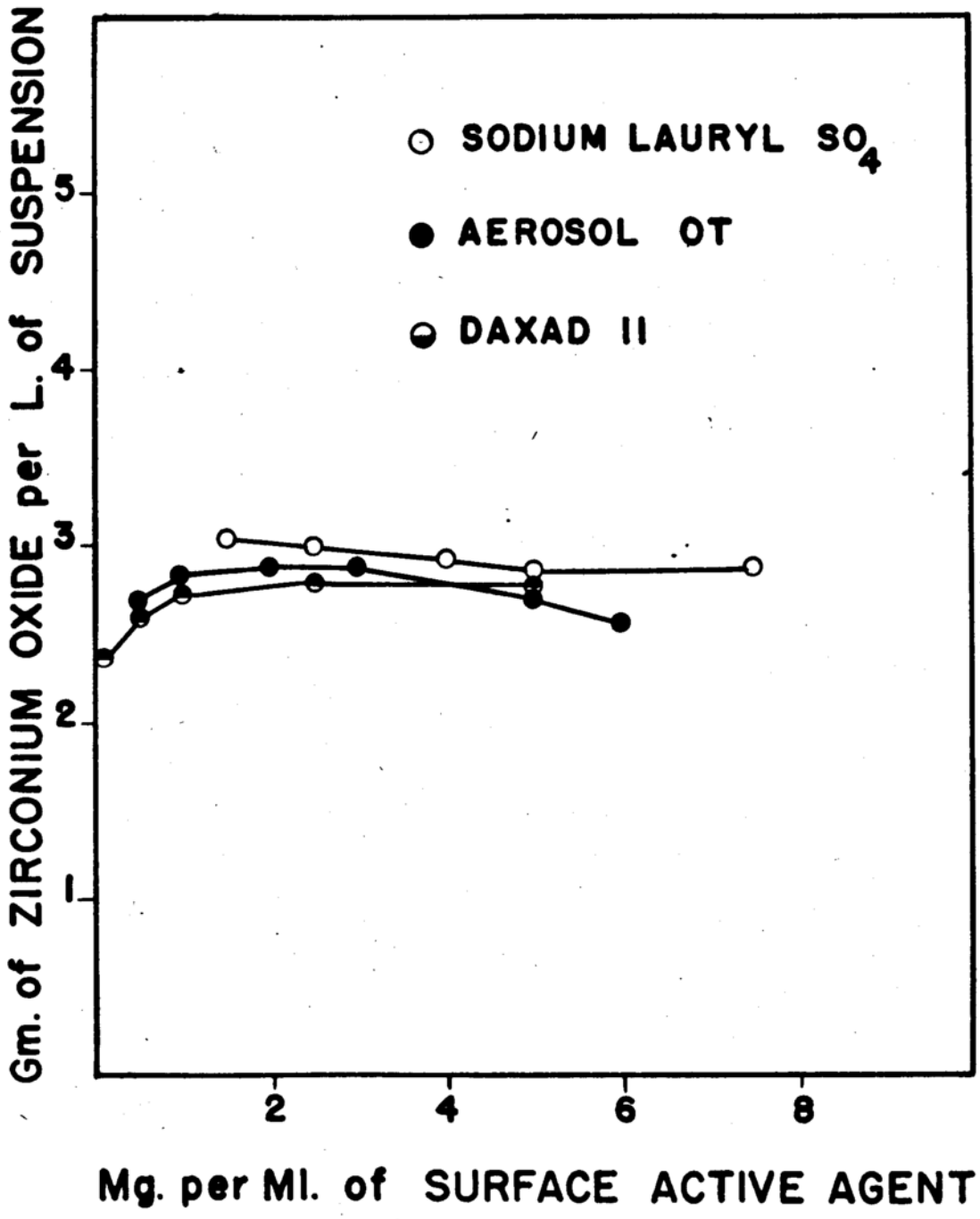

FIGURE VI

Suspension of Zirconium Oxide by Anionic Surface Active Agents at 30°C.

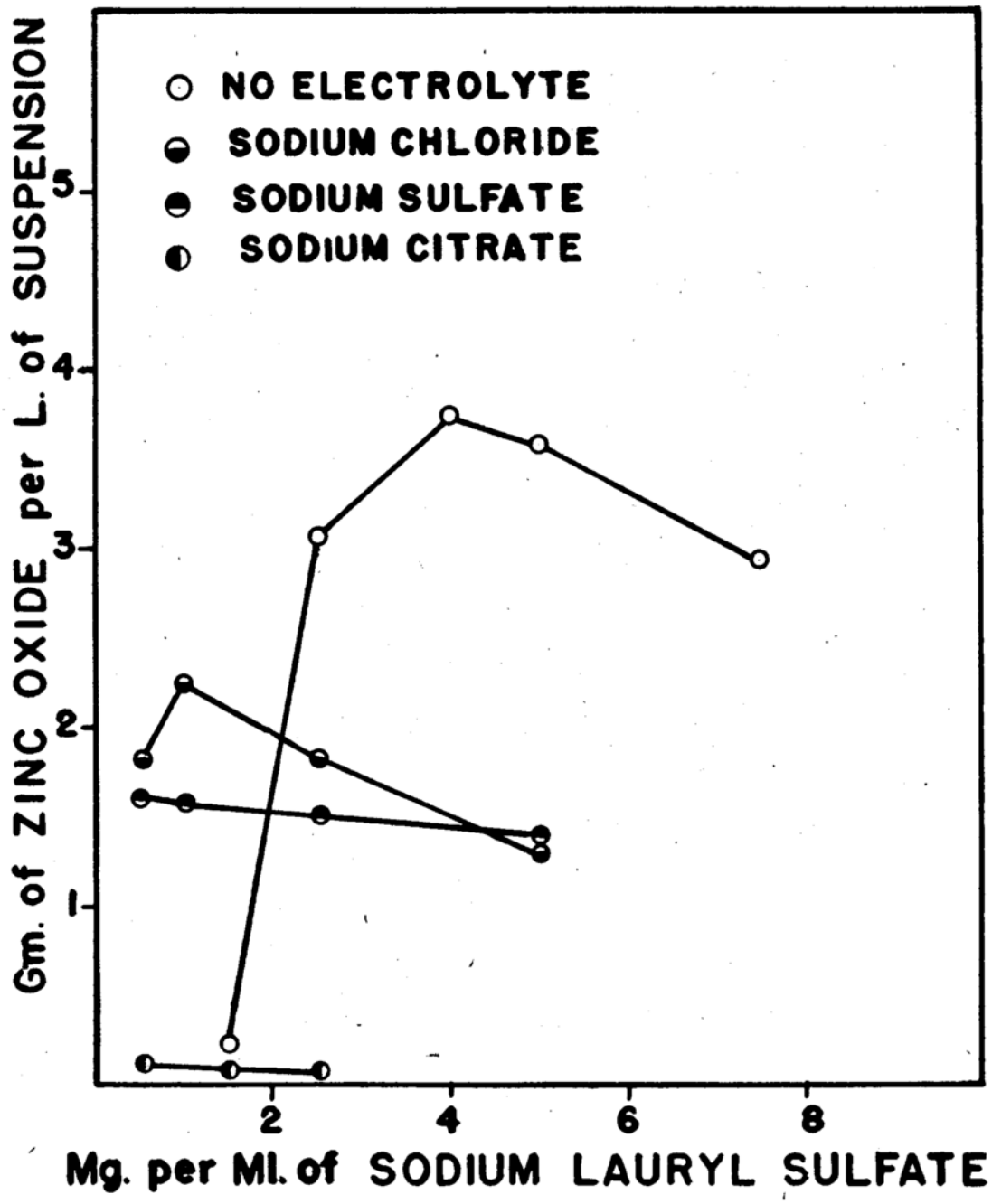

FIGURE VII

Suspension of Zinc Oxide by Sodium Lauryl Sulfate in the Presence of Electrolytes at 30°C.

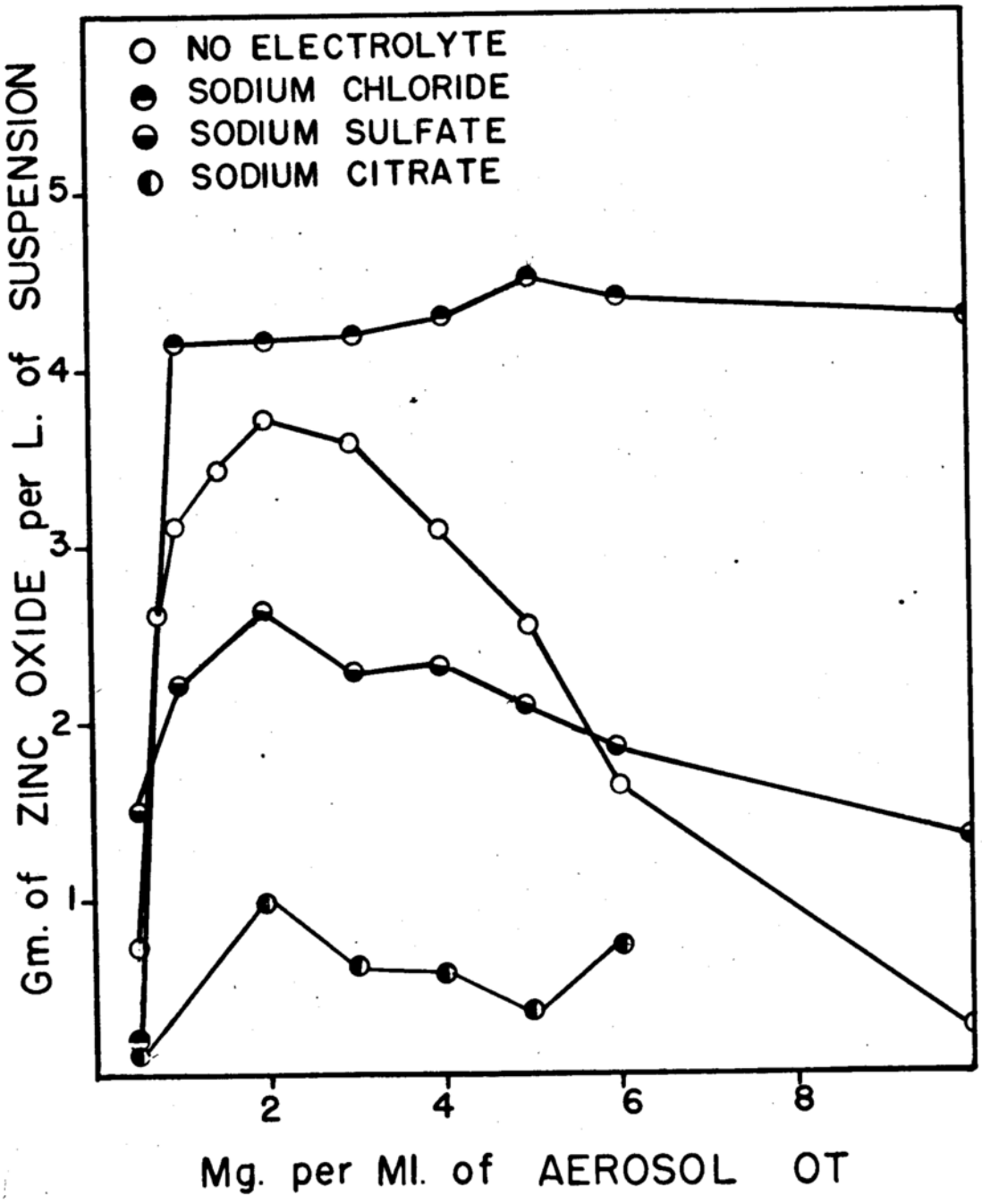

FIGURE VIII

Suspension of Zinc Oxide by Aerosol OT in the Presence of Electrolytes at 30°C.

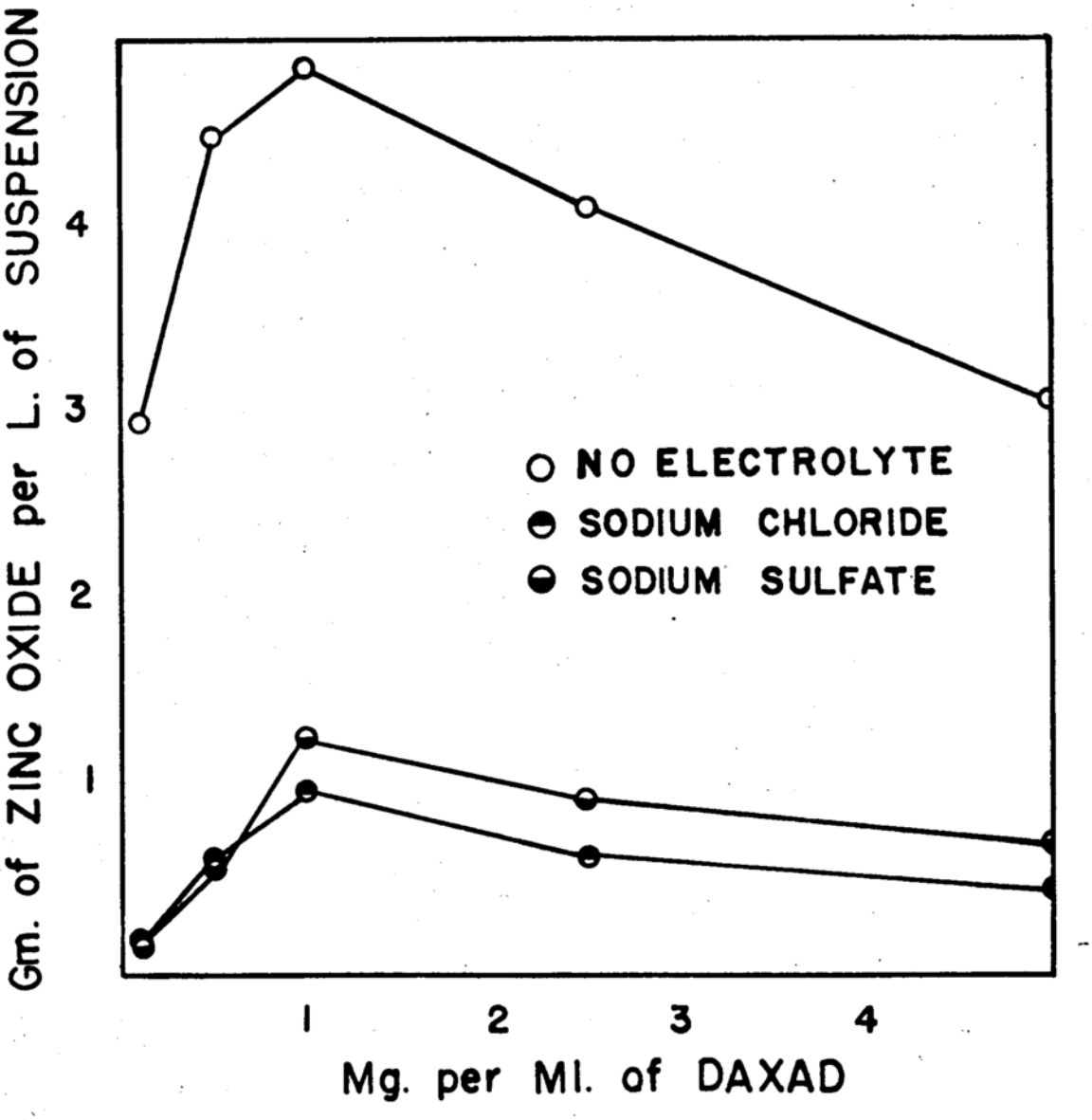

FIGURE IX

Suspension of Zinc Oxide by Daxad 11 in the Presence of Electrolytes at 30°C.

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APPENDIX

TABLE I

Adsorption of Sodium Lauryl Sulfate on Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.092	1.02	0.09
0.089	1.04	0.08
0.197	1.86	0.106
0.211	1.72	0.123
0.307	2.94	0.104
0.359	2.42	0.149
0.539	3.20	0.168
0.542	3.17	0.171
0.643	3.46	0.185
0.635	3.54	0.179
1.000	5.00	0.200
1.000	5.00	0.200
1.925	6.46	0.298
1.921	6.50	0.295
1.971	6.00	0.328
3.368	7.45	0.452
3.385	7.28	0.465
4.500	6.43	0.699
4.392	7.50	0.585
4.428	7.15	0.619
4.442	7.85	0.565
9.357	9.38	0.997
9.142	11.42	0.800
9.400	8.85	1.060

TABLE II

Adsorption of Sodium Lauryl Sulfate on Calcium Carbonate

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.130	0.64	0.203
0.128	0.72	0.168
0.242	1.40	0.173
0.223	1.60	0.140
0.227	1.68	0.135
0.226	1.69	0.133
0.314	2.87	0.109
0.320	2.81	0.114
0.422	4.36	0.097
0.408	4.51	0.090
0.457	4.40	0.103
0.700	7.15	0.098
0.707	7.08	0.100
0.929	10.14	0.092
0.922	10.21	0.093
1.475	10.96	0.134
1.271	12.28	0.103
1.500	10.71	0.140
3.928	11.42	0.344
4.000	11.43	0.350
9.142	11.44	0.711
9.214	10.71	0.860
9.000	11.71	0.769

TABLE III

Adsorption of Sodium Lauryl Sulfate on Bismuth Subcarbonate

$\frac{C \text{ equil.}}{(mg./ml.)}$	$\frac{X/M}{(mg./gm.)}$	$\frac{C}{X/M}$
0.002	1.92	0.001
0.004	1.91	0.002
0.033	3.50	0.010
0.034	3.48	0.010
0.105	4.96	0.021
0.103	4.80	0.021
0.225	6.34	0.036
0.236	6.24	0.038
0.357	6.10	0.059
0.367	6.01	0.061
0.341	5.70	0.059
0.339	5.72	0.059
0.362	6.19	0.058
0.372	6.09	0.061
0.551	7.12	0.077
0.535	7.28	0.074
0.710	7.82	0.091
0.712	7.80	0.091
1.95	9.53	0.204
1.90	10.07	0.188
3.14	9.71	0.323
3.10	10.10	0.307

TABLE IV

Adsorption of Sodium Lauryl Sulfate on Titanium Dioxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.346	1.11	0.314
0.275	1.82	0.151
0.678	3.10	0.218
1.125	3.75	0.300
1.835	6.64	0.276
2.146	4.25	0.505
2.042	5.29	0.386
4.735	4.08	1.160
4.714	4.29	1.090
4.707	4.57	1.03

TABLE V

Adsorption of Sodium Lauryl Sulfate on Zirconium Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.358	1.34	0.267
0.342	1.50	0.228
0.739	2.61	0.283
0.761	2.39	0.318
1.167	2.35	0.496
1.161	2.42	0.479
2.214	2.85	0.776
2.382	1.90	0.835
4.785	3.58	1.33
4.858	2.86	1.69
4.978	3.43	1.45
10.085	2.02	4.99
9.914	3.73	2.65
9.985	3.02	3.31

TABLE VI

Influence of Sodium Chloride on the Adsorption of Sodium Lauryl Sulfate on Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.096	1.11	0.087
0.152	2.42	0.063
0.149	2.45	0.061
0.181	4.23	0.043
0.184	4.20	0.044
0.246	5.63	0.044
0.229	5.80	0.040
0.256	7.64	0.034
0.292	7.28	0.040
0.405	8.55	0.047
0.397	8.62	0.046
0.669	8.31	0.087
1.119	8.80	0.127
1.113	8.62	0.131
1.598	8.31	0.192
1.559	8.69	0.179

TABLE VII

Influence of Sodium Sulfate on the Adsorption of Sodium Lauryl Sulfate by Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.121	0.68	0.178
0.102	0.88	0.116
0.180	2.14	0.084
0.176	2.18	0.080
0.190	2.75	0.069
0.191	2.73	0.070
0.264	5.63	0.047
0.287	6.52	0.044
0.679	8.20	0.082
0.697	8.02	0.086
1.151	8.48	0.135
1.154	8.45	0.136
1.637	8.62	0.189
1.630	8.69	0.187

TABLE VIII

Influence of Sodium Citrate on the Adsorption of Sodium Lauryl Sulfate by Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.128	0.71	0.181
0.140	0.59	0.237
0.202	2.11	0.096
0.204	2.08	0.098
0.225	3.09	0.072
0.215	3.16	0.068
0.274	3.55	0.077
0.243	3.87	0.063
0.549	4.50	0.121
0.461	5.39	0.085
1.084	4.22	0.257
1.109	3.79	0.278
1.500	5.00	0.300
1.475	5.24	0.282
2.042	5.14	0.203

TABLE IX

Adsorption of Aerosol OT by Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.120	3.92	0.031
0.113	4.02	0.028
0.151	4.56	0.033
0.112	4.03	0.077
0.186	5.21	0.036
0.212	5.51	0.039
0.260	5.43	0.048
0.462	5.79	0.080
0.455	5.74	0.079
0.887	5.89	0.151
0.976	5.89	0.166
1.535	5.89	0.261
1.509	5.82	0.259
1.523	5.67	0.268

TABLE X

Adsorption of Aerosol OT by Calcium Carbonate

C_e equil. (mg./ml.)	X/M (mg./gm.)	$\frac{C}{X/M}$
0.088	1.79	0.050
0.094	1.73	0.055
0.143	3.63	0.040
0.126	3.81	0.033
0.183	6.16	0.030
0.191	6.08	0.032
0.254	7.92	0.032
0.257	7.90	0.033
0.509	9.96	0.051
0.490	10.15	0.048
0.894	11.05	0.081
0.896	11.04	0.081

TABLE XI

Adsorption of Aerosol OT by Bismuth Subcarbonate

C. equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.004	2.64	0.002
0.003	2.65	0.001
0.011	4.96	0.002
0.013	4.95	0.003
0.085	7.14	0.012
0.081	7.17	0.011
0.245	8.01	0.031
0.214	8.32	0.026
0.568	9.37	0.061
0.561	9.45	0.059
1.077	10.14	0.117
1.078	10.13	0.116

TABLE XII

Adsorption of Aerosol OT by Titanium Dioxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.357	1.47	0.243
0.332	1.72	0.193
0.567	1.92	0.295
0.543	2.16	0.251
0.670	3.18	0.210
0.663	3.24	0.204
1.092	3.79	0.288
1.101	3.70	0.294
1.713	3.85	0.445
1.721	3.76	0.457

Page 86 is missing.

TABLE XIV

Influence of Sodium Chloride on the Adsorption of Aerosol OT on Zinc Oxide

$\frac{C \text{ equil.}}{(mg./ml.)}$	$\frac{X/M}{(mg./gm.)}$	$\frac{C}{X/M}$
0.057	1.99	0.028
0.064	1.91	0.034
0.056	1.93	0.029
0.052	2.15	0.024
0.057	2.11	0.027
0.1051	3.99	0.026
0.1144	3.90	0.029
0.0946	4.11	0.023
0.0625	4.11	0.015
0.0724	4.01	0.018
0.202	5.53	0.036
0.233	5.22	0.044
0.207	5.51	0.037
0.186	5.64	0.033
0.172	5.77	0.055
0.439	6.17	0.071
0.492	5.63	0.088
0.451	5.98	0.075
0.369	6.68	0.055
0.429	6.07	0.070
1.035	5.83	0.177
1.007	6.11	0.165
0.934	5.96	0.156
1.408	5.91	0.238

TABLE XV

Influence of Sodium Sulfate on the Adsorption of Aerosol OT on Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.064	1.91	0.033
0.060	1.96	0.030
0.072	4.36	0.016
0.178	6.27	0.028
0.181	6.25	0.029
0.425	6.50	0.065
0.439	6.36	0.069
0.845	6.54	0.129
0.974	5.26	0.185
1.322	6.78	0.195
1.338	6.61	0.202

TABLE XVI

Influence of Sodium Citrate on the Adsorption of Aerosol OT on Zinc Oxide

$\frac{C \text{ equil.}}{(mg./ml.)}$	$\frac{X/M}{(mg./gm.)}$	$\frac{C}{X/M}$
0.083	1.66	0.050
0.155	3.88	0.040
0.139	4.04	0.034
0.245	5.58	0.043
0.231	5.72	0.040
0.460	6.12	0.075
0.474	5.98	0.079
1.000	5.71	0.175
0.943	6.27	0.150

TABLE XVII

Adsorption of Daxad 11 by Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.0212	0.75	0.028
0.049	1.61	0.030
0.051	1.49	0.034
0.126	2.91	0.043
0.105	2.14	0.049
0.143	3.09	0.052
0.174	2.44	0.071
0.201	3.26	0.061
0.296	3.01	0.099
0.263	3.33	0.079
0.279	3.31	0.084
0.357	3.43	0.104
0.380	3.41	0.111
0.373	3.48	0.107
0.471	3.50	0.135
0.465	3.57	0.130
0.459	3.41	0.104
0.574	3.26	0.176
0.552	3.47	0.159

TABLE XVIII

Adsorption of Daxad 11 on Calcium Carbonate

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.030	0.77	0.040
0.031	0.76	0.041
0.294	0.74	0.039
0.081	1.20	0.068
0.069	1.31	0.053
0.825	1.19	0.060
0.109	1.92	0.057
0.111	1.91	0.058
0.121	2.02	0.060
0.155	2.40	0.065
0.156	2.39	0.065
0.157	2.52	0.062
0.198	2.97	0.067
0.202	3.03	0.066
0.263	3.32	0.079
0.337	2.94	0.115
0.336	3.64	0.092
0.319	3.80	0.084
0.384	3.23	0.118
0.410	3.89	0.105
0.402	3.98	0.101
0.436	3.68	0.118
0.519	3.77	0.137
0.523	3.71	0.141
0.588	4.13	0.142
0.587	4.12	0.142

TABLE XIX

Adsorption of Daxad 11 on Bismuth Subcarbonate

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.083	0.88	0.009
0.079	0.96	0.008
0.025	1.75	0.014
0.038	1.63	0.023
0.072	2.48	0.029
0.086	2.37	0.036
0.125	2.93	0.042
0.129	3.24	0.040
0.168	3.47	0.046
0.187	3.28	0.057
0.247	3.71	0.066
0.258	3.51	0.073
0.307	4.15	0.073
0.334	3.88	0.086
0.375	4.57	0.082
0.386	4.36	0.088
0.461	4.38	0.105
0.447	4.52	0.099

TABLE XX

Adsorption of Daxad 11 on Titanium Dioxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.045	0.20	0.225
0.030	0.35	0.087
0.104	0.30	0.346
0.115	0.55	0.211
0.116	0.45	0.257
0.210	0.69	0.304
0.212	0.66	0.321
0.366	0.52	0.703
0.341	0.99	0.353
0.430	0.92	0.467
0.415	0.95	0.436
0.423	0.86	0.491
0.534	0.93	0.574
0.627	0.92	0.681

TABLE XXI

Adsorption of Daxad 11 on Zirconium Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.086	0.34	0.253
0.081	0.38	0.213
0.186	0.37	0.502
0.183	0.39	0.469
0.261	0.52	0.501
0.259	0.54	0.479
0.359	0.54	0.664
0.359	0.54	0.664
0.450	0.60	0.750
0.448	0.70	0.640

TABLE XXII

Influence of Sodium Chloride on the Adsorption of Daxad 11 by Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.027	0.75	0.030
0.026	0.77	0.030
0.030	0.73	0.040
0.028	0.75	0.040
0.055	1.50	0.037
0.062	1.38	0.045
0.107	1.95	0.055
0.102	2.00	0.051
0.104	2.02	0.052
0.101	2.05	0.050
0.151	2.45	0.062
0.160	2.36	0.068
0.154	2.52	0.061
0.205	2.87	0.072
0.208	2.83	0.074
0.210	2.94	0.072
0.209	2.95	0.071
0.267	3.27	0.082
0.284	3.09	0.092
0.274	3.29	0.083
0.293	3.10	0.094
0.348	3.70	0.090
0.347	3.71	0.094
0.434	3.65	0.119
0.431	3.69	0.117
0.520	3.79	0.137
0.519	3.80	0.137

TABLE XXIII

Influence of Sodium Sulfate on the Adsorption of Daxad 11 by Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.045	0.51	0.080
0.043	0.52	0.081
0.100	1.07	0.094
0.106	1.00	0.105
0.170	1.36	0.126
0.165	1.40	0.118
0.229	1.61	0.143
0.232	1.58	0.147
0.298	2.16	0.138
0.300	2.13	0.141
0.370	2.20	0.168
0.366	2.34	0.157

TABLE XXIV

Influence of Sodium Citrate on the Adsorption of Daxad 11 by Zinc Oxide

$\frac{C \text{ equil.}}{(mg./ml.)}$	$\frac{X/M}{(mg./gm.)}$	$\frac{C}{X/M}$
.058	0.37	0.157
.056	0.39	0.141
0.119	0.88	0.135
0.186	1.19	0.155
0.184	1.21	0.151
0.263	1.27	0.207
0.262	1.24	0.213
0.341	1.73	0.198
0.337	1.76	0.191
0.413	1.87	0.221
0.424	1.75	0.242
0.504	1.98	0.255
0.513	1.89	0.271
0.593	2.00	0.296
0.610	1.83	0.334

TABLE XXV

Influence of Sodium Phosphate on the Adsorption of Daxad 11 by Zinc Oxide

C equil. (mg./ml.)	X/M (mg./gm.)	C/X/M
0.211	0.22	0.959
0.200	0.11	1.820
0.381	0.38	1.00
0.381	0.38	1.00
0.561	0.33	1.70
0.556	0.35	1.59
0.766	0.33	2.32
0.760	0.40	1.65

TABLE XXVI

Suspension of Insoluble Powders by Sodium Lauryl Sulfate

Mg./ml. Sodium Lauryl Sulfate	Zinc Oxide	Calcium Carbonate	Bismuth Subcarbonate	Titanium Dioxide	Zirconium Oxide
1.5	0.33	1.22	0.16	1.12	3.03
2.5	3.08	3.09	1.63	2.16	2.98
4.0	3.72	4.55	2.52	3.82	2.91
5.0	3.59	2.98	2.21	2.48	2.82
7.5	2.92	3.65	1.72	2.44	2.87
10.0	-	3.54	-	-	-

TABLE XXVII

Influence of Electrolytes on the Suspension of Zinc Oxide by Sodium Lauryl Sulfate

Mg./ml. Sodium Lauryl Sulfate	g./liter of Zinc Oxide			
	Sodium Chloride	Sodium Sulfate	Sodium Citrate	Sodium Phosphate
0.5	1.81	1.61	0.13	-
1.0	2.25	1.56	0.07	-
2.5	1.81	1.50	0.06	-
5.0	1.30	1.37	-	-

TABLE XXVIII

Suspension of Insoluble Powders by Aerosol OT

Mg./ml. Aerosol OT	g./liter of Insoluble Powder: Zinc Oxide	Calcium Carbonate	Bismuth Subcarbonate	Titanium Dioxide	Zirconium Oxide
0.25	-	-	-	-	-
0.50	0.17	-	0.16	0.51	2.68
0.75	2.58	-	-	-	-
1.00	3.13	3.96	0.40	1.31	2.84
1.50	3.43	-	-	-	-
2.00	3.72	4.56	0.91	2.91	2.87
3.00	3.59	4.29	2.91	2.07	2.88
4.00	3.07	4.45	2.20	1.83	2.77
5.00	2.54	6.30	1.92	2.38	2.70
6.00	1.62	6.39	1.68	2.59	2.74
10.00	0.24	6.25	0.38	2.64	-

TABLE XXIX

Influence of Electrolytes on Aerosol OT Suspension of Zinc Oxide

Mg./ml. Aerosol OT	g./liter of Zinc Oxide			
	Sodium Chloride	Sodium Sulfate	Sodium Citrate	Sodium Phosphate
0.50	0.70	1.50	0.12	0
1.00	4.15	2.21	-	-
2.00	4.15	2.63	1.00	0
3.00	4.20	2.28	0.60	0
4.00	4.28	2.32	0.59	0
5.00	4.51	2.06	0.34	-
6.00	4.38	1.84	0.84	-
10.00	4.27	1.35	0.75	-

TABLE XXX

Suspension of Insoluble Powders by Daxad 11

Mg./ml. Daxad 11	g./liter of Powder				
	Zinc Oxide	Calcium Carbonate	Bismuth Subcarbonate	Titanium Dioxide	Zirconium Oxide
0.10	2.96	2.18	0.96	2.16	2.35
0.50	4.48	2.97	2.58	3.27	2.60
1.00	4.85	2.86	2.68	3.54	2.72
2.50	4.21	4.71	2.76	3.36	2.78
5.00	3.07	3.39	2.73	3.03	2.75

TABLE XXXI

Influence of Electrolytes on Suspension of Zinc Oxide by Daxad 11

Mg./ml. Daxad 11	g./liter of Powder			
	Sodium Chloride	Sodium Sulfate	Sodium Citrate	Sodium Phosphate
0.10	0.14	0.13	-	-
0.50	0.62	1.09	-	-
1.00	0.99	0.96	-	-
2.50	0.63			
5.00	0.47	0.71	-	-

A STUDY OF THE EFFECT OF CERTAIN ANIONIC SURFACE ACTIVE AGENTS IN SUSPENSIONS OF SELECTED PHARMACEUTICAL POWDERS

by Gordon Arnold Groves

Under the Supervision of Professor A. P. Lemberger

ABSTRACT

A study of the adsorption of three anionic surface active agents by some insoluble powders commonly employed in pharmaceutical suspensions has been carried out. The ability of the surface active agents to promote the suspension of these powders has been determined. The effect of the presence of certain electrolytes in the dispersion medium on both the adsorption and suspension tendencies of the surface active agents has been investigated.

The adsorption and sedimentation studies were made with anionic surface active agent concentrations ranging from 0.1 to 10 mg. per ml. The electrolytes were employed in a concentration equivalent to 0.1 gram-ion of sodium ion per liter of solution. All studies were performed at a temperature of 30°C.

The adsorption of the anionic surface active agents was found to be of the type represented by the Class One Langmuir Isotherm. This adsorption was found to meet the requirements of Langmuir's equation.

The study has shown that the degree of adsorption is, in general, related to the surface area of the powder occupied by a molecule of the surface active agent. In particular it was determined that saturation of the surface occurred with less Aerosol OT than with sodium lauryl sulfate. The relative surface areas occupied by one molecule of these agents has been used to explain this occurrence. It has been postulated that the lower concentration of Daxad 11 required to saturate the surface of the powder is due to the greater area of the surface occupied by one molecule of this agent.

Some indication has been shown that the extent of adsorption of the anionic surface active agents is not entirely dependent upon the surface area of the powders involved.

The addition of electrolytes to the solutions of surface active agents has been shown to produce changes in the adsorption pattern. It has been determined that sodium dihydrogen phosphate completely eliminated adsorption of all the surface active agents with the exception of Daxad 11. Other electrolytes were found to either increase or decrease the amount of surface active agent adsorbed and/or to cause the saturation level to be reached with a lower concentration of the surface active agent.

The study has shown that the suspending ability of the surface active agent does pass through a maximum with

a low concentration of the agent. It has been shown that this maximum is quite apparent with all powders except zirconium oxide. The adsorption data was compared with the suspending data and it was observed that the maximum suspending concentration was in close agreement with the concentration at which the saturation level was reached in the adsorption studies.

In general it has been shown that Daxad 11 is a better dispersant than Aerosol OT or sodium lauryl sulfate. Daxad 11 has been found to maintain a greater amount of powder in suspension and to produce its maximum suspending power at a lower concentration than Aerosol OT or sodium lauryl sulfate. An exception has been noted in the suspension of calcium carbonate by Daxad 11.

The study has shown that in most instances the addition of electrolytes to the dispersion medium has inhibited the formation of the suspension. Sodium dihydrogen phosphate has been found to completely inhibit the suspension of zinc oxide by all three anionic surface active agents. Other electrolytes have been shown to reduce the amount of zinc oxide remaining in suspension. An exception has been observed in the suspension of zinc oxide by Aerosol OT in the presence of sodium chloride. This solution has been found to suspend more zinc oxide than the solution of Aerosol OT alone.

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