

EXPLORATORY EVALUATION OF SOME ORGANIC CATIONS AS SOIL STABILIZING AGENTS¹

DONALD T. DAVIDSON, *Assistant Professor of Civil Engineering, Iowa State College*

SYNOPSIS

In the search for new soil stabilizing agents the effects of six organic cations on plastic limit, liquid limit, shrinkage limit, air-dry strength and rate of slaking of a highly plastic clay subsoil were studied. In all cases the plasticity index and shrinkage were reduced by the treatments. The air-dry strength was lowered in varying degree, which was the only undesirable effect noted. With one exception resistance to slaking was improved. It is concluded that large organic cations show promise as possible stabilizing agents for highly plastic fine-grained soils.

Ever since soil has been used as a material for building roads, engineers have searched for methods or materials to make it stable under traffic in all kinds of weather. Myers (1)² has well expressed the goal of this search:

"The alchemists of ancient times sought the philosopher's stone, which was believed to have the power to transmute the baser metals into gold. The philosopher's stone that intrigues the imagination of the highway engineer is the thing or method that will have the power to transmute cheaply any kind of soil into a material that will resist abrasion and displacement under traffic in all kinds of weather, and that will retain these properties indefinitely."

Numerous reports on the ionic-exchange method of altering the engineering properties of cohesive fine grained soils have been made in the literature (2, 3). Most investigators, however, have been primarily concerned with the inorganic cations. Very little work has been reported on the use of organic cations. This paper presents the results of an exploratory investigation to evaluate as soil stabilizing agents six cationic compounds that furnish large organic cations when dissolved in water.

MATERIALS

The six water-soluble organic compounds used are available commercially under the trade names Armac T, Armac 18D, Armac

12D, Rosin Amine-D Acetate, Amine 220, and Ammonyx T. They are all cationic in character, dissociating in water to furnish, with the exception of Amine 220, large monovalent cations. Amine 220 furnishes divalent cations. The composition and constants of each compound are given in the manufacturer's literature (4).

The soil treated with the cationic compounds was Edina subsoil, a dull gray, highly plastic clay from Wayne County, Iowa. Figure 1 shows its grain-size distribution curve. A differential-thermal analysis of the minus one micron (0.001 mm.) portion indicated that montmorillonite type clay minerals were predominant. Additional engineering properties of Edina subsoil are presented in Table 1.

EXPERIMENTAL PROCEDURE

Grim, Allaway, and Cuthbert (5) found that organic cations in amounts less than equivalent to the base exchange capacity of the soil are rather completely adsorbed in base exchange reactions; and that amounts in excess of the base exchange capacity tend to be adsorbed by a different reaction, probably dependent on the action of the van der Waals' forces. In the present investigation, organic cations were added in amounts less than equivalent to the base exchange capacity of Edina subsoil.

Prior to cationic treatment, the air-dry soil was ground by means of a mortar and pestle to pass the No. 40 sieve and then divided into 1000-g (oven-dry weight) samples. Initially each compound was added to three soil samples in amounts sufficient to satisfy their base exchange capacities to the extent of 1, 10, and

¹ An Abridgement of the Report, "Large Organic Cations as Soil Stabilizing Agents," by Donald T. Davidson, Bulletin No 168, Iowa Engineering Experiment Station, Iowa State College.

² Italicized figures in parentheses refer to the list of references at the end of the paper.

75 percent of saturation. Later the investigation was extended to include samples having their base exchange capacities 25 and 50 percent saturated with Armac T and Armac 18D, and 5 percent saturated with Rosin Amine-D Acetate. Table 2 gives the relation-

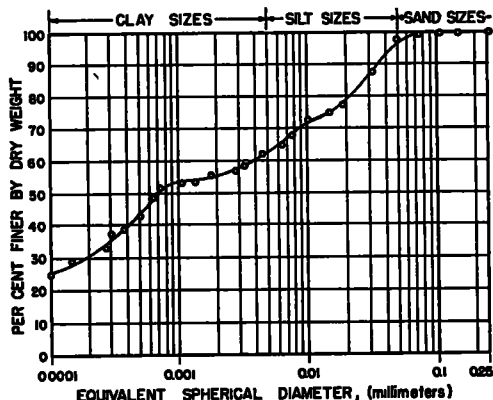


Figure 1. Grain Size Distribution of Edina Subsoil

TABLE 1
ENGINEERING PROPERTIES OF EDINA SUBSOIL

Liquid limit, percent of oven-dry wt of soil	78.0
Plastic limit, percent of oven-dry wt of soil	26.3
Plasticity index, percent of oven-dry wt of soil	51.7
Shrinkage limit, percent of oven-dry wt of soil	6.0
Shrinkage ratio	2.02
Hygroscopic moisture ^a , percent of oven-dry wt of soil	7.02
Centrifuge moisture equivalent, percent of oven-dry wt of soil	29.7
Specific gravity	2.74
Organic content, percent of oven-dry wt of soil	0.72
pH value	4.90
Base exchange capacity ^b , m.e. per 100 g	40.0
Max. Standard Proctor dry density, p.c.f.	88.2
Optimum moisture, percent of oven-dry wt of soil	29.9
Max. Modified A.A.S.H.O. dry density, p.c.f.	104.4
Optimum moisture, per cent oven-dry wt of soil	18.6
Textural classification	Clay
Revised (1945) Public Roads classification	A-7-6 (20)

^a After being exposed to air at room temperature (80°F ± 5°) for fourteen days.

^b Determined by the Soils Subsection, Iowa Agricultural Experiment Station, Iowa State College, Ames, Iowa.

ship between percent saturation of base exchange capacity and percent by oven-dry weight of soil for each admixture.

The weights of each cationic material required to satisfy the base exchange capacities of the soil samples to the various percentages of saturation were calculated by means of the equivalent weight of the chemical and the base exchange capacity of the soil. A sample calculation for Armac T will illustrate the procedure.

Example—Calculate the weight of Armac T needed to saturate to 75 percent the base exchange capacity of 1000 grams of Edina subsoil.

Given: Molecular weight of monovalent Armac T = 322 and the base exchange capacity of Edina subsoil = 40 milliequivalents per 100 g.

Solution:

Gram-molecular wt of Armac

T = 322 g.

Equivalent wt. of Armac T

= 322 - 1 = 322 g.

1 milliequivalent of Armac T = 322 mg.

Therefore, 75 percent saturation of 1000 g of soil will require $40 \times 10 \times 0.75 \times 322 = 96600$ mg. = 96.6 g of Armac T.

TABLE 2
RELATIONSHIP BETWEEN PERCENT SATURATION OF BASE EXCHANGE CAPACITY AND PERCENT BY OVEN-DRY WEIGHT OF SOIL

Chemical admixture, saturation b.e.c.	Chemical admixture, percent of oven-dry weight of soil					
	Armac T	Armac 18D	Armac 12D	Rosin Amine-D Acetate	Amine 220	Ammonyx T
%						
0	0.00	0.00	0.00	0.00	0.00	0.00
1	0.13	0.13	0.10	0.22	0.07	0.17
5	—	—	—	1.07	—	—
10	1.29	1.30	0.98	2.15	0.70	1.74
25	3.22	3.26	—	—	—	—
50	6.44	6.52	—	—	—	—
75	9.66	9.78	7.32	16.11	5.25	13.08

Before being added to the soil, each amount of chemical was dissolved in 1000 ml of distilled water. The solutions were immediately added to the soil samples in large, shallow pans and the slugs stirred thoroughly for 10 min with a stiff-bladed spatula. Drying was at room temperature over a period of several days. When air-dry, the treated samples were ground with a mortar and pestle to pass the No. 40 sieve.

The tests used to determine the effect of the cationic treatments were: 1. plastic limit; 2. liquid limit; 3. plasticity index; 4. shrinkage limit; 5. ratio of shrinkage limit to liquid limit; 6. air-dry strength; 7. rate of slaking. Since most of these tests were performed in accordance with standard procedures of the American Society for Testing Materials (6), only the non-standard test procedures will be described. However, the significance of all tests will be briefly covered.

The plastic limit (A.S.T.M. Designation: D424-39) represents the moisture content, expressed as percentage of the oven-dry soil weight, of change from the friable to the plastic consistency. According to the film theory of plasticity, orientation of particles and their subsequent sliding over each other takes place at this point; since sufficient water has been added to provide a film around each particle.

The liquid limit (A.S.T.M. Designation: D423-39) signifies the moisture content at which the water films become so thick that cohesion is decreased and the soil flows under an applied force.

The plasticity index is the numerical difference between the liquid limit and the plastic limit. Essentially it is the amount of water necessary to thicken the films from the moisture content at which plasticity develops to that at which flow occurs under an applied force. As its name implies, the plasticity index is a qualitative measure of soil plasticity. The higher its value, the more plastic the soil.

The shrinkage limit (A.S.T.M. Designation: D427-39) is the moisture content, expressed as a percent of the oven-dry soil weight, below which further loss of moisture by evaporation does not result in a reduction of volume.

The ratio of shrinkage limit to liquid limit, expressed as a percentage, is indicative of the shrinkage properties of a soil (7). The larger this ratio, the smaller will be the tendency of a soil to shrink.

The air-dry strength of chemically treated soil specimens may be considered as a measure of the effect of the admixtures on the cohesive properties of the soil. The specimens used in this investigation were air-dried shrinkage pats prepared in circular porcelain milk dishes having a flat bottom and being about 1½-in. in diameter and about ½-in. high. The pats were molded in accordance with A.S.T.M. Designation: D427-39 and then air-dried to constant weight at room temperature.

The relative strengths of the air-dried pats were determined by loading them to failure with a soil penetrometer of the type used for measuring penetration resistance in the standard Proctor density test (A.S.T.M. Designation: D698-42T). The needle tip having $\frac{1}{8}$ -sq. in. bearing area was found to be most suitable for Edina subsoil. The testing procedure consisted of placing a pat on a smooth

steel surface and manually loading it with the penetrometer at a slow and uniform rate until either the maximum measurable load was applied or the pat ruptured (Fig. 2). A sliding ring on the calibrated portion of the penetrometer gave the failure load in pounds. Usually the first break of a full size specimen divided it into two or more pieces (Fig. 3) each of

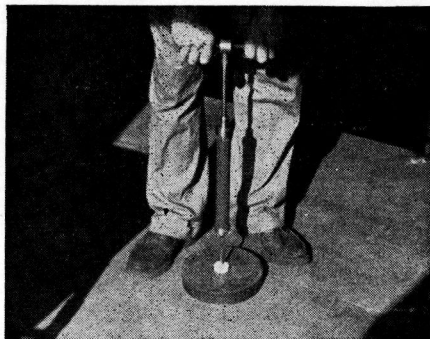


Figure 2. Soil Penetrometer Used to Load and Rupture Air-Dried Shrinkage Pat

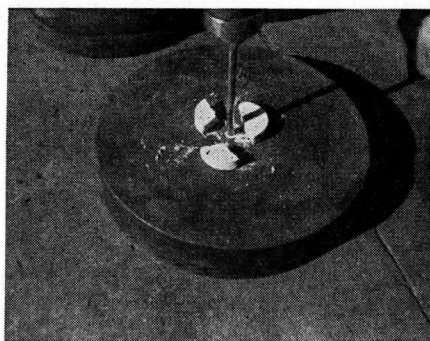


Figure 3. First Break of an Air-Dried Shrinkage Pat

which was large enough to be used for further testing. The average failure load of several tests on two pats made from the same material, divided by the area of the needle tip, was recorded as the air-dry strength in pounds per square inch. Since 110 lb. was the maximum load that could be measured with the penetrometer, pats that were not ruptured by this load had their strengths recorded as 2200 + lb. per sq. in.

The slaking test is essentially a determination of the rate at which a soil specimen disintegrates when immersed in water. The rate of

slaking depends upon such factors as the affinity of the soil for water, the amount of expansion of the soil when wetted, the speed with which the water penetrates the soil, and

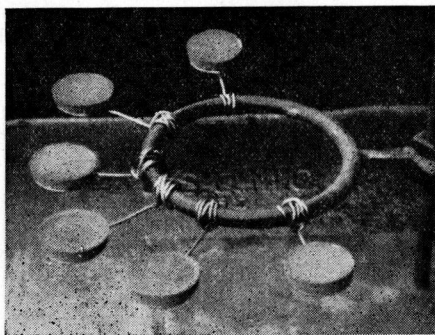


Figure 4. Slaking Pats Ready for Immersion

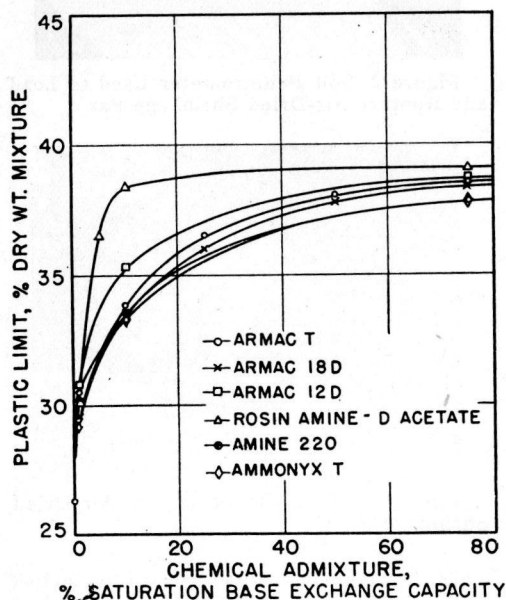


Figure 5. Effect of Cationic Compounds on Plastic Limit

the character of the cracking produced by unequal expansion of the sample. This test may be used to determine the effectiveness of different admixtures as water-proofing agents for a given soil.

The slaking specimens used were air-dried shrinkage pats similar to those used for measuring air-dry strength. Prior to immersion, the pats were placed on copper wire rings

whose diameters were $\frac{1}{8}$ of an inch smaller than the bottom diameters of the soil pats supported on them (Fig. 4). The testing procedure consisted of immersing the pats in distilled water and observing the time in minutes for each pat to drop through its supporting ring. The recorded slaking time was the average of two tests. Pats that did not disintegrate sufficiently to drop through their rings were kept immersed for 7 days. The slaking time of these pats was recorded as "didn't fail". The water was at room temperature throughout

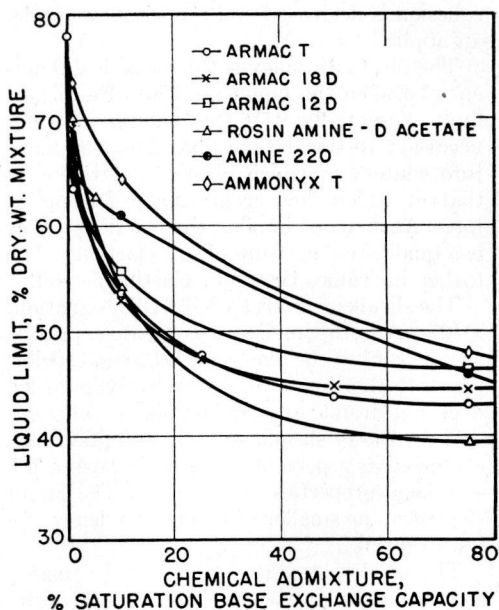


Figure 6. Effect of Cationic Compounds on Liquid Limit

the tests, and the depth over the pats was maintained at 1-in.

RESULTS

The curves in Figure 5 indicate the manner in which admixtures of the six cationic compounds increased the plastic limit. Figure 6 shows the effect of the same admixtures in decreasing the liquid limit. The numerical difference between the two limits is the plasticity index, and Figure 7 illustrates how it was decreased.

The relative effectiveness of the cationic materials in raising the shrinkage limit is shown in Figure 8. Figure 9 illustrates the

manner in which the ratio of shrinkage limit to liquid limit was increased.

Table 3 shows how air-dry strength was reduced by the cationic admixtures. Table 4 indicates the effect of the admixtures on slaking time.

DISCUSSION OF RESULTS

The plasticity index of Edina subsoil was lowered by all cationic treatments. Since the

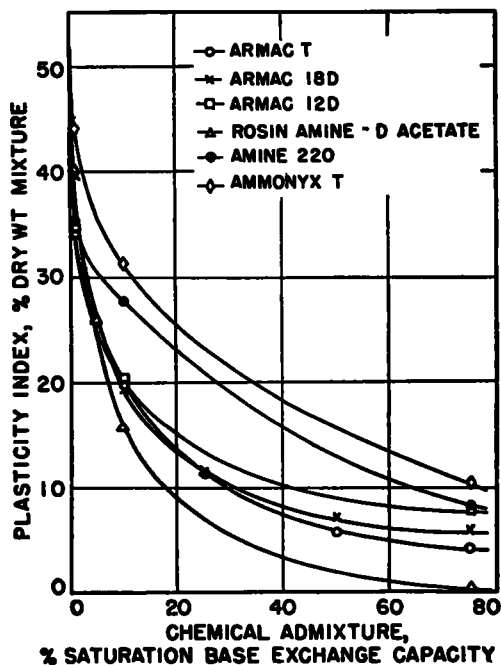


Figure 7. Effect of Cationic Compounds on Plasticity Index

plasticity index is a qualitative measure of soil plasticity, it may be concluded that all admixtures were effective in reducing this property. Likewise all treatments reduced shrinkage, as indicated by an increase of both the shrinkage limit and the ratio of shrinkage limit to liquid limit. The rate of reduction of plasticity and shrinkage varied with the type of cationic compound and the percent saturation of the soil's base exchange capacity; but, in the case of each compound, the sharpest reduction was caused by the initial 10 percent saturation. Rosin Amine-D Acetate was especially effective in lowering both properties.

Admixtures of all compounds caused a re-

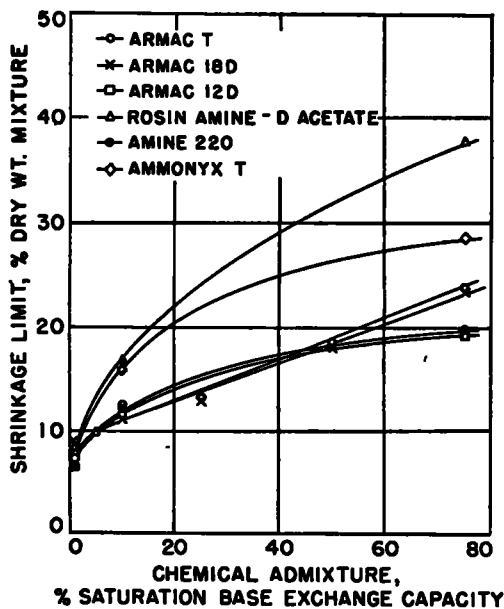


Figure 8. Effect of Cationic Compounds on Shrinkage Limit

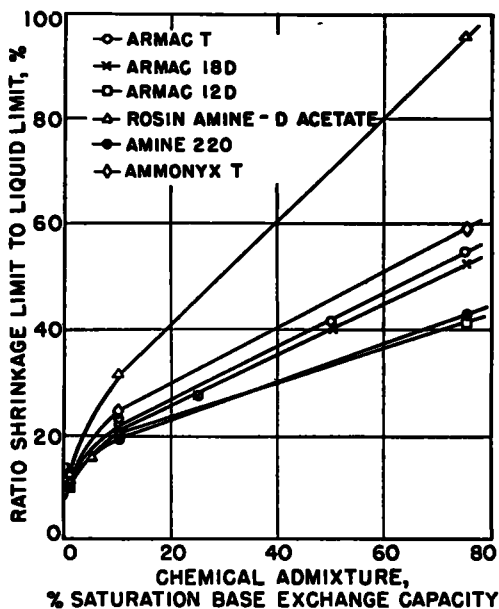


Figure 9. Effect of Cationic Compounds on Ratio of Shrinkage Limit to Liquid Limit

duction of Edina subsoil's air-dry strength by decreasing its cohesive properties. With the

exception of Rosin Amine-D Acetate, the loss was not great for admixtures up to 10 percent saturation of the base exchange capacity. Rosin Amine-D Acetate in dosages larger than 5 percent caused very great loss of strength. For Armac T and Armac 18D, the loss was only gradual up to 25 percent saturation. All

TABLE 3
EFFECT OF CATIONIC COMPOUNDS ON AIR-DRY STRENGTH

Chemical admixture, saturation b.e.c.	Air-dry Strength, psi					
	Armac T	Armac 18D	Armac 12D	Rosin Amine-D Acetate	Amine 220	Ammonyx T
%						
0	2200+	2200+	2200+	2200+	2200+	2200+
1	2200+	2200+	2200+	2200+	2200+	2200+
5	—	—	—	2200+	—	—
10	2200+	2040	2120	420	2200+	2040
25	2120	1960	—	—	—	—
50	1000	720	—	—	—	—
75	400	40	350	10	160	120

TABLE 4
EFFECT OF CATIONIC COMPOUNDS ON SLAKING TIME

Chemical admixture, saturation b.e.c.	Slaking time, minutes					
	Armac T	Armac 18D	Armac 12D	Rosin Amine-D Acetate	Amine 220	Ammonyx T
%						
0	4 5	4 5	4 5	4 5	4 5	4 5
1	7 0	6 5	11 0	369 0	6 5	5 7
5	—	—	—	Didn't fail	—	—
10	Didn't fail	Didn't fail	Didn't fail	Didn't fail	Didn't fail	3 5
25	Didn't fail	Didn't fail	—	—	—	—
50	Didn't fail	Didn't fail	—	—	—	—
75	Didn't fail	32 0	14 5	1.5	2 5	13 0

75 percent treatments greatly reduced air-dry strength. Armac T admixtures caused the least loss of strength. For example, 10 percent Rosin Amine-D Acetate caused almost as great a reduction as 75 percent Armac T.

Ten percent saturation of Edina subsoil's base exchange capacity with all compounds except Ammonyx T greatly improved its resistance to disintegration during the slaking test. Ammonyx T had practically no beneficial effect on the rate of disintegration. Five percent Rosin Amine-D Acetate was very beneficial. In general, admixtures larger than

10 percent did not appreciably increase slaking resistance. With the exception of Armac T, the 75 percent treatments did not prevent pats from dropping through their supporting rings; and in some cases the slaking time was less than for the untreated pats. This was probably due to the very low air-dry strength of the 75 percent saturated pats that failed. Observation of these pats during disintegration revealed that the individual pieces that broke off were not wetted by the water.

CONCLUSION

This investigation, while only of an exploratory nature, indicates that large organic cations have considerable promise as stabilizing agents for highly plastic fine-grained soils. Reduction of air-dry strength was the only undesirable property change caused by the cations studied. All other modifications were decidedly beneficial from the standpoint of all-weather stability.

Of the six cationic compounds investigated, Armac T and Rosin Amine-D Acetate showed the most promise. Both should receive further study.

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AN ORGANIC COMPOUND AS A STABILIZING AGENT FOR TWO SOIL-AGGREGATE MIXTURES

DONALD T. DAVIDSON, *Assistant Professor of Civil Engineering, Iowa State College* AND JOHN E. GLAB, *Captain, Corps of Engineers, United States Army*

SYNOPSIS

Laboratory investigations at Iowa State College have indicated that certain organic compounds which furnish large organic cations when dissolved in water have considerable promise as admixtures to increase the all-weather stability of soils. An investigation is described in this paper wherein one promising compound was evaluated as a stabilizing agent for two soil-aggregate mixtures having plasticity indices higher than considered desirable for highway subgrade material.

The test results indicate that water solutions of the chemical admixtures had the same qualitative effect on the two soil-aggregate samples. The following properties were decreased: plasticity, shrinkage, maximum modified AASHO density and optimum moisture content, and unsoaked California Bearing Ratio. The soaked CBR of both samples was increased and swelling was reduced.

The need for more research is indicated before any definite recommendations can be made regarding the use of water-soluble organic compounds for soil stabilization purposes. However, the results of this investigation show that admixtures of the compound evaluated had a beneficial effect on some engineering properties related to the all-weather stability of the soil-aggregate mixtures.

In 1845 H. S. Thompson observed that clays have the property of carrying adsorbed cations¹ which can be exchanged for other cations. During the ensuing years the ionic exchange method of altering the properties of the clay fraction of soil has been the subject of a considerable amount of research. Most investigators, however, have been principally concerned with the use of inorganic cations such as sodium (Na^+), calcium (Ca^{++}), hydrogen (H^+), and aluminum (Al^{+++}).

During the last three decades a large number of organic compounds have been developed which promote or effect lubrication, wetting, detergency, foaming, emulsification, water repellancy, and other effects associated with the term "surface activity." Many of these surface active agents have a molecular structure which is essentially oblate, that is,

considerably longer than it is wide. Usually they are dipolar, one end of the oblate structure comprising a hydrocarbon radical of hydrophobic (water-hating) nature, whereas the other end is of a hydrophilic (water-loving) nature. The cation-active or cationic surface active agents are characterized by the fact that the hydrophobic group forms part of a cation when the compound is dissolved in water. A typical example of this class is octadecyl ammonium chloride which dissociates in water according to the equation



Research being carried on at Iowa State College, while only in the exploratory stage, has indicated that organic cations have considerable promise as stabilizing agents for fine-grained soils. The investigation reported herein covers only one phase of this research.

¹ Positively charged ions