

Closing Remarks by Chairman

With all due respect for our modern, highly refined, physical methodologies, especially those involving electromagnetic and corpuscular radiation, we must keep in mind that the picture obtained by their use is often in a similar relationship to the object of our interest as is an X-ray picture to the real thing. As a matter of fact, better pictures or models of the "reality" obtained within the range of dimensions in which the engineer is interested are often derived with some of the more old-fashioned tools of physical and colloid chemistry. This seems to be true especially for the case of the strained or bound water that has lost its solvent properties. There exists a large literature on this subject dispersed in various scientific fields. An excellent critical view, covering significant Western work on this subject and supplementing it with the more recent Japanese research results, was published in 1955 by Ken'iti Higasi (1). Also, this subject is well covered by M. W. Tschapek (2) in his most recent book, the entire contents of which are very pertinent for the present conference.

I should also mention in this connection the recent, small, but pregnant book entitled "Relations Between Water and Soil" by T. J. Marshall (3) of Australia written from an agricultural point of view and the proceedings of a conference on "Water in Porous Media" (4) held in 1959 in Paris under the chairmanship of Robert L'Hermite, Director of the Institute of Building Research and Public Works of France. The papers contained in these proceedings breathe the spirit of modern engineering material science.

To return to some specific aspects of the soil-water problem and crawl around the atoms and molecules in order to observe them more closely. One may start out with a single crystal flake of montmorillonite in as dry a condition as possible without affecting its behavior toward water. In this condition, it will still have some strongly adsorbed water molecules on the surface and also, if the material is surrounded by air, some adsorbed oxygen molecules probably arranged so as to continue, as well as possible, the pattern of the adsorbed water molecules, inasmuch as hydrophilic materials are generally oxophilic. In this state, the exchangeable cations will be located within the void surface of the mineral. If water is added in small increments, possibly by adsorption from atmospheres of increasing water vapor pressure, this water will tend to reduce the pattern of the first adsorbed layer with disturbances of the organization becoming greater as the thickness of the water film increases. The degree of restraint exerted by the molecules in the various layers manifests itself in a lower specific and surface heat as compared with that of normal water, the difference being given off as heat of wetting.

As the water film reaches a certain thickness, the more energetic of the exchange ions are induced to leave their places within the solid mineral surface and venture into the water. These are followed by others, with increasing water film thickness, in a manner that the actual concentration of the exchange ions in the water remains constant over a considerable range. This has been known for a long time from pH measurements made at different water contents. Depending on their size and charge, the cations bind or restrain vicinal water molecules which again will manifest itself in heat of hydration that will add to the total amount of the heat of wetting of the soil. The displaced cations now give rise to osmotic swelling if in contact with free water. The impermeable wall normally required for osmotic swelling is simulated by the electric field that issues from the surface of the mineral and holds the cations within its sphere of influence (5, 6). The different "types" of water that may exist in an aqueous dispersion of clay minerals have been enumerated in my symposium paper.

As the water content of a clay water system is decreased from a condition where there is plenty of room for the hydrated exchange ions to swim freely in the water phase to the initial condition of dryness, then various hysteresis phenomena will be encountered because the hydrated cations will require time to shed their hydration hull and

return to their proper places within the mineral surface. Hence, depending on the rate of wetting and drying, respectively, mineral-water systems may at the same water content exhibit markedly different properties if this content is reached by wetting in one case and by drying in the other.

There is another interesting point that deserves mentioning. The bond energy per mole of water is 3600 calories. The average heat of wetting per gram of water, as determined on clays dried over powdered phosphor pentoxide is 50 to 90 calories, or about 900 to 1600 calories per mole. While this is less than one-half of the bond energy of liquid water, it is of the same order of magnitude as the heat released in the freezing of water under normal conditions. Hence, hydration of soil particles under release of the indicated heat of wetting may be expected to have a similar effect on the consistency of the water involved as has the freezing of normal water. Now, Pickett referred to an apparent paradox that relatively large effects of water bonding on the consistency of clay-water systems are associated with relatively small effects of such bonding with respect to the viscosity of the restrained water itself.

Of course, very thin water films between mineral particles may act as strong cementations, but appreciable effects on consistency properties of soils are observed even with a water content that falls within the range where osmotic swelling predominates. Here, the tendency of the exchange ions to get as far away as possible from the charged surfaces may induce the soil minerals to form cell-like structures (like houses made of playing cards or honeycombs) that are stabilized by the mutual repellency of the exchange ions deriving from the mineral surfaces. Analogies to this picture are the turgidity of healthy plants, as compared with the lower mechanical resistance properties of wilted plants and the stiffness of a well-filled air mattress.

In line with these comments, there exists a good body of evidence that the differences in consistency properties of monoionic variations of the same clay mineral at the same moisture content is due more to differences in state of dispersion and structure of the clay minerals, affected by the ions in interplay with the water present, than to the direct effect of the ions on the viscosity of the water involved.

There is so much more that we should discuss this afternoon, but our time has already run out. It may be pertinent to mention here that while still under the fresh impression of the symposium as given in January 1958, I had an opportunity to formulate a synoptic picture of the subject matter on occasion of a Water Supply Conference at Princeton University. This was printed in Bulletin 12, Water Supply, the Princeton University Conference 1958, which is available on request. The paper was deemed of sufficient importance to have been translated into German and has already been reprinted in Germany and Austria in three different publications.

REFERENCES

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