General Report on Thermal Characteristics of Soils, Thermodynamics of Soil Systems, Fluid Flows, and Frost Action

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•PART I isdevoted to a consideration of the thermodynamics of soil systems, fluid flow, frost action, and certain thermal characteristics of soils. Two papers touching upon the thermodynamics of soil systems have been contributed: the paper by A. Holl focuses on the granular nature of soils, whereas the paper by R. Yong, R. K. Chang, and B. P. Warkentin touches on the thermodynamics of soil water. Dr. Holl's thermodynamic treatment of soil compression follows by analogy to classical thermodynamics in a straightforward manner. Because of this, the approach has a certain intrinsic appeal. The potential value of a thermodynamic approach to soil mechanics is difficult to calculate. One reflects that classical thermodynamics is useful chiefly because it is a convenient, systematic method of arranging and cataloguing the results of experimental observations that permits in advance the prediction of spontaneous processes and in many cases helps in arranging conditions so that borderline processes can be accomplished in a desired manner. Equally important are the limitations of classical thermodynamics: (a) as yet, it is not designed to predict the spontaneity of processes under non-isothermal conditions, nor (b) does it furnish information on process mechanisms or process rates. One also is somewhat in awe of the enormous body of experimental data upon which the discipline rests, much of it accumulated by investigators doubtful of the conclusions derived from thermodynamic theory. Thus one is brought to the realization that a transfer of thermodynamic methods to new disciplines is likely to be widely accepted and hailed as a benefit only after a very long period of doubt and testing. Subsequently it will probably be found that the validity of the method rests as much on the results of the many experimental investigations undertaken to establish or test it as upon the intrinsic value of the thermodynamic method, itself. Perhaps this point and the problem of the selection of variables posed by this paper need further exploration. As is well known, the utility of thermodynamic theory depends crucially on the proper selection of variables of state; the degree to which this has been done successfully has yet to be determined.

For practical engineering purposes the effect of temperature on the state of soil water was found by Yong, Chang, and Warkentin to be negligible. In agreement with the findings of previous investigators, at a given soil water suction they observed that the amount of water retained decreases as the temperature increases, probably in the main because the air-water surface tension decreases as the temperature increases. In accordance with earlier investigations and in agreement with the prediction of double layer theory, swelling (imbibition of water) increased with an increase in temperature. There are difficulties in terminology and perhaps the basis for a disagreement in concept in maintaining that the matrix potential is made up of ". . . swelling and capillary forces."

Two papers on thermo-osmosis have been contributed. Again from the practical point of view both conclude that in saturated soils thermoelectric and thermo-osmotic flow is completely negligible. In unsaturated soils, water transport occurs primarily in the vapor phase and sometimes it is of practical significance. For example, the transport and collection of water under pavements and airport runways due to thermal gradients is a possibility that must always be evaluated when materials and construction methods are selected. The nature and significance of the interfacial energy and the various types of interfaces present in soils are discussed in the paper by Gray. Another point considered is the current status of the practice of utilizing electro-osmosis to dewater frozen and unfrozen soils. The paper by Globus and Mogilevsky contributes a coherent concept of the processes involved in the thermal transfer of liquid in porous materials. They propose that the net pressure difference developed in a liquid-saturated porous substance subjected to a temperature gradient is brought about by three flow components: a thermo-osmotic component in the direction of higher temperature, a thermo-self-diffusion component in the direction of lower temperature, and a Poiseuille flow component opposing the resultant of the other two. This explains how one may observe a pressure rise at the warm end of a flow column in the early stages of a thermo-osmosis experiment with a reversal at some later time. This phenomenon and the concept advanced by Globus and Mogilevsky to explain it deserve further exploration, inasmuch as the point arises in both papers.

In contrast to most situations in unfrozen soils, the effect of temperature on the properties and behavior of frozen ground is of undisputed importance. The unfrozen water contents of frozen soils change markedly with temperature. Important soil properties also depend critically on thermal regime: shear strength, bearing capacity, rheological response, and electrical properties. The paper by Hoekstra reviews recent work bearing on these points and re-emphasizes the need, expressed by many at the International Symposium on Permafrost at Purdue University in 1963 (1), for a better understanding of frozen soils. As the artificial freezing of ground becomes a more widespread engineering practice (e.g., earth stabilization, to aid in excavations, and for cryogenic storage) the need for methods of generalizing experimental data pertaining to mechanical properties of frozen and thawing soils and the establishment of standard strength and deformation parameters becomes evident. The specific surface area of soils appears in the context of this paper as a soil parameter of fundamental importance. Globus and Mogilevsky also direct attention to its fundamental significance in thermo- and electro-osmosis. It is a soil property that has been too frequently neglected, or overlooked, in soil characterizations by engineers who have not yet become aware of the useful information that can be deduced from it.

The paper by Aylmore, Quirk, and Sills is devoted to the subtle effects of partial or complete dehydration on the subsequent swelling of illite and kaolinite. They suggest the possibility that when kaolinite is physically mixed with illite, individual particles may be cross-linked through hydrogen bonding. This is a point of some interest in view of recent work indicating that hydrogen bonding in water immediately proximate to clay surfaces is less than for water in bulk (2, 3). In certain situations, it is suggested by Goetz and Mueller that the consequence of the sinusoidal, daily temperature cycle is to aid in establishing the boundary between the A and B soil horizons. They conclude that the daily temperature wave sometimes plays a distinct role in soil genesis. One is reminded in this instance of the process of particle sorting brought about by frost action. Perhaps a relationship with paleoclimate resides in the observations reported. A new equation for heat conduction in granular materials is proposed in the paper by McGaw. An outstanding feature in his development is his recognition of the thermal resistance of interfaces separating the mineral grains from surrounding substances. The paper provides a brief but comprehensive overview and comparison of the leading formulations of thermal conduction in soils. It is pointed out that several formulations in current use are adequate in representing much of the available data. Justification for seeking other formulations lies primarily in the hope that the effect of wider ranges in value of the essential variables may be more accurately predicted.

From an engineering point of view, temperature effects on soil properties generally have been of practical significance only insofar as radically different soil properties could be achieved by the artificial heating or cooling of earth materials. Higher soil strength and resistance to the deleterious effects of water have been achieved by baking or sintering earth materials, for example. The same result is achieved in another way by artificial freezing. Processes of this kind involve large quantities of energy and yield large returns in desired effect; they are, therefore, important. On the other hand, the effect of temperature on soil water-holding capacity, on the state of soil water, in inducing water transfer, etc., has been and currently still is of marginal significance from the practical point of view. This is largely because troublesome soils generally can be avoided or excavated and discarded. This being the case, one can sympathize with a reader who is unfamiliar with the disciplines involved as he strives to follow closely reasoned arguments encumbered by cryptic notations and strange definitions, only to find at the end of the paper that the results are inconclusive or inconsequential. However regrettable, to some extent this appears to be the case here. It is easily foreseen, however, that the situation may soon be radically different. Forced utilization of soil materials of marginal suitability, when it comes, will require that effects such as described in the papers of this part of the Symposium be predictable and manageable. The investigators are wrestling to obtain an understanding of topics recommended in the past as being vital to an improved mastery of earth materials. To this end, one can only recommend patience to those who suffer and unremitting effort to those who have succeeded in penetrating the difficult scientific problems.

REFERENCES

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