Keynote Address

HANS F. WINTERKORN, Princeton University

•IT IS a very happy occasion for me to see this symposium become a reality through the great efforts of Dr. Mitchell and the members of the Committee on Physico-Chemical Phenomena in Soils, and the splendid response of scientists and engineers from many parts of our globe to the requests for pertinent papers. The theme selected for this symposium should require no special justification. Soil itself owes its formation to the thermal energy received by the earth surface from the sun, working through many different physical, chemical, and biologic mechanisms. This rhythmic pattern of energy acceptance during daytime and radiation loss during the night, and the seasonal variations in thermal gain and loss, result in daily and seasonal temperature waves that penetrate into the earth surface. These temperature waves not only help in fashioning the characteristic soil profile but are also responsible for water accumulation, frost heave, stability loss, corrosion, and other problems that plague the highway engineer.

In the old days, the highway engineer worked mainly within a restricted climatic area and built his roads by traditional methods if he could afford them. Otherwise, there were no roads. Also, at least in the northern regions, he knew that construction was a seasonal occupation and nobody but a fool would try to build roads or other structures during the inclement weather or season. While this is still a wise working philosophy, we are forced to deviate from it more and more in our modern civilization. The work range of the modern civilian and military soil engineer extends from the torrid to the arctic regions, and the construction season is continuously expanded. Therefore, design and construction must take into account the thermal properties and behavior in a thermal energy field of the systems we call soil and of their solid, liquid, and gaseous components. To the thermal engineering problems caused by the differences in terrestrial temperatures and temperature ranges we may soon have to add those to be encountered on the lunar surface, the temperatures of which may reach a maximum of 404 K during daytime and a minimum of 120 K during nighttime.

Although it is sincerely hoped that nuclear bombs will never be used again, the soil engineer and the nuclear engineer are seriously interested in what happens to a soil surface that is exposed to the fireball of a fusion bomb, and in how thick a soil layer is required to protect man from the thermal consequences of his madness. A less impressive but perhaps even more important result of peaceful use of nuclear energy is the thermal pollution of our rivers, streams, and lakes, which is transmitted to the contiguous soil and affects its physical, chemical, and biologic properties and behavior.

The effect of temperature on the time rate of chemical reactions is well known and is of greatest theoretical and practical importance. Obviously, we should make a systematic study of this effect in all methods of soil stabilization that involve chemical reactions. Of course, heating alone may stabilize cohesive soils, as has long been known from brickmaking. Also, the recording of the exothermal and endothermal reactions that occur upon heating of minerals, as in the differential thermal method, and of the accompanying weight losses, as in thermogravimetric analysis, represent very valuable diagnostic tools for the determination of soil minerals and for the understanding of what happens to these minerals with increase in temperature.

Even though these are but a few examples of the many problems encountered by the soil engineer in which knowledge of soil thermal properties is of primary importance, they would suffice as justification for this symposium. However, the need to know as much as possible about these thermal properties was only one of several reasons for this symposium. This is apparent from the topics listed in the invitations as falling within the scope of the symposium. They read as follows:

1. The physical nature of thermal energy; capacity and intensity factors; the states of matter as functions of thermal energy content; basic thermodynamic concepts, activation energy and reaction rates.
2. Thermal characteristics of the main solid components of soils. Thermal characteristics of the water substance and the normal gaseous components of soils.
3. The effect of temperature on the interaction of soil components including lessons from ceramics.
4. Thermally induced moisture flow in soils and accompanying electric phenomena.
5. The influence of temperature on consistency, strength, and compressibility of soils.
6. Effect of temperature on hardening and curing rates of soil-cement, soil lime, and other stabilized soil systems.
7. Thermal stabilization of soils.
8. Other engineering applications.

Obviously, the concept of the symposium was much more ambitious than to serve only the strictly practical needs of the present and near future. We wanted to bring to the consciousness of the soils engineer the existence of thermodynamics, not as a collection of equations from which one selects those that appear pertinent and plugs the right data into them, but as a working philosophy of both qualitative and quantitative character that combines philosophical universality with practical applicability to everything that happens or may happen under the sun. It is a great pity that modern teaching of thermodynamics overemphasizes the quantitative and mathematical aspects of this science, or rather "natural philosophy," and neglects to point out the qualitative aspects and their usefulness. This is especially regrettable in the case of soil systems in which, because of the great number of components and phases and the lack of quantitative data on their thermal properties, a true quantitative treatment is usually impossible. On the other hand, qualitative use of thermodynamics can indicate with great certainty the direction in which a soil system changes under known or expected environmental influences and can point out the type of testing or experimentation that should be done on the system to obtain practically and theoretically meaningful information. Very useful thermodynamic tools of qualitative or semiquantitative character are, for example, the phase rule of Willard Gibbs and Le Chatelier's principle.

The kind of thermodynamics we have in mind is not restrictive, such as the energetics of Helmholtz or even the concept of Wilhelm Ostwald, who, up to the late twenties, saw no good reason for accepting the molecular hypothesis. My concept of a working thermodynamics for a soil engineer is that of a mansion in which there is room for all coordinated knowledge on heat and its interrelation and interaction with other forms of energy. Basic for this concept is the recognition that heat is a "form of motion" of the molecules composing a system. Nor should it be alien to this concept that the motion energies of the individual molecules in a system at a certain temperature cannot be identical but follow a distribution law such as the Maxwell-Boltzmann distribution in gases. If we accept this into thermodynamics, then the door is also opened for acceptance of the theory of rate reactions and the most valuable concept of the activation energy.

While this is not the place for a treatise on thermodynamics or for a controversy on what is a proper part of thermodynamics and what is not, I want to plead for a greater use of thermodynamic thinking in all its qualitative and quantitative aspects wherever they are applicable. An important example of such an application is the rapidly developing discipline of the thermodynamics of granular systems. Some of the most elegant demonstrations of thermodynamic laws are in the field of electrochemistry, that is, in systems whose components are predominantly of ionic and generally polar character. Most soils and especially the highly swelling clays are of this character. Therefore, electric testing methods are especially useful in routine and research work with soils. Thus, the commonplace electric pH determination is actually a thermodynamic test. If I were asked what would be the greatest boon for soil engineering I would unhesitatingly say: "More thermodynamic thinking and more electrochemical methodology."

But it is time to close these remarks and come to the real meat of the program, the presentation and discussion of the splendid papers that have been contributed to this symposium.