Water Movement in Porous Solids: Some Recent Progress

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This report gives some recent contributions to the diffusion analysis of water movement in unsaturated solids, to the thermodynamics of water held in such solids, to moisture movement under temperature gradients, and to the study of the effects of entrapped air*. The latter, rather novel, field of inquiry has theoretical and practical implications of great importance.

● THIS SHORT communication is essentially a footnote to the author's symposium article (1). In accordance with the Chairman's suggestion, certain more recent work with which the author has been associated is reported.

LIQUID FLOW OF WATER IN UNSATURATED POROUS SOLIDS

Early Stages of Absorption and Infiltration

The author's article (1) stated that it is "possible that perceptible deviations from Darcy's law may occur during the very early stages of absorption or infiltration into unsaturated systems." This was expected because the "diffusion analysis" predicts that, very close to the start of these phenomena, the flow rate, and hence the Reynold number of the system, must be so large that Darcy's law fails. Further, Darcy's law implies a force equilibrium with no resultant to impart momentum to the system, whic is initially at rest. These considerations suggested that the diffusion analysis might b open to some question, at least during the early stages of phenomena such as absorpti and infiltration.

An analysis based on Newton's second law has been carried out and has resolved these various difficulties. The net result is that the error in the diffusion analysis du to the neglect of inertia effects is entirely negligible, except for a short initial period of less than 10^{-4} sec; the maximum Reynolds number of the motion is shown to be finit and the observed small deviations from the diffusion analysis during the early stages o absorption and infiltration are in the wrong sense to be explained as due to inertia or high Reynolds number. They appear to be due to the effects of entrapped air. This work is fully reported by the author (2).

Viscous Dissipation of Energy During Absorption and Infiltration.

The problem of just when and where energy is dissipated in unsaturated porous solids when they are taking up water does not seem to have been investigated hitherto. An investigation of the viscous dissipation of energy during this process has been carried out, and is an extension of the previous diffusion analysis. One by-product of the study is a novel definition of hydraulic conductivity in which it is related to the point rate of viscous dissipation in the solid. The profiles of energy dissipation reveal a characteristic peak near the "wet front" in terms of energy dissipation. This study is described by the author (3, 4).

* Chairman's note: See statement concerning effect of entrapped air, HRB Special Repor 40:335 (1958); also, "Das Verhalten des Bodens gegen Luft," Handbuch der Bodenlehre, Julius Springer Verlag, Berlin, 6:253-342 (1930).

Absolute Thermodynamic Functions in Study of Porous Solids

The potential function commonly used in soil-water studies is equivalent to the specific differential Gibbs function. It has been found (5) that it is more useful in problems in which one wishes to examine changes in the total potential energy of the system to use the absolute form of thermodynamic function. As an example, the differential function does not distinguish between the energy state of water in a saturated porous solid and that of free water at the same level. The absolute function does so.

Mathematics of Concentration-Dependent Diffusion

The mathematics of concentration-dependent diffusion is basic to the diffusion analysis of water movement in unsaturated solids. Hitherto, numerical methods have been necessary to solve these problems, except in certain quite special cases. A general method of solution of problems in concentration-dependent diffusion by analytical means has been developed (6) and promises to make the mathematical problem more tractable. Details of a function entering into this new method are given in a second paper (7).

MOISTURE MOVEMENT UNDER TEMPERATURE GRADIENTS

Although there seems to be general agreement that the theory of moisture movement n porous solids under temperature gradients put forward by Philip and De Vries (8) is roadly correct (9), certain workers appear to have misunderstood some aspects and have been led into erroneous criticisms (10). De Vries and Philip (1) emphasize the ifferences between the fine structure of the temperature field and the vapor field and lear up other misconceptions that have arisen.

EFFECTS OF ENTRAPPED AIR IN POROUS SOLIDS

For quite some time now, the presence of entrapped air in naturally saturated porous olids (12) and its effect on hydraulic conductivity of such solids (13) have been clearly ecognized. Recognition of the importance of the air-phase in unsaturated solids has een somewhat more tardy.

The possibility that entrapped air would produce nonuniqueness of the moisture potenal function in the surface layers of a porous solid was recognized (14) in 1955. This plained the characteristic "dog-leg" transition zone observable in moisture profiles ring infiltration (15) and also the observed small deviations from the diffusion analys (2).

emperature Dependence of Moisture Potential

Another phenomenon that has long been puzzling is the failure of the temperature pendence of moisture potential to be related in any consistent manner to the temperae dependence of surface tension. A proper understanding of the temperature dependce of moisture potential is necessary before the problem of liquid phase transport der temperature gradients can be studied in a meaningful way.

In the author's symposium paper (1) it was stated that "the explanation seems to be t as temperature increases, the volume of totally entrapped air bubbles expands, ding to an altered configuration of the meniscal surface between the liquid water in medium and the external atmosphere. Experimental study of this effect is in progss in the Australian C.S.I.R.O. Division of Plant Industry."

The experiments and a detailed working-out of the theory confirm the suggestion de in HRB Special Report 40. Peck has been responsible for the experimental prom and for going into the details of the theory. He has reported part of the work (16) l has a further paper in preparation.

ect of External Air Pressure on Moisture Potential

Intimately connected with the temperature effect previously discussed is the effect hanges of the external pressure on the volume of entrapped air, and hence on menis configuration and on moisture potential.

Experimental work has confirmed the reality of the effects of external air pressure which the "trapped air" theory demands (16). This effect is also of great practical importance. For example, systematic changes of water table level with atmospheric pressure are to be expected, and have been observed experimentally by Peck (17).

Perhaps of greater importance is the fact that this work indicates that moisture characteristics determined by pressure-plate methods do not necessarily agree with those determined by "suction" methods. There will certainly be important discrepancies at the wet end of the moisture range. It is more difficult to predict the importanc of this effect at moisture potentials greater than 1,000 cm.

The significance of this work on trapped air for soil mechanics is that it underlines the importance of treating the soil as a three-phase system—solid, liquid, and gas. Perhaps all have been too prone to work with the two-phase system of just soil particles and water.

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