MEASUREMENT OF BLOCKED AIR PORE VOLUME IN SOILS (POROUS MEDIA)

by G. C. AGGARWAL *and* P. K. SHARMA, *Department of Soils and Chemistry, Agricultural Complex, Palampur-176061 (H.P.)*

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A simple method based on volume-weight relationships in soils was developed for the measurement of blocked air pore volume. A given clod is saturated with water or kerosene and then weighed in air and in kerosene. This clod is thoroughly crushed and is weighed again in kerosene. Blocked air pore volume is computed from these weights using simple equations. Blocked air pore volume was measured when saturation was achieved under atmospheric pressure or under vacuum. For the soils studied, the proposed method gave as good results as the indirect method. The blocked air pore volume was independent of soil bulk density, organic carbon content and soil texture.

INTRODUCTION

Since methods of measuring hydraulic conductivity of unsaturated soils are tedious, attempts have been made to calculate it on the basis of particle properties (Carman 1939) and pore size distribution (Childs & Collis-George 1950; Marshal 1958; and Millington & Quirk 1959). Generally these methods were tested with media where the pores had greater degree of uniformity and consequently good agreement was found between the computed and measured values throughout the entire moisture content range. However, Tripathi and Ghildyal (1975), who worked with different textured soils, found that pore size distribution methods (Childs & Collis-George 1950; Marshal 1958; and Millington & Quirk 1959) underestimated the hydraulic conductivity at lower moisture contents. This discrepancy may be due to the use of total porosity in these formulae. It is the interconnected pore volume only that contributes to flow through porous media and even a part of it e.g., dead end pore volume, does not contribute to steady state flow through the medium.

As regards the flow through porous media, a small fraction of the pore space i.e., blocked pore volume is totally ineffective. Blocked pore volume may be defined as the volume which may contain a fluid but does not contribute to fluid flow. Information on blocked air pore volume will aid in better description of the soil pore geometry and increase the accuracy of the predictive methods for computing hydraulic conductivity. But so far no work has been done to measure this volume though dead end pore volume has been estimated (Jackson & Klute 1967). The purpose of this study was to develop a simple method for measuring blocked air pore volume.

Method and Material

Theory

For a moist natural clod of weight $W(g)$ and volume V(ml) one may write

$$W = V_s D_p + V_w D_w + (V_a + V_b) D_a \qquad ..(1)$$

and $V = V_s + V_w + V_s + V_b$ ..(2)

Here V_s is the volume of soil solids, V_w is the volume of soil water, V_a is the volume of soil air and V_b is the volume of the blocked air pores. D_p is the soil particle density, D_w is the density of water and D_a is the density of air.

After equilibrating the clod on a water saturated sand column (Prihar & Hundal 1971) let it weigh W_1 g where,

$$W_1 = V_s D_p + (V_a + V_t) D_w + V_b D_a \qquad ..(3)$$

This saturated clod when submerged in kerosene shall weigh W_2 g (Archimedes principle) where

$$W_2 = V_s (D_p - D_o) + (V_w + V_a)(D_w - D_o) + V_o (D_a - D_o), \qquad ..(4)$$

where D_o is the kerosene density.

Afterwards the clod is thoroughly crushed so as to eliminate all the blocked air pores and then reweighed under kerosene. Its weight W_3 will be

$$W_3 = V_s (D_p - D_o) + (V_w + V_a)(D_w - D_o). \qquad ..(5)$$

From Eqs. (4) and (5)

$$W_3 - W_2 = V_b (D_o - D_a) \qquad ..(6)$$

and from Eqs. (3) and (4)

$$W_1 - W_2 = V D_o. \qquad ..(7)$$

Hence, Blocked air pore volume (%) $= \frac{V_b}{V} \times 100 = \frac{W_3 - W_2}{W_1 - W_2} \times 100,$ ...(8)

(assuming $(D_o - D_a) = D_o$, as air density is very low).

Procedure

Natural soil clods were equilibrated on water saturated sand columns (Prihar & Hundal 1971). Equilibrium was achieved either under atmospheric conditions or in a vacuum desiccator connected to a rotary pump that could produce a vacuum of 10^{-2} Torr. However, actual pressure in the desiccator was not measured. A water saturated clod was weighed in air (W_1) and was transferred to a moisture box that served as a pan of the balance. Earlier additional weights had been added to this box so that the balance was counterpoised when the box alone was immersed in kerosene. Then the saturated clod was weighed in kerosene (W_2). The moisture box was taken out of kerosene and the clod was thoroughly crushed and the crushed clod was weighed in kerosene (W_3). In some soils the clods may crumble down during saturation with water. Consequently the study was repeated with clods equilibrated on kerosene saturated sand columns. However, any non-aqueous liquid can be used for saturating the clods. Final equation (Eq. 8) holds even in this situation. But now W_1 is the weight of non-aqueous liquid saturated clod in

TABLE I

Some characteristic properties of the experimental soils

Soil	Organic carbon (%)	Bulk density (g/cc)	pH	Mechanical composition (%)		
				Sand (0.02–2.0 mm)	Silt (0.002–0.02 mm)	Clay (<0.002 mm)
Silty clay loam	1.17	1.45	5.6	27.0	39.4	33.6
Silty loam	0.99	1.50	5.8	52.0	34.0	14.0
Silty loam	0.99	1.45	6.8	54.0	30.0	16.0
Loam	1.38	1.44	6.3	55.8	24.6	18.6

air, W_2 is weight of the saturated clod in the non-aqueous liquid, and W_3 is the weight of the crushed clod in the non-aqueous liquid.

Blocked air pore volume was calculated indirectly also in the following way. For an oven dry clod, Eq. (2) may be rewritten as

$$V_b = V - V_s - V_a.$$

Total volume (V) was computed with Eq. (7). Volume of soil solids was calculated from the relation $V_t = M_d/D_p$, where M_d is the weight of oven dry clod. This necessitated determination of particle density of the individual clods. Soil air volume was calculated from the increase in weight of the given clod on saturation. Thus blocked air pore volume was computed.

The various soils tested and some of their chararetistics are listed in Table I.

RESULTS AND DISCUSSION

The results of blocked air pore volume determination of different soils as measured by the proposed method and the indirect method are given in Table II. Replicate determinations by the proposed method gave as consistent results as the indirect method which proves reliability of the proposed method. Moreover, the proposed method is simple and rapid whereas indirect measurements are tedious and time consuming.

In some soils it may be difficult to get clods and maintain them during transport and handling. To overcome this limitation Keen's box was used for collecting soil samples. A blotting paper pad was placed at the bottom of this box and the box was lightly pressed at the sampling spot—preferably moistened—and the box was removed with a hand hoe. Soil surface in the box was not smoothened to ensure minimum disturbance of the soil fabric. The sample was of an unknown volume and purpose of the box was to facilitate collection and handling of the sample.

A study was made to find the dependence of blocked air pore volume on soil physical properties. Blocked air pore volume measurements of clods, equilibrated on water saturated sand columns under atmospheric conditions, from six different soils varyring in clay from 14.4 to 26.8 per cent, silt from 20.6 to 47.2 per cent, organic carbon from 0.87 to 1.62 per cent and soil bulk density from 1.28 to 1.70 g/cc were

TABLE II

Comparison of indirect and proposed methods for blocked air pore volume determinations

Percent blocked air pore volume ± S.D.

Soil	Clod saturated with water				Clod saturated with kerosene			
	Under atm. pressure		Under vacuum		Under atm. pressure		Under vacuum	
	Proposed	Indirect	Proposed	Indirect	Proposed	Indirect	Proposed	Indirect
Silty Clay Loam	4.10±0.200	3.87±0.307	2.82±0.162	2.86±0.262	2.16±0.250	1.86±0.183	1.48±0.419	1.15±0.314
Silty Loam	4.94±0.485	5.35±0.451	1.56±0.245	1.60±0.409	0.98±0.101	1.13±0.087	0.42±0.112	0.50±0.158
Silty Loam	3.27±0.543	3.58±0.358	2.12±0.249	2.26±0.357	2.14±0.245	2.70±0.156	1.16±0.219	1.21±0.169
Loam	3.08±0.374	3.33±0.243	2.82±0.463	2.17±0.419	2.12±0.216	1.85±0.176	0.84±0.119	0.98±0.141

made. Analysis of the data showed that blocked air pore volume did not depend on these parameters.

To conclude, this method is accurate, direct and rapid. It is hoped that the proposed method, because of its simplicity, will be used for measuring blocked air pore volume. Knowledge about the blocked air pore volume will aid in a quantitative theoretical approach to the description of soil pore geometry, water flow relations and will increase the predictivity of pore size distribution methods for calculating the hydraulic conductivity.

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