Article Information

Journal Title: Nature

Volume: 183 **Issue:**
Month/Year: 1959**Pages:** 397-388

Article Author: Millington, R.J. and J.P. Quirk

Article Title: Permeability of porous media

Loan Information

Loan Title:

Loan Author:

Publisher:
Place:
Date:
Imprint:

Customer Information

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Article Delivery Method: E-Mail
Loan Delivery Method: Hold for Pickup
Electronic Delivery? Yes

28.09.05

showers incident in preferred directions the experiment was discontinued.

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Permeability of Porous Media

OVER the past decade much significance has been given to distribution of pore size characteristics in computing both saturated and unsaturated permeability of porous materials. Oil industry investigators[1] and soil scientists have adopted this approach to permeability computation with considerable success.

Childs and Collis-George[2] proposed a theory wherein flow is determined by the pore radii and by the probability of continuity of pores of different radii in adjacent planes. Marshall[3] greatly facilitated computation by using arbitrary equal volume components of the porosity.

Both these approaches show defects. The ratio of the observed and calculated permeability at saturation was used by Childs and Collis-George as a 'matching factor' to compute values for unsaturated permeability. If instead of the 'matching factor' (M), pore radii (not $1/h$) and the Poiseuille coefficient $1/8$ are used, the computation yields the same result as the method of Marshall. Using the $1-\frac{1}{2}$ mm. sand data of Childs and Collis-George, both the above methods give a calculated permeability at saturation of 76×10^{-8} cm.^{2} against the experimentally determined value of 144×10^{-8} cm.^{2}. The form of the curve calculated by these methods for permeability against water-filled pore space does not fit the experimental findings. In the following paragraphs an alternative theory is proposed.

In a porous medium of porosity ε, the effective area available for flow may be defined with reference to the volume distribution of pore space thus :

$$\frac{\text{effective pore area}}{\text{pore volume}} = (n^2\pi r^2/n^3\pi r^3) \cdot (k_1/k_2)$$

where there are n^3 pores or radius r in unit volume of the medium ; k_1 and k_2 are characteristics of the shape of pore and for nearly spherical pores may be neglected in the subsequent derivation. From this relationship it can be shown that the effective pore area available for flow per unit area of section is $\varepsilon^{2/3}$. If there are m pore classes each occupying a volume component ε/m of the total porosity, then the effective flow area presented by each pore class is $\varepsilon^{2/3}/m$. However, flow is determined by the pore interaction or continuity between adjacent sections, so that permeability is determined by the sum of :

$$a_1a_1r_1^2 + a_1a_2r_2^2 \ldots \ldots a_1a_mr_m^2$$
$$\vdots$$
$$a_ma_1r_m^2 + a_ma_2r_m^2 \ldots \ldots a_ma_mr_m^2$$

where a_1, a_2, etc., are the pore areas devoted to pores of radius r_1, r_2, etc., in unit area of section.

Fig. 1
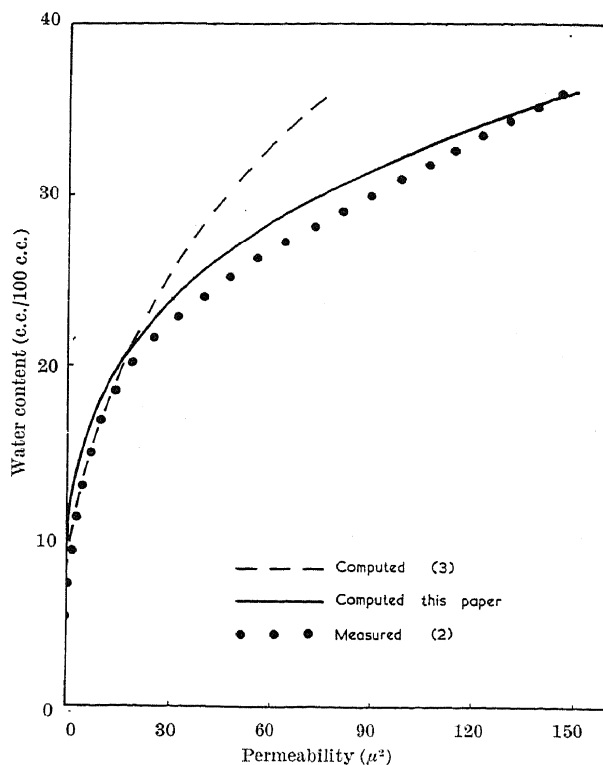
Since there are m equal volume components of the porosity :

$$a_1a_1 = a_1a_2 = \ldots a_ma_m \text{ and}$$
$$a_1a_1 = \varepsilon^{2/3}/m \cdot \varepsilon^{2/3}/m = \varepsilon^{4/3}/m^2 ;$$

when the Poiseuille coefficient is included the intrinsic permeability (K) is then given by :

$$K = \varepsilon^{4/3}m^{-2} [r_1^2 + 3r_2^2 \ldots \ldots (2m-1) r_m^2]/8 \quad (1)$$

The units of K are cm.^{2} but for convenience in Figs. 1 and 2, K is expressed as μ^2.

For calculation of unsaturated permeability the value of ε adopted is that of the water-filled pore space and m remains constant. The r^2 series is commenced at the largest water-filled pore class. The basis for the variation of ε is due to changes in the water velocity which are not accounted for in the r^2 term of (1).

Figs. 1 and 2 enable a comparison to be made between the various methods for calculating permeability and the experimental results obtained by Childs and Collis-George for their $1 - \frac{1}{2}$ and $\frac{1}{2} - \frac{1}{4}$ mm. sands respectively. It can be seen from these figures that over a wide range of water content the curves calculated by the method herein proposed lie close to the experimental curves of permeability plotted against water content. The computed curves obtained either by the method of Childs and Collis-George (excluding M but including r and Poiseuille's $1/8$) or by the method of Marshall are included for comparison ; these latter curves clearly indicate that at high water contents the computed permeabilities are lower than those found experimentally.

Carman[4] has obtained the pore radius – volume curve for a Linde silica plug ($\varepsilon = 0.506$) ; using these data and assuming an immobile monolayer the permeability of the plug has been calculated to be 2.6×10^{-15} cm.^{2}. This compares with the measured permeability[5] to CF_2Cl_2 at $-33.1°$ C. of 3.1×10^{-15} cm.^{2}. It is interesting to note that the proposed
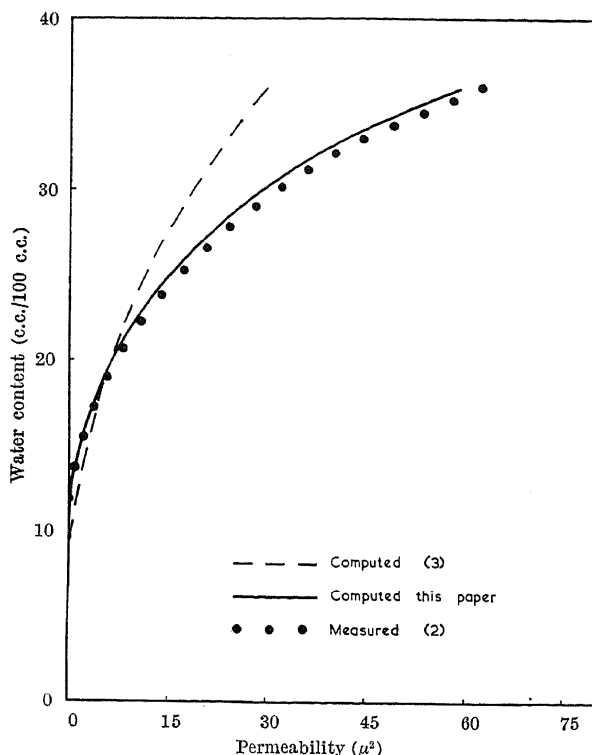
Fig. 2

equation for permeability calculation applies over a wide range of permeability, since the permeability of the Linde silica plug is almost 10^{-9} less than that for the $1 - \frac{1}{2}$ mm. sand.

A more extensive report of this work is being prepared for publication.

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CHEMISTRY

Effect of Thermal Neutron Irradiation on Oxide Catalysts for the Decomposition of Nitrous Oxide

EFFECTS of radiation on catalysis have been investigated in various ways[1], including those of thermal neutron irradiation[2]. As thermal neutrons are of low
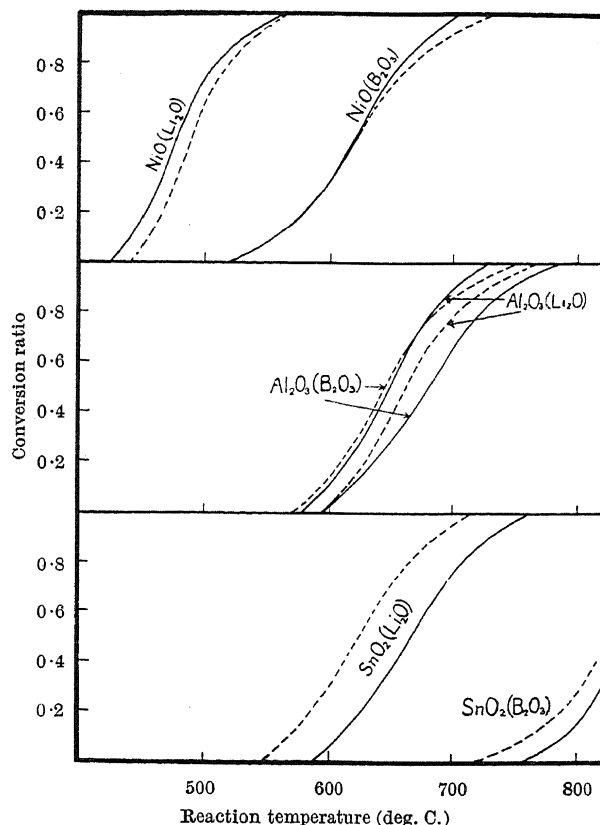

Fig. 1. Conversion ratio of nitrous oxide as a function of reaction temperature. The curves show the effect of thermal neutron irradiation on oxide catalysts. ——, Before irradiation; - - -, after irradiation

energy, usually only a high flux density or a long exposure induces any change in catalytic activities. In this communication, however, we can report distinct effects on the catalytic activities of nickel oxide, aluminium oxide and stannic oxide used for the decomposition of nitrous oxide. The conditions were as follows: flux density, $10^{11}n/cm.^2sec.$; exposure time, 3 hr. With the aid of the (n, α) reaction of lithium-6 or boron-10 atoms, we may expect an intimate relationship between the catalytic activity and the lattice defects in the semi-conductor catalysts.

Separate samples of matrix powders of basic nickel carbonate, aluminium hydroxide and stannic hydroxide were dipped into aqueous solutions of lithium carbonate and boric acid, dried and fired at 750° C. for 2·5 hr. Lithium or boron atoms probably become distributed uniformly in matrices as oxides, the mixing ratio of atoms being 10 per cent, except for 1 per cent for lithium oxide in nickel oxide. The catalysts were irradiated in the *JRR*-1 nuclear reactor of the Japan Atomic Energy Research Institute at Tokaimura under the conditions mentioned above.

Table 1

Catalyst	NiO				Al₂O₃				SnO₂			
Addition	Li₂O		B₂O₃		Li₂O		B₂O₃		Li₂O		B₂O₃	
Irradiation*	bef.	aft.	bef.	aft.	bef.	aft.	bef.	aft.	bef.	aft.	bef.	aft.
Frequency factor ratio	1·7	1	1·1	1	1·6	1	1	2·5	1	2·9	1	2·5
Apparent activation energy (kcal./mole)	22	23	19	19	23	23	23	24	21	20	43	30

* bef. and aft. refer to before and after irradiation, respectively.