

THE FILTRATION PROPERTIES OF POROUS DIATOMITE

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Abstract

The filtration properties of porous diatomite have been studied using the flow of water. Application of differential pressure heads indicates that flow through this material is fractal in the regime of low intensity transport. No fractal behaviour was observed under high intensity, indicating that the geometry of the material is subdued under high external driving forces.

Keywords: Filtration, porous media, diatomite, intensity transport, fractal.

Introduction

The porous medium is ubiquitous, ranging from biological systems, such as sponges, to foams, rocks, man-made sintered materials, and the universe. It has found applications in processes, such as the pore diffusion of gases (heterogeneous catalysis), and in liquid diffusion through porous media (filtration, crude oil recovery (Al-Farris, 1990)). These processes are essential in diverse fields of medicine, biochemical engineering, water works, manufacturing, and petroleum engineering. The rheological properties of fluids are known to change by confinement in very small spaces (Drake and Klafter, 1990). It is, therefore, necessary to measure the properties in geometry similar to the application as much as possible.

Diatomite is a siliceous material that is commonly used in the manufacture of filter elements for domestic and industrial filtration. This paper presents a study of flow of water (filtration) through diatomaceous filters, under low and high intensity forces.

Theory

The porosity, ϕ , of the medium is defined as

$$\phi = \frac{V_p}{V_s} = 1 - \frac{V_s}{V_T} \quad (1)$$

where V_p is the pore volume, V_s is the volume of the solid matrix, and V_T is the total volume of the sample.

The 'resistivity factor', F , is defined as (Archie, 1942)

$$F = \frac{R_s}{R_w} \quad (2)$$

where R_s is the resistivity of a sample that is completely saturated with brine having a resistivity of R_w .

When a fluid flows through a porous medium, it does not follow a straight path, but it travels in a tortuous manner. The tortuosity, τ , of the medium is defined by

$$\tau = F^2 \phi^2 \quad (3)$$

The respective equations of continuity and motion for fluid flow in porous medium are (Muskat, 1937; Hubbert, 1956).

$$\phi \frac{\partial \rho}{\partial t} = -(\nabla \cdot \rho \mathbf{v}_0) \quad (4)$$

and

$$\mathbf{v}_0 = -\frac{k}{\mu} (\nabla p - \rho \mathbf{g}) \quad (5)$$

Equation 5 is Darcy's law, where k is the permeability of the porous medium, μ is the viscosity of the fluid, ρ is the fluid density, g is the acceleration due to gravity, and v_0 is the superficial velocity, given by

$$v_0 = \frac{q}{A} \tag{6}$$

where q is the volume flux per unit time, i.e., the discharge rate, and A is the sample area perpendicular to the direction of flow. If we introduce

$$\nabla P = \nabla p - \rho g \tag{7}$$

we have that

$$\left(\frac{\phi\mu}{k}\right) \frac{\partial p}{\partial t} = (\nabla \cdot (\rho \nabla P)) \tag{8}$$

Equation 7 describes the motion of a fluid in a porous medium.

Another useful form of equation 5 is (Bowles, 1979)

$$q = -\frac{AKh}{L_p} \tag{9}$$

where K is the hydraulic conductivity, L_p is the length of the porous sample, A is the cross-sectional area of the sample, and h is the hydrostatic head across the sample.

Equations (5) and (9) are equivalent if (Verruijt, 1982)

$$k = \frac{K\mu}{\rho g} \tag{10}$$

The modelling of fluid flow in a porous medium is achieved by equating to the flow in a bundle of small cylindrical parallel tubes. If the equivalent tube radii for the pores are, d , and their length, L , with a number of parallel tubes, n , analysis shows that (Dullien, 1979)

$$d = \left(\frac{8k\tau^2}{\phi}\right) \tag{11}$$

$$L = \tau L_p \tag{12}$$

$$n = \frac{\phi D^2}{d^2 \tau} \tag{13}$$

D is the radius of the sample.

Experimental Methods

The porous sample for this experiment was commercially available filter aid (Celite, from Johns-Manville, Denver, Colorado). The characteristics as supplied by the manufacturers are listed in Table 1. The sample was a solid annulus of outer diameter of 5cm and inner diameter of 3cm. The length of the sample, $L_p = 20$ cm. The inner hole was plugged with a 3cm diameter pipe of PVC and sealed at the top and sides with epoxy. The effective cross sectional area of the sample, $A = 12.57$ cm².

The mass, M_s , of the dry sample was measured.

A constant head permeameter was used for low intensity transport, as shown in Fig. 1. The high intensity transport set-up is as shown in Fig. 2.

Table 1: Properties of celite porous sample

Screen Analysis % retained in 150 mesh	Specific gravity	% Chemical Analysis								
		Ignition Loss %	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	P ₂ O ₅	TiO ₅	CaO	MgO	Na ₂ O + K ₂ O
8.8	2.3	0.2	89.6	4.0	7.3	0.2	0.5	0.6	0.6	3.3

Table 2: Modelling parameters for porous sample

Low intensity drive		High intensity drive
Low end	High end	
Average	Average	
$k = 8.49 \times 10^{-8} \text{ cm}^2$	$k = 5.5 \times 10^{-8} \text{ cm}^2$	$k = 1.28 \times 10^{-7} \text{ cm}^2$
$a = 0.28 \text{ cm}$	$a = 0.30 \text{ cm}$	$a = 0.34 \text{ cm}$
$n = 4$	$n = 3$	$n = 2.5$

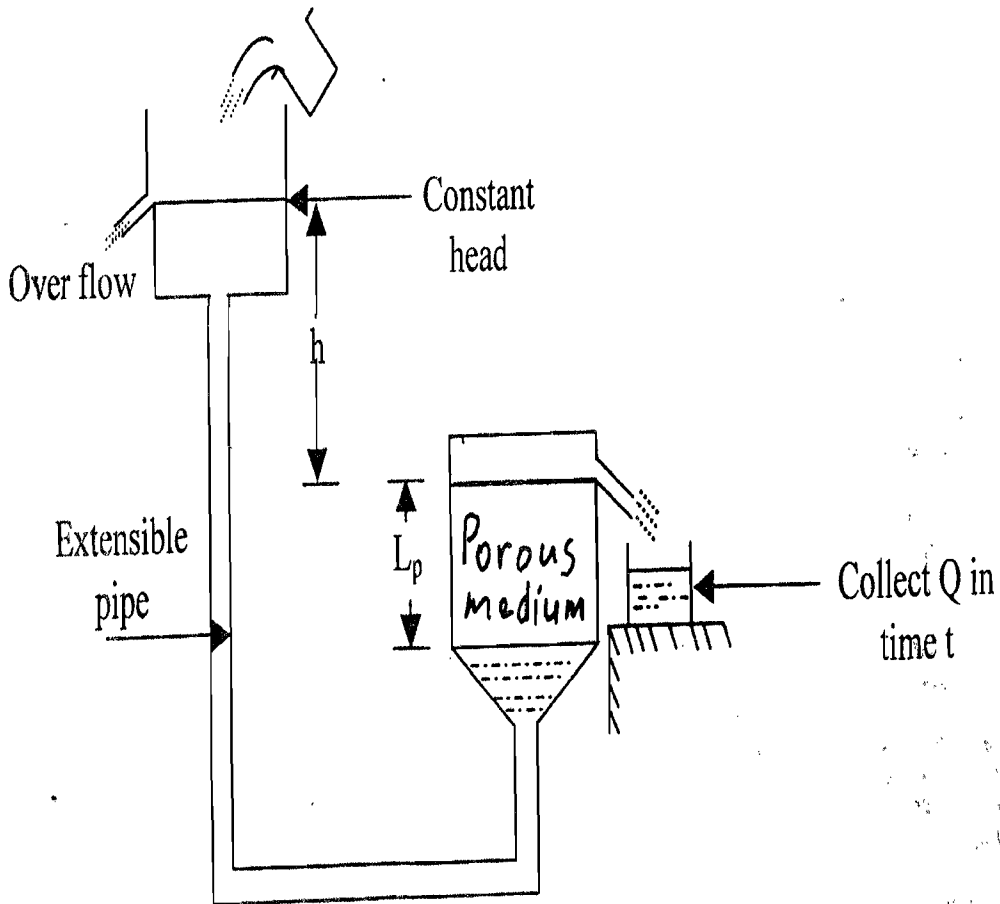


Fig. 1 Constant head permeameter (low intensity)

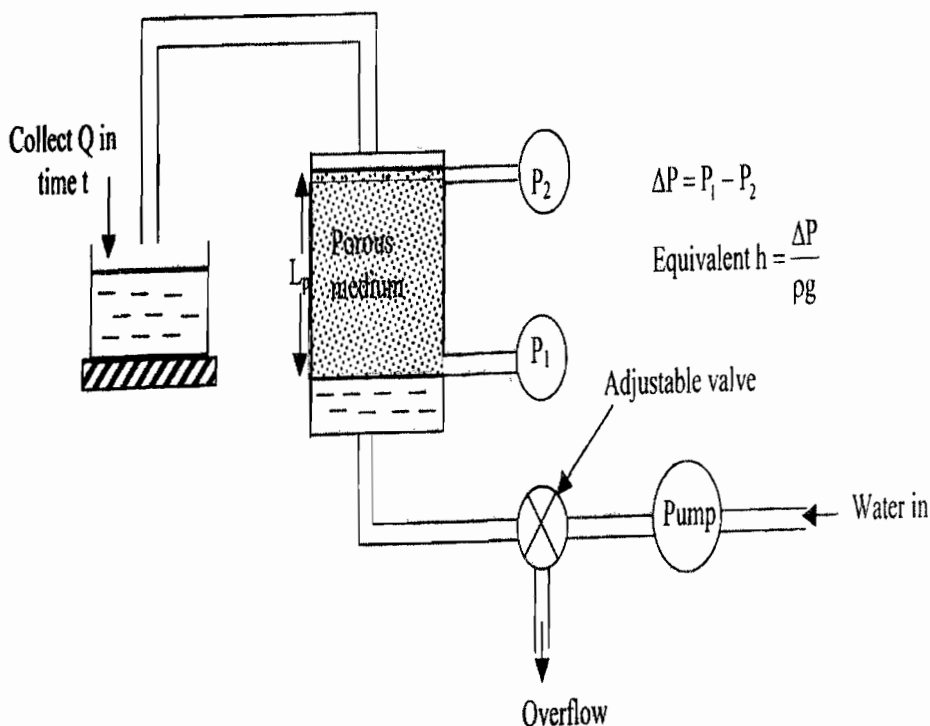


Fig. 2 High pressure permeameter

The sides of the sample in contact with the walls of the permeameter (except the source and sink surfaces) were coated with liquid epoxy and allowed to cure and dry in the hot sun. The sample was loaded into the cell, and the discharge, Q , of deaerated water at low intensity drive was measured from 0 to 1.5m of water head, h , at increment of 0.1m. The time, t , for flow in each case was 1200s, while allowance was made for the attainment of steady state after each adjustment. The equivalent water head for the high intensity drive ranged from 2.5m to 6.4m. However, it was not possible to achieve a constant increment from the adjustment of the valve and overflow.

Brine imbibition by the sample was done in a ram vessel. A more desirable approach is by vacuum impregnation (Wagh and Douse, 1989). The resistivity of brine was determined by measuring the resistance of a known column of brine in a capillary tube. The resistivity of the soaked sample was determined by measuring the resistance of

the soaked sample in a resistance bridge. The open faces of the sample were covered with brine-soaked filter paper, and brass discs of the same diameter as the sample were clamped on the filter papers. The brass discs acted as electrodes for electrical connections (Sawyer et al, 2001). In both of the resistivity determination, low voltage 50Hz alternating current was used, to avoid polarization at the electrodes. The resistance bridge employed a small loudspeaker for null detection.

Results and Discussion

The mass of the dry element, $M_s = 373\text{g}$, and with $V_T = 25\text{cm}^3$, we have the bulk density, $\rho_b = 1.49\text{g/cm}^3$. From the data sheet, density of solid material, $\rho = 2.3\text{g/cm}^3$, which gives a porosity $\phi = 35\%$.

The flow versus pressure results are shown in figs. 3 and 4 for low and high intensity transport, respectively. The log-log plot shows three distinct regions at low intensity.

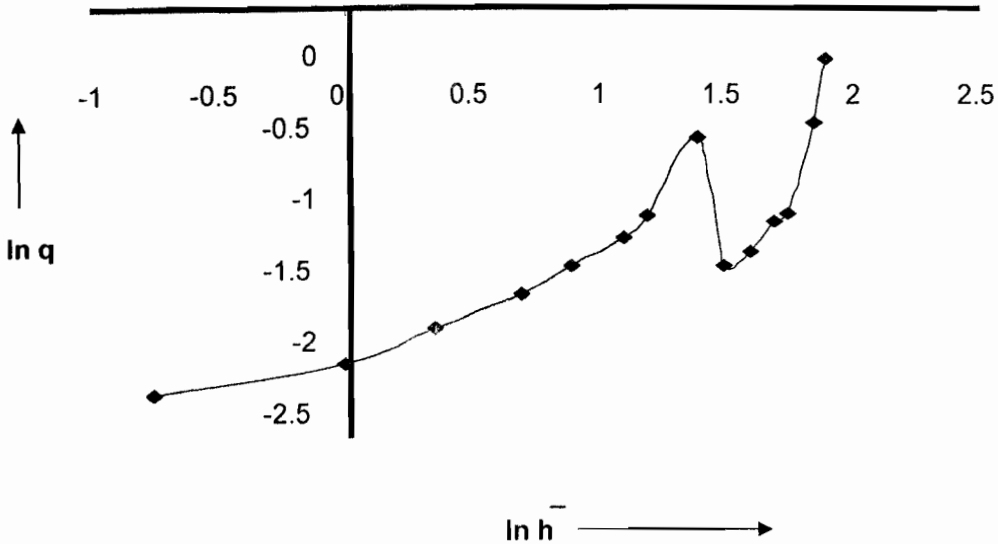


Fig. 3: Low intensity transport

The discharge rate, $q = \frac{Q}{t}$ shows power law relationship with the hydraulic gradient, $\bar{h} = \frac{h}{L_p}$.

This power law is of the form $q = n \bar{h}^m$, where n and m are parameters dependent on

the pressure regime. This indicates that fractal processes are in effect, and can arise from the fractal distributions of the particle and pore dimensions. The permeability, k, calculated from equation 5 varies from 1.75×10^{-7} to $6.59 \times 10^{-8} \text{cm}^2$ at the low end of fig. 3, and has the value of 3.60×10^{-8} to $8.88 \times 10^{-8} \text{cm}^2$ at the high end of Fig. 3.

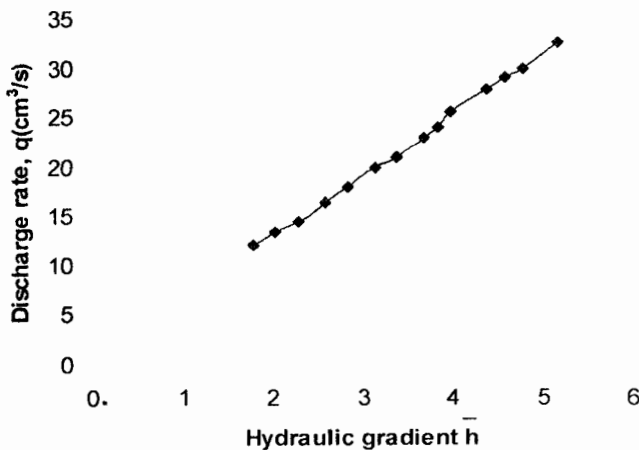


Fig. 4: High intensity transport

As observed from Fig. 3, there is a kink at mid range, and this might result from a slip in the adsorbed surface water, as the pressure increases. The high pressure graph (fig. 4) is linear and shows no fractal behaviour, indicative that the geometry of the sample is subdued at high pressure. The permeability in this range as calculated from the gradient of the graph and the application of equations 8 and 10 is approximately $1.28 \times 10^{-7} \text{ cm}^2$.

The resistivities measured give a factor, $F = 40.2$, therefore, $\tau = 198$, and, $L = \tau L_p = 40\text{m}$.

For modelling purposes, we have the result for the pressure ranges as in Table 2.

Conclusion

The flow characteristics in a filter sample have been studied. It was found that the permeability is pressure dependent, and that fractal processes are in effect at low pressures. It is apparent that the geometry of the sample is important in the flow characteristics. The test fluid was deaerated water, which is Newtonian. For non-Newtonian fluids, the rheology might be markedly altered by the porous medium. It is, therefore, the practice that test be performed in actual environments of application.

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