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Radius and Length of Sephadex G Gel Fibers

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Sephadex G Gel 섬유의 반경과 길이

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ABSTRACT

The dimensions of dextran gel fiber described by the Ogston-Laurent gel model were estimated for Sephadex G gels. The length of fibers are ranging from 12.48x10[12](G-25) to 1.76x10[12](G-200) cm/ml. The radius of gel fiber and the partial specific volume of dextran gel are 7.21x10[8] cm and 0.586 ml/g, respectively.

INTRODUCTION

The Ogston-Laurent gel model (OLM) is one of the most popular geometric models which predict the gel pore volume available to solute in size exclusion chromatography. The model originally derived by Ogston [1] considers a three-dimensional network of gel polymer as randomly distributed rigid fibers. According to the model the fraction of volume available to a spherical particle (K_{av}) is expressed as follows.

$$K_{av} = \exp[-\pi L(r + R)^2] \quad [1]$$

where L, R are the length [cm/ml] and the radius [cm], respectively, of the polymer rods and r is the radius [cm] fo a solute. Laurent and Killander [2] have estimated the radius of a corresponding sphere for a large number of molecules and calculated K_{av} values for Sephadex G gels from their own and other measurements on different Sephadex gel types.

In this paper, a more realistic approach to estimate the dimensions and the partial specific volume of dextran gel fiber using a forcing function is described. The series expansion of OLM is also studied from a geometrical viewpoint.

MATERIALS AND METHODS

Internal volume of swollen gel

There are several ways to determine the pore volume of a swollen gel [3]. A simpler one is based on the mass balance of gel material and liquid.

$$(V_m + V_w)d = V_m d_m + V_w d_w \quad [2]$$

where V_m, V_w are the volumes occupied by the swollen gel material and the free liquid in a gel particle, respectively, d is the density of swollen gel particle, d_m, d_w are the densities of the swollen gel material and liquid, respectively. The fraction of volume available to very small molecules ($K_{av}(r=0)$) can be considered to be the ratio of the free liquid volume to the sum of the volumes occupied by the gel material and the free liquid,

$$K_{av}(r=0) = \frac{V_w}{V_m + V_w} \quad [3]$$

By combining above two equations, we obtain

$$K_{av}(r=0) = \frac{(d_m - d)}{(d_m - d_w)} \quad [4]$$

Water is usually the liquid of choice ($d_w = 1$). Note that $K_{av}(r=0)$ is the porosity.

Forcing function

A least square method was used to fit the experimental data into OLM (K_{av} versus r). Equation [1] was rearranged and used to have the curves pass through the precalculated K_{av} when r is zero.

$L = -\log(K_{av}(r=0)) / \pi R^2$ [5]

The experimental data from Lawrent and Killander [2] was curve-fitted into OLM by using the least square computer program RNLIN (IMSL subroutine) with R as the only parameter.

Radius and length of dextran fiber

The radius of dextran fiber is assumed to be the same while the length varies for different gel type by the least square method was used as the radius of Sephadex gel (R). Then the dextran chain length (L) for each gel type was calculated from the forcing function with this R.

Partial specific volume of dextran gel

The partial specific volume of dextran gel can be obtained from the correlation between the length of gel fiber and the dextran concentration.

$v_s W = \pi R^2 L$ [6]

where v_s is the partial specific volume of dextran gel [ml / g], W is the dextran concentration in gel [g / ml] Therefore v_s can be calculated from the slope ($v_s / \pi R^2$) of a line correlating L and W. The W values for each Sephadex gel type can be calculated from the water regain (W_r) and the density of swollen gels.

$$W = \frac{d}{(1 + W_r)}$$ [7]

The water regain data in Laurent and Killander [2] were used in this study.

RESULTS AND DISCUSSION

$K_{av}(r=0)$ consists a part of a forcing function and depends on the densities (d_m) or the partial specific volumes ($1/d_m$) of swollen gel materials. In this study the partial specific volume was determined to be 0.586 ml / g by trial and error. The density of swollen Sephadex gels [3] and $K_{av}(r=0)$ calculated by the method above are shown in Table I. The fraction of swollen gel particle not occupied by dextran gel material ($K_{av}(r=0)$) increases as the dextran gel concentration decreases (as Sephadex gel type number increases). With the $K_{av}(r=0)$ values in Table I and the forcing function, curve-fits were done for the experimental data on biological molecules [2]. Table II presents the results of computer calculations. The radius of the dextran fiber is calculated to be 7.2×10^{-8} cm. The maximum deviation of the calculated radio from the mean value is rather large (15%) due to the large dispersion of the experimental data. The length of dextran fiber (L) decreases from 12.5×10^{12} for Sephadex G-25 to 1.8×10^{12} cm / ml for Sephadex G-200.

The correlation between the length of dextran fiber and the dextran concentration is presented in Fig. 1.

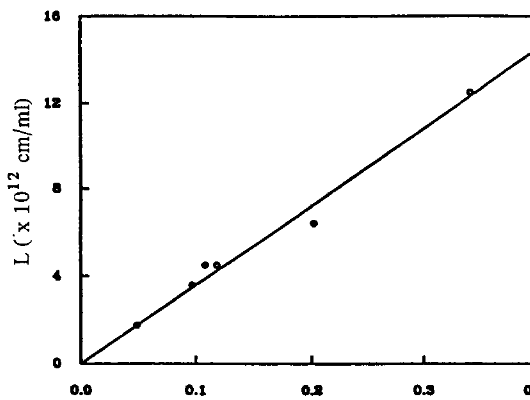

Fig. 1. The dextran chain length (L) in Sephadex G gels calculated from the experimental data.

Table 1. Densities and internal porosities (K_{av} (r=0)) of swollen dextran gels.

Sephadex type	Density of swollen gel (g/ml)	Porosity
G-25	1.13	0.816
G-50	1.07	0.901
G-75	1.05	0.929
G-100	1.04	0.943
G-200	1.02	0.972

Table 2. Results of curve fitting for fiber radius and length[1]

Sephadex type	log ($K_{av}(R=0)$)	Radius ($x10^{-8}$cm)	Length[2] ($x10^{12}$cm/ml)
G-25	−0.203	6.74	12.48
G-50	−0.104	6.11	6.40
G-75	−0.074	7.11	4.50
G-75[3]	−0.074	7.15	4.50
G-100	−0.059	8.06	3.58
G-200	−0.028	8.06	1.76
		7.21[4]	

1. Experimental data from Laurent and Killander [2] (Killander *et al.* (G-200, W_r=1.99), Andrews (G-75, G-100)).
2. When radius is 7.21 x 10^{-8} cm.
3. Two sets of experimental data for G-75 [2].
4. Mean value of radii.

The partial specific volume of swollen dextran gel material is calculated to be 0.586 ml / g from the slope of the line in the figure. This value equals the partial specific volume assumed at the beginning. The partial specific volume calculated from the results of Laurent and Killander [2] is larger than 0.62 ml / g, while they used 0.61 ml / g to calculate the dextran volume. The calculated dimensions and thermodynamic properties of dextran gel may have different values depending on the experimental data used. However, as a result, the method employed in this study is easier to follow and produces more consistent value at least for v_s than the work by Laurent and Killander.

A series expansion shows that OLM is a sound model in the sense of geometry even though the model was originally derived from a different geometrical concept.

$$Kav = 1 - x + \frac{X^2}{2!} - \frac{X^3}{3!} + \ldots (x = \pi L(r+R)^2) \qquad [8]$$

When x is small, K_{av} approximates to 1-x as the terms with higher powers become negligible. Additionally, when r=0, K_{av} equals to $1-\pi LR^2$. This is the volume not occupied by gel material in 1 ml of swollen gel particle (note $\pi R^2 L$ is the volume of cylinder with radius R and length L). The $K_{av}(r=0)$ values from OLM and from the series expansion with the calculated dimensions of fiber are compared in Table III. The values are very close when L is small but show a larger discrepancy as L becomes larger (smaller Sephadex gel type number) as expected. By the same reasoning, the series expansion also explains why OLM predicts K_{av} better for smaller solutes (smaller r).

Table 3. Comparison between ($K_{av}(r=0)$) and volume fraction not occupied by gel fiber.

Sephadex type	$K_{av}(r=0)$	$(1-\pi R^2 L)/1$
G-25	0.816	0.796
G-50	0.901	0.895
G-75	0.929	0.927
G-100	0.943	0.942
G-200	0.972	0.971

요 약

Dextran gel 섬유인 Sephadex G gels의 크기를 Ogston-Laurent의 gel model에 의하여 측정한 결과 섬유의 길이는 12.48 × 10^{12} (G-200) cm / ml 범위이고, 섬유의 지름과 partial specific volume은 각각 7.21×10^{-8}cm와 0.586ml/g이었다.

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