



Hydrodynamic chromatography using flow of a highly concentrated dextran solution through a coiled tube



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ABSTRACT

Separation of colloidal particles in non-Newtonian fluid is important in food engineering. Using hydrodynamic chromatography, colloidal particles and starch granules originating from corn were individually injected into dextran solutions (Mw 2,000,000 g/mol) flowing through a coiled tube for efficient size separation. Rheological properties of dextran solutions ranging from 50 to 250 g/L were determined, revealing pseudoplastic fluid behavior. Velocity profiles for dextran solution flow in coiled tubes were obtained from rheological power law parameters. Suspensions of colloidal particles of diameters 1.0 and 20 μm were individually injected into the dextran flows, demonstrating that dextran solutions at high concentration separated colloidal particles. Starch granules were separated by size using a dextran solution flow (250 g/L). Thus, we expect to obtain efficient separation of colloidal particles in foods using highly concentrated dextran solutions.

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1. Introduction

Hydrodynamic chromatography is a technique for separating colloidal particles (Small, 1974; Noel et al., 1978; Okada, Harada, & Kido, 2005). In this technique, colloid particles of different sizes are injected into a solution flowing through a coiled tube for separation. Under laminar flow, the velocity profile will be parabolic and injected colloidal particles move in the direction of flow. However, individual particles move radially to a position in the tube related to their size, and therefore move through the tube at different speeds. The elution time of colloidal particles thus depends upon particle size, meaning that particles can be separated by flowing them through a coiled tube. Compared with high-performance liquid chromatography, hydrodynamic chromatography avoids fouling of the tube and there is less conformational change in the colloidal particles, irrespective of the shear stress in the fluid. Usually, Newtonian fluids such as water or organic solvents are used for hydrodynamic chromatography (Harada, Kido, Masudo, & Okada, 2005), to maintain a parabolic velocity profile. Separation performance would likely differ when using a non-Newtonian fluid.

Dextran is a polymer mainly composed of α -(1,6)glycoside bonded glucose, with a flexible and random-coiled structure. Some authors proposed that dextran in solution forms hydrogen bonds

with water (Icoz & Kokini, 2007a, 2007b). Several papers have experimentally and computationally identified conformation of dextran in solution in the presence of metal ions and in alternative solvents to water (Koliandlis et al., 2010; De Vito, Veytsman, Painter, & Kokini, 2015). With increasing dextran concentration in solution, some random coils overlap, showing a transition-like change in the intrinsic viscosity (Tirtaatmadja, Dunstan, & Boger, 2001). The viscosity of dextran solutions was found to be dependent on the molecular weight and concentration. Solutions of dextran of low molecular weight (500,000 g/mol) at low concentration (5.0 (w/w)%) in water display Newtonian behavior (McCurdy et al., 1994); whereas the rheological properties of high molecular weight dextrans at high concentration have not been addressed in detail.

This study demonstrates the separation of colloidal starch granules of differing sizes using hydrodynamic chromatography with highly concentrated dextran solutions. Injected colloidal particles and starch granules to the circular tube in flowing fluid moves via convection and diffusion. When dextran solution is used for the fluid on behalf of water such as Newtonian fluid, the elution profiles of colloidal particles injected would be changed to separate particles. Simple separation techniques for controlling quality of granules are desirable, especially in food engineering (Dias, Fernandes, Mota, Teixeira, & Yelshin, 2008). The technique outlined, as mentioned by Barham et al. (2010) might have interesting outcomes when used in molecular gastronomy. Granules composed of polysaccharides, such as starch granules, usually have been used in cooking. The ingredients in cooking have the several molecules

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Nomenclatures

d	Diameter of the tube, m
L	Length of the tube, m
m	Constants characterizing fluid, Pa s ⁿ
M_r	Molecular weight of dextran, g/mol
n	Constants characterizing fluid, dimensionless
N_{AV}	Avogadro number, 1/mol
R_c	Radius of curvature of tube, m
D_n	Dean number, dimensionless
Q	Flow rate, m ³ /s
R	Radius of the tube, m
r	Radius direction
Re	Reynolds number, dimensionless
u	Average velocity of solution, m/s
v_z	Velocity in z direction, m/s
z	Direction of flow
$\dot{\gamma}$	Rate of strain, 1/s
η	Viscosity, Pa s
μ	Viscosity of the solution, Pa s
ρ	Density of solution, kg/m ³
τ	Shear stress, kg/(m s ²)

and macromolecule and have sometimes the characteristics of non-Newtonian fluid. Solution at the time of cooking has the nature of a non-Newtonian fluid in which a variety of molecules are dissolved. Thus, development of a method for separating colloidal particles dispersed in a non-Newtonian fluid, can contribute to the cooking of considering the level of molecules or colloids.

In this study, the viscosity properties of dextran solutions exceeding a concentration range of 50–250 g/L were determined to obtain the relationship between shear stress and shear rate. It is important to know this relationship when calculating the velocity profile for dextran across a coiled tube as a function of concentration. Colloidal particle suspensions of diameter 1.0 and 20 μm were individually injected as impulses into a coiled tube containing dextran solutions under flow, to determine the elution profile for separation. Finally, a starch granule suspension was injected for size separation, and characterized by direct microscope observation and quantitative evaluation of eluted granule sizes.

2. Experimental

2.1. Materials

Dextran (2,000,000 g/mol) was purchased from Sigma-Aldrich Co. (St. Louis, MO, USA). Coiled TeflonTM tubes with inner and outer diameters of 1.0 and 3.0 mm, respectively, were obtained from

Nichias Corporation, Japan. Colloidal latex beads (1.0 and 20 μm) were used as particles and obtained from Sigma-Aldrich Co. Starch granules, originating from corn, were purchased from Wako Pure Chemical Industries (Osaka, Japan). Deionized water was used and all chemicals were of analytical grade or higher.

2.2. Dextran solutions viscosity determination

Dextran powder was dissolved in water at concentrations of 50, 100, 150, and 250 g/L with stirring at room temperature. The pH values of the solutions were not adjusted. The solutions were then applied to a Couette-type viscometer (Brookfield DV II + Pro) to determine the relationship between shear stress and shear rate at 303 K (Wonderlich & Brunn, 1989; Kelessidis & Maglione, 2006; Kim, Han, & Kim, 2000).

2.3. Separation of colloid particles using hydrodynamic chromatography

The experimental apparatus is shown in Fig. 1. The length of the coiled tube was set at 1.0 or 2.0 m. The diameter of the coil of the tube was 4.2 cm. Dextran solution was fed with a syringe pump (S-1235, Atom Medical International, Inc.) at flow rates of 100 mL/h (concentrations of dextran: 50 and 100 g/L) and 50 mL/h (concentration of dextran: 250 g/L). Attainment of steady state flow was checked with a pressure gauge, and 0.5 mL of a latex beads (8.0×10^{-3} (w/w)%, 1.0 μm or 20 μm) suspension was individually injected through a three-way stopcock. The colloidal particles eluted from the coiled tube were continuously monitored by UV-vis (Shimadzu UV-1800, Japan) (Cardoso, Samios, & Silveira, 2006; Xijun, Kunsheng, Qingfeng, Chen, & Xueyan, 2012). The solution from the tube was flowed to the flow cell (SPD-20A, Shimadzu, Japan) set at UV-vis and the concentration of colloidal particles was determined at the wavelength of 600 nm. The volume and light length of flow cell were 6.5 μL and 0.5 mm, respectively. The data of UV-vis are transferred to PC for analysis.

2.4. Separate elution of starch granules through the coiled tube

A suspension of starch granules was prepared at a concentration of 5.0 g/L using deionized water. The solution was injected as described in Section 2.3 and monitored continuously at 600 nm. The elution samples in each fraction were observed by optical microscopy (VH-1000, Keyence) and the size distribution of the starch granules was determined quantitatively from more than 200 microscopy images. The sizes of starch granules were directly determined by the software of the microscopy (VH-1000, version 1.0.1.0, Keyence).

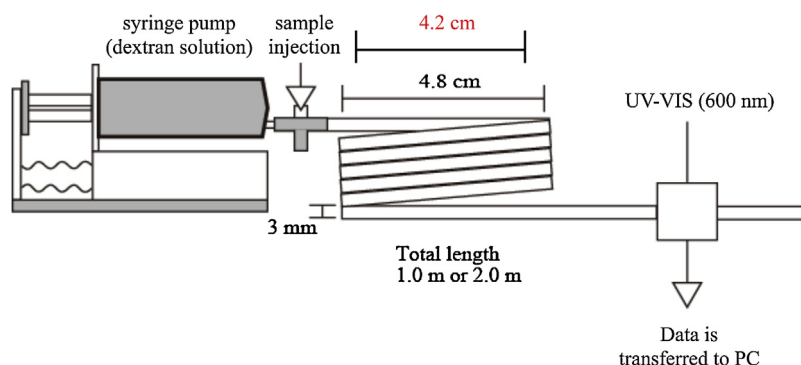


Fig. 1. Experimental apparatus using a coiled tube.

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