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Filtration and recovery of starch granules using assembled magnetite filter

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ABSTRACT

A magnetite structure was assembled using a ring magnet. Magnetite particles were packed in a column by application of a magnetic field. Colloidal particles of a specific size from 1.0 μm to 90 μm were filtered from various solutions flowed through the column by the gaps among the magnetite particles. After filtration, the magnetic field was switched off, and the magnetite particles and filtered colloidal particles were washed out of the column. Finally, the filtered colloidal particles were recovered and separated using a magnet. With a view to applications in molecular gastronomy and food engineering, a starch granule solution from 1.0 μm to 100 μm was flowed through the magnetite filter, and the starch granules were filtered out. The filtered starch granules were recovered after removal of the magnet. This novel filter consisting of magnetite has good filtration performance and recovery of filtered colloidal particles, and has potential filtration applications.

1. Introduction

Membrane filtration is widely used for adsorption and filtration in water treatment, recovery of metal ions and proteins, and food engineering. Microfilters composed of inorganic and polymeric materials are used for separation of colloidal particles of size 100 nm to 10 μm. The pore diameter is important in filtration of colloidal particles. The pore properties can be controlled by including colloidal particles in the membrane [1,2], chemical incorporation of polymers into the pore wall [3,4], and formation of an asymmetric layer on the pore surface of a trunk membrane [5]. Pore control enables selective separation of target molecules or colloidal particles via chemical interactions. However, after filtration or permeation using a membrane, it is difficult to recover the filtered colloidal particles and residues from the membrane. The easy recovery of filtered residues is important for subsequent processing of obtained materials.

Magnetite (Fe_3O_4) particles can be simply prepared from iron ions. A magnetic field induces anisotropic changes in assembled magnetite structures [6]. Based on the characteristics of the magnetite assembly, a filter made of magnetite particles can be formed by application of a magnetic field to magnetite in a column. Because the magnetic field provided by a magnet is not constant over the entire column, an anisotropic assembled magnetite structure can be formed [7,8]. This type of assembled structure can be controlled by the strength of the magnetic field, the column scale, and magnetite particle diameter. The packed magnetite can function as a filter because there are gaps among the assembled magnetite particles. Colloidal particles of a specific size in a flowing solution can be filtered out by the assembled magnetite particles. This filtration method has already been used for gas purification and colloidal particle removal [9,10]. The filtered colloidal particles are washed out and recovered by removing the magnet; the magnetite particle assembly is disrupted by removal of the magnet and the magnetite particles flow through the column in the solution. The filtered colloidal particles and magnetite particles in the filtrate can be separated using a magnet.

In this study, we developed a novel magnetite filter and recovery system for colloidal particles; the system is shown in Fig. 1. Magnetite particles were packed in a column by application of a magnetic field. Colloidal particles, starch granules in this study, of a certain size in solutions flowed through the column were filtered by the gaps among magnetite particles. After filtration, the magnetic field was switched off, and the magnetite particles and filtered colloidal particles were washed out of the column. Finally, the filtered colloidal particles were recovered by magnetic separation.

Starch granules consisting of amylopectin and amylose [11] are widely used in food engineering. The size of starch granules is generally in the range 1.0–60 μm [12]; the size and shape of the

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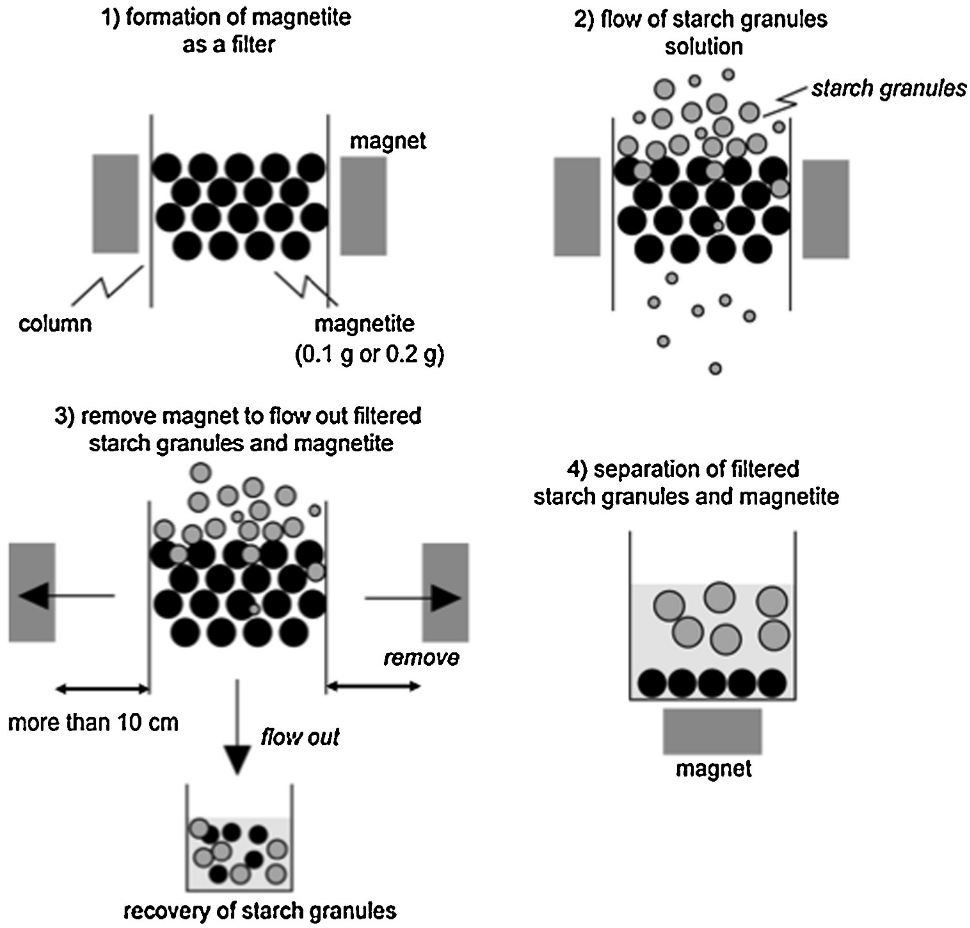

Fig. 1. Strategy of magnetite filter to recover filtered starch granules.

granules depend on the origin and conditions of the solution [13]. Use of the proposed system enabled filtration to be controlled by the size of the magnetite particles and the strength of the magnetic field, with easy recovery of the filtered colloidal particles. The development of techniques based on molecular gastronomy for high-quality food is being explored. The taste of a food is directly related to the molecules and colloidal particles in food materials.

The objectives of this study were 1) preparation of magnetite particles, 2) filtration of colloidal particles (latex beads of diameter 1, 20, 45, and 90 μm) using assembled magnetite particles, and 3) filtration of actual starch granules and recovery of filtered starch granules of specific size. The filtered and recovered starch granules were examined using optical microscopy and the size was determined.

2. Experimental

2.1. Materials

Starch granules (origin: potato, KPH7012), $FeCl_3 \cdot 6H_2O$, and $FeCl_2 \cdot 4H_2O$ were obtained from Wako Pure Chemical Industries, Ltd. (Japan). Colloidal particles of size 1.0–90 μm were obtained from the Sigma-Aldrich Co. Other chemicals were of analytical grade or higher.

2.2. Preparation of magnetite particles

$FeCl_3 \cdot 6H_2O$ (0.2 M) and $FeCl_2 \cdot 4H_2O$ (0.1 M) were dissolved in water (200 mL). An aliquot (8 mL) of sodium hydroxide solution (10 M) was added to the solution with stirring at 500 rpm for 1 h at 303 K. After the reaction, sonication was performed for 10 min. The particles in the solution were recovered by centrifugation for 30 min at 12 000 rpm. The obtained black precipitate was washed with water, and dried under vacuum. The magnetite particles were examined using optical microscopy (VH-SS, Keyence, Japan). The powder yield was 1.9 g.

2.3. Filtration of colloidal particles and starch granules using magnetite filter

Five ring-shaped magnets were stacked to a height of 36 mm. A glass column (inner diameter 4 mm, outer diameter 6 mm) was inserted into the hollow at the center of the magnets. The magnetization strength was determined using a Gauss meter (Magna, MG-701). Magnetite particles (0.10 and 0.20 g) were inserted in the column at heights of 1.2 and 2.1 cm, respectively, to form a magnetite filter. The detailed condition of column experimental is summarized in Table 1. The porosity (ε) of the

Table 1
Experimental condition of magnetite-particle packed column.

Column	inner radius [mm]	2.0	
	outer radius [mm]	6.0	
	height [mm]	36	
Magnetite particle	amount of magnetite particle [g]	0.1	0.2
	height of packed magnetite particle [mm]	12	21
	porosity calculated [−]	0.88	0.86