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Developments for A Fluid Pump Using Magnetic Gels

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We have developed a fluid pump using magnetic hydrogels synthesized by ferromagnetic fine particles and natural polymers. The pump is mainly consisted of a rotor made of the magnetic gel and a driving magnet. The driving magnet drives the rotor in a fluid tube without any physical contact. The rotor of the fluid pump rotates corresponding to the rotation rates of the driving magnet. The shape of the rotor was a screw so as to deliver water easily. Diameters of the rotor and the tube for delivering water were approximately 5.5mm and 6mm, respectively. Flow rates pumped by the rotor increased with increasing diameter, length of the rotor, and rotation rates. The maximum flow rates of 34 ml/min was achieved when the rotation rates was 5000 rpm. Factors affecting the flow rate of water will be presented.

Key words: gel, magnetic gel, composite gel, pump, actuator

1. INTRODUCTION

Actuators using polymer gels have been widely investigated since the past decade. There are a variety of polymers applied for actuators. Ionic conductive polymer gels such as polyelectrolyte gels undergo bending motion under ac electric fields. Actuators using the bending motion of poly[2-(acrylamido)-2-methyl-propanesulfonic acid] gel were reported, and they were called gel-looper [1] and gel-eel [2]. Amphiphilic polymer gels swollen by an organic solvent show a motion by spreading the organic solvent. A tetrahydrofurane-swollen gel equipped with a spouting hole made a controlled translational motion with a velocity of 77 mm/s or rotational motion with a maximum speed of 400 rpm and a torque of 10^{-9} Nm on the water surface [3,4]. Conductive polymers also have a potential to be an actuator. Polypyrrole films undergo rapid and intensive bending in the solid state induced by the reversible and anisotropic adsorption [5]. Photo reactive polymers show a deformation by UV light. Liquid crystalline gel films containing freestanding azobenzene undergo a significant and anisotropic bending toward the irradiation direction due to the isomerization [6].

Magnetic gel is magnetic field-responsive gel and has a great potential for actuators. The magnetic gel consisted of poly(vinyl alcohol) and magnetic fluids elongates under non-uniform magnetic fields [7,8]. Elastic modulus of magnetic gels such as PVA-magnetic fluids [9], PVA-barium ferrite [10-12] and κ-carrageenan-barium ferrite [13] gels changes due to magnetization. These studies revealed that the magnetic gels could respond faster and deform larger compared to the other stimuli-responsive gels. Moreover, the magnetic gel can be driven without electrical leads such as electric devices.

There are some papers demonstrating a pump made of polymer gels for microfluidic systems. The pump was made from fluid-responsive polymer particles of Poly (acrylic acid) [14]. For a high-pressure pump, low-voltage electroosmosis pumps were developed using a gel salt bridge [15]. These pumps need a physical contact such as electrical leads to drive them. A pump that is not necessary for the physical contact would be appropriate for microfluidic applications.

We have tried to fabricate a fluid pump which is free from a driving unit using magnetic gels. Processability of magnetic gels, effects of the rotor size and rotation

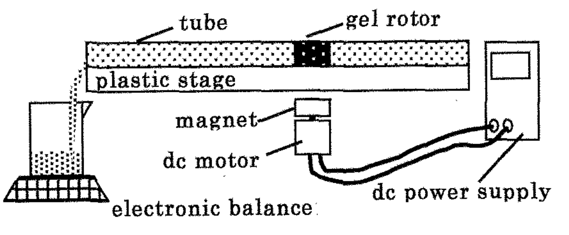

Fig. 1 Schematic illustration of the apparatus to measure the flow rate used in the present study.

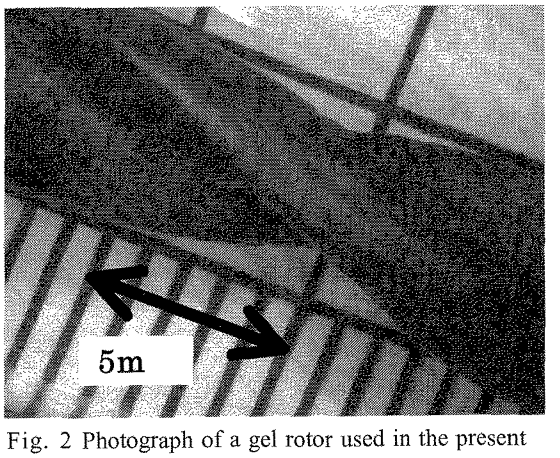

Fig. 2 Photograph of a gel rotor used in the present study.

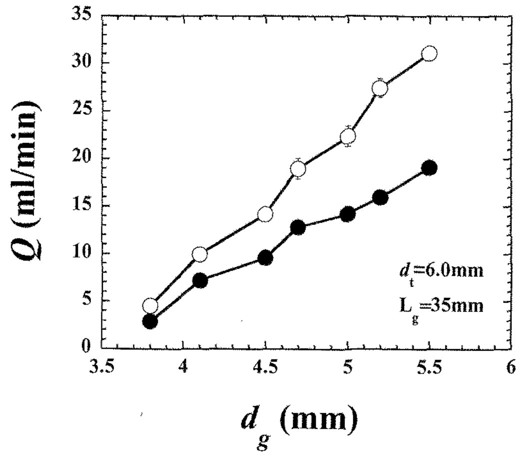

Fig. 3 Relation between flow rate and the diameter of a gel rotor; (○) 5000rpm, (●) 3000rpm of rotation speed.

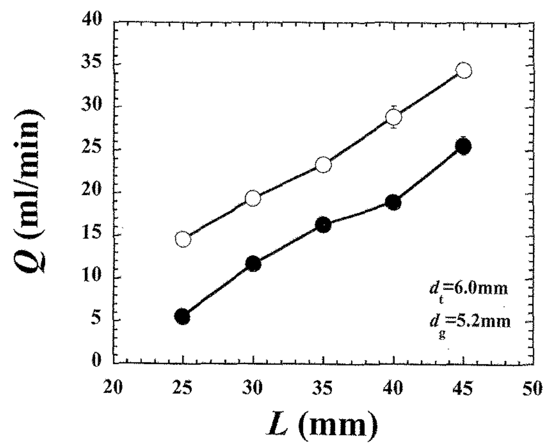

Fig. 4 Relation between flow rate and the length of a gel rotor; (○) 5000rpm, (●) 3000rpm of rotation speed.

speed on the flow rates have been investigated.

2. EXPERIMENTAL PROCEDURES

2.1 Synthesis of Magnetic Gel Rotor

Magnetic gel rotor is made of a finely dispersed powder of barium ferrite and sodium alginate of a natural polymer. A Pre-gel solution of the magnetic gel rotor was prepared by mixing the 1 wt.% sodium alginate (I-5, Kimitsu Chemical Industries) aqueous solution and the barium ferrite $BaFe_{12}O_{19}$ (Sigma-Aldrich Co.) in a water bath. The mean diameter of a magnetic particle was determined as 20 μm. The pre-gel solution was poured into a mold with the shape of a screw, and was cross-linked by adding $CaCl_3$ aqueous solution with the concentration of 3wt.%. The diameter and length of the rotor were ϕ3.8-5.5 mm and 20-45 mm, respectively. The obtained rotor was kept for a day in a purified water to remove excess ions and to give an equilibrium swelling. The weight ratio of ferrite to that of sodium alginate was 0.25. The gel rotor was put under a uniform magnetic field of 1 T in order to give the gel a remanent magnetization. The diameter of barium ferrite is much larger than that of the magnetic domain as a result the gel rotor has a remanent magnetization under no magnetic field.

2.2 Flow Measurements

The flow rate was calculated by the weight of water that was delivered during 5 sec. The weight of water was measured by an electronic balance. Schematic illustration representing an apparatus used in the present study is shown in Figure 1. We assume the rotation rate of the gel rotor equals to that of the driving magnet placed below the rotor. The rotation speed of the magnet ω was calculated from the relationship between driving currents and rotation rates of the magnet.

3. RESULTS AND DISCUSSIONS

Figure 2 shows a microphotograph of the gel rotor that has a screw shape. As seen in the photograph, surfaces of the mold were firmly imprinted on the gel rotor. It is important for fabrication of the gel pump to process gel rotors precisely.

Figure 3 shows the relationship between flow rate Q and diameter of the gel rotor. The flow rate linearly increased with increasing the diameter of the rotor. The flow rate showed a threshold of the diameter that the rotor could not deliver water below the threshold. The threshold did not depend on the rotation speed and lied approximately d_g~3.5 mm corresponding to 58% of the diameter of the tube d_t. Influences of the rotation speed on the flow rates were enhanced in a larger diameter of the gel rotor.

Figure 4 shows the flow rate Q as a function of the length of the gel rotor. The flow rate increased proportional to the length of the gel rotor. The flow rate had a threshold not only in a diameter but also in a length of the gel rotor. The threshold strongly depended on the rotation speed, and was estimated as 10mm and 18 mm when the rotation speed was 5000 rpm and 3000 rpm, respectively. On the other, the slope was independent of the rotation speed.

Figure 5 shows the rotation speed dependence of the flow rate Q. The flow rate increased proportionally to the rotation speed below 4200rpm. A threshold was also found for the rotation speed and the value of the threshold was approximately ~870rpm.

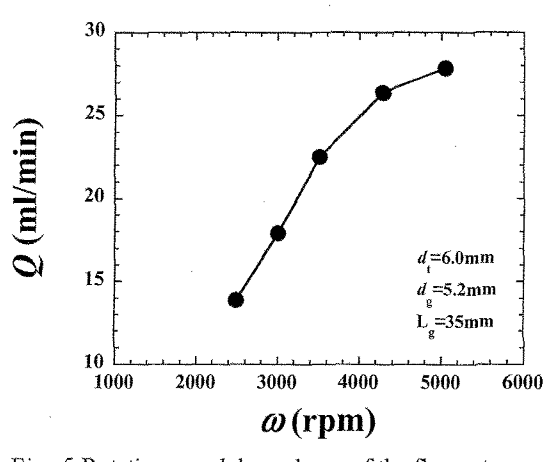

Fig. 5 Rotation speed dependence of the flow rate.

4. CONCLUSION

A fluid pump using magnetic hydrogels has been constructed. The fluid pump mainly consists of a gel rotor and a driving magnet. The gel rotor was made from sodium alginate gel containing magnetic fine particles. It was demonstrated that the gel rotor delivered water using a rotational magnetic field. Since the driving force is a magnetic field, no electrical leads to the pump are needed. The gel rotor is very flexible and the fluid delivery system is very simple. Flow rates pumped by the rotor increased with increasing diameter, length of the gel rotor, and rotation speed. The maximum flow rates of 34 ml/min was achieved when the rotation rates was 5000 rpm.

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