

## Electrical Dehydration of Agar Gels

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The evolution of electric conductivity during the drying process of agar gels has been measured in order to investigate the motions of ions. In the measurements, we have observed a remarkable electrical dehydration: rather amount of water exuded from agar gel within a half-hour after the electric current begin to pass through the gel. The weight loss of a sample gel due to this phenomenon reached 33% by 24 minutes.

Key words: polymer gel, hydrogel, agar, dehydration, electric conductivity

### 1. INTRODUCTION

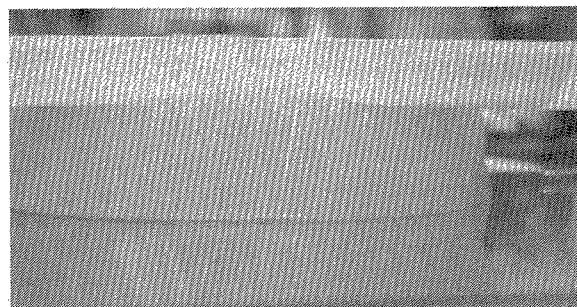
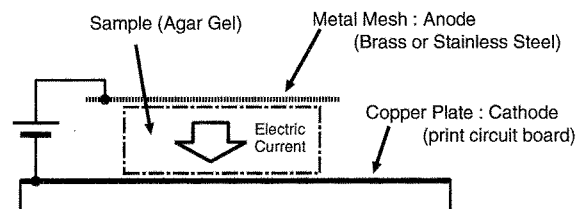
Interactions between polymer network and solvent molecule of gels show interesting behavior during the drying process [1-3]. It has been reported that some hydrogels turn into glass like materials.

In order to investigate the motions of ions, which will have some important role in the process, we have tried to observe the changes of the electric conductivity of agar gel on drying process. At first, it was intended to observe the interactions between polymer network and solvent molecule of gels, which revealed interesting features during the drying process: the conductivity shows a logarithmic decay similar to the weight change. In the measurements, we have also observed an interesting rapid dehydration phenomenon in the early stage.

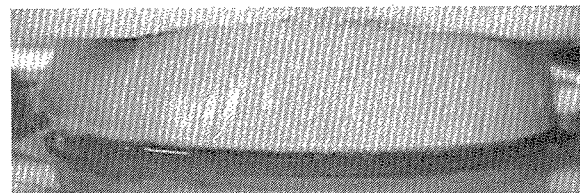
In ref. 4, Tanaka *et al.* reported the volume phase transition induced by applying electric field. Although they mentioned the existence of a stationary current resulting from electric field, they did not measured the electric current. Whereas, the present study investigated the relation between the dehydration and the electrical response of agar gel.

### 2. EXPERIMENTALS

At first, for the purpose of observing the changes of electric conductivity, a simultaneous voltage-and-electric current measurement was performed during drying process of agar gels. While performing the experiments, we noticed much amount of water leaked out from the gels in the early stage of dehydration. Therefore, turning our attention to this phenomenon, the measurements of the weight change by applying a dc voltage were performed.



**Fig. 1:** A schematic diagram and a picture of experimental arrangements for observing changes of electric conductivity in drying process of agar gel. A metal mesh was used as an anode electrode in order not to prevent water evaporation. The sample gel in the picture has a diameter of about 85 mm and a thickness of about 10 mm.



**Fig. 2:** A picture of a sample gel at about an hour after applying a dc voltage. It is easily seen that considerable amount of water had leaked out from the gel. It seems that water leaked out at the surface in contact with a cathode plate.

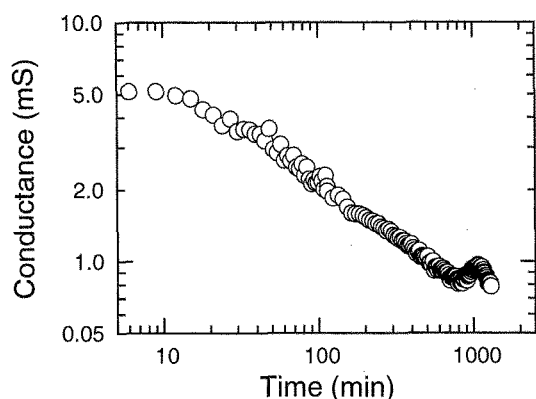


Fig. 3: Observed change in the electric conductivity during the dehydration process of an agar gel.

### 2.1 Measurement of electric conductivity

Figure 1 shows a schematic diagram and a photograph of the experimental arrangements. A metal mesh was used as an anode electrode in order not to prevent water evaporation. The sample gel was a thick disk in shape with a diameter of  $\sim 85$  mm and a thickness of  $\sim 10$  mm.

A picture of a sample gel at an hour after applying electric voltage is shown in Fig. 2. As can be easily seen from the figure, considerable amount of water leaked out from the gel. It seemed that water leaked out at the surface in contact with a cathode plate. Although it might be difficult to know only from this picture, the anode side of the specimen became yellow and then the colored area expanded toward the cathode with time. In this case, a stainless steel mesh was used as the anode. Similarly, in the case of a brass mesh anode, the specimen showed a blue-green color. These results strongly suggest that chromium ion in stainless steel and copper ion in brass diffused into sample gels, respectively.

Figure 3 shows an observed change in the electric conductivity during the dehydration process of an agar gel, which shows a logarithmic decay similar to the weight change [2]. With a minute examination, one may tell that there may be a small rise around 1000 minute, which can be caused by the ion diffusion mentioned above.

### 2.2 Observation of weight changes due to electrical dehydration

In order to investigate the electric effect on the dehydration of the agar gel, we constructed an experimental system shown in Fig. 4. Two aluminum plates are used as the anode and cathode electrodes. While the cathode is fixed to a Bakelite plate, the anode is movable and pulled toward the cathode with a small tension generated by hanging down a weight of 50 g.

For observing the weight change, the measurement was carried out as follows: Firstly, a sample gel was placed between the electrodes and a dc voltage

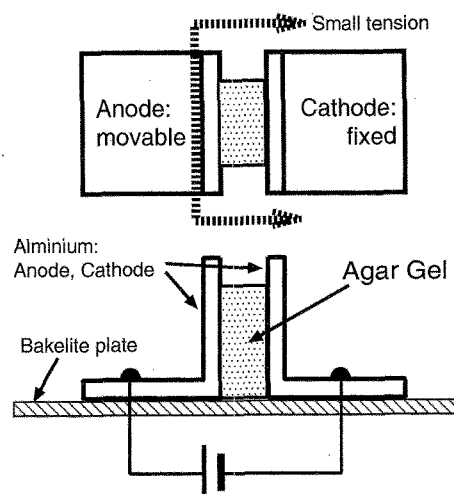


Fig. 4: A schematic diagram of experimental system for observing change in the weight of agar gel due to electrical dehydration.

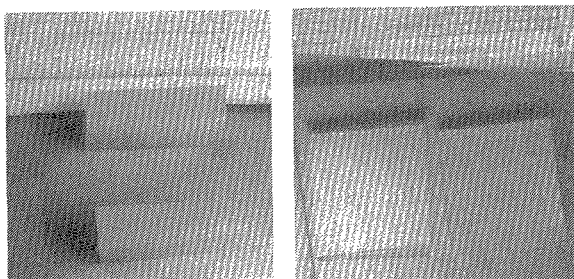


Fig. 5: Pictures of a pair of agar gel blocks just before experiment. One portion was used as a sample and the other was used as a reference of the natural evaporation. Each block was about  $35 \text{ mm} \times 25 \text{ mm} \times 5 \text{ mm}$  in dimensions.

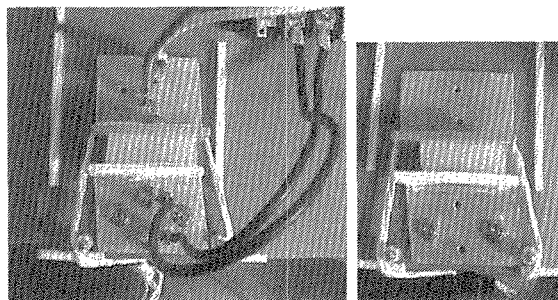


Fig. 6: Pictures of the experimental system during the process of observing sample and reference simultaneously. An overall view of the experimental system (top). Sample gel block between electrodes connected with wires for applying voltage (left). Reference gel block between dummy electrodes with no wire (right).

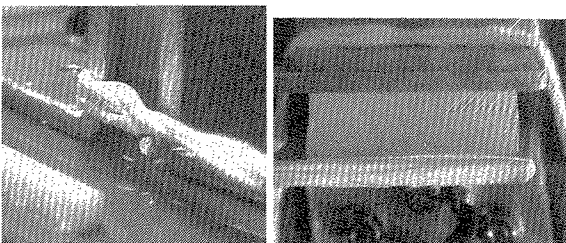
was applied, then the current and the voltage were measured continuously for an appropriate period. Secondly, the sample was brought out to measure its weight. Lastly, the sample was returned to the original position between electrodes and the electric measurement was repeated several times.

The weight of the gel also changes without electricity due to drying in the atmosphere, which should be estimated to know the effect of the electricity application. Therefore, we prepared a pair of the agar gel blocks cut out from a single gel lump, which are shown in Fig. 5, one portion was put in the apparatus and the other was used as a reference of the natural evaporation. As shown in Fig. 6, during the measurement mentioned above, experimental conditions of the specimen and the reference gels were set to be almost equal except for the application of the electricity.

Agar powder was dissolved in water and heated to boiling, and then left to cool down to the room temperature to become a gel. The concentration of agar was 5.0 wt% in the dissolved solution. As mentioned above, two blocks were cut out from the lump of the agar gel. Both of the gel blocks were around 35 mm × 25 mm × 5 mm in dimension.

### 3. RESULTS AND DISCUSSIONS

Figure 7 demonstrates the water which comes out from the agar gel. For only about 10 minutes after the electricity application, remarkable amount of water had come out of the gel.

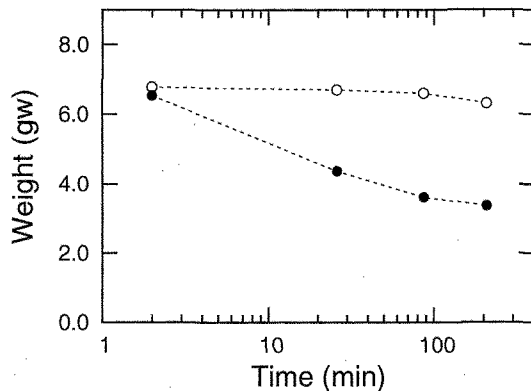


**Fig. 7:** Pictures of discharged water from agar gel as the result of experiment. Water flowed down to form a drop at the bottom of the gel (left). Water exuded at the top of the gel (right).

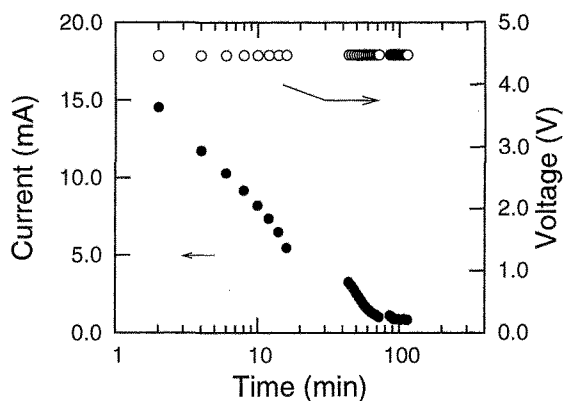
The observed changes in the weight of the sample and the reference gel blocks are shown in Fig. 8. It shows that the weight of the sample gel immediately decreased while that of the reference gel remained almost constant until 100 min.

Weight losses of the sample at three periods in Fig. 8 are 33.0%, 17.4%, and 6.8%, whereas those of the reference, 1.15%, 1.43%, and 4.38%. It is clear that these significant weight losses, especially in the period from 2 min to 26 min, should be attributed to the electricity applied to the sample.

However, the rate of the weight loss of the sample for the second period, from 26 to 87 min, in Fig. 8 is rather smaller than that of the first period. Figure 9 shows the evolution of the voltage and the current of the sample gel during the electric dehydration



**Fig. 8:** Observed changes in the weight of an agar gel due to electrical dehydration in the present study. Closed circle denotes the changes of the sample gel with a dc voltage applied, while open circle denotes that of the reference gel with no voltage applied.



**Fig. 9:** Result of measurement of voltage and electric current for the sample gel during experiment. Open circle and closed circle denote the voltage and the electric current of the sample, respectively. Although the applied voltage was kept almost constant, the electric current decreased rapidly.

process. It revealed that the voltage remains almost constant, while the current decreases with time. As the electric power applied to the sample was less than 64 mW, the effect of the Joule heating should be negligible.

With these results, observed dehydration in the agar gel should be caused by the electric current flowing through the sample. The maximum current density in the sample was about  $26 \mu\text{A}/\text{mm}^2$ .

Electric charges that were passed through the sample during the three periods in Fig. 8, which seem to correspond with the amount of dehydration, are estimated by integrating the electric current values in Fig. 9 to be 10.3 C, 3.4 C, and 1.6 C, respectively. However, because the current data did not obtained completely covering these periods, the electric charge results were insufficient to conclude.

Because the present study intended to confirm the electrical dehydration phenomenon, many factors are left to be investigated in further study. For example, the interaction between the electrodes and the sample gel, as shown in Fig. 10, the sample gel

dehydrated to shrink and its surface was deformed. Moreover, the interface between electrodes and the sample should form a structure during the voltage applied. Besides, aluminum ion might diffuse to the sample, although it did not obvious in the present study.



**Fig. 10:** A picture of the sample gel and the electrodes after experiment.

On the other hand, because this electrical dehydration seems to occur at the cathode side surface of the gel, if the applied voltage is reversed, the solvent water will begin to exude from the opposite electrode side surface. However, if the rate of the reversing voltage, i.e. the frequency increases, the amount of exuded water would decrease. Thus, the frequency dependence of this dehydration will have some important characteristic which reflects the interaction between polymer network and solvent molecule of the gel.

#### 4. CONCLUSION

We have observed that the agar gel can be dehydrated electrically at a considerable faster rate than

the natural evaporation. It strongly depends on the electric current density flowing through the gel but seems not to depend on the electric field.

It is important for the further study and applications to make electrical contact between electrodes and gel more effectively with some methods such as selecting electrodes' material and shape. It is also interesting whether the gel suffers the chemical decomposition or not.

Although the present study only deal with direct current response, the frequency response is supposed to have important characteristics, especially in relatively low-frequency region, which is now in progress.

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