희박 고분자용액을 액막으로 사용하는
에멀젼형 액막계에서 페니실린 G의 추출

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Extraction of penicillin G in emulsion liquid membrane systems with dilute polymer solutions

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1.INTRODUCTION

Lately, special attention has been paid to the recovery of biochemicals by emulsion liquid membrane (ELM) processes because of their high degree of extraction and enrichment ratio. However, the ELM processes have been seriously flawed by emulsion swelling and membrane breakage. Although current remedies for such emulsion instabilities are to increase the concentration of a stabilizing surfactant in the membrane phase and increase the viscosity of the membrane phase using a viscous Newtonian liquid, the remedies increase the mass transfer resistances within the emulsion and thus can nullify their own advantage of a high permeability.

The use of dilute polymer solutions as the membrane phase has been known to improve the emulsion stabilities [1,2]. According to our previous work [3], the extraction efficiency of penicillin G, such as its degree of extraction and enrichment ratio, strongly depended on a w/o ratio (i.e. volume ratio of internal aqueous phase to organic membrane phase) as well as membrane composition. In this work, therefore, we have investigated the effects of composition of a dilute polymer solution on the extraction efficiency of penicillin G in ELM systems with different w/o ratios, thereby discussing the applicability of an ELM process to its extraction.

2.EXPERIMENTAL

A citrate buffer solution was used as the external aqueous phase in order to reduce emulsion swelling and keep pH of the external phase constant throughout the ELM experiments. Penicillin G potassium salt was added to the external phase to prepare a feed solution. The internal aqueous phase was prepared by dissolving sodium carbonate in deionized water. The organic membrane phase was prepared by dissolving a mixture of PARANOX 147 and Span 80 as an emulsifier, Amberlite LA-2 as a carrier, and a small quantity of polymer in kerosene. The polymer used was an 1:1 mixture of styrene/butadiene block copolymer (분자량: 140,000, 30% styrene) and styrene/isoprene block copolymer (분자량:150,000, 14% styrene).

A water-in-oil (w/o) type emulsion was made by slowly adding the internal phase to the organic membrane phase with intensive mixing provided by a homogenizer. For the ELM experiments, 70 cm^3 of the w/o emulsion was dispersed in 420 cm^3 of the feed solution, in which the concentration of penicillin G was 20 mmol/dm^3. All of the extraction runs were conducted at the stirrer speed of 330 rev/min. In all of the experiments, the initial concentration of Amberlite LA-2 in the membrane phase was 20 mmol/dm^3. The emulsification speed and time were 12,000 rev/min and 10 min, respectively. The initial mass of Na$_2$CO$_3$ in the internal phase was fixed as 3.5×10^{-3} mol, regardless of the w/o ratio.

The ultra low adapter (ULA) accessories of a digital viscometer (DV-II+, Brookfield) were used to make accurate and reproducible measurements on the membrane phase of low viscosity.

Emulsion stability was investigated by measuring the extents of emulsion swelling and membrane breakage in the ELM experiments. The degree of emulsion swelling (E_s) is defined as the ratio of the volume increment at any time (V_{em}) to the initial volume of the emulsion phase ($V_{em,0}$):

$$E_s = \frac{V_{em} - V_{em,0}}{V_{em,0}} \times 100 \ (\%) \tag{1}$$

Potassium ion (0.1 mol/dm^3) was added to the internal phase as a tracer to measure the extent of leakage of the internal phase to the external phase due to membrane breakage. The degree of membrane breakage (M_b) is represented by:

$$M_b = \frac{C_e V_{e,0}}{C_{i,0} V_{i,0}} \times 100 \ (\%) \tag{2}$$

3.RESULTS AND DISCUSSION

<u>Facilitated transport mechanism of penicillin G</u>

The facilitated transport of penicillin G in the emlusion liquid membrane system is as shown in Fig. 1. As illustrated in the previous works by the current author [4-6], amines such as Amberlite LA-2 (extractant) and polyamine surfactants (ECA 4360J, PARABAR 9551 or PARANOX 147) can function as a carrier of penicillin G in an ELM system. Generally, the reaction of the amines with undissociated penicillin acids at the external and the internal interfaces can be expressed by:

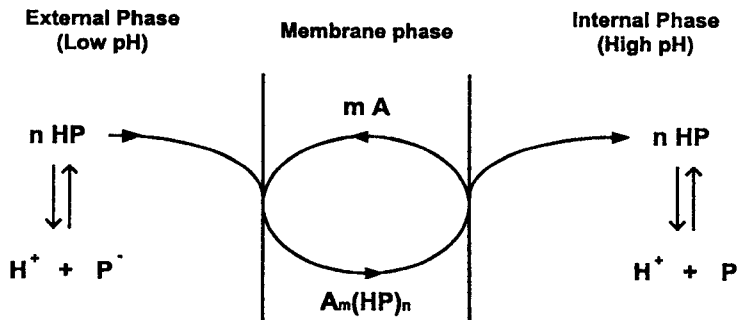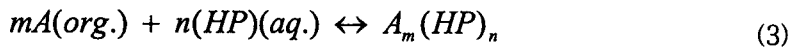$$mA(org.) + n(HP)(aq.) \leftrightarrow A_m(HP)_n \tag{3}$$

Fig. 1. Transport mechanism of penicillin G in the ELM system

<u>Effect of membrane composition on extraction efficiency</u>

Fig. 2 shows the viscosity of the membrane phase as a function of the concentration of polymer in the membrane phase where the volume ratio of Span 80 to PARANOX 147 was 5:95. The viscosity of the membrane phase was higher at a higher polymer concentration. Also, the viscosity of the polymer-dissolved membrane phase at a given polymer concentration decreased with an increase in the shear rate, indicating that the Newtonian-type organic membrane solution was converted into a non-Newtonian fluid with the addition of the polymer. Such non-Newtonian behavior is more splendid at a higher polymer
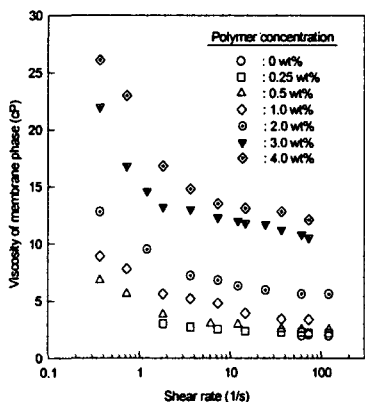
concentration.

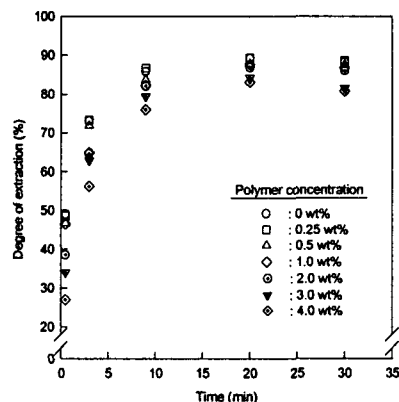Fig. 2. Variation of viscosity with shear rate at different polymer concentrations.

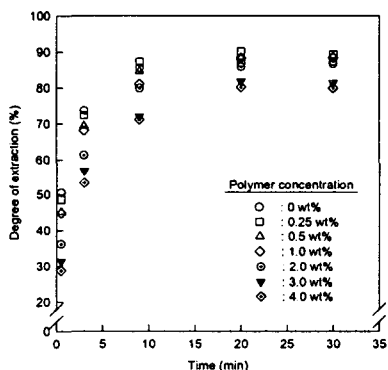Fig. 3. Effect of polymer concentration on degree of extraction at the w/o ratio of 1/4

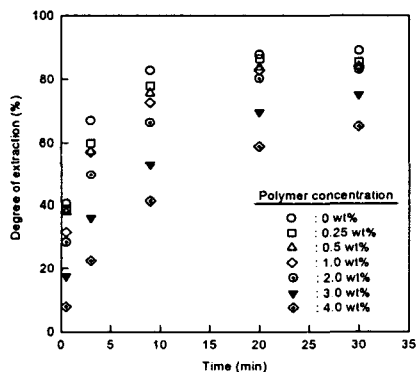Fig 4. Effect of polymer concentration on degree of extraction at the w/o ratio of 1/3

Fig. 5. Effect of polymer concentration on degree of extraction at the w/o ratio of 1/1

Figs. 3-5 show the effects of the concentration of polymer in the membrane phase on the degree of extraction of penicillin G at three different w/o ratios. The degree of extraction is defined as the percentage of penicillin G extracted from the external phase with regard to its initial concentration. The similar extraction behavior occurred, independent of the w/o ratio. In other words, the initial extraction rate of penicillin G decreased with the increase in polymer concentration and also there were no big differences between the degrees of extraction at the polymer concentrations lower than about 1 wt%. At every w/o ratio, the initial extraction rate in the ELM system without any addition of the polymer was higher than that with 0.25 wt% of polymer concentration (see the degree of extraction at 0.5 min), which can be estimated to be higher

than the critical polymer concentration. There are two possible explanations for this extraction tendency: First, the interaction and overlapping of polymer molecules at the polymer concentrations equal to 0.25 wt% or higher lowered the extraction rate. Second, the higher viscosity of the membrane phase with a higher polymer concentration produced a lower mass transfer area between the external phase and the emulsion drops due to the formation of larger emulsion drops, thereby resulting in the lower degree of extraction.

Table 1. Time-dependent enrichment ratio (ER) of penicillin concentration and degree of extraction (%, DE) with the change in concentration of polymer in the membrane phase at each w/o ratio.

Polymer Conc.	w/o=1/4				w/o=1/3				w/o=1/1			
	20 min		30 min		20 min		30 min		20 min		30 min	
	ER	DE	ER	DE	ER	DE	ER	DE	ER	DE	ER	DE
0 wt%	2.7	89.2	2.4	88.2	4.2	86.9	3.6	86.7	6.3	87.8	5.3	89.0
0.25 wt%	3.2	89.3	3.0	88.6	5.3	90.1	3.7	89.3	6.6	86.5	6.2	88.5
0.5 wt%	4.4	87.8	3.5	87.5	6.0	88.3	4.8	88.8	7.1	83.8	6.3	84.1
1.0 wt%	5.5	87.7	4.5	86.8	6.8	88.3	6.5	88.4	8.2	82.9	6.7	83.9
2.0 wt%	6.1	86.9	5.1	86.0	7.2	85.9	6.9	87.4	9.2	80.2	9.0	83.0
3.0 wt%	5.6	84.3	4.9	81.5	6.0	81.8	5.6	81.4	8.6	69.6	7.6	75.2
4.0 wt%	4.9	83.1	4.0	80.7	5.8	80.2	5.1	80.0	6.4	58.8	5.8	65.1

Table 1 describes the time-dependent enrichment ratio of penicillin G concentration with the changes in concentration of polymer in the membrane phase at different w/o ratios. The enrichment ratio is defined as the ratio of penicillin G concentration in the internal phase at any time to its initial concentration in the external phase. The enrichment ratio at 30 min was lower than that at 20 min for all of the runs, and it was higher at a higher w/o ratio when the polymer concentration is the same. This implies that emulsion swelling continues to occur with time during each run and is lower at a higher w/o ratio. Also, the enrichment ratio had a maximum value at a specific polymer concentration for each w/o ratio because the degree of emulsion swelling and the degree of

extraction simultaneously decreased with the increase in polymer concentration. The polymer concentration happened to be 2 wt%, independent of the w/o ratio. Fig. 6 shows the change in degree of emulsion swelling with respect to time as a function of the polymer concentration at the w/o ratio of 1/4. It was found that the degree of emulsion swelling was significantly reduced with addition of the polymer. When no polymer was added to the membrane phase, severe emulsion swelling after 10 min caused a sudden rupture of the membrane phase and finally resulted in a sharp drop in the degree of emulsion swelling. Fig. 7 shows the change in degree of membrane breakage with respect to time. A large change in the degree of membrane breakage after 10 min supports the fact. Table 2 shows the degree of membrane breakage at 30 min at each w/o ratio. We could see that the emulsion at the w/o ratio of 1/1 was more stable than those at the w/o ratios of 1/3 and 1/4.
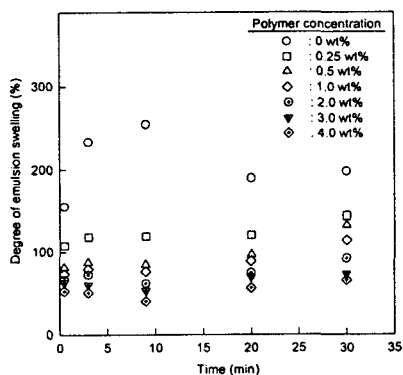

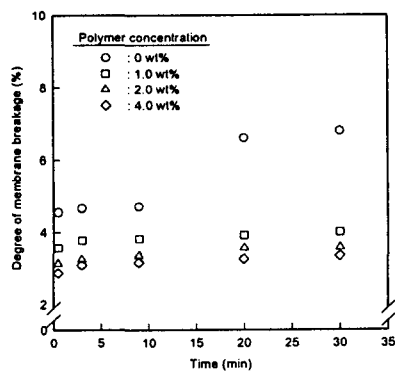Fig. 6 Effect of polymer concentration on degree of emulsion swelling at the w/o ratio of 1/4

Fig. 7. Effect of polymer concentration on degree of membrane breakage at the w/o ratio of 1/4

Table 2. Degree of membrane breakage (%) at 30 min with the change in concentration of polymer in the membrane phase at each w/o ratio.

Polymer Concentration	w/o=1/4	w/o=1/3	w/o=1/1
0 wt%	6.8	7.0	2.4
1.0 wt%	4.0	4.3	2.2
2.0 wt%	3.6	4.0	1.6
4.0 wt%	3.3	3.4	1.4

Table 3. Time-dependent degree of emulsion swelling (%) with the change in concentration of polymer in the membrane phase at each w/o ratio.

Polymer Concentration	w/o=1/4		w/o=1/3		w/o=1/1	
	20 min	30 min	20 min	30 min	20 min	30 min
0 wt%	190.1	198.0	66.9	119.6	15.1	13.1
0.25 wt%	120.3	143.4	64.2	92.5	10.1	15.3
0.5 wt%	96.8	132.6	57.8	79.9	-3.6	-2.6
1.0 wt%	89.2	114.1	50.8	63.6	-7.9	-5.4
2.0 wt%	75.1	92.1	28.4	48.1	-8.0	-4.7
3.0 wt%	69.8	73.2	27.7	43.8	-11.1	-8.8
4.0 wt%	56.4	65.8	26.1	38.8	-11.6	-7.1

Table 3 shows the time-dependent degree of emulsion swelling. We could see that the degree of emulsion swelling rapidly decreased with the increase in w/o ratio at the same polymer concentration. This is because the concentration of Na_2CO_3 in the internal phase is not only lower at a higher w/o ratio, but also the amount of surfactant in the membrane phase as a carrier of water is smaller. In addition, the degree of emulsion swelling decreased with the polymer concentration, independent of the w/o ratio. The viscoelastic polymer used seems to retard the transport of water. In the run with no polymer addition at the w/o ratio of 1/4 as shown in Fig. 6, the initial rate of emulsion swelling was very high and the rate decreased slowly with time. Also, the same behavior was observed in the other two runs with no polymer addition at the w/o ratios of 1/3 and 1/1. The rate of emulsion swelling keeping high for about 10 min could not be explained only by the osmotic pressure difference between two aqueous phases as one of the driving forces of emulsion swelling, because the concentration of salts in the external phase was still higher than that in the internal phase during the run. Therefore, we could presume that the transport of penicillin G, a kind of hydrophilic solute, is accompanied by the transport of water. In the case of the w/o ratio of 1/1, the degree of emulsion swelling around the end of a run had even negative values at the polymer concentrations higher than 0.25 wt%, because the back transport of water occurs from the

internal phase to the external phase due to a high citrate buffer concentration in the external phase and a low extraction rate of penicillin G at that time. In sum, these preceding results prove that the extraction efficiency of penicillin G, such as enrichment ratio of penicillin G and emulsion stability, could be improved by adding a small quantity of polymer to the membrane phase. Thus, development of the more practical ELM system for extraction of penicillin G seems to be accomplished in the near future.

4.REFERENCES

[1] A.H.P. Skelland and X.M. Meng, "Non-newtonian conversion solves problems of stability, permeability, and swelling in emulsion liquid membranes", J. Memb. Sci., 158, 1 (1999).
[2] A.H.P. Skelland and X.M. Meng, "A new solution to emulsion liquid membrane problems by non-Newtonian conversion", AIChE J., 42(2), 547 (1996).
[3] S.C. Lee, "Effect of volume ratio of internal aqueous phase to organic membrane phase (w/o ratio) of water-in-oil emulsion on penicillin G extraction by emulsion liquid membranes", J. Memb. Sci., 163, 193 (1999).
[4] S.C. Lee and W. K. Lee, "Extraction of penicillin G from simulated media by an emulsion liquid membrane process, J. Chem. Technol. Biotechnol.", 55 251 (1992).
[5] S.C. Lee, J.H. Chang, B.S. Ahn and W.K. Lee, "Mathematical modeling of penicillin G extraction in an emulsion liquid membrane system containing only a surfactant in the membrane phase", J. Memb. Sci., 149, 39 (1998).
[6] S.C. Lee, B.S. Ahn and J.G. Kim, "Reaction equilibrium of penicillin G with Amberlite LA-2 in a nonpolar organic solvent", Biotechnol. Progress., 18, 108 (2002).