Urine concentration by forward osmosis process

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Abstract
The urine concentration is required for reuse of urine as a fertilizer in urban slam. The FO process with sucrose solution was performed to assess the feasibility of urine concentration and the effect of the water permeability on the sucrose concentration. As a result, urine was concentrated to reduce the volume and to increase in concentrations of nutrients by a FO process. Concentrations of ions were concentrated, although the urea was not concentrated because urea passed thorough the membrane. Nitrogen concentration can be achieved by hydrolyzing urea to produce ammonia. High concentration of sucrose solution had an impact on water permeability by high viscosity. The overall mass coefficient was correlation to the permeability because of formation of the boundary layer.

Keywords
Multi component model, osmotic pressure, activity, resource recycle

Introduction

The demands of the major nutrients of nitrogen, phosphorus and potassium for fertilizers are forecast to reach respectively 119 Mtons, 46.6 Mtons and 34.5 Mtons in the world at 2018 (FAO, 2015). They are produced from mining minerals and fossil fuels which are limited resources. The nutrients in the fertilizers are used for food production, then metabolized to excreta in human body, finally discharged to environmental water body. Human urine contains 12 g/L of nitrogen, 1 g/L of phosphorus and 2 g/L of potassium while has a potential to reuse as a fertilizer (Wilsenach *et al.*, 2007). In an urban slum of Bandung in Indonesia, excreta from households discharged in to a river directly or with poor treatment to pollute environmental water body. On the consideration of reuse of excreta, urine and feces should be converted to fertilizer in the house, then transported to farmland, although there is a little farmland to be reused, resulting in requiring long-distance transportation to outside of urban area. The collection and transportation cost of especially urine is huge owing to its volume by increasing in frequency of collection. Thus, urine volume reduction is required for reducing the cost. Deguchi (2012) estimated the cost for reusing excreta as a fertilizer in the area as shown in Fig. 1. The major cost was for collection and transportation of urine, while we can achieve less cost than current chemical fertilizer by reducing 80% of its volume. There are several concentration systems of urine and other solutions, e.g. evaporative concentration (EC) (Masoom., 2008), electro dialysis (ED) (Pronk *et al.*, 2006) and reverse osmosis (RO) etc. The

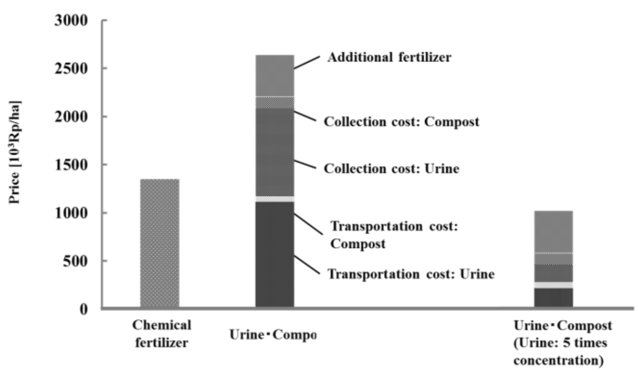

Fig. 1. Cost for reusing excreta as a fertilizer

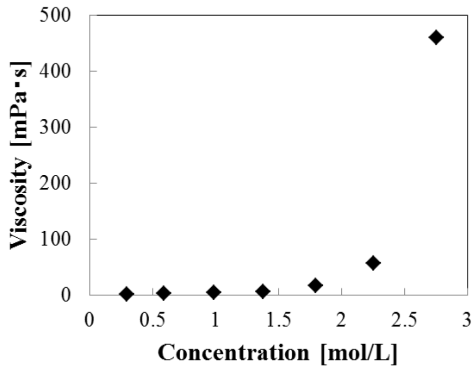

Fig. 2. Effect of sucrose solution concentration on its viscosity

Table. 1. Osmotic pressure and concentration level

	Concentration level	Osmotic pressure	Conversion of NaCl mole
Non-hydrilyzed urine (pH5.3-5.5)		MPa	mol/L
	1	1.87	0.754
	2	3.63	1.47
	5	8.16	3.29

feasibility of EC without heat supply is one of the low operation cost technology, but strongly depends on the climate condition. ED and RO require complex system and electricity resulting in high cost for concentration of urine. Therefore, we are proposing a simple system by forward osmosis (FO) for concentration of urine in households which has a low energy consumption and a low fouling tendency (Zhao *et al*., 2012). The osmotic pressure calculated from the data of Oishi (2013) was summarized in Table 1, while high concentration solution was required for concentration of urine. Here, sucrose is a candidate for draw solution because it is easy to obtain and safe which can be drunk. High concentration, more than 2 mol/L, of sucrose solution has very high viscosity, as shown in Fig. 2 (Handbook of chemistry, 1958), to change the convection of the solution, such as a thick boundary layer. Therefore, the objectives of this paper are to assess the feasibility of urine concentration by FO process and the effect of water permeability on concentration of sucrose solution.

Theory

The concentration profile though a membrane is shown in Fig. 3. The water flux, J_w [m/s], through the membrane in FO process is proportion to the difference of osmotic pressures, $\Delta\pi$ [Pa], in the draw and feed solutions as follows;

$$J_w = P\Delta\pi = PRT\left(\sum_i a_{i,\mathrm{draw}} - \sum_i a_{i,\mathrm{feed}}\right) \tag{1}$$

where P is a water permeability coefficient [m/s/Pa], R is the gas constant [J/K/mol], T is a temperature [K], and a_i is an activity of component i in the draw or feed solution [mol/m^3]. In boundary layer at the membrane surface, the mass transportation occurs by diffusion and convection as following equation (2);

$$\frac{\partial C}{\partial t} = -k\frac{\partial C}{\partial x} + J_w\frac{\partial C}{\partial x} \tag{2}$$

where k is an overall mass transfer coefficient in the boundary layer [m/s], C is a concentration in draw or feed solution [mol/m^3]. k corresponds to the Sherwood number, Sh [-], as following equation (3);

$$Sh = \frac{kL}{D} \tag{3}$$

where L is a characteristic length [m], D is a diffusion coefficient in the solution [m^2/s]. Sh can be evaluated by equations (4),

$$Sh = 0.664Sc^{1/3}Re^{1/2}\ (Re < 5\times 10^5) \tag{4}$$

where Sc is the Schmidt number [-] and Re is the Reynolds number [-]. Sc and Re can be calculated as follows;

$$Sc = \frac{\mu}{\rho D} \tag{5}$$

$$Re = \frac{\rho v L}{\mu} \tag{6}$$

where μ is a viscosity coefficient [Pa·s], ρ is a density of the solution [kg/m^3], and v is a flow velocity of solution at the membrane surface [m^2/s].

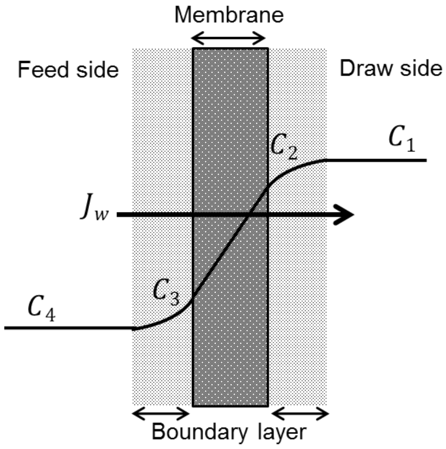

Fig. 3. The profile of concentration of feed and draw solution in membrane

Material & methods

Fig. 4 shows the schematic illustration for FO test. The membrane of cellulose triacetate embedded with a polyester woven mesh was placed in the middle of a FO cell with symmetric cross-flow channels whose cross section was a rectangle of 1 cm width and 0.2 cm height. The effective membrane surface area for water permeation was 98 cm^2. The feed and draw solutions were continuously circulated with 14 L/h of flow rate in co-current flow. The synthetic urine with the composition listed in Table 2 (Wilsenach *et al*., 2007), and 2.5 mol/L of sucrose solution were respectively the feed and draw solutions in run 1. Deionized water and sucrose solution with the concentrations of 0.4, 0.5, 1.0, 2.0 and 2.6 mol/L were respectively the feed and draw solutions in run 2. The water flux was continuously measured by weighting draw solution with electric balance. The concentrations of ions were measured by an ion chromatograph analyzer (ICP-90 Ion Chromatography System, DIONEX), urea was by a LC/MS system (W3100, Waters) and sucrose was by a TOC analyzer (TOC-VCSH, Shimadzu). The osmotic pressure was estimated as the sum

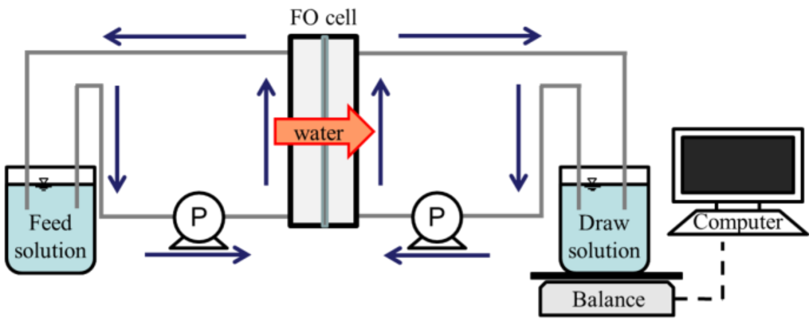

Fig. 4. Schematic diagram of FO test

Table. 2. Composition of synthetic urine

Salt	Concentration [mM]
$MgCl_2 \cdot 6H_2O$	3.2
NaCl	78.7
Na_2SO_4	16.2
KCl	21.5
$CaCl_2 \cdot H_2O$	4.4
KH_2PO_4	30.9
NH_4Cl	18.7
$(NH_2)_2CO$ (urea)	417

of the activities of the all components in the solution which calculated with an equilibrium simulation program, Phreeqc (Parkhurst *et al.*, 2013).

Results & discussion

The time courses of concentrations of solutes are shown in Fig. 5. The concentration of the ions in feed solution increased with time, while the concentration of sucrose in draw solution decreased. Urea concentration was constant in feed and increased in draw solution. The volume of feed solution decreased from 500 mL to 300 mL in contract that of draw increased from 200 mL to 400 mL. The mass balance of urea and ammonia, shown in Fig. 6, indicates urea permeated from feed to draw solution, although ammonia and other solutes didn't pass through the membrane. Therefore, the FO process with 2.5 mol/L of sucrose solution can concentrate ions 1.7 times except urea, while more concentration is required to achieve 5 times. Urea can be transformed to ammonia for farther concentration of nitrogen by contaminating microorganisms such as feces. Fig. 7 shows the effect of the osmotic pressure difference between draw and feed solutions on water flux thorough the membrane. The water permeability might be 4.38×10^{-13} m/s/Pa with the assumption of linear relation

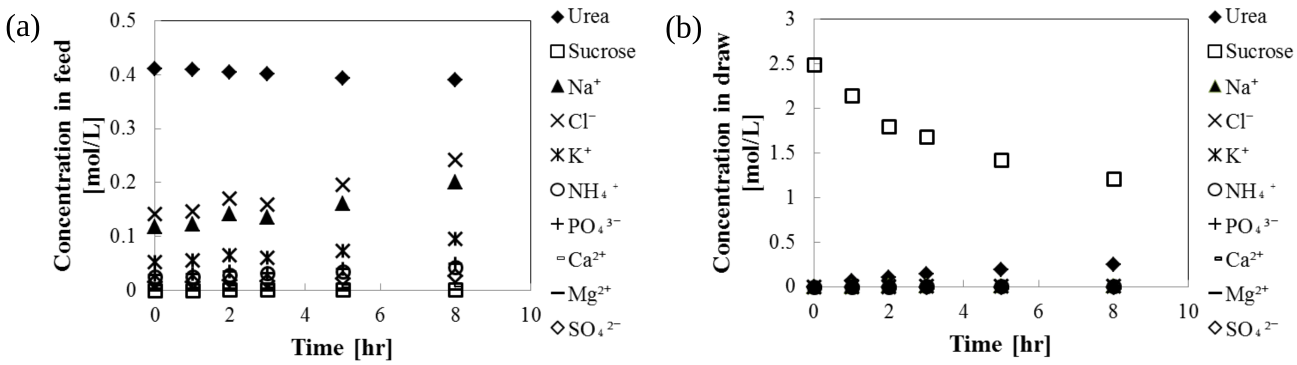

Fig. 5. Concentrations of solutes in (a) feed and (b) draw solutions

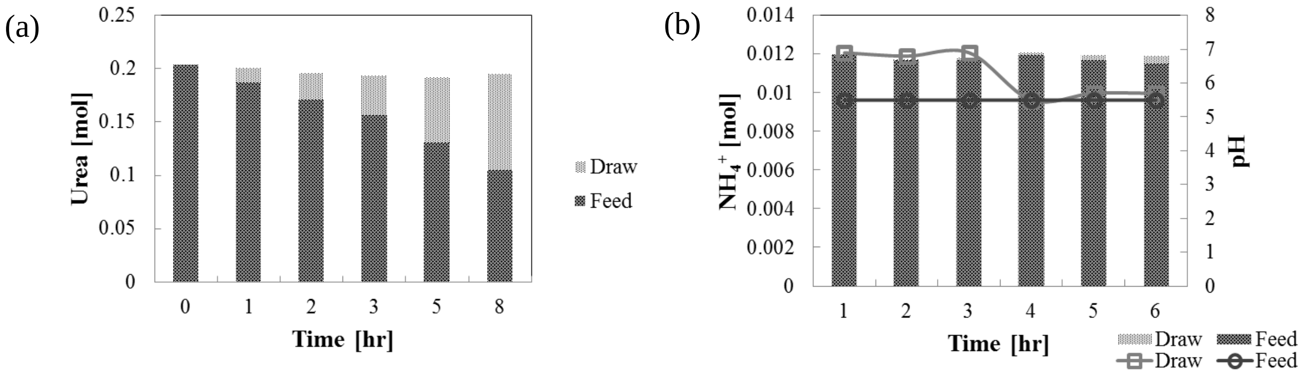

Fig. 6. Mass balances of (a) urea and (b) ammonium ion

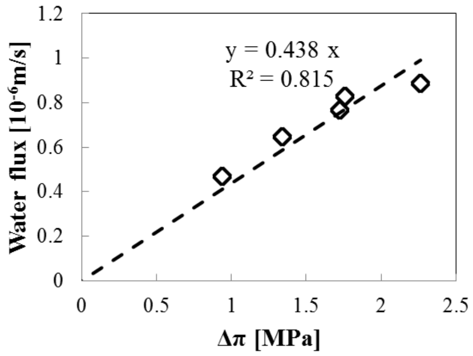

Fig. 7. Effect of the difference of osmotic pressure on water flux

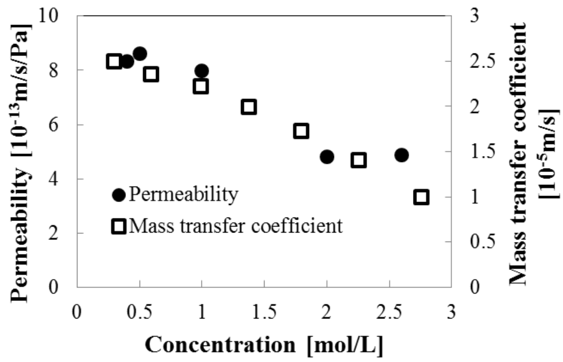

Fig. 8. Effect of sucrose concentration on water permeability and mass transfer coefficient

of equation (1), although the plots were not linear. This fact indicates the permeability in equation (1) should be a function of other parameters. Fig. 8 illustrates the effect of the sucrose concentration on the permeability. High concentration of sucrose gave low permeability while it might be linear correlation. This is because the hydraulic flow pattern, such as the thickness of boundary layer, might change with viscosity. To verify this, the overall mass transfer coefficient was estimated from equations (3)-(6), as shown in Fig. 8, while the mass transfer coefficient has similar trend to the permeability.

Conclusion

Urine was concentrated to reduce the volume and to increase in concentrations of nutrients by a FO process with sucrose solution. As a result, the volume of urine was reduced to 1.7 times with 2.5 mol/L of sucrose solution, except urea. Hydrolysis of urea to ammonia can achieve concentration of nitrogen. The water flux was not linear to the osmotic pressure difference between the feed and draw solutions. This is because the high concentration of sucrose solution had an effect on water flow pattern on the membrane surface owing to high viscosity. The overall mass coefficient correlated to the permeability by consideration of thickness of the boundary layer.

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