e-ISSN: 2455-5703

Nutrient Recovery from Urine through Membrane Techniques

[1]Gautam
[1]M.Tech student
[1]Department of Environmental Engineering
[1]NIT, Patna

Abstract

A paradigm shift is currently underway from an attitude that considers urine as a waste to be treated, to a proactive interest in recovering materials and energy from these streams. This paper is concerned with the development and application of a systematic, model-based methodology for the development of membrane based nutrient recovery systems that are both economically attractive and sustainable. With the array of available treatment and recovery options growing steadily development of reliable, yet simple, performance based is a key issue with this approach in order to allow for a reliable solution based on global optimization. We argue that commercial urine simulators can be used to derive such models, and we illustrate this approach with a simple recovery system. A conceptual decision making algorithm is developed aiming at the configuration and optimization of nutrient recovery treatment trains. This, in turn, may stimulate and hasten the global transition from urine wastage to urine resource recovery facilities. On top of that, the proposed roadmap may help adjusting the choice of nutrient recovery strategies to local fertilizer markets, thereby speeding up the transition from a fossil-reserve based to a bio-based circular nutrient economy.
Keyword- Nutrient Recovery, Phosphate Recovery, Ammonia Recovery, Membrane Based Process

I. INTRODUCTION

Urine has been investigated as a source for nutrient recovery for two reasons: firstly it contains a high concentration of nutrients; and secondly, it exists in large quantities. Recovering nutrient from urine can minimize the environmental footprint of wastewater treatment; simultaneously, the recovered nutrient can be added to fertilizer production to ensure food security. The membrane is a promising method to recover nutrient from urine since the membrane can enrich nutrient. It can subsequently increase the technical and economic feasibility of the nutrient recovery process. Phosphorus (P) and nitrogen (N) are essential nutrients for the growth of organisms.

However, such nutrients can also cause eutrophication which may seriously impair the quality of water and even cause aquatic life to die. Therefore, the discharge of nutrient should be strictly controlled. For this reason, nutrient removal from urine is necessary and the discharge concentration of nutrient is required to be below 1-3 mg·N/L and 0.1mg·P/L, respectively. In urine, ammonium and phosphate ions are the main present forms of N and P respectively. The former ions are always removed by ammonia stripping and nitrification- denitrification while the removal of the latter is mainly achieved by chemical precipitation and biological uptake. However, nutrient removal does consume a large amount of energy and chemicals.

Nutrient removal may also aggravate global warming due to the emission of 0.9kg CO2/m3 as a consequence of this process. The explosive growth in the world's population has in turn sparked an increase in the demand for nutrient-based fertilizers, approximately 1.8% per year for food production. However, the current production of fertilizers faces many challenges. Firstly, around 90% of global phosphate demand is utilized for food production, but the remaining accessible deposits of phosphate rock will be completely consumed in 30-300 years. Secondly, nomaterials can substitute the role of P in the fertilizers production. Consequently, the environment is subjected to great risks. More importantly, the generation of ammonia from air depletes around 35-50 MJ/kg·N of energy, which accounts for 2% of global energy.

As discussed above, nutrient recovery is more valuable than nutrient removal because:

i) it can produce nutrient-based fertilizers to ensure food security; ii) it can minimize the environmental footprint of wastewater treatment such as production of much less excess sludge and reduced eutrophication; and iii) N recovery can decrease the consumption of natural resources and save costs associated with N fixation.

A wide range of wastewater sources containing rich nutrient such as sewage, urine and leachate has been utilized for the purposes of nutrient recovery.

In the nutrient recovery process, the coexisting heavy metals and toxic substances exert serious effects on nutrient recovery such as impairing the quality of recovered nutrient. For example, Xie et al. Concluded that the recovered struvite crystals were found to have toxic heavy metals contents, in which the arsenic concentration was even greater than 570 mg/kg.

As a result of this, the application of such recovered struvite may be forbidden in agriculture due to its low quality and purity. Therefore, it is essential to separate nutrient from the foreign matter to enhance the application potential of recovered nutrient. Since membranes have selective high-rejection for ions, the nutrient can be enriched and separated from foreign substances in the streams. Fig. 1 illustrates the membrane separation process for ions from feed solution.

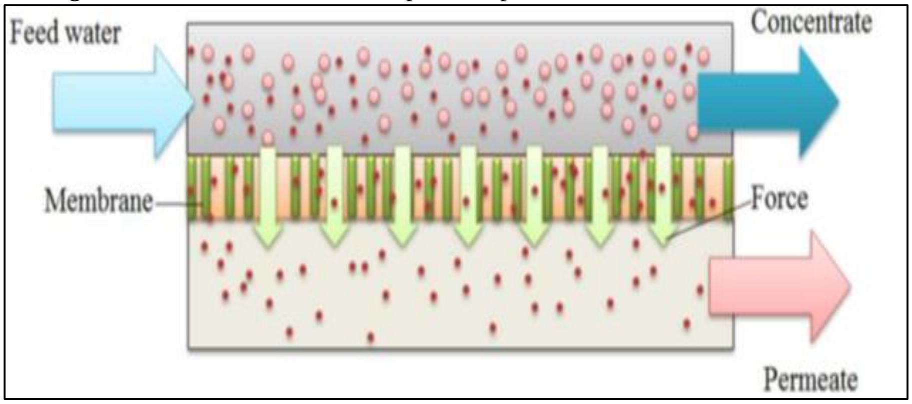

Fig. 1: Mechanism of membrane to concentrate and separate feed water

From Figure 1, it can be seen that a membrane filtration process mainly relies on the pore size of a membrane and water in the feed solution could penetrate the membrane under pressure. The membrane separation technique is a simple physical process, so no chemicals and energy are included in it. For this reason the membrane separation process is more economical than other separation processes in terms of operational and maintenance costs. Currently, some membrane techniques have been integrated with chemical precipitation and biological processes as the membrane hybrid systems for nutrient recovery from urine. In such cases the technical and economic feasibility of the nutrient recovery system can be improved.

A. Emerging Membrane Processes Advance Wastewater Nutrient Recovery

The challenges of higher nutrient enrichment and membrane selectivity open opportunities for emerging membrane processes to advance urine nutrient recovery. Reverse osmosis, Forward osmosis (FO), membrane distillation (MD) are three membrane-based processes that are best suited to overcome the challenges in urine nutrient recovery, and could potentially represent a paradigm shift in wastewater nutrient management. As described herein, these technologies can achieve high concentration factor for struvite precipitation, their selectivity is conducive to the fraction of valuable nutrient substances in various formats, and their energy requirements and associated costs are competitive with more conventional, pressure-driven membrane processes.

B. Mechanism of Nutrient Recovery in the Wastewater Treatment

It is important to comprehend the mechanisms of nutrient recovery inurinetreatment because they provide useful information on optimizing the recovery process and subsequent application of recovered nutrient in large-scale scenarios. There are three main ammonium recovery mechanisms, namely: (i) struvite precipitation; (ii) ammonia stripping coupled with adsorption and (iii) membrane concentration (Huang et al., 2014; Sotres et al., 2015; Xie et al., 2016; Yan et al., 2018).

C. Membrane Concentration

Membrane technology can enrich ammonium and separate it from foreign substances (e.g. heavy metals and pathogen) with low energy input, so membrane concentration for ammonium recovery is also an economic approach. The technically feasible membrane technology to recover ammonium mainly includes forward osmosis (FO), reverse osmosis (RO), membrane distillation (MD) and electro dialysis (ED).

In FO, natural osmotic pressure is used to force movement of water molecules from the feed side to draw side. Consequently, ammonium can be concentrated in the feed side. In contrast to this, RO relies on the hydraulic pressure which is against the osmotic pressure between the feed solution and draw solution. In this scenario, water molecules can be driven from low concentration of solute to high concentration of solute. Actually, the mechanism of ammonium concentration through the RO system is similar to that via the FO membrane. This is despite the fact that more energy is consumed in the RO process compared to the FO process. The main drawback associated with the FO process for ammonium recovery is that the draw solute is gradually diluted, which decreases the osmotic pressure gradient and thus detrimentally affects the ammonium concentration in the feed side.

D. Materials and Methods

1) Basic Process Configuration

The basic configuration of the process evaluated in the experiments is shown in Fig. 2. The overall goal was torecoverthe nutrients taking advantage of the several membrane such as ultra-filter membrane and Reverse Osmosis membrane

Fig. 2: The basic configuration of the process evaluated in the experiments

E. Membrane Process:-Ultrafiltration

Driving Force	: -	Hydrostatic Pressure Difference
Typical Separation Mechanism	: -	Sieve
Operating Structure (pore size)	: -	(2-50) nm
Typical Operating Range	: -	0.005-0.2, m
Permeate Description	: -	Water + Small molecules
Typical Constituent Removed	: -	Macromolecules, Colloids, Most bacteria viruses

F. Membrane Process: - Reverse Osmosis

Driving Force	: -	Hydrostatic Pressure Difference
Separation Mechanism	: -	Solution/Diffusion, Exclusion
Operating Structure (pore size)	: -	Dense (<2) nm
Typical Operating Range	: -	0.0001-0.001, m
Permeate Description	: -	Water + very Small

Molecules, ionic solutes

Typical Constituent Removed	: -	Very small molecules,

Color, hardness, nitrate,
Sulphates, sodium etc

The Raw cow urine is kept in feed box from where it passes to a ultra-filter membrane which then passes urine to a pump from where it gains sufficient pressure to pass through reverse osmosis membrane. Osmosis membrane then discharges one to permeate and another to concentrate part.

1) Ultrafiltration

An ultrafiltration filter has a pore size around 0.01 micron. A microfiltration filter has a pore size around 0.1 micron, so when water undergoes microfiltration, many microorganisms are removed, but viruses remain in the water. Ultrafiltration would remove these larger particles, and may remove some viruses. Neither microfiltration nor ultrafiltration can remove dissolved substances unless they are first adsorbed (with activated carbon) or coagulated (with alum or iron salts).

2) Reverse Osmosis

In reverse osmosis, the two solutions are still separated by a semi-permeable membrane, but pressure is applied to reverse the natural flow of the water. This forces the water to move from the more concentrated solution to the weaker. Thus, the contaminants end up on one side of the semi-permeable membrane and the pure water is on the other side.

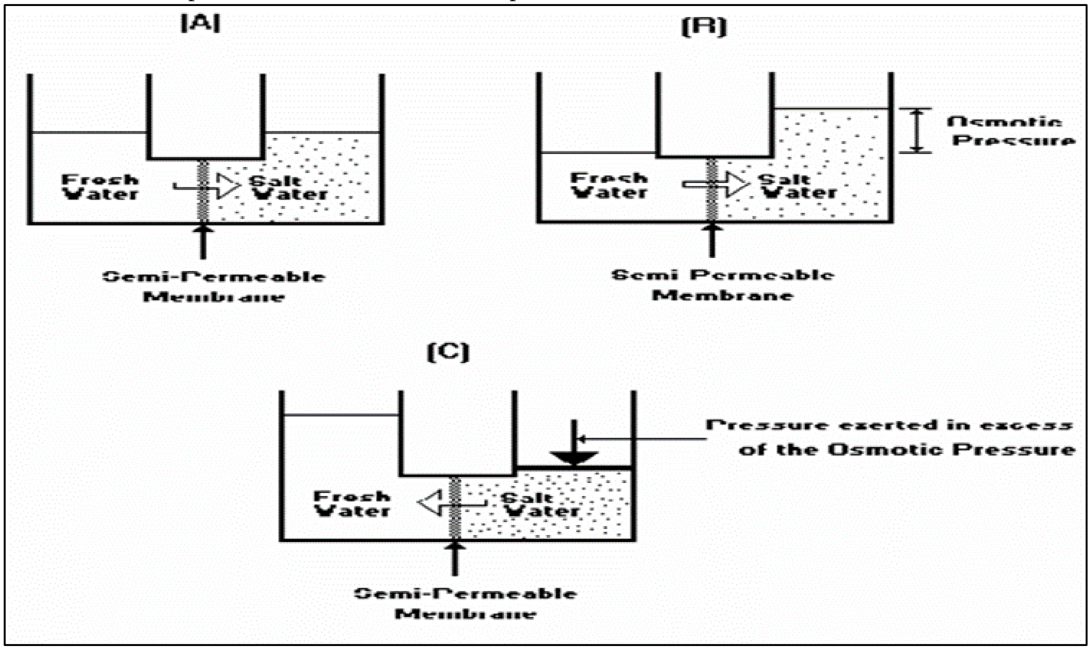

Fig. 3: Reverse Osmosis

On subsequent feeding of urine sample to the process the ultra-filter rmembrane was clogged. After rigorous exercise it was seen that when urine when allowed to settle for 20 minutes the white colour solid precipitated at bottom and this was supposed to be the reason of chocking UF membrane.

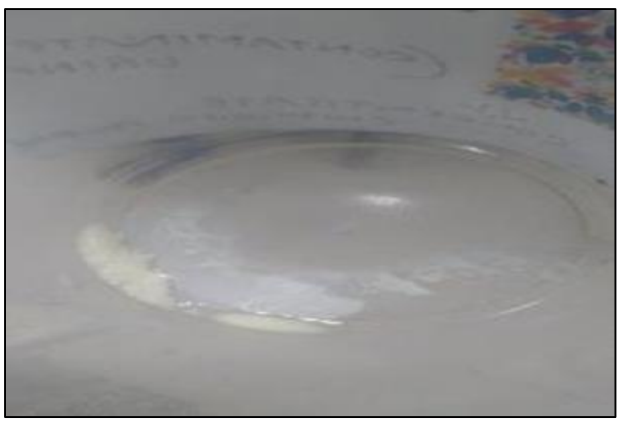

Fig. 4: Solid Precipitate at Bottom

G. RO Pre-treatment

Proper pre-treatment using both mechanical and chemical treatments is critical for an RO system to prevent fouling, scaling and costly premature RO membrane failure and frequent cleaning requirements.

II. ANTISCALANTS AND SCALE INHIBITORS

Antiscalants and scale inhibitors, as their name suggests, are chemicals that can be added to feed water before an RO unit to help reduce the scaling potential of the feed water. Antiscalants and scale inhibitors increase the solubility limits of troublesome inorganic compounds. By increasing the solubility limits, you are able to concentrate the salts further than otherwise would be possible and therefore achieve a higher recovery rate and run at a higher concentration factor. Antiscalants and scale inhibitors work by interfering with scale formation and crystal growth. The choice of antiscalant or scale inhibitor to use and the correct dosage depends on the feed water chemistry and RO system design.

Therefore a Pre-filter treatment was used prior to passage in Ultra Filter Membrane using a sponge filter and anti scalent tablet in it.

Fig. 5: Sponge filter with anti scalene tablet

A RO system has a very selective semi-permeable membrane which typically rejects 99% of the impurities from source water resulting in very pure water on the other side of the membrane. The rest of the water which has all the impurities is sent down the drain as reject. A typical RO operates at a recovery rate of 15% to 60%.

The recovery rate is defined as:

Percent Recovery = Permeate (Purified Water) Flow rate x 100%/ Feed water flow rate

S.No	PARAMETER TEST	RAW COW URINE	REJECT COW URINE	PERMEATE COW URINE
1	Volume (L)	4.0	3.16	0.84
2	Total Solids (mg/l)	3650.0	3557.5	102.5
3	Urea (mg/l)	2930.0	3540.2	92.5
4	Phosphorous (mg/l)	116.49	182.459	24.6
5	Nitrate (mg/l)	81.32	119.47	34.39
6	Ammonia (mg/l)	6.10	19.6	3.2

Table 1: Result

$$\% \text{ Recovery } = \frac{0.5}{3.5} x\ 100$$

Hence, recovery rate comes out to be = 16 %.

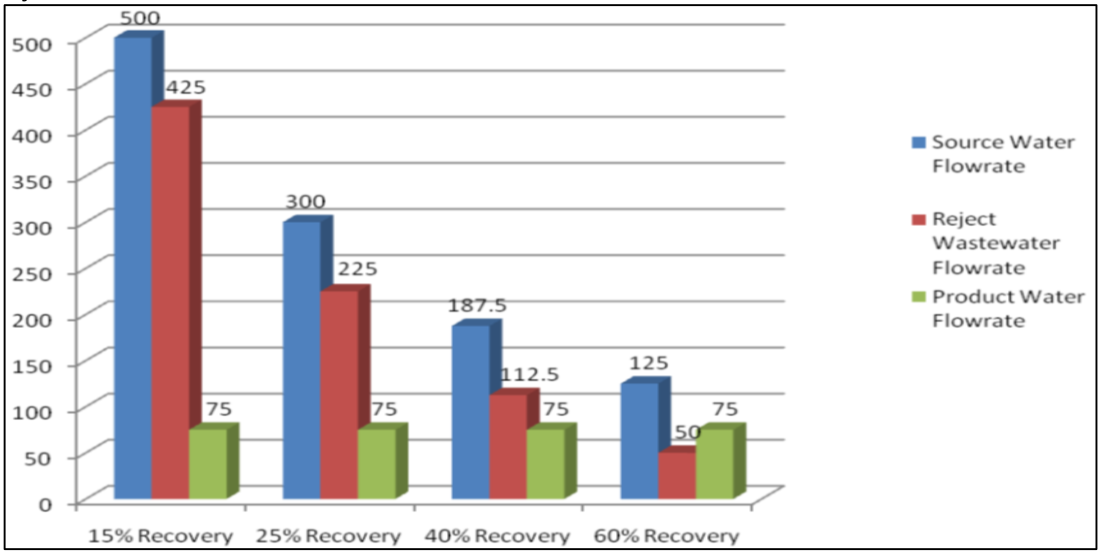

Fig. 6: Recovery Rates

As seen in Figure, in a higher recovery RO system, less water is rejected. However, the concentration of pollutants increases with increasing the recovery rate. As shown in Figure, at lower recoveries, more waste water is generated which is either the same pollution level as source water or starts to increase in pollution concentration as recovery is increased. Thus, at higher recoveries (> 60%) the effluent pollution concentrations have more than doubled.

In a one stage RO system, the feed water enters the RO system as one stream and exits the RO as either concentrate or permeate water.

In a two-stage system the concentrate (or reject) from the first stage then becomes the feed water to the second stage. The permeate water is collected from the first stage is combined with permeate water from the second stage. Additional stages increase the recovery from the system.

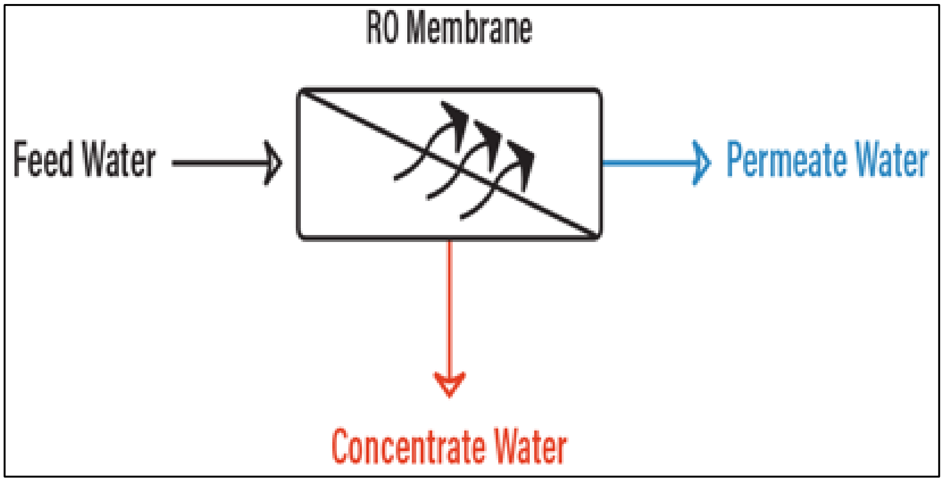

Fig. 7: 1st Stage of RO System

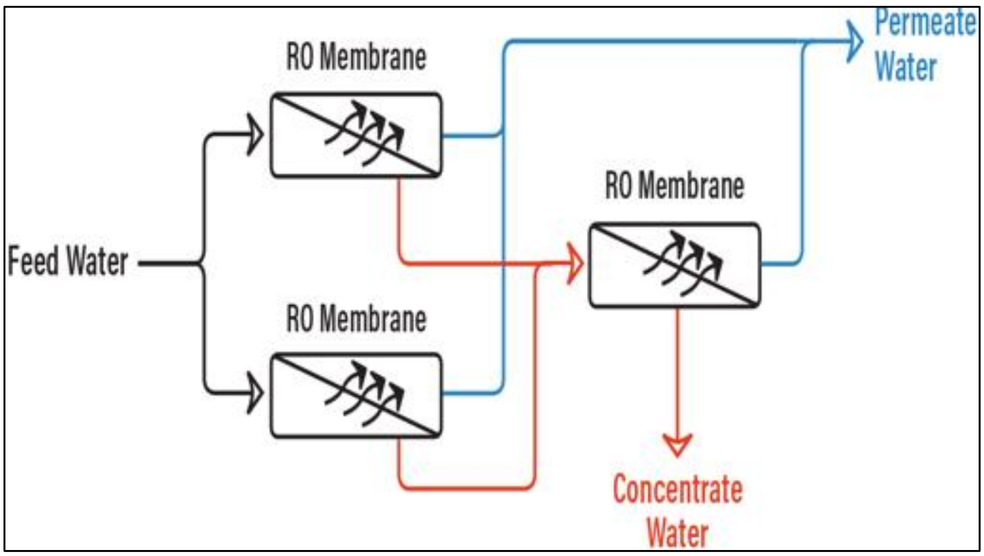

Fig. 8: 2nd Stage of RO System

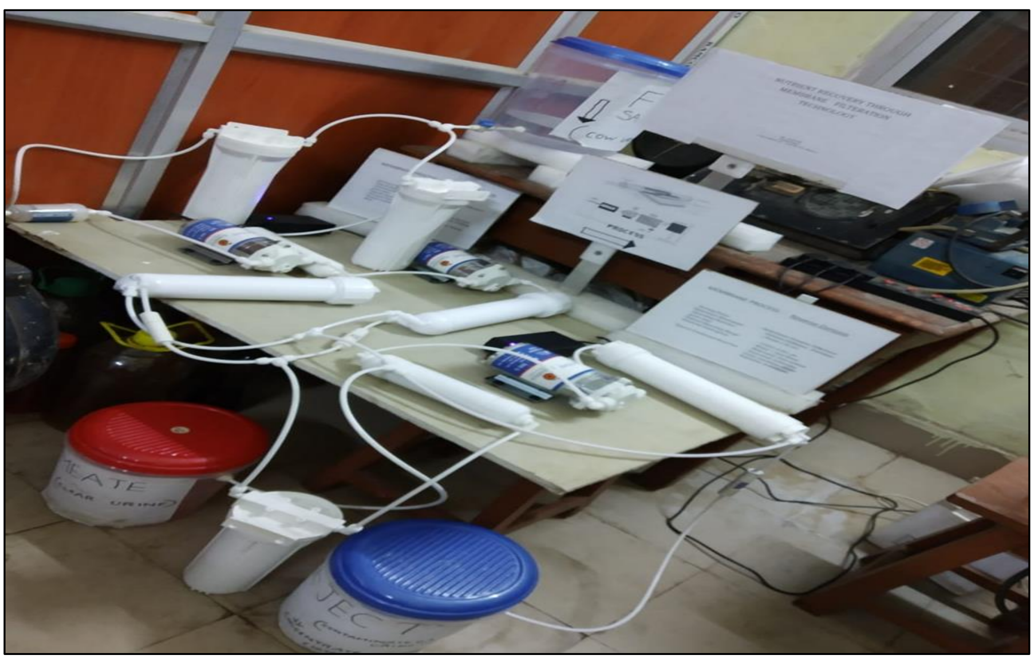

Fig. 9: passing urine through 2 Stage urine

S.No	*PARAMETER TEST*	*RAW COW URINE*	*REJECT COW URINE*	*PERMEATE COW URINE*
1	*Volume (L)*	*8.0*	*4.32*	*3.68*
2	*Total Solids (mg/l)*	*25390.0*	*25352.0*	*38.0*
3	*Urea (mg/l)*	*5220.0*	*22880.0*	*19.6*
4	*Phosphorous (mg/l)*	*79.7*	*412.5*	*15.4*
5	*Nitrate (mg/l)*	*81.32*	*422.6*	*16.1*
6	*Ammonia (mg/l)*	*100.8*	*538.2*	*3.2*

Table 2: Result of passing urine through 2 stage

III. CONCLUSION

Currently, recovering nutrient from urine is more valuable than nutrient removal. The possible explanation is that this recovery can provide a supplementary source for fertilizer production, thus easing the burden of increasing demand for food production.

Another advantage associated with nutrient recovery is that it can reduce the serious impacts of wastewater treatment on the environment and save costs. Membrane technology can enrich nutrient with high purity, which can improve the economic feasibility of the nutrient recovery process. Considering the membrane fouling as a big challenge for the application of membrane hybrid system to recover nutrient, the integration of membrane technology with biological process such as BES- and OMBR-based hybrid systems may be the most promising technology since this method could effectively remove organics through biological activity and thereby reduce the potential for membrane fouling. In this scenario, the technical and economic feasibility of nutrient recovery is enhanced.

REFERENCES

[1] García Martín, H., Ivanova, N., Kunin, V., Warnecke, F., Barry, K.W., McHardy, A.C.,Yeates, C., He, S., Salamov, A.A., Szeto, E., Dalin, E., Putnam, N.H., Shapiro, H.J.,Pangilinan, J.L., Rigoutsos, I., Kyrpides, N.C., Blackall, L.L., McMahon, K.D.,Hugenholtz, P., 2006. Metagenomic analysis of two enhanced biological phosphorus removal (EBPR) sludge communities. Nat. Biotechnol. 24,1263–1269.

[2] Happe, M., Sugnaux, M., Cachelin, C.P., Stauffer, M., Zufferey, G., Kahoun, T., Salamin,P.A., Egli, T., Comninellis, C., Grogg, A.P., Fischer, F., 2016. Scale-up of phosphate remobilization from sewage sludge in microbial fuel cell. Bioresour. Technol.200, 435–443.

[3] He, Z., Kan, J., Wang, Y., Huang, Y., Mansfeld, F., Nealson, K.H., 2009. Electricity production coupled to ammonium in a microbial fuel cell. Environ. Sci. Technol.43, 3391–3397.

[4] Heffer, P., Prud'homme, M., 2014. Fertilizer outlook 2014–2018. In: 82nd IFA Annual Conference, Sydney.

[5] Hirooka, K., Ichihashi, O., 2013. Phosphorus recovery from artificial wastewater by microbial fuel cell and its effect on power generation. Bioresour. Technol. 137,368–375.

[6] Ichihashi, O., Hirooka, K., 2012. Removal and recovery of phosphorus as struvite from swine wastewater using microbial fuel cell. Bioresour. Technol. 114, 303–307.

[7] Wang, X., Wang, Y., Zhang, X., Feng, H., Li, C. and Xu, T. (2013) Phosphate Recovery from Excess Sludge by Conventional Electrodialysis (CED) and Electro dialysis with Bipolar Membranes (EDBM). Industrial & Engineering Chemistry Research 52(45), 15896-15904.

[8] West, P.C., Gerber, J.S., Engstrom, P.M., Mueller, N.D., Brauman, K.A., Carlson, K.M.,Cassidy, E.S., Johnston, M., MacDonald, G.K., Ray, D.K. and Siebert, S. (2014) Leverage points for improving global food security and the environment. Science 345(6194), 325-328.

[9] Wilsenach, J. and Loosdrecht, M.v. (2003) Impact of separate urine collection on wastewater treatment systems. Water SciTechnol 48(1), 103-110.

[10] Wilsenach, J.A. and Van Loosdrecht, M.C.M. (2004) Effects of Separate Urine Collection on Advanced Nutrient Removal Processes. Environmental Science & Technology 38(4), 1208-830 1215.

[11] Withers, P.J.A., Sylvester-Bradley, R., Jones, D.L., Healey, J.R. and Talboys, P.J. (2014) Feed the Crop Not the Soil: Rethinking Phosphorus Management in the Food Chain. Environmental Science & Technology 48(12), 6523-6530.

