Feed solution: The feed solution concluded synthetic urine and real urine taken from a public toilet. The recipe of synthetic urine is shown in table 1 (Wignarajah K, 2006). In the experiment, a dilution factor of 1.5 (1 L synthetic urine, 0.5 L tap water) for synthetic urine was used considering flush water.

Draw solution: Considering the possibility for recovery using reverse osmosis, the draw solution in the experiment was 0.5-2.0 mol/L NaCl.

Table 1. The recipe of synthetic urine g/L

Components	Fresh urine	Hydrolyzed urine
Urea	25.06	-
$(NH_4)_2CO_3$	-	40.07
NaCl	4.60	4.60
KCl	1.60	1.60
KH_2PO_4	2.79	2.79
NH_4Cl	1.00	1.00
Na_2SO_4	2.30	2.30
$C_4H_7N_3O$	1.10	1.10
$CaCl_2 \cdot 2H_2O$	0.65	0.65
$MgCl_2 \cdot 6H_2O$	0.65	0.65
$Na_3C_5H_5O_7 \cdot 2H_2O$	0.65	0.65
$Na_2C_2O_4$	0.02	0.02

Experimental Set-Up for Pilot Scale System

The pilot scale toilet and its resource recovery system was deployed at the northwest corner of the playground of Tsinghua University Primary School. A flow diagram of the pilot-scale system is illustrated in Figure 2.

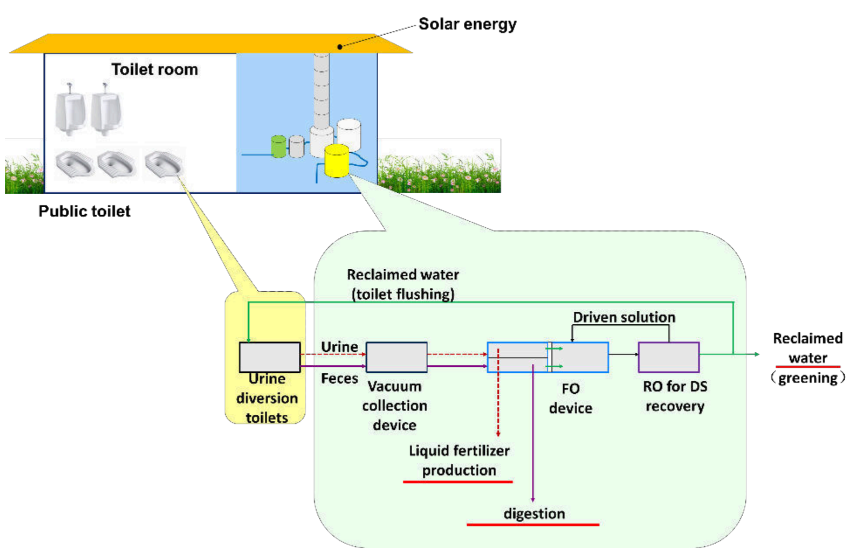


Figure 2. The flow diagram of the pilot-scale system.

The system consisted 2 urinals and 4 squats and a treatment system, and was designed to be capable of 100 users per day. Water-saving source separated vacuum toilets and urinals were adopted in the system, which had significant efficiency of flushing, consuming only 1 L and 0.1 L water per flush for urine and feces.

The toilets and urinals and its collecting system—vacuum station were provided by *EnviroSystems Engineering & Technology Co., Ltd*. The human excreta were collected separately through the special design of the stool, which was divided in to 2 parts, the former is the collecting bowl for urine, and the latter was for feces. The structure of the stool is shown in Figure 3.

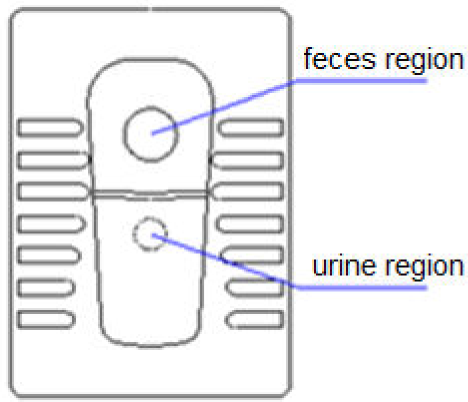


Figure 3. The structure of the source separated toilet.

The urine from the urinals and the urine region of squats was collected and treated separately from the feces. The treatment system included a FO+RO hybrid membrane system for urine enrichment and reclaimed water production. The urine was enriched by the draw solution through the FO membrane. After use, the DS was recovered by RO, and the reclaimed water was produced at the same time. As for feces treatment, a mesophilic anaerobic digester with SRT of 25 d was used for elimination of the pathogens.

Materials for pilot scale project

Membrane**:** The reformed RO membrane was used to reduce the cost of the FO module. The module was designed as flat sheet with a dimension of 20 cm×60 cm, with an effective area of 0.075 m^2 each membrane. 100 membranes were put together with 0.3 mm mesh spacers.

Feed solution**:** Source separated urine collected from the vacuum toilet.

Draw Solution**:** 2 M NaCl was used initially, and recovered by the RO system.

Operation conditions

Both the bench scale and pilot scale experiments were conducted intermittently, each time running for 4 hours under room temperature with the FO mode (Feed facing the active layer). The cross velocity was controlled by the pump at 55 ± 2 cm/s.

Data collection and analysis

The weight loss or volume change of the feed was measured to calculate the water permeation of the membrane. And the feed samples were taken before and after concentrated by the FO process, the ions and nutrients content were analyzed. The ions concentrations were measured by IC (Dionex, ICS 2000), TN, TP were measured by *Alkaline potassium persulfate digestion UV spectrophotometric* and *Ammonium molybdate spectrophotometric.* The scanning electron microscopy (SEM) was used to observe the surface and cross-section of FO membrane.

The water flux was calculated by following equation.

$$J_w = \Delta w / (\rho s t)$$

In the equation, Δw: weight incremental of DS(kg); ρ: density of liquid(kg·L^{-1}); s: effective area of membrane(m^2); t: time interval(h)

The rejection of nutrients in feed was calculated by the equation as follows:

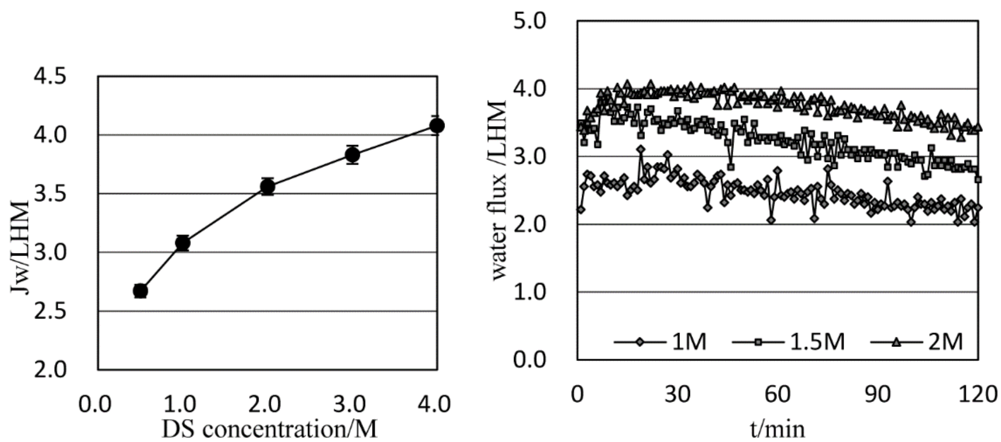
$$R_f = 1 - \frac{C_p}{C_f}$$

In the equation, C_f: concentration of the feed(mol·L^{-1}); C_p: concentration of the permeate(mol·L^{-1}).

RESULTS AND DISCUSSION

Results and discussion for bench scale

Draw solution concentration: A range of different concentrations of NaCl were used to find out the most suitable concentration for practical use. The influence of draw solution concentration on water flux is shown in Figure 4.



(a) (b)

Figure 4. Influence of draw solution concentration on water flux.

As shown in Figure 4(a). the water flux increases as the draw solution concentration goes up, but the increasing rate declines. The decline in the increasing rate of water flux mainly due to the loss in electrolyte solution activity (Robinson, R. A, 1949) and the increase in dilutive internal concentration polarization, DICP and concentrative external concentration polarization, CECP (McCutcheon, J. R, 2006). With the increase of the concentration of DS, the higher pump pressure is needed in RO system for DS recovery, which will lead to more energy consumption (Zhu, A., 2009). Moreover, in practical situation, the pump pressure that can be provided is limited. Due to the limitation of the pump pressure and energy consumption of reverse osmosis for draw solution recovery, 2 M NaCl solution was used as the draw initially. As the FO process went on the concentration of draw solution went down to 1-1.5 M, and then the RO process to recovery its concentration started. Figure 4(b) shows the ability of draw solution at different concentration within its working range. In addition, the RO system was operated subsequently after the FO process because after the enrichment of the feed solution, the draw solution was diluted and was more energy saving for recovery.

Influence of the flow rate on the water flux: Higher flow rate mainly contributes to the turbulence besides membranes and mass transfer across membranes (Choi, H, 2005). Besides, the hydrodynamic shear forces brought by the cross-flow have a positive effect on the decrease of membrane fouling (Mi, B, 2008). However, these effects are limited when the cross velocity increase to a certain level at around 60 cm/s. After that, the promotion in flow velocity brings little help to increase the efficiency of the process but consumes more energy. In the module design and operation control, 55 cm/s of cross flow velocity was chosen to for the balance of efficiency and energy consumption. The influence of the flow rate on water flux is shown in Figure 5.

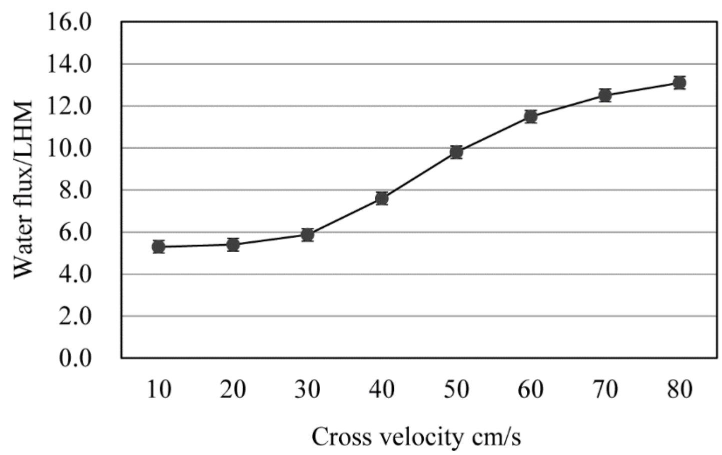


Figure 5. Influence of flow rate on water flux

Comparison of fresh urine and hydrolyzed urine: The main difference between fresh urine and hydrolyzed urine is that the urea in urine is hydrolyzed by urease into ammonium salt (Udert, K. M, 2003). The water flux and nutrients (calculated as $N+P_2O_3+K_2O$) rejection are compared in Figure 6. The water flux for fresh urine is much higher (over 2.5 LHM) than hydrolyzed urine (around 1.0 LHM) under both concentration of DS. However, the rejection rate for nutrients was over 85% for hydrolyzed urine compared to about 65% for fresh urine.

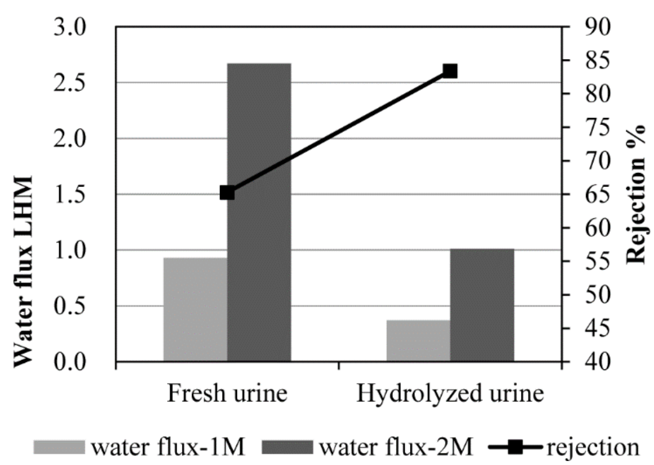
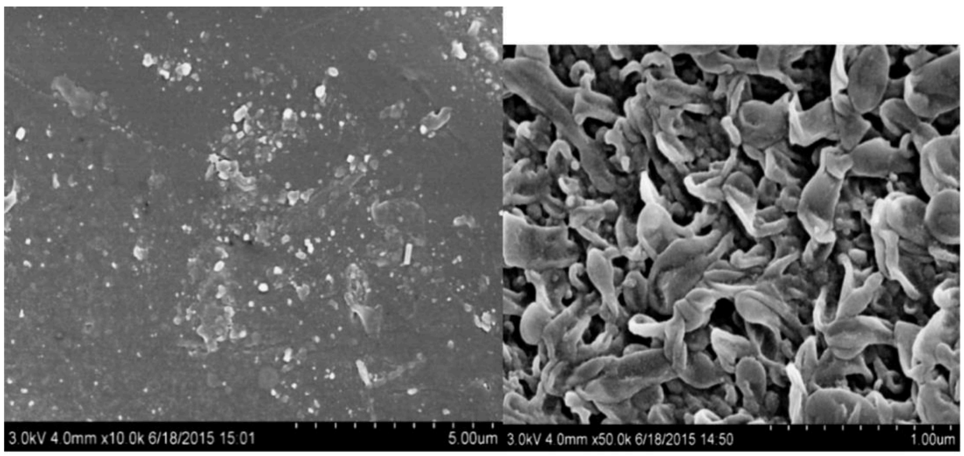


Figure 6. Comparison of fresh urine and hydrolyzed urine.

When the urea is hydrolyzed, the ions in urine increase as with the conductivity and osmotic pressure, which leads to a lower water flux. On the other hand, when urea is hydrolyzed, the neutral molecule (urea) becomes polar (ammonia), and the membrane has a higher rejection for ions than for small neutral molecules (Jiefeng Z, 2014), and this can promote the efficiency of liquid fertilizer. Besides, in practical situation, urine can hardly be collected and treated immediately after excretion, and the hydrolysis is rapid and can be completed within hours without any inhibition methods. Under this circumstance, hydrolyzed urine is better and more practical for enrichment by FO.

Membrane fouling: After operation for 1 month, the SEM of the membrane was taken to investigate the membrane fouling condition. As in Figure 7(a), some pollutants were seen on the surface, they clustered as irregular crystals. But when magnified the picture as in Figure 7(b), the inner space of the membrane stayed clean. This phenomenon means the pollutants just adhere to the surface and can be easily cleaned out by simple physical back wash, which indicates the FO process behaves well on the aspect of membrane fouling (Mi, B., 2010).



(a) (b)

Figure 7 SEM of the used membrane

Results and discussion for pilot scale system

Appearances: The final appearance of the pilot scale project is shown in Figure 8. and has been used since Nov, 2015. The users accepted the toilet well.

Figure 8. Appearance of the pilot scale project

The enrichment effect of urine: The collected urine was diluted about 1.3-1.5 times by the flush water (0.1 L of flushing water and 0.2-0.3 L urine). After the FO process the urine could be enriched for 2.5 times, the volume was reduced enormously, and the concentration of nutrients increases and could be used as a liquid fertilizer. The quality of the urine before and after enrichment (liquid fertilizer) is shown in table 2.

Table 2. The concentration effect of urine.

Indicator	Urine	Liquid Fertilizer
Organics g/L	27.8	70.2
$N+P_2O_3+K_2O$ g/L	11.8	27.9
Cl^- g/L	3.42	8.75
pH	9.3	9.7

The water quality of reclaimed water: The reclaimed water was produced from urine, after pre-treatment by FO, the RO process produced a high quality reclaimed water for toilet flushing. The water quality basically met the standards (GB/T 18920-2002) for reuse except for TDS. The standard for TDS is 1000 mg/L, while the TDS reclaimed water flocculated from 890-2340 mg/L. This was mainly due to the high concentration of NaCl in the DS (around 1 M), and the rejection ability for single stage RO system was limited.

Pathogen kill in feces: The feces collected from the source separated toilet was diluted by 1 L of flushing water and crushed by the pressure of the vacuum pump when going through the pipe, after digestion for more than 25 d under 35±10℃ (controlled by heater band and temperature controller), the pathogens were eliminated for more than 99.9%.

CONCLUSIONS

In this work, the influential factor for FO process was studied and the optimal operational parameters were selected: draw solution concentration 2 M, cross flow velocity 55 cm/s, and hydrolyzed urine over fresh urine. The FO process achieved 2.5 times concentration of urine and nutrients rejection of over 80%. Besides, better performance was observed compared to other membrane process in terms of fouling behavior.

In the pilot scale implementation and operation, the system produced high quality fertilizer without additional input of water and other substances. The installation process did not require much reformation of the location, and the whole system ran on the excreta produced by people. The system can be integrated and manufactured as modules, and used under circumstances such as: sightseeing places, parks, islands, and other places where municipal pipelines are unavailable.

ACKNOWLEDGEMENTS

The authors would like to acknowledge *Bill & Melinda Gates Foundation* for funding for this study. Thank *EnviroSystems Engineering & Technology Co., Ltd.* for the contribution in building up the pilot scale toilet and *Tsinghua Primary School* for providing the onsite field.

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LID-Based Ecological Planting Groove for Road Runoff Purification Research

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ABSTRACT

In order to control road runoff's impact on adjacent water environment, this paper developed an ecological planting groove with multi-layer structure including planting soil layer, infiltration purification layer, and aquifer layer. In addition, a design method based on initial runoff purification and drainage was proposed. A series of indoor experiments with different sawdust-sand mixing volume ratio in 1:3, 1:4, 1:5 were conducted to analyze the impact of the ratio on nitrogen and phosphorus removal effect. The removal efficiency in this three ratios are 80.71%, 83.40%, 85.63% for NH_3-N; 80.13%, 83.87%, 84.38% for TN; and 92.06%, 91.03%, 88.55% for TP. Results show that optimal purification effect of different mixed packing ratio was 1:4 (sawdust: sand). Based on Erhai Lake East Ring Road, a field test showed that water quality purified by ecological planting groove is superior to the value of grade-III standard of surface water.

KEYWORDS: LID; road runoff; ecological planting groove; water purification; Erhai Lake

INTRODUCTION

In China, urbanization has been stepping forward to a new stage of transformation and development, of which main approach is quality improvement (Chen Zhong-nuan, Gao Quan, *et al.*, 2014). In order to minimize the impact on urban ecosystem, the central government has proposed a developing and constructing concept to build sponge cities with natural functions of rainwater storage, permeation, and purification. Roads are important infrastructures of the city (Ministry of Housing and Urban-Rural Development, 2015). The application of LID (Low Impact Development) technology in road construction plays a key part in the development of low impact storm-water system. Due to impermeability of urban roads, pollutants especially nitrogen and phosphorus are dissolved and washed into road runoffs during the rainfall. Pollutants moving into adjacent waters will lead to eutrophication and aquatic ecosystem destruction. Thus, runoff pollution control is necessary in water conservation district, drinking water head site and other environmentally sensitive watersheds. A study found that 50% of particulate matters, 16% of hydrocarbons and 35% to 75% of heavy metal in receiving water come from the road runoff (Ellis J. B., Revitt D. J., *et al.*, 1987). Domestic and foreign scholars have carried out some research on LID techniques for road runoff pollution control. Through several depressions, infiltration galleries and perforated pipes set by the roadside, Germany MR system realized zero runoff growth (Zhou Qiang-jian, 2015). Barett *et al.* (1998) used planting channel on road runoff purification and obtained ideal results with 54%, 91%, 30%, 73% and 83% removal efficiency for TSS, grease, COD, Zn and Pb, respectively. Study from Davis (2006) has shown 70% to 85

% removal efficiency for TP, 60% to 80 % for NH_3-N and poor removal for TN in road runoff within the use of biological retention facilities. Zhong (2007) conducted a study on Guang-Yu-Zhan highway runoff treatment effect with ecological ditches. It came out with a good overall result showing that COD, BOD_5, SS and oil removal efficiency reached 82%, 94%, 75% and 97 %, respectively. Environmental sensitive waters close to the road has been facing many pollution challenges. Although the conventional LID technique in the studies above has some purification effect on runoff, it fails to have an organic combination of road drainage, greening and transport safety. Based on highway characteristics, this study raises the design method of ecological planting groove, conducts a series laboratory experiments, and apply it on Erhai road, which shows that it can be applied on initial rainwater runoff collection, processing, utilization and emergency management for hazardous chemicals transport leakage.

Ecological planting groove technique

Ecological planting groove unit

In order to satisfy the needs of unobstructed roadbed drainage, convenient maintenance for roadside green belts and emergency treatment for hazardous chemicals in highway field, this study raises ecological planting groove technique to be applied in runoff collection, purification, storage and plants growth. Set below the road surface, the ecological planting groove consists of planting soil layer, infiltration purification layer, supporting layer, aquifer layer and impermeable layer. Figure 1 showed the unit structure. Planting soil layer contains plants and local soil, which needs allocation with a poor permeability. With multi-fillers of strong adsorbing and filtering ability for nitrogen and phosphorus removal, infiltration purification layer is the core unit of ecological planting groove. The supporting layer is made of geogrids and nonwoven fabric. Filled with big stone, the aquifer layer plays a supportive and water storage role. In addition, anti-seepage geotextile is set in impermeable layer to prevent groundwater pollution from the leakage of hazardous contaminants. In highway longitudinal direction, ecological planting grooves are in series connection in descending order. To realize automatic drainage between grooves, aquifer layer of the higher position groove is connected to infiltration purification layer of the lower one in each pair of adjacent grooves. Studies have shown that initial road runoff has initial pollution effect while later runoff is relatively cleaner which will be directly drained out through overflow device without entering ecological planting grooves (Li Hua, Chen Yu-cheng, *et al*., 2011).

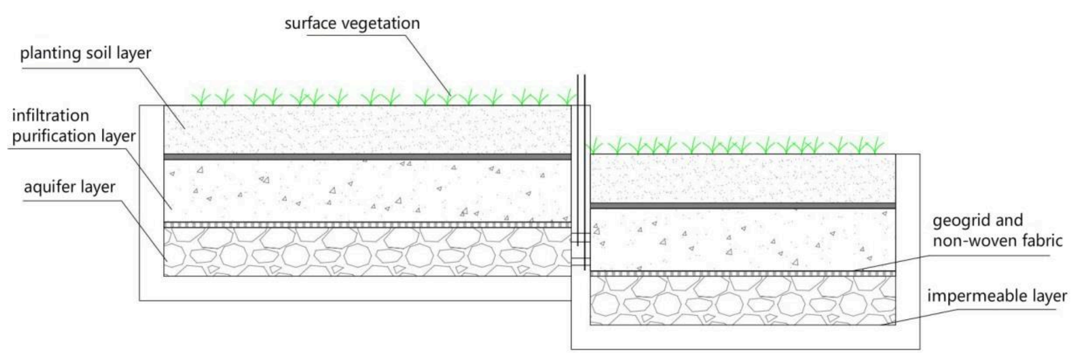

Figure 1. Unit structural representation