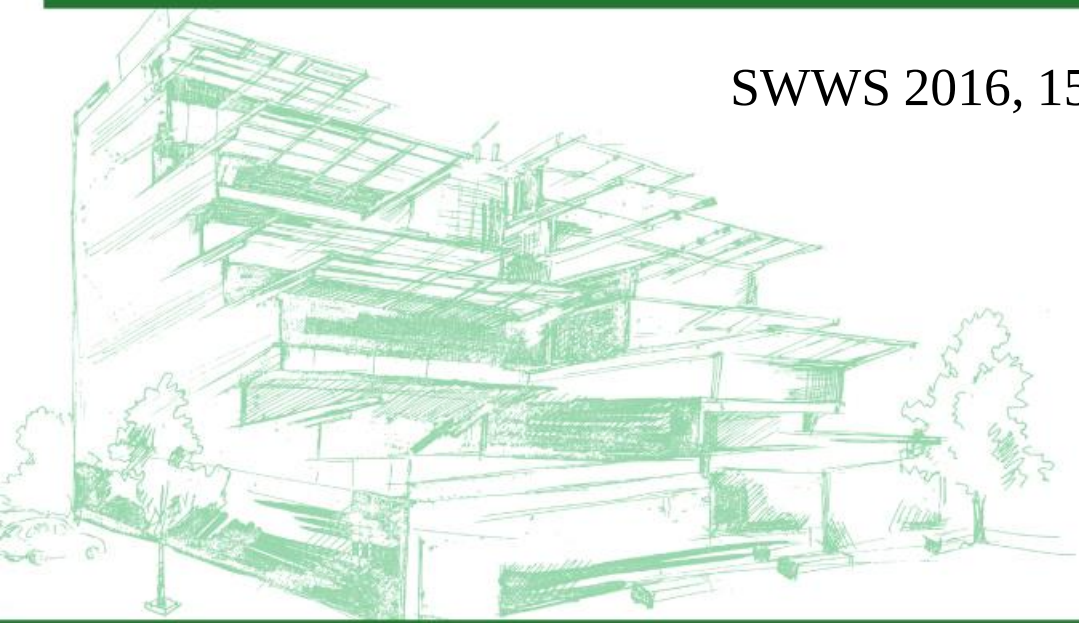
School of Environment, Tsinghua University

Nutrients recovery of source separated urine by forward osmosis and a pilot scale resources-oriented sanitation system

SWWS 2016, 15 September



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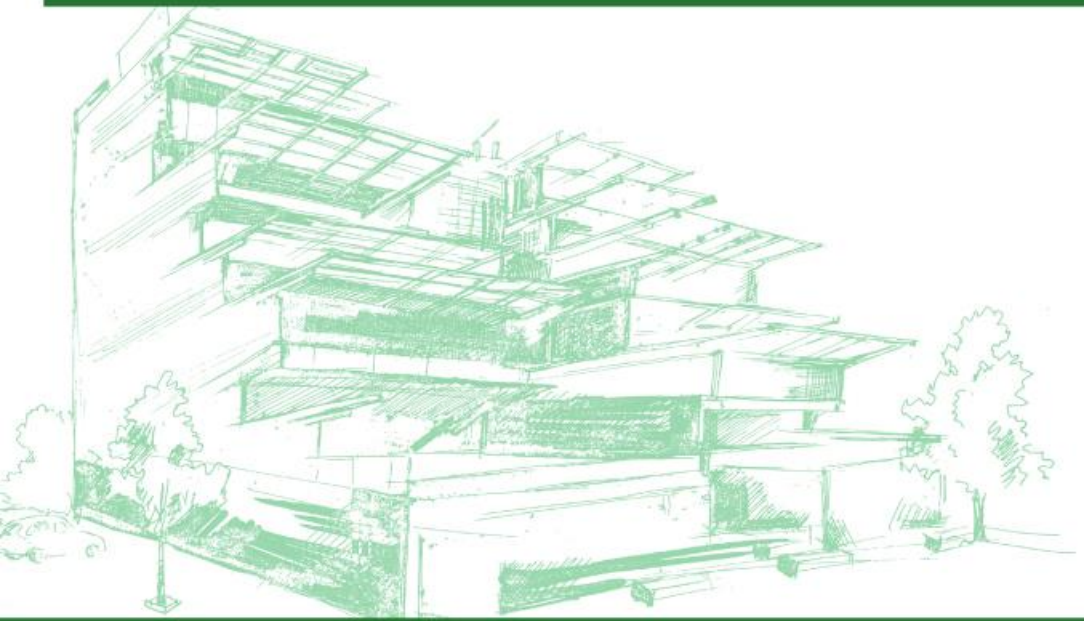
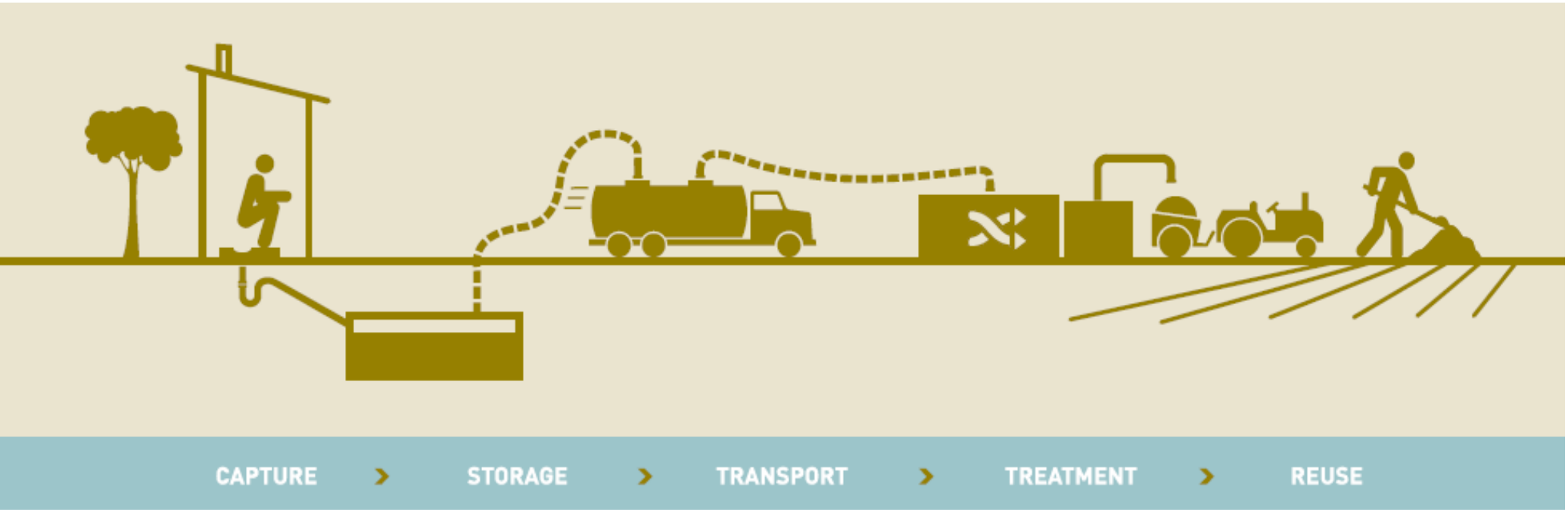


1.Introduction



Source: Bill&Melinda Gates Foundation

Disadvantages of end-of-pipe systems:

- Expensive: lands, energy, water O&M, etc.
- Human excreta contain large amount of nutrients (N, P, K), crucial for the growth of plants, but costly to eliminate in wastewater.

1.Introduction

Urine:

- Almost sterile
- 1.5L/(cap·d)
- 1.4% inorganics(K, P, etc.)
- 1.3% urea

➡ Resource recovery

Faeces:

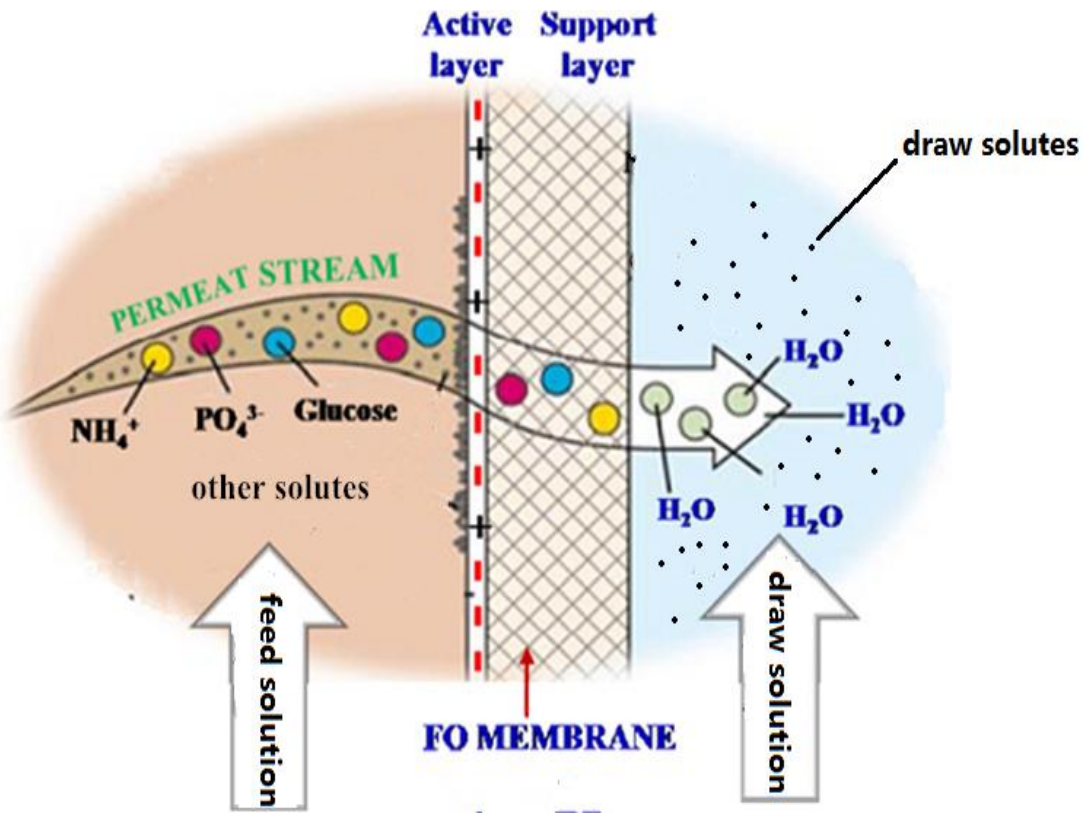
- 0.4kg/(cap·d)
- 30% bacteria
- 30% undigested fibers and dead cells

➡ Harmless

Human excreta contribute to >50% N&P in sewage

Source separation is important!

1.Introduction



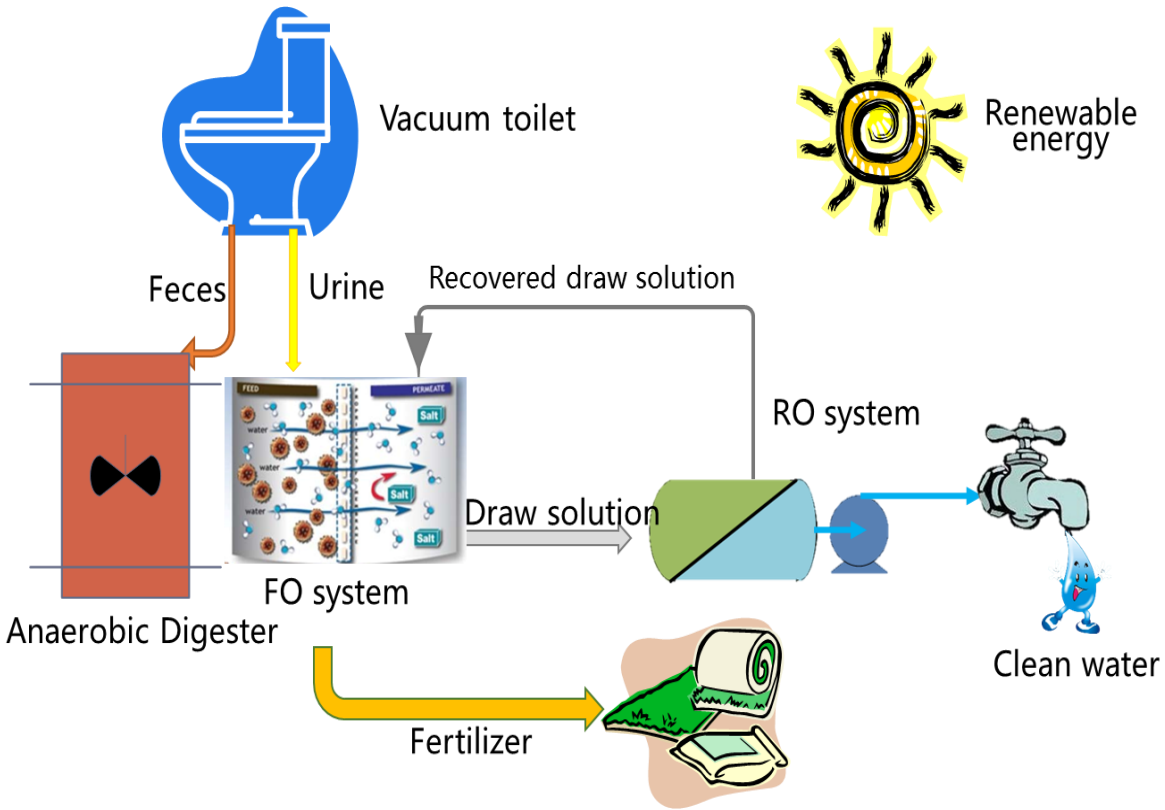
Forward osmosis (FO), or direct osmosis uses the osmotic pressure differential(π) across the membrane, as the driving force for transportation of water through the membrane.

Advantages:

- Low or no hydraulic pressure
- Membrane support is less of a problem
- High rejection for a wide range of contaminants
- Lower membrane fouling tendency
- Simple equipment and less area occupation

Cath, 2006; Lutchmiah, 2014; Xue, 2016

1.Introduction

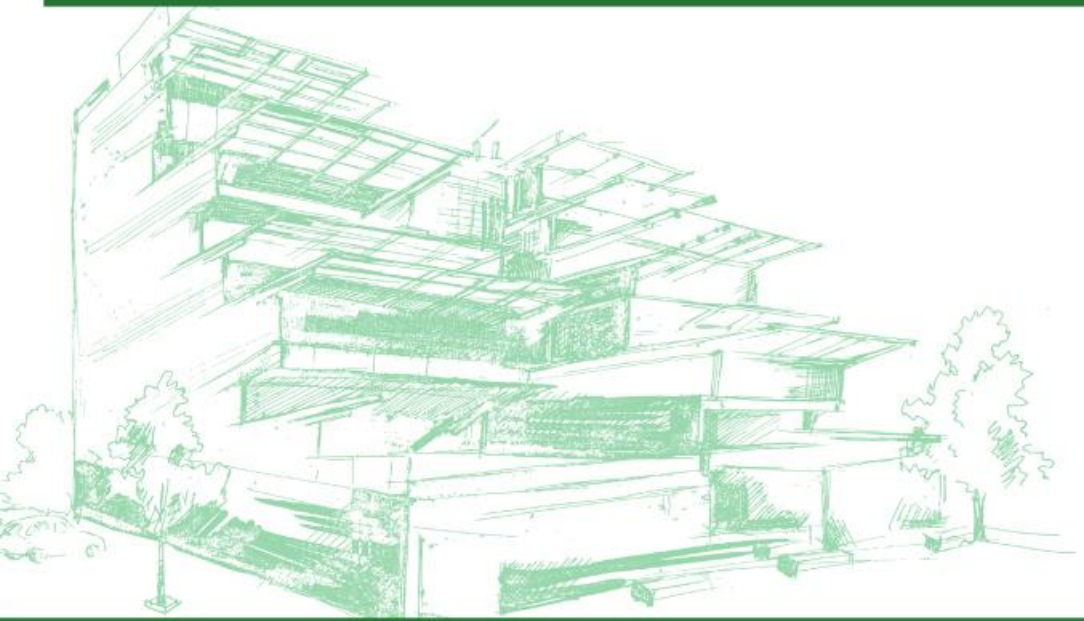


Source separated urine concentration by FO is a promising way for pollution prevention and resource recovery, but studies for FO application in urine concentration has some drawbacks:

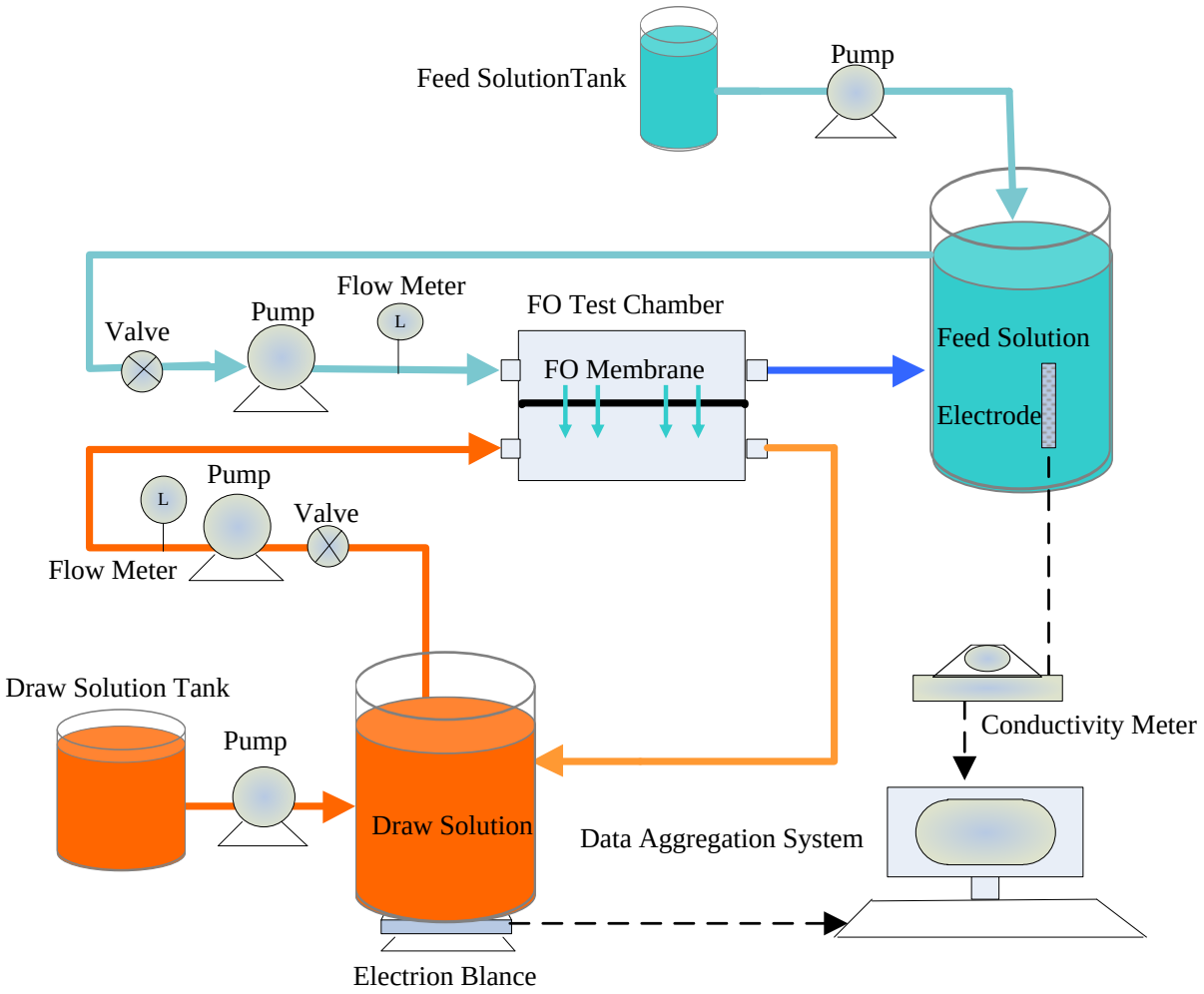
- Low water flux due to the high concentration of urine;
- Low rejection for nitrogen;
- Draw solution contamination;
- Synthetic urine can be different from the practical situation.

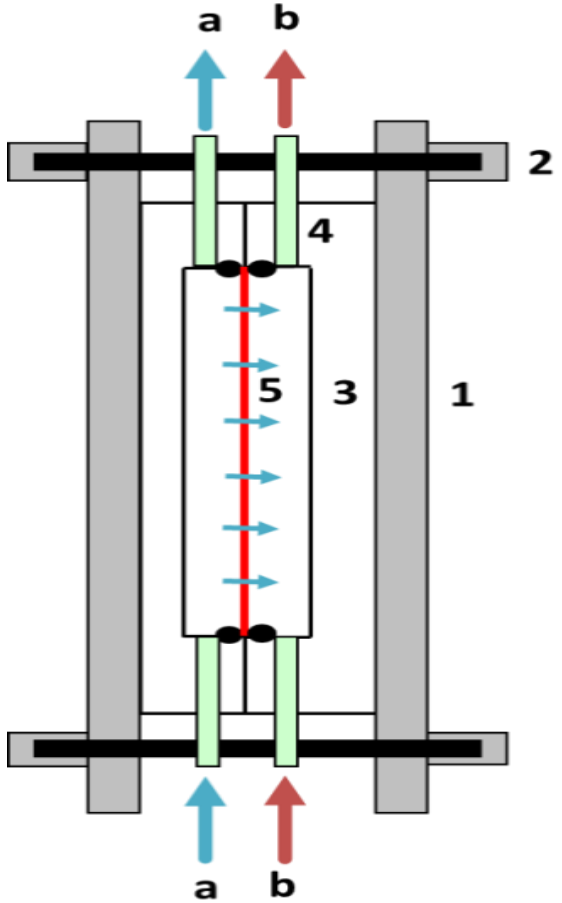
Zhang, 2014; Xue, 2015; Liu, 2016

2. Performance of FO in urine concentration



2.Performance of FO in urine concentration



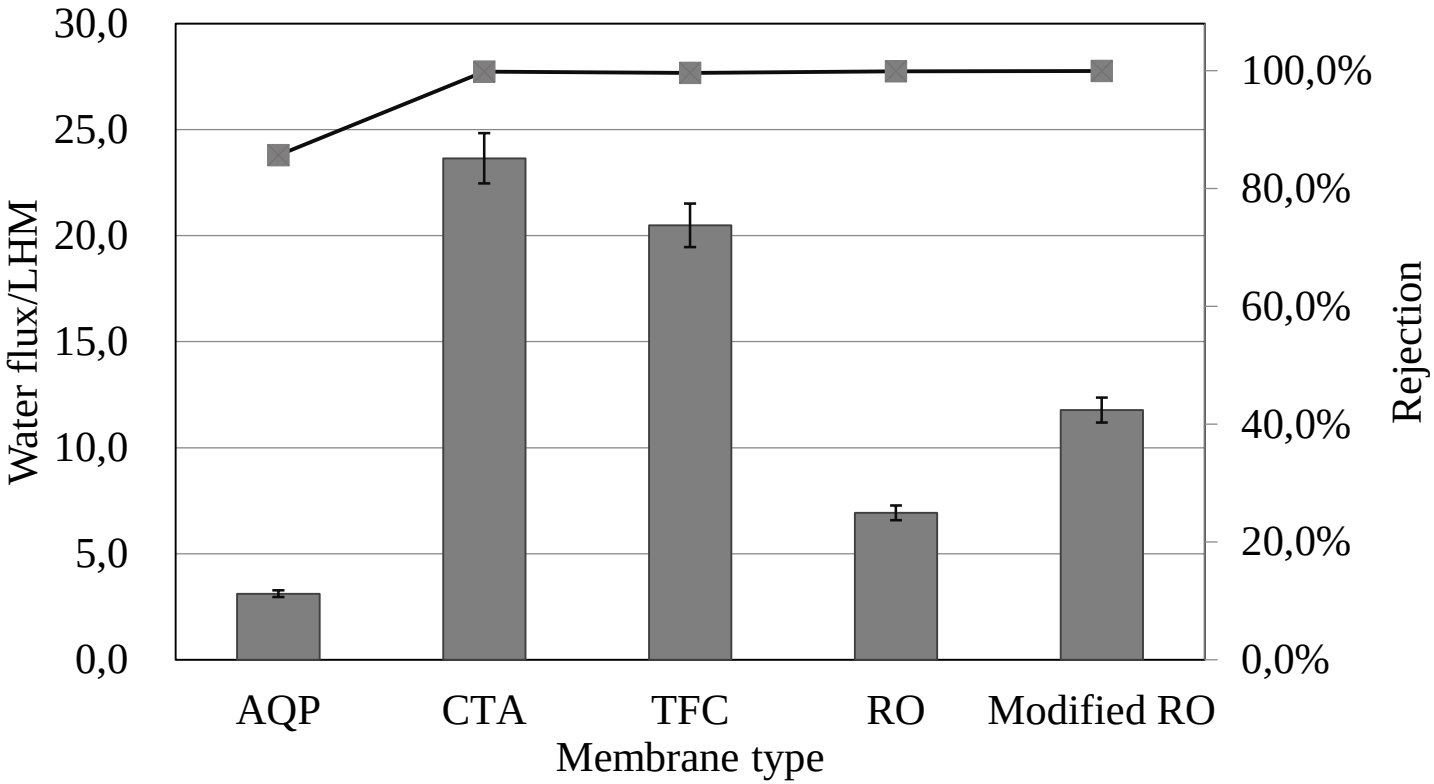


1: fixed splint; 2: strap bolt; 3: flat water channel; 4: draft tube; 5: FO membrane.
a: FS; b: DS

Feed: synthetic and real urine; Draw: NaCl solution; Membrane: CTA HTI

2.Performance of FO in urine concentration

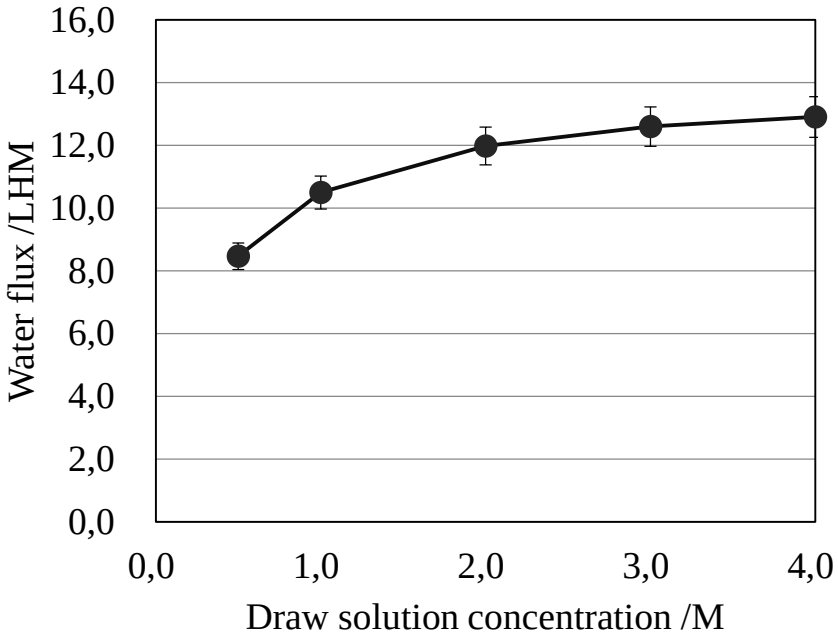
2.1.Comparison of different membrane

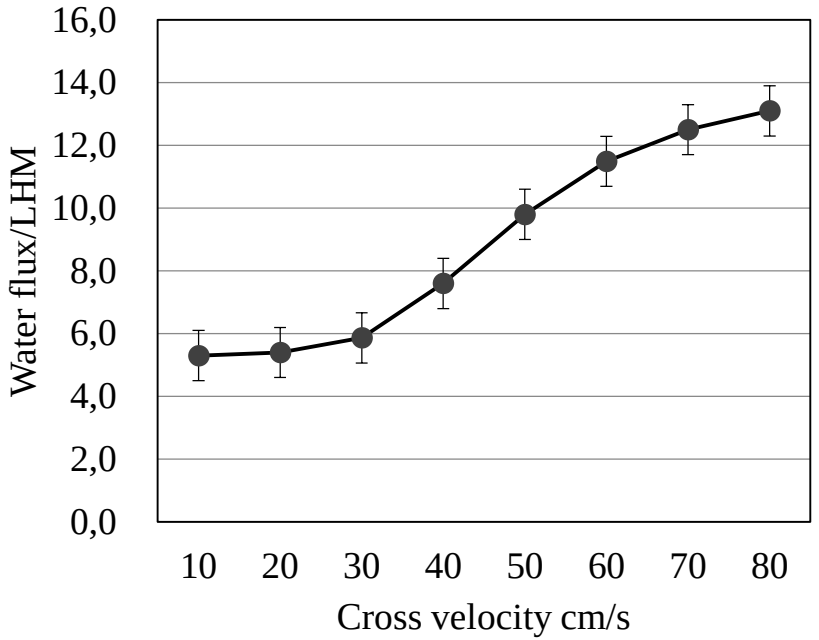


- The CTA, TFC membrane showed the best performance with water flux of 23.6 LHM and 20.5 LHM, rejection of 99.8% and 99.6% respectively.
- The modification of the RO membrane contributes to the increase in water flux mainly due to the decrease of concentration polarization.

2.Performance of FO in urine concentration

2.2.Influence factors





The water flux increases as the draw solution concentration goes up. The increasing rate declines. Thus, 2M NaCl was used initially.

Cross velocity mainly affects the external concentration polarization (ECP), and higher velocity has a positive effect on the decrease of membrane fouling.

2.Performance of FO in urine concentration

2.3.Comparison of synthetic urine and real urine

- In the practical situation, the separation of urine and faecal matters are not complete.
- The composition of the urine can be very different from the synthetic urine.

2.Performance of FO in urine concentration

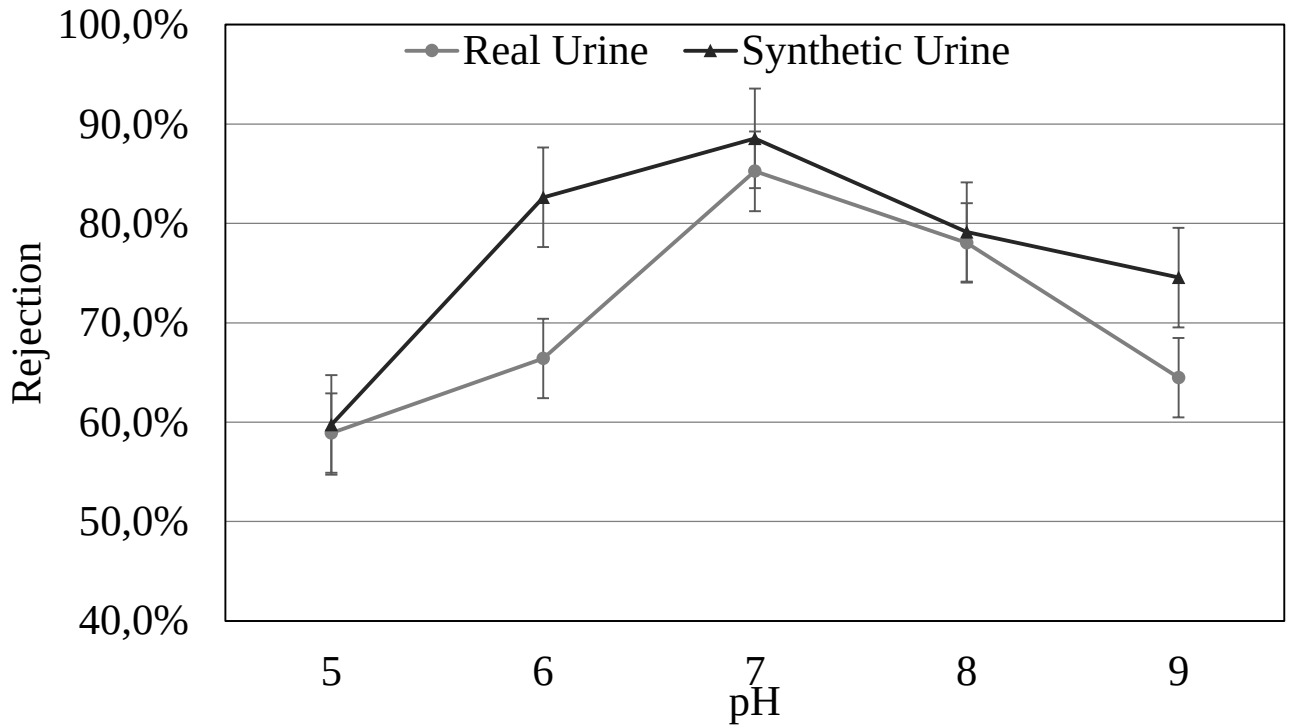
2.3.Comparison of synthetic urine and real urine

Urine type		TP (mg/L)	TN (mg/L)	NH_3-N (mg/L)	COD_{Cr} (mg/L)	K (mg/L)
Synthetic urine	Before	3210±5	12550±5	12440±5	4550±5	840±5
	After	6240±5	16950±5	16370±5	7630±5	1480±5
	Rejection	97.2%	73.4%	65.8%	83.9%	88.1%
Real urine	Before	2110±5	2460±5	2350±5	4030±5	575±5
	After	4140±5	3160±5	2570±5	6960±5	970±5
	Rejection	97.9%	64.5%	54.7%	86.3%	84.1%

- The FO membrane has a high rejection for P, and a relatively low rejection for organics and K. The rejection for nitrogen is not ideal. Nitrogen exists as ammonia, which is similar to the H_2O molecule.
- The nutrients concentration of real urine is lower than synthetic urine, mainly due to the natural difference of people and flush water dilution.

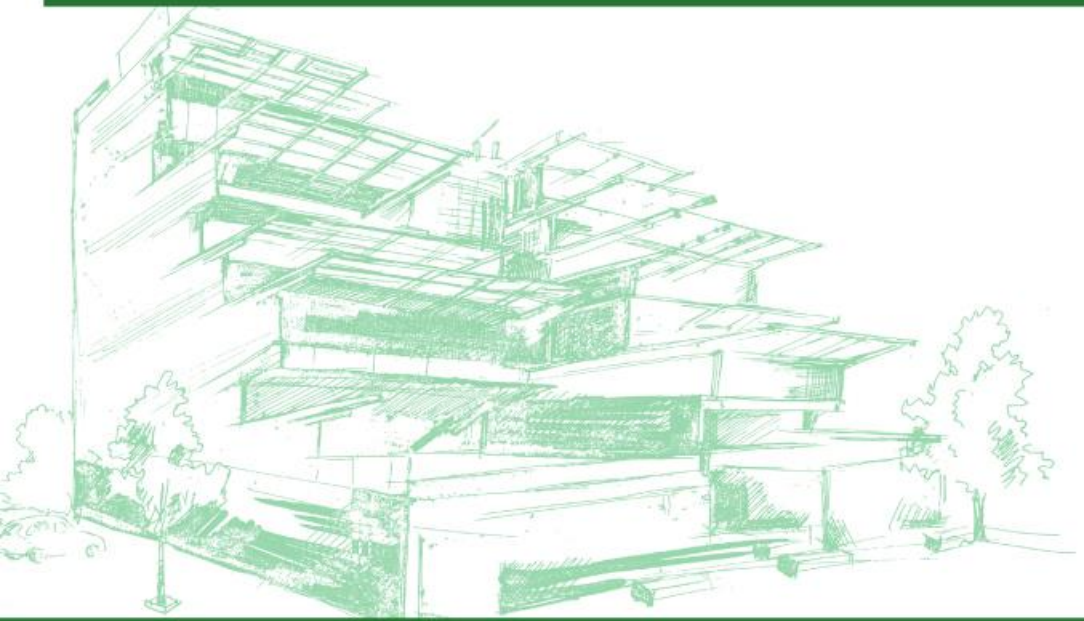
2.Performance of FO in urine concentration

2.4.pH adjustment to promote the rejection for nitrogen



- The highest rejection is achieved at pH=7.
- When pH=7, ammonia mainly exists as NH_4^+, the combination of screening and Donnan effect has the best results. The permeability of the membrane is not influenced.
- When pH is lower, the permeability of the membrane increases thus allowing more ammonia molecules to get through. The durability of the membrane will be affected.
- When pH is higher, ammonia exists as NH_3 , the Donnan effect will decrease.

3. Pilot-scale sanitation system



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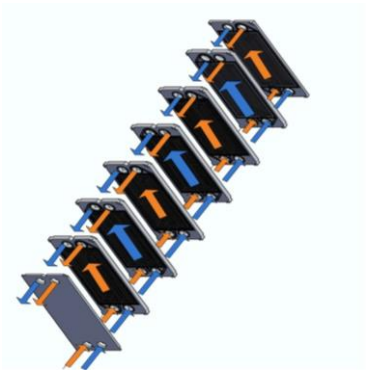
Air flush urinal

Urine diversion vacuum toilet

Solar panel



Flat sheet FO membrane module

Fertilizer

Anaerobic digester

3. Pilot-scale sanitation system

Indicator	Target value	Results
Cost	<0.3 CNY/(capita·d)	0.22 CNY/(capita·d)
Energy consumption	<3.5 kWh/d	2.4 kWh/d
Water consumption	Urine <0.1 L/ flush	Urine 0.1 L/ flush
	Feces <1.0 L/ flush	Feces 1.0 L/ flush
Fertilizer efficiency (N+P2O5+K2O, g/L)	>38.4 g/L	11.9 g/L
Hygienic indexes	Egg death rate above 95% and a value fecal Escherichia Coli number less than 10^{-2}	Egg death rate >99% fecal Escherichia Coli number 10^{-4}

- The urine can be concentrated for 2-3 times, and further concentration takes too long and energy consumption will rise.
- The low concentration of nutrients in real urine leads to low efficiency of the liquid fertilizer.
- The reclaimed water meets the standards for reuse, but the RO system cost too much energy.

4.Conclusions

- The application of FO in urine concentration is a promising solution for the pollution prevention and nutrients recovery.
- The improvement in water flux and rejection of the FO membrane is essential for the application.
- The synthetic urine can be very different from the practical situation, the design of the FO process and module should take it into consideration.
- The FO application is more feasible in places where high osmotic solution exists and has no need for recovery, such as coastal areas.

Thanks !