Organics and nitrogen recovery from domestic sewage via membrane-based pre-concentration combined with ion exchange process

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In response to global resource shortage, domestic wastewater should not be treated as waste anymore, but a resource of water, energy, and plant fertilizing nutrients (nitrogen and phosphorus). However, the objective of sustainable resource recovery from domestic wastewater is far from being achieved at present, which is limited by the disadvantages of conventionally activated sludge (CAS). CAS and its modification processes require high-energy consumption during aeration to supply oxygen for organic matter removal by aerobic microorganism in activated sludge. The anaerobic digestion of sludge can offset part of energy requirement, but only a portion of energy potential in organics is captured. Wastewater treatment now accounts for 0.3% and 3% of the total electrical energy load in China and the U.S., respectively [1, 2]. Nitrogen, mostly in form of N_2, is removed and not recovered during CAS process. Water reuse is widely practiced in water shortage regions, but this also increases energy consumption because of long process to satisfy high-quality requirements for water reuse. Therefore, novel short-procedure technologies/processes for resource recovery are in demand.

As shown in Figure 1, this study proposes the recovery of organics and nitrogen from sewage through membrane-based pre-concentration (MPC) combined with ion exchange (IE) process. Unlike conventional activated sludge process, MPC–IE redesigned organic carbon flow to increase chemical oxygen demand (COD) conversion for energy recovery via anaerobic digestion (AD). This process also achieved nitrogen recovery instead of destruction.

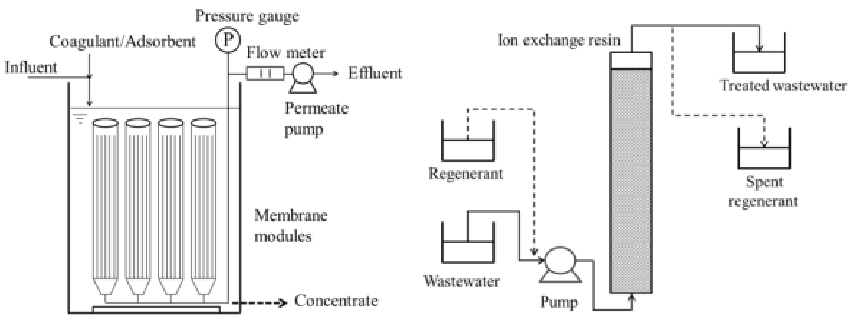

Figure 1. Schematic diagram of MPC (left) and IE resin reactor for nitrogen recovery (right)

Membrane-based pre-concentration of COD was conducted using actual sewage for one month. Figure 2 showed that efficient sewage pre-concentration was achieved. The COD of influent raw sewage was not high (260±32mg/L), but concentrated COD increased to 9640 mg/L in 360 h in the first stage. Concentrate started to be discharged with SRT at 3.5 d in the second stage (360 to 600 h). Concentrated COD was stable in the range of 9,000 to 10,000 mg/L. As high as 65% COD was recovered.

Batch IE adsorption and regeneration experiments were conducted. However, these experiments recovered only 37.5% NH_4-N because of the selectivity of IE for hard ions over ammonium. Despite the low rate of recovery, the process could achieve a total of 0.38 kWh/m^3 energy recovery by combining energy production with anaerobic digestion of pre-concentrated organics (0.26 kWh/m^3) and energy saving via nitrogen reuse (0.12 kWh/m^3). Highly efficient energy and nitrogen recovery from sewage via MPC–IE process was expected after optimization.

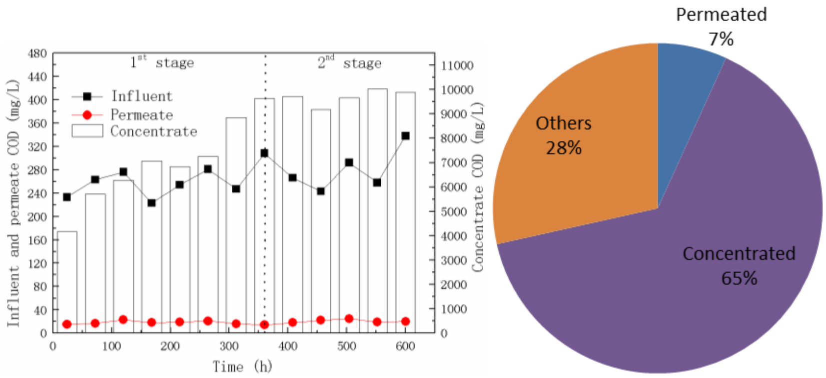

Figure 2. COD of influent, permeate and concentrate of MPC reactor over time (Left) and COD balance during MPC (Right, second stage, 360 to 600 h)

Two scenarios based on the data obtained from this study and 100% ideal recovery were analyzed to evaluate the potential energy recovery of MPC–IE (Table 1). Energy recovery of 0.38 kWh/m^3 can be achieved by combining the energy produced by AD (anaerobic digestion) process (0.26 kWh/m^3) and that saved via N reuse (0.12 kWh/m^3). A total of 0.89 kWh/m^3 could be expected as the maximum in the ideal situation of 100% recovery. MPC-IE has high potential for energy recovery from sewage, which can address the average electrical consumption of 0.29 KWh/m^3 in China [1]. Energy production by AD (0.26 kWh/m^3) could nearly cover energy consumption. The influent sewage examined in this study has lower strength (260±32mg/L of COD) than that of typical wastewater (around 430 mg/L of COD). Increased energy recovery can be expected when high COD sewage is treated.

Table 1. Potential energy recovery by MPC-IE process

	Scenario 1[a]	Scenario 2[b]
Recovered COD	65%	100%
Energy production by AD (kWh/m^3) [c]	0.26	0.39
Recovered NH_4-N	37.5%	100%
Energy saved via N reuse (kWh/m^3) [d]	0.12	0.31[e]/0.50 [f]
Total energy recovery (kWh/m^3)	0.38	0.70/0.89

[a] Scenario 1 was based on data in this study; [b] Scenario 2 was based on 100% recovery; [c] Estimated by 1 g of COD producing 350 mL of CH_4; 40% of methane energy can be converted into electrical energy; energy yield through 890 kJ/mol methane combustion; [d] Based on 19.3 kWh/kg N production energy by Haber–Bosch process; [e] Estimated by 100% recovery of permeate NH_4-N after COD pre-concentration; [f] Estimated by 100% recovery of influent NH_4-N

The MPC–IE process redesigned carbon flow during sewage treatment. More organic CODs were collected by MPC−IE than by the traditional process. Organic CODs in the form of concentrated state for AD energy production was essential for pursuing energy neutrality in WWTPs.This result indicates the potential of COD pre-concentration as a self-sufficient energy process. The MPC–IE process increased energy savings via N reuse, which was not considered in the current CAS process.

In the integrated MPC–IE process, MPC generally has the following advantages. 1) High proportion of organic matter is concentrated for improved energy recovery. 2) Suspended and colloidal solids are removed, which reduces the propensity for clogging in operation of fixed bed granular IE resins and thus, increasing nitrogen recovery effectiveness and longevity. 3) High water quality fit for reuse is guaranteed by combined membrane and IE process.

References:

[1] X. Hao, R. Liu, X. Huang, Evaluation of the potential for operating carbon neutral WWTPs in China, Water research 87 (2015) 424-431.

[2] USEPA, Wastewater Management Fact Sheet: Energy Conservation, Office of Water 2006, pp. EPA 832-F-806-024; U.S. Environmental Protection Agency: Washington DC, 2006; p 2007.