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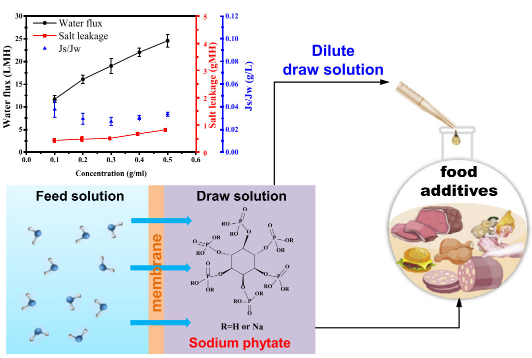
# Evaluation of food additive sodium phytate as a novel draw solute for forward osmosis

Jiaqi Huang[a,b,c,1], Shu Xiong[a,b,c,1], Qingwu Long[d], Liang Shen[a,b,c], Yan Wang[a,b,c,*]

[a] Key Laboratory of Material Chemistry for Energy Conversion and Storage (Huazhong University of Science and Technology), Ministry of Education, Wuhan, 430074, PR China
[b] Hubei Key Laboratory of Material Chemistry and Service Failure, School of Chemistry and Chemical Engineering, Huazhong University of Science & Technology, Wuhan, 430074, PR China
[c] Shenzhen Institute of Huazhong University of Science and Technology, Shenzhen 518000, PR China
[d] School of Chemistry and Chemical Engineering, Lingnan Normal University, Zhanjiang 524048, PR China

## GRAPHICAL ABSTRACT

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## ABSTRACT

Proper draw solution is a crucial factor to generate a high performance in FO process. In this study, a phytic acid and its salt (PA-Na) were evaluated as novel draw solutes in FO process. The effects of the solution pH and concentration on the physicochemical properties were investigated systematically. Using 0.45 M PA-Na draw solution (pH = 7) and DI water feed solution, a relative high water flux of 19.02 LMH and a low solute flux of 0.51 gMH can be obtained, with HTI-TFC membrane in the PRO mode. An even better performance of a 30.35 LMH water flux and a 0.61 gMH solute flux can be achieved using the self-made HPAN-TFC membrane. The comparison of PA-Na and NaCl draw solutions shows that PA-Na draw solution has a much lower draw solute leakage and a competitive water flux. In addition, the application of PA-Na draw solution for the brackish water desalination was explored. The diluted PA-Na draw solution after FO may be used directly in food production by further dilution. In general, the non-toxicity and satisfactory FO performance of this food additive demonstrate its great potential as a draw solute for FO applications.

* Corresponding author at: Key Laboratory of Material Chemistry for Energy Conversion and Storage (Huazhong University of Science and Technology), Ministry of Education, Wuhan 430074, PR China.
*E-mail address:* wangyan@hust.edu.cn (Y. Wang).
[1] The first two authors contribute equally to this study.

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## 1. Introduction

Forward osmosis (FO) is a membrane-based technology driven by the osmotic pressure between the feed solution and the draw solution [1–5]. Compared to traditional reverse osmosis and nanofiltration driven by external hydraulic pressure, FO has a lower energy requirement and exhibits a reduced membrane-fouling tendency [6–9]. Thus, FO has attracted increasing research interest in recent years and exhibited great potential for various applications in desalination, water treatment, power generation, and so on [10–14].

Draw solutions play a critical role as osmotic pressure suppliers; regardless, research about draw solutions relatively lags behind [15] because of prerequisites that have to be fulfilled, including the following: (1) a high osmotic pressure to generate a high water flux; (2) a suitable molecular size to ensure low reverse draw solute leakage; (3) convenient recovery at a low cost; (4) nontoxicity; and so on [16]. Commonly used draw solutes include inorganic salts such as sodium chloride (NaCl) and magnesium chloride ($MgCl_2$) [17,18]. These salts can be ionized completely and generate high osmotic pressure in the aqueous solution, ensuring considerably high water fluxes in FO; however, salt leakage is also extremely severe and entails high energy consumption in the draw solution recovery. Magnetic nanoparticles, thermosensitive polyelectrolytes, and thermally responsive hydrogels have been developed as potential draw solutes [19,20] with negligible solute leakage and easy recovery. However, they generally exhibit low water fluxes. As draw solutes, thermolytic salts [10,21,22], such as ammonium bicarbonate ($NH_4HCO_3$), can produce high water fluxes in FO and be easily recovered by decomposition with industrial waste heat. However, the corrosive and harmful nature of ammonia gas ($NH_3$) may deteriorate the quality of the product water with even a slight residue of the draw solute. Various organic acid salts were subsequently developed as potential draw solutes with superior FO performances because of their ionogenic chemical structures in the aqueous solution and suitable molecular size, which can ensure high water flux, low viscosity, and relative ease in draw solution recovery [23–28].

Draw solutes based on natural compounds present advantages over other compounds because draw solutes cannot be used to obtain potable water directly without a regeneration step. For instance, a “draw water” bag with edible products as the draw solute can obtain water from contaminated water in the wilderness [29]. Nontoxic gluconate salts have also been reported as novel FO draw solutes with good FO performance for the reconcentration of various fruit juices [29]. Similarly, sodium lignin sulfonate and commercial fertilizers reported as FO draw solutes can also be directly applied in crop irrigation after dilution via FO [30,31].

In the present study, phytic acid (PA) and its sodium salt (sodium phytate, PA-Na), which are natural green additives used in the food and pharmaceutical industries [32–35], are explored as draw solutes for applications in FO for the first time. Fig. 1 shows the chemical structure of phytic acid. Numerous phosphate groups are found in the molecule, which can easily ionize and produce high osmotic pressure in the aqueous solution. The molecular weight of PA is 660, which can sufficiently ensure low-solute leakage in FO. In addition, both PA and PA-Na are environment- and human-friendly [32]. These advantages of PA suggest its potential as a desirable draw solute. In the current study, the effects of both the pH and concentration of the PA solutions on FO performance are systematically evaluated. The PA-Na draw solution is further evaluated for brackish water desalination by FO. This study can potentially contribute to the development of new draw solutes for FO.

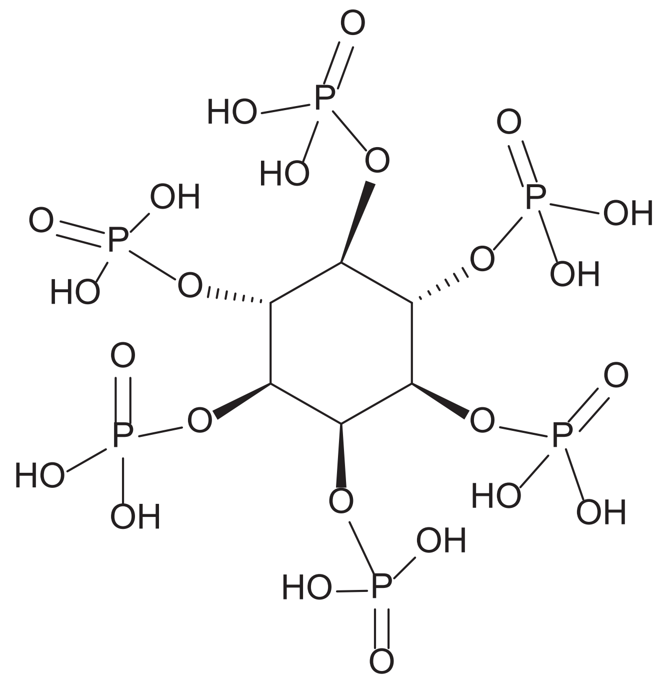

**Fig. 1.** Chemical structure of phytic acid.

## 2. Materials and methods

### 2.1. Materials

Phytic acid (PA) (70% aqueous solution) was supplied by Aladdin (Shanghai, China). Sodium chloride (NaCl, ≥99.5%). Sodium hydroxide (NaOH) (≥96%) were acquired from Sino-pharm Chemical Reagent Co. (Shanghai, China). Deionized water (DI water) with a resistivity of 18.25 MΩ·cm was generated from Wuhan Pin Guan Ultrapure Water LAB System (China).

### 2.2. Preparation of PA-Na draw solution

PA-Na draw solutions of different pH values were prepared by diluting the PA aqueous solution with the designed concentration and adjusting the pH with NaOH, where the solution pH was determined with a pH meter (Mettler toledo, FE28).

### 2.3. Osmotic pressure and relative viscosity of PA-Na solution

The osmotic pressures of PA-Na aqueous solutions were measured using a home-made lab-scale setup [23] based on the freezing point depression method and calculated by Eq. (1):

$$\pi = \frac{T_0 - T_t}{1.86} \times 22.66 \tag{1}$$

where $T_0$ and $T_t$ are the freezing points of DI water and the PA-Na solution respectively.

The determination of relative viscosities ($\eta_r$) of PA-Na aqueous solutions was conducted with a commercial Ubbelohde viscometer at 25 ± 1 °C and calculated with Eq. (2):

$$\eta_r = \frac{\eta}{\eta_0} = \frac{\rho t}{\rho_0 t_0} \tag{2}$$

where $t_0$ and $t$ (s) are the outflow time of the DI water and PA-Na solution, respectively, $\rho_0$ and ρ (g/cm$^3$) are the densities of DI water and PA-Na solution detected by a density meter (KEM DA-130 N, Japan).

### 2.4. FO process

FO tests were carried out by a commercial lab-scale FO faclity (Suzhou Faith Hope Membrane Technology) with a fixed effective membrane area of 3.87 cm$^2$. Two kinds of FO membranes were used to evaluate the FO performance of PA-Na draw solution, i.e., the commercial thin film composite (TFC) FO membrane from HTI (Hydration