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# Iodide recovery from thin film transistor liquid crystal display plants by using potassium hydroxide - driven forward osmosis

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ABSTRACT

For the first time, KOH in the waste stream of a thin film transistor liquid crystal displays (TFT-LCD) plant was utilized as a draw solution to recover iodide in the waste stream through forward osmosis (FO). In long-term operation, the pressure-retarded osmosis mode provided concentration efficiency greater than that of the FO mode. The maximum water flux achieved 11.7 LMH at pH 11 of KOH draw solution, and the iodide concentration reached 6.9% for reuse in TFT-LCD plant from the initial iodide concentration of 0.6% after 120 h. Analysis of scanning electron microscopy and energy dispersive X-ray spectroscopy images revealed a thin fouling cake layer of KI on the support layer of the membrane. The overall performance of the proposed FO system with KOH as the draw solution indicated that the FO system is promising for concentrating iodide for reuse in TFT-LCD plants. The proposed FO system offers excellent benefits: (1) the liquid discharge is minimal and (2) the cost of the FO system is extremely low because draw solution recovery is not required.



## 1. Introduction

Thin film transistor liquid crystal displays (TFT-LCD) is one of the most important high-tech industries in Taiwan. A series of policies aimed at attracting investments in the TFT-LCD industry has been enacted by the Taiwan government since 2000 [1]. Moreover, the research institutes and manufacturers have jointly contributed funds for research and development, for improving production technology, making Taiwan the world leader in TFT-LCD production within 30 years [1]. Consequently, the shipment volume of Taiwanese large-area TFT-LCD panels reached approximately 58.8 million units in the last quarter of 2014, up 6.6% year-on-year [2,3]. In TFT-LCD manufacturing facilities, a polarizer is an important process for converting a beam of light of undefined or mixed polarization into a beam with well-defined polarization. The main manufacturing process of polarizer is to soak polyvinyl alcohol in iodine/potassium iodide aqueous solution to form complex film. These facilities produce a large amount of iodine-containing wastewater, and the treatment of the wastewater is a major challenge for biological treatment because iodine has adverse impacts on microbial activity [4].

To overcome the drawback of conventional biological treatment, various advanced methods have been proposed for dealing with the problem of iodine in the TFT-LCD wastewater. Lee et al. [5] investigated reductive transformation of iodine by zero-valent iron (ZVI), and their results showed that ZVI pretreatment could be an effective option for the iodine removal in TFT-LCD processing wastewater. Sánchez-Polo et al. [6] studied the enhanced iodine adsorption by using activated aerogels impregnated with silver ions based on increasing electrostatic attraction. Madrakian et al. [7] used silica-coated magnetite nanoparticles for removal of high concentrations of iodine from wastewater and observed that the optimum pH for iodine removal was 7.0–8.0; they achieved an iodine recovery efficiency of approximately 90%. Nevertheless, the synthesis of magnetic nanoparticles is complicated, costly, and difficult for practical applications. Currently, in Taiwan, thermal distillation and reverse osmosis (RO) are widely used for concentrating iodide for reuse in TFT-LCD plants. However, these techniques pose environmental and health risks because of their

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high energy consumption (1250 kWh/$m^3$) and the production of blue iodine gas.

Forward osmosis (FO) is a recent innovation in the field of membrane separation, with considerably lesser energy than reverse osmosis; moreover, FO offers higher water recovery [8–12]. In FO, natural osmosis is the driving force for separation mechanism, and the water flux occurs from a region of the low osmotic pressure to the high osmotic pressure, subsequently, the feed solution is concentrated and the draw solution is diluted [13,14]. Therefore, FO is potential to (i) consume less energy (ii) involve lesser fouling than pressure-driven membrane processes, and (iii) achieve high rejection of many pollutants [15,16]. These apparent advantages have recently encouraged many scientists to focus on FO R&D works, and promising results have been reported in a variety of fields such as desalination [17,18], sludge dewatering [15,19,20], wastewater treatment [21–26] and power generation [27–29]. In particular, many studies have successfully used FO to recover phosphorus and metals and to concentrate foods, as shown in Table 1.

In FO process, firstly energy is spent for FO to extract water into draw solution and then the diluted draw solution must be recovered to separate draw solution from the product water. However, the high energy required for the recovery (typically, RO) of the diluted draw solution is the main challenge in developing a marketable FO technique [35,36]. Clearly, FO is applicable and reliable when the diluted draw solution need not be recovered. Hence, the utilizing used draw solutions as end products (fertilizer [37], seawater [15], brine after RO unit [38] or wastes from industry) is promising solution to avoid high recovery costs, whereby FO could be completely replaced for RO. In this study, a high concentration of potassium hydroxide (KOH), which is widely used as a developer in the TFT-LCD industry and is subsequently discharged as waste, was used as the draw solution in the FO process. A literature survey confirmed that the present study is the first to use a high concentration of KOH obtained from the waste stream of a TFT-LCD plant as the draw solutions in a FO system employed for recovering iodide from wastewater. The main advantages of this FO system are that iodide can be concentrated up to the required level with low energy consumption for reuse in TFT-LCD manufacturing facilities. In Taiwan, the iodide concentration higher than 6% becomes a recycled product in the market since these high concentrated iodide solution can be refined to high value iodine by oxidation and furthermore purification in the manufacture process. The diluted KOH obtained at the end of the process can be reused for adjusting the pH of the acidic surface cleaning stream in TFT-LCD plants. Accordingly, there is no need to regenerate the draw solution.

The purpose of this study was to evaluate FO as a new technique for concentrating iodide from polarizer manufacturing wastewater, with special focus on the following parameters/aspect: (1) flux performance, (2) concentration yield of iodide, and (3) membrane fouling during long-term FO with thin film composite (TFC) and cellulose triacetate (CTA) membranes. Scanning electron microscopy and energy dispersive X-ray spectroscopy (SEM–EDS) were used for the evaluation.

## 2. Materials and methods

### 2.1. Materials

FO experiments were conducted with KOH as the draw solution and KI as the feed solution. Real KI wastewater was collected from the polarizer process in a TFT-LCD manufacturing facility in northern Taiwan. Furthermore, real KOH wastewater (pH 12) was collected from the TFT-LCD facility during the cleaning of products. The characteristics of KI and KOH obtained from the wastewater of the TFT-LCD plant are presented in Table S1.

In this study, two types of flat sheet FO membranes were used, and they were supplied by Hydration Technology Innovations (ALBANY, OR, USA). CTA and TFC FO membranes were used in all the FO experiments. The characteristics of the FO membranes are provided in Table 2. The mean pore sizes of the CTA and TFC FO membranes were determined by using the method presented in reference [39], and the thickness of the FO membranes was provided by the manufacturer. The contact angle of the CTA and TFC FO membranes was measured by using a contact angle meter (CAM 100; Holmarc Opto-Mechatronics Pvt. Ltd., India), as shown in Fig. S1.

### 2.2. Experimental setup

Experiments involving an FO system were conducted using the lab-scale module setup shown in Fig. 1. The FO test cell (Sterlitech,

**Table 1**
Studies conducted by various researchers on the use of FO for recovering and concentrating materials.

| Recovering/ Concentrated Products | Draw solution | Feed solution | Water flux | Recovery/ Concentration yield | Reference |
|---|---|---|---|---|---|
| Phosphorus | Seawater | Digested sludge centrate | water flux decline of 30% from the initial value | 92% recovery of phosphate | [30] |
| Valuable metals ($Pb^{2+}$, $Cd^{2+}$, $Cu^{2+}$, and $Hg^{2+}$) | 1 M $Na_4[Co(C_6H_4O_7)_2]\cdot 2H_2O$ | heavy metal salts concentration of 2000 ppm | 11 LMH | heavy metals rejections of more than 99.5% | [31] |
| Grape juice | 6 M NaCl | Sugar plus 0.1% pectin | 7.9–11.2 LMH | Grape juice was concentrated 57.1 fold | [32] |
| Sugar solution | 2–4 M NaCl | 0.29 M sucrose | 2.9–5.8 LMH | Concentration factor obtained was 5.7°brix | [33] |
| Pineapple | Sucrose plus NaCl | Pineapple juice (12.4°Brix) | 0.5–2 LMH | The pineapple juice was concentrated up to 60°Brix | [34] |

[Note: All FO experiments used orientation membrane of active layer facing the feed solution, ND (no data) – References did not provide data].

**Table 2**
Characteristics of the TFC and CTA FO membranes.

| FO Membrane | Pore size | Contact angle | Hydrophilic/ hydrophobic | Thickness (μm) | pH operation |
|---|---|---|---|---|---|
| TFC | 0.47 nm | 35.3 ± 2.1° | More hydrophilic | 76 ± 3.0 | 2–12 |
| CTA | 0.37 nm | 70.6 ± 2.9° | Relatively hydrophilic | 144 ± 24 | 3–8 |