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Evaluation of chemically-enhanced seeded precipitation of RO concentrate for high recovery desalting of high salinity brackish water

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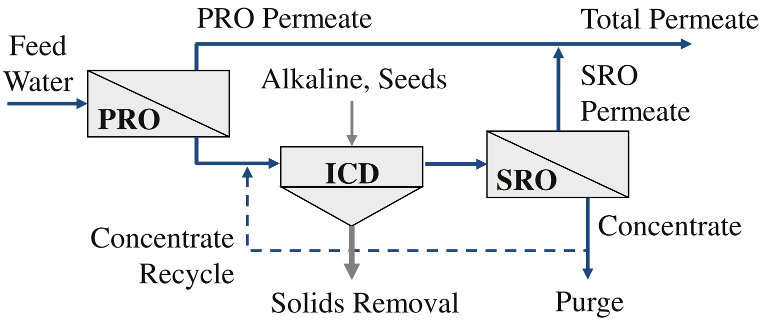
HIGHLIGHTS

- ► Successful field evaluation of chemically-enhanced seeded precipitation (CESP)
- ► CESP effectively desupersaturates RO concentrate with respect to mineral scalants.
- ► CESP enables high recovery RO desalination of high salinity inland brackish water.
- ► High recovery desalination is economically feasible by integrating CESP and RO.

GRAPHICAL ABSTRACT



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ABSTRACT

The feasibility of utilizing chemically-enhanced seeded precipitation (CESP) for primary reverse osmosis (PRO) concentrate demineralization was evaluated, via both experimental field tests and process analysis, to assess its potential use in enabling recovery enhancement via secondary RO (SRO) desalting. Field evaluations of batch CESP along with process simulations for desalting of agricultural drainage (AD) water (6700–14,400 mg/L TDS, *SIg* = ~0.9) have suggested that a PRO-CESP-SRO desalting approach is both technically and economically feasible to enable overall desalting recovery of about 83% and, with partial concentrate recycling, of up to 93%. In the CESP process, initial partial lime treatment provides adsorptive removal of residual antiscalant from the PRO concentrate. This enables subsequent concentrate desupersaturation (with respect to the major scaling salt calcium sulfate) to occur via seeded gypsum precipitation, unimpeded by residual antiscalant. The desupersaturated PRO concentrate (~34% reduction in *SIg* from ~1.7 to ~1.1) can then be further desalted in an SRO step up to the limit that is feasible with antiscalant dosing for scale control. When considering the cost of residual brine disposal, the cost of AD water desalination by PRO-CESP-SRO on the basis of desalted water volume is lower than RO by up to 39%.

1. Introduction & background

Development of new water sources is crucial in order to address the crisis of dwindling water supplies in California and around the globe. In this regard, reverse osmosis (RO) desalination is a technology that is now in common practice for developing new water sources

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via desalting of seawater [1–3], brackish surface water and groundwater [4–9], as well as municipal wastewater [10–13]. The growth of the RO desalination market has been spurred by advances in reverse osmosis (RO) technology that have led to significant reduction in the production cost of water desalination [14]. It is noted that RO desalination of brackish water is also viewed as a potential solution for confronting the rising salinity of agricultural drainage (AD) water, which is a major threat to the economy throughout California's agricultural heartland in the San Joaquin Valley (SJV) [9]. While RO is considered a mature technology, its application for desalination of brackish water remains challenging due to the high costs associated with residual RO concentrate disposal and membrane mineral scaling, thus preventing wide-spread use of RO technology for inland brackish water desalination [3,15,16]. Gypsum membrane mineral scaling in particular is a major concern for AD water and other inland water sources [9].

Previous methods attempting to partially overcome the problem of mineral scaling in brackish water RO desalting have relied on operation at low recovery levels and chemical feed conditioning (e.g., pH adjustment and use of antiscalants) both leading to high operational cost and a large volume of residual concentrate. As a consequence, traditional RO desalination approaches are limited with respect to the achievable product water recovery due to mineral scaling that ensues once the recovery exceeds the saturation threshold of sparingly soluble mineral salts (e.g., calcium sulfate, calcium carbonate, calcium phosphate, and barium sulfate). For example, it has been reported that product water recovery is limited to ~40–60% for most brackish water sources in the SJV [17]. However, it has also been argued that high recovery operation (above ~85%–95%) is essential for inland water desalting of brackish groundwater, AD water, as well as in municipal wastewater reuse applications, in order to reduce the volume of generated residual concentrate and reduce the overall process cost.

High recovery desalination via RO with intermediate concentrate demineralization (ICD) has been proposed as a promising method to address the challenge of managing high salinity drainage water (e.g., mine drainage, AD, dumpsite leachate) with high mineral scaling propensity at inland locations [12,18–23]. In the ICD approach to high recovery RO desalination, brackish water is first desalted in a primary RO (PRO) stage up to the PRO product water recovery limit imposed by membrane mineral scaling, followed by PRO concentrate treatment (ICD) to reduce scale precursor (e.g., calcium, sulfate, carbonate, phosphate) concentrations, thereby reducing the scaling propensity of the PRO concentrate. The treated PRO concentrate is filtered to remove solids and then further desalted in a secondary RO (SRO) stage to achieve the desired overall recovery (Fig. 1). The overall PRO-ICD-SRO process can reach product water recoveries of up to 85–98%, minimizing the volume of the residual RO concentrate waste [20,21,24]. ICD via alkaline-induced precipitation of $CaCO_3$ from PRO concentrate (i.e., precipitation softening) has been successfully demonstrated in a number of laboratory [8,13,25–28] and pilot-scale studies [21,22,24,29] for treating brackish water of sufficient bicabonate content to remove calcium via $CaCO_3$ precipitation, thereby reducing the gypsum scaling propensity. However, ICD via precipitation softening (PS) is often chemically-intensive for bicarbonate-lean brackish waters since the addition of an alkaline chemical containing bicarbonate (e.g., soda ash) is required to sufficiently deplete calcium concentration via $CaCO_3$ precipitation [18,20,30].

ICD may also be carried out via seeded gypsum precipitation (SGP) [18,20,31,32] in which gypsum seeds are added to the supersaturated PRO concentrate. This induces gypsum precipitation in order to achieve PRO concentrate desupersaturation. In the SGP process, the rate of gypsum precipitation depends on the gypsum saturation level [20]. However, gypsum precipitation kinetics are significantly reduced by antiscalants (AS) presence (due to carry over) in the PRO concentrate [20]. It has also been suggested that AS adsorbtion onto gypsum seed surfaces inhibits heterogeneous gypsum crystal growth (i.e., seed poisoning), and thus retards PRO concentrate desupersaturation [33]. For example, previous work has demonstrated that AS (3 mg/L polyacrylic acid in the concentrate) can reduce the rate of gypsum precipitation by ~65% [20]. Clearly, in order to successfully implement an SGP process for RO concentrate desupersaturation, AS-action inhibition of gypsum precipitation must be counteracted prior to SGP treatment.

Previous work [20,33] has demonstrated that minimal alkaline use (0.25 g/L lime) during chemically-enhanced seeded precipitation (CESP) (i.e., the sequential combination of PS and SGP) can prevent gypsum seed poisoning by AS in the demineralization of AS-containing (3 mg/L) model PRO concentrate solution that is a factor of 2.5 above saturation with respect to gypsum. It was reported [33] that lime-induced $CaCO_3$ precipitation removed up to ~90% of the AS in model RO concentrate solution for the case of nearly gypsum-saturated RO feed water ($SI_g = 0.96$, $SI_c = 3$; where the saturation index is defined as $SI_x = IAP_x/K_{sp,x}$, where IAP_x and $K_{sp,x}$ are the ion activity and solubility products, respectively, of mineral salt x). The above level of AS removal facilitated subsequent $CaSO_4$ precipitation with minimal retardation due to AS-action [20,33]. Using this approach it was suggested, for the above source water, that the PRO-CESP-SRO process could enhance overall water recovery to ≳85%.

Whereas previous work explored the CESP process with model solutions, the goal of the present work was to: (a) demonstrate the feasibility of the CESP process in the field and, (b) to assess the

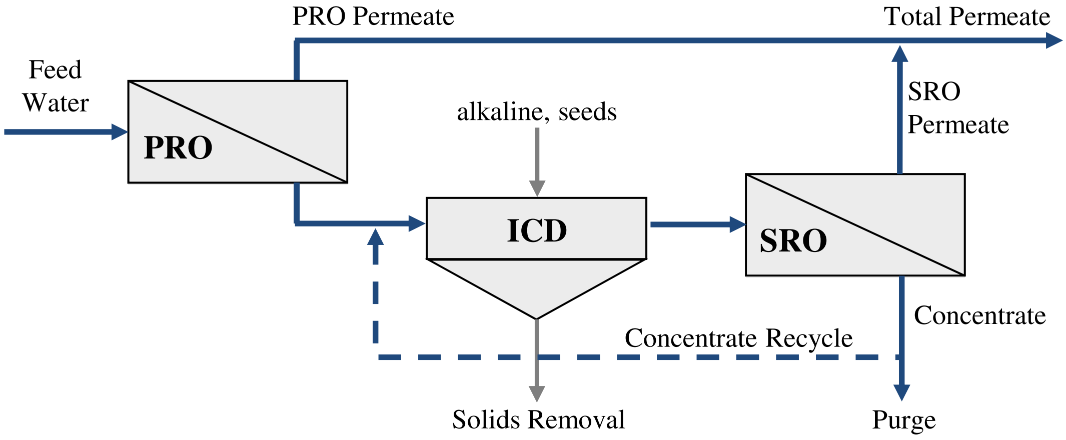

Fig. 1. High recovery RO process utilizing intermediate concentrate demineralization (ICD) treatment of primary RO (PRO) prior to secondary RO (SRO) desalination.