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Improved high recovery brackish water desalination process based on fluidized bed air stripping

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ABSTRACT

Very high water recoveries can be achieved in brackish water RO desalination by air stripping of a carbonate-rich concentrate which provides high pH conditions for precipitating calcium hardness without necessitating the use of chemicals. The scale-free concentrate solution can be then processed with a secondary RO unit to recover additional product. Simple precipitation in an MSMPR crystallizer requires relatively high retention times of the order of 2 h. The present paper describes an improved high recovery process in which precipitation is carried out in a fluidized bed (FBR) air stripping system. Experimental results are presented, showing that FBR crystallization enables very high precipitation conversion of calcium carbonate reaching 90% at considerably reduced retention times of the order of 15 min.

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1. Introduction

Brackish water desalination has a marked potential for alleviating water scarcity in arid regions. The main obstacle hindering widespread use of brackish water desalination is that most raw water sources are located inland, rendering safe disposal of the concentrate waste stream uneconomic in many cases [1,2]. Considerable efforts are therefore undertaken to develop processes enabling high water recoveries so as to reduce the volume of the waste stream [3–6].

We have recently developed a novel high recovery process in which the alkaline scale species present in a carbonate-rich concentrate are precipitated by pH increase. After discarding the precipitate, the scale-ions depleted concentrate is fed to a secondary RO unit which provides additional permeate product (Fig. 1).

The novel aspect of the process is that the pH increase is induced by air stripping of CO_2 [7]. The process was tested in a pilot plant [8] constructed at the location of the 1.5 MCM per year brackish water desalination plant in Atlit, Israel. The precipitation step performed on the concentrate emanating from the Atlit Desalination plant (Table 1) was carried out in MSMPR crystallizers. The pilot plant data confirmed that the air stripping process can provide a significant increase of the water recovery without using any chemicals. A $CaCO_3$ precipitation conversion of 70% (based on initial feed composition) was achieved. The process combining air stripping with a secondary RO unit enabled a total water recovery of 90% at a $CaCO_3$ crystallizers retention time of 2 h.

The aim of the present research was to improve the process by a more efficient crystallization system. The work presented in this paper shows that use of a fluidized bed crystallizer provides significant improvements, allowing shortened retention times and increased precipitation conversion levels.

2. Fluidization techniques for water softening

Processes for water treatment by fluidized bed crystallization are receiving wide attention. The use of a fluidized bed reactor has been reported for water softening of drinking water [9–11], scale reduction from seawater [12], wastewater treatment for phosphate and fluoride removal [13,14] and heavy metals recovery [15–17]. Currently, the so called Crystalactor fluidized bed reactor which was developed in the Netherlands is considered to have significant advantages in water-softening applications.

The typical fluidized bed reactor, illustrated in Fig. 2, consists of a cylindrical vessel, partly filled with a suitable seed material. The feed nozzles provide vertical plug flow of the solution and improve the chemicals mixing. At the bottom of the bed is a distributor plate of pierced caps which acts as a support to the bed and evenly disperses the fluid over the vessel cross section. The raw water and chemicals are injected through the plate by separate nozzles. The water is introduced at the bottom of the reactor at a sufficiently high rate to generate fluidization but without causing solids to be washed out in the effluent. The larger and heavier pellets accumulate at the base of the reactor where they are removed periodically and replaced by smaller size seeds.

Efficient performance requires proper water and chemical distribution, intensive mixing of the chemicals to avoid local high supersaturation

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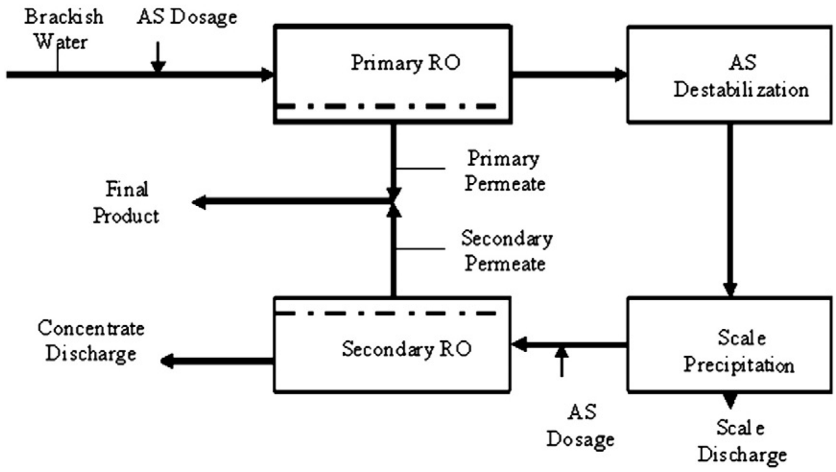

Fig. 1. High recovery brackish water desalination process.

and sufficient turbulence in the reactor to prevent scaling of the nozzles and of the reactor wall [9]. The performance of a fluidized bed crystallizer is determined by pellet diameter, superficial velocity, bed height and temperature [10,11].

3. Experimental

3.1. Precipitation system

The fluidized bed used in this study integrated the Crystalactor concept with the CO_2 air stripping technique. The system consisted of two units: a fluidized bed reactor (FBR) open to the atmosphere and a calcite gravity filter. The seeds floating in the FBR unit provided a large crystallization surface and grew into spherical pellets through the precipitation process.

The unit was provided with an inlet for the feed solution, an inlet for the stripping air stream and an outlet connecting the effluent stream to the gravity filter (Fig. 3). The gravity filter had two functions: it served to relieve residual supersaturation and to capture fine particles.

The feed solution was held in a 200 L vessel. Precipitation conditions in the FBR column were achieved by CO_2 stripping induced through air bubbling.

The properties of the quartz particles used as seeds in the FBR column are listed in Table 2. The large diameter Quartz 2 particles were not fluidized and served only as support to the fluidizing seeds.

All experiments were carried out at a solution feed rate of 1.5 l/min providing a superficial flow velocity of 1.6 mm/s and an air flow rate of 75 l/min. The solution retention time in the FBR was about 15 min. It may be noted that the solution velocity of 1.6 mm/s is below the minimum fluidization velocity of the tested particles. The air injection promoted fluidization at this sub-fluidization velocity.

The characterizing features of the system investigated appear to be the height of the fluidized bed (19 to 35 cm), the diameter of the particles relative to the fluidization velocity (particle diameter in the range of 0.3–2.5 mm and velocity of 2.4 mm/s) and the mass of particles relative to the initial bed height (1 to 8 kg for bed heights of 2.5 to 18.5 cm respectively).

Table 1
Composition the Atlit desalination plant concentrate.

Ion	Concentration (PPM)	Ion	Concentration (PPM)
Ca^{2+}	1109	SO_4^{2-}	614
Mg^{2+}	356	Total alkalinity	1457 as $CaCO_3$
Na^+	1014	Cl^-	4917

3.2. Test solutions

The test solution composition simulated a typical carbonate-rich concentrate (Table 3). The solution was prepared using practical grade $CaCl_2 \cdot 2H_2O$, $NaHCO_3$, $MgCl_2 \cdot 6H_2O$, $MgSO_4 \cdot 7H_2O$ and analytical grade NaCl.

3.3. Analyses

Crystallizer solution composition (pH, Ca^{2+}, total alkalinity) was periodically monitored in the course of an experiment. Dissolved calcium concentration was determined by EDTA titration according to the ASTM standard method D 511, using Murexide (Riedel-de Haen) as the indicator. The total Ca^{2+} was measured by EDTA titration, using Eriochrome Black T (Fluka) as the indicator. The total alkalinity was determined by HCl titration to pH 4.3 according to the ASTM standard method D 1067.

3.4. Experimental program

The first experimental series was performed with a $NaHCO_3$ solution and served to characterize the CO_2 stripping volumetric mass

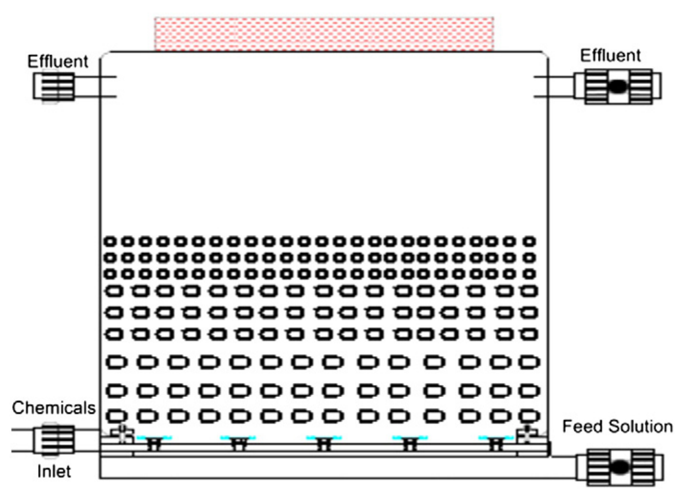

Fig. 2. Fluidized bed crystallizer.

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