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Feasibility of salt production from inland RO desalination plant reject brine: a case study

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Abstract

Production and disposal of reject brine are an integral part of an overall desalination process. For inland desalination plants, this poses a serious challenge to operators, as the option of ocean disposal of reject brine is not available. Various disposal options such as reinjection, lined and unlined evaporation ponds and natural depressions (lake) are currently being used. An alternative approach is to further process the reject brine to extract all the salts. This has the advantages of being environmentally friendly and producing commercial products (i.e., salts and fresh water). A desktop pre-feasibility study using data from Petroleum Development Oman (PDO), operating plants in Bahja, Rima, Nimr and Marmul, confirmed the technical feasibility of treating reject brines in simple processing routes using SAL-PROC technology. SAL-PROC is an integrated process for sequential extraction of dissolved elements from inorganic saline waters in the form of valuable chemical products in crystalline, slurry and liquid forms. The process involves multiple evaporation and/or cooling, supplemented by mineral and chemical processing. An analysis indicated that various types of salts including gypsum, sodium chloride, magnesium hydroxide, calcium chloride, calcium carbonate, and sodium sulphate can be produced from the reject brine of PDO desalination plants. These products have an approximate market value of US $895,000 annually.

Keywords: Brine; Salt; Oman; SAL-PROC; PDO; Gypsum; Sodium; Chloride; Sulphate; Magnesium

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1. Introduction

Disposal of saline effluent from salt-affected agricultural lands, desalination plants and other industries is an increasing problem in many parts of the world. The traditional approach has been to treat saline water as a waste disposal problem. However, changing the paradigm to "saline resource" opens up a number of opportunities to recover some of the costs in dealing with "reject brines". For example, Ahmed et al. [1] describes how these elements can be integrated for large saline flow rates. The Options for Productive Use of Salinity (OPUS) database [2] provides a number of contact points for use of saline effluent in agriculture, forestry, fauna and algae production minerals and energy production. This is further developed by SRD [3] to facilitate business opportunities.

Successful uses of saline water have been practiced in agriculture through the use of serial biological concentration (SBC). One such experimental system at Griffith, NSW, Australia, uses saline effluent of up to 6000 mg/l to irrigate cropping sequences which include lucerne, barley and saltbush; the drainage water (20,000 mg/l) is then used for aquaculture [4]. A similar approach [5] used low-salinity brine for irrigation of crops and landscape plants in Arizona, USA. In aquaculture, a number of existing commercial and research enterprises were reviewed by Allan et al. [6], and an assessment checklist developed for Australian conditions. OPUS [2] provides additional examples of successful saline aquaculture in Australia. When using "reject bitterns" for aquaculture, the potential for bioaccumulation of heavy metals needs to be assessed. In the USA, for example, selenium in drainage water was found to have bioaccumulated 1540-fold from water–algae–zooplankton–aquatic invertebrate–fish [7]. Brine shrimp may be particularly well suited to evaporation basin cultivation as they are hardy, easy to grow, thrive in hyposaline conditions, and are relatively easily marketed. Brine shrimp can be harvested as cysts, live biomass, or processed as dried flakes, and marketed overseas. Commercial *Artemia* production already exists in the Philippines, USA, Vietnam and Australia. Beta-carotene from *Dunaliella salina* requires brine of 200,000 mg/l, some nutrients (phosphorus and nitrogen), a salt bed in culture ponds to 5 cm, overlain by brine to 20 cm, and some "fresher" water (30,000 mg/l) to augment brine supplies [8]. Solar pond technology has been progressing significantly over the last 30 years, with 60 installations around the world. Solar-pond-powered desalination has been investigated in detail at El Paso, Texas, since 1987 with a 3000 m^2 pond linked to a three-effect, four-stage flash distillation unit [9].

Salts have been produced from saline waters for centuries. Al-Mutaz and Wagialla [10] noted that projects had been established 10 years previously in Kuwait and Abu Dhabi to utilise desalination plant brine. The SAL-PROC process, described in greater detail in the following section, has direct application here.

SAL-PROC is an integrated process for sequential extraction of dissolved elements from inorganic saline waters in the form of valuable chemical products in crystalline, slurry and liquid forms. The process involves multiple evaporation and/or cooling, supplemented by mineral and chemical processing. No hazardous chemical is used in the process. The technology is based on simple closed processing and fluids flow circuits, which enable comprehensive utilisation of inorganic saline streams to produce a group of valuable chemicals from one or more saline streams, while minimising waste discharge requirements. The SAL-PROC has gone through over 10 years of technology development and improvements. Recent large-scale pilot trials and public demonstrations have confirmed the capacity of the technology to completely consume a number of saline waste streams for recovery of saleable chemical products, while achieving zero effluent discharge to the environment [11].

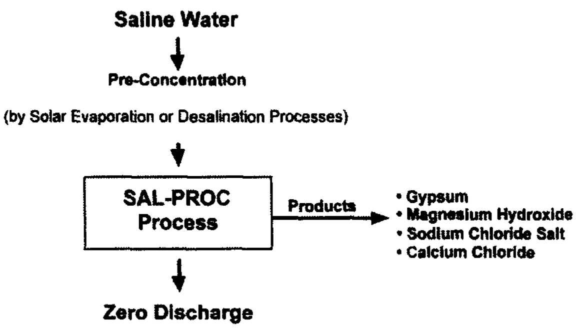

Fig. 1. A typical SAL-PROC process.

Fig. 1 represents a typical SAL-PROC™ process route and the chemical product streams commonly derived in the treatment of seawater-type saline streams. As shown in this diagram, the sodium chloride (halite) salt is only one of a range of the chemical products of commercial value which may be obtained by using this technology. Saline waters vary in their chemical composition and would therefore produce different product streams in the SAL-PROC process.

The chemical products recovered using SAL-PROC™ technology are high quality and in demand by various industries. Independent market evaluations of SAL-PROC products have identified the following application areas:

- Feedstock, fillers, reagents, coating material and supplements for:
  - Animal dietary needs
  - Fire retardants
  - Manufacture of magnesium metal
  - Manufacture of light-weight and fire-proof plaster boards and other building products
  - Manufacture of salt-tolerant building footing, wall panels and other construction products
  - Various applications in food and chlor-alkali industries
  - Applications in tanneries
  - Production of quality paper products
  - Manufacture of plastics, paint, ink, and sealant products
- Soil conditioners for remediation of sodic and acidic soils
- Sealants for irrigation channels and earthen ponds
- Premium stabilisers for road base construction
- Flocculating agents for water/wastewater treatment
- Dust suppressant

Table 1 provides further details on markets for specific products. It should be noted that these data are based entirely on Australian market demand and product prices.

The overall objective of this study was to investigate the possibility of commercial production from salts of reject brine of some inland RO desalination plants in Oman operated by Petroleum Development Oman (PDO). More specifically, the feasibility of commercial salt production was investigated using the SAL-PROC process of sequential extraction of dissolved elements from saline waters.

2. Methodology

PDO operates 14 desalination plants at eight locations with installed capacity to produce more than 7,000 m^3/d of fresh water [11]. Inevitably, large quantities of reject brine are also produced. Disposal of reject brine is an integral part of the overall desalination process. Various disposal options such as reinjection, lined and unlined evaporation ponds and natural depressions (lake) are currently being used in the disposal of reject brine from these desalination plants (Table 2). It is the policy of PDO to manage its operations in a systematic way complying with local regulations and minimising environmental impact. RO plant reject in PDO is managed in line with this policy. A combination of techniques is used for RO plant reject management. Primarily re-injection back to the aquifer is practiced. Where there are constraints, other techniques such as lined evaporation ponds or disposal along with

Table 1
Potential products from treatment of reject brine from PDO-operated RO facilities and relevant market information (quoted product prices are in Australian dollars)

Product name	Chemical composition	Physical form	Indicative price, $	Potential applications/markets
Gypsum–magnesium hydroxide	$CaSO_4.2H_20$ $+Mg(OH)_2$	Fine grain slurry	150/t	• Sodic soil remediation • Fertiliser additive • Drip feed application
Magnesium hydroxide	$Mg(OH)_2$	Fine grain slurry	400/t	• Wastewater treatment • Agriculture • Cattle feedstock additive • Refractories
Sodium chloride (halite)	NaCl	Crystalline salt	70/t	• Food processing • Agriculture • Chlor-alkali
Precipitated calcium carbonate (PCC)	$CaCO_3$	Fine grain, crystalline	300–900/t	• High value paper coating pigment • Filler in plastics paint, ink, and sealant production
Sodium sulphate	Na_2SO_4	Crystalline	170–200/t	• Pulp and paper industries
Calcium chloride	$CaCl_2$	Concentrated solution (35–38%)	220/t	• Road base stabilisation • Sodic soil remediation • Dust suppression • Drip feed application

Note: 1 AUD = 0.55 USD.

Table 2
Basic data on the desalination plants

Items	Bahja	Nimr	Marmul	Rima
Year of operation	1996	1996	2000	1996
Purpose	Domestic	Domestic	Domestic	Domestic
Capacity (m^3/d)	600	850	1500	300
Method of desalination	RO	RO	RO	RO
Source of water	Groundwater	Groundwater	Groundwater	Groundwater
Recovery rate (%)	65	65	75	65
Disposal method	Reinjection	Reinjection	Reinjection	Evaporation pond
Rainfall	Very little	Very little	Very little	Very little
Land use around the plant	Desert	Desert	Desert	Desert
Any specific regulation followed regarding waste disposal	No	No	No	No

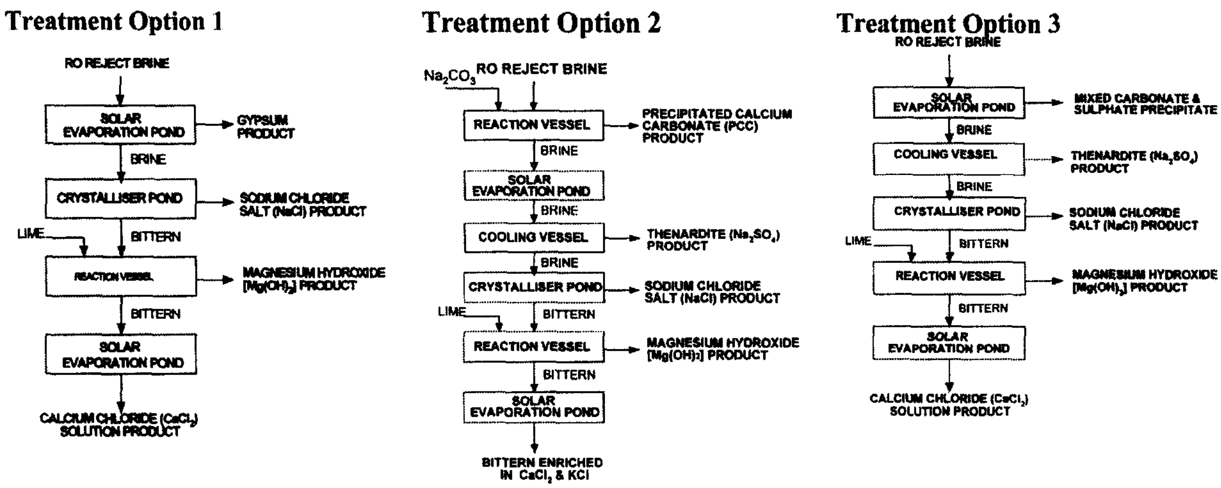

Fig. 2. Proposed process routes for the treatment of reject brines generated by PDO-operated RO desalination plants.

other oil industry production water is practiced. Chemical analyses of reject brine show that the desalination process does not lead to enrichment of reject brine with any particular major ion. Salinity of reject brine showed a high degree of variability [11].

A desktop pre-feasibility study using available information (for plants in Bahja, Rima, Nimr and Marmul) confirms the technical feasibility of treating reject brines in simple processing routes using the SAL-PROC technology. Based on this analysis, it is clear that various types of salts including gypsum, sodium chloride, magnesium hydroxide, calcium chloride, calcium carbonate, and sodium sulphate could be produced. These four plants have significant variations with regard to reject brine quality parameters such as TDS, chloride, bicarbonates, etc.

Proposed reject brine treatment options — Based on available data on the chemical composition of brine streams and their output volumes for four of the PDO-operated RO plants, three process routes were proposed for the treatment of reject brines. These are schematically shown in Fig. 2 and an indication of the reagent requirements for each of these options for the treatment of saline reject from each of the RO facilities are given in Table 3.

Table 3
Indicative reagent usage for each SAL-PROC treatment option

RO plant	Option 1 Lime (t/y)	Option 2	
		Lime (t/y)	Na_2CO_3 (t/y)
Bahja 1 & 2	110	60	500
Rima	90	48	325
Nimr 1 & 2	130	70	538
Marmul 1 & 2	43	NA	NA

It should be noted that the bulk of land area needed for operation of the treatment plant is for solar preconcentration, temporary storage ponds and sodium chloride salt harvesting.

3. Results and discussion

Available reject brine quality data (Table 4) from desalination plants at Bahja, Rima, Nimr and Marmul were collected and annual salt load calculated (Table 5). The indicative yields of products from these brines, using the proposed treatment options, are given in Table 6. An analysis of data in Tables 1, 5, and 6 shows that

Table 4
Reject brine quality data for the PDO-operated RO desalination plants

Constituent	Bahja 1	Bahja 2	Rima	Nimr 1	Nimr 2	Marmul 2	Marmul 1
TDS	23,500	22,800	25,750	19,600	19,140	4,570	4,510
Total alkalinity	27	19	358	618	595	403	396
Calcium hardness	4,800	4,450	7,160	4,150	3,775	1,303	1,287
Magnesium hardness	1,772	1,895	2,760	1,417	1,269	761	795
Total hardness	6,572	6,345	9,885	5,567	5,044	2,664	2,082
Calcium	1,920	1,780	2,850	1,660	1,510	522	515
Magnesium	430	460	670	344	308	185	193
Sodium	6,030	5,860	5,600	5,045	5,100	750	740
Potassium	215	225	152	143	140	32	32
Bicarbonate	33	23	437	754	725	491	483
Sulphate	2,944	2,857	2,806	2,223	2,137	1,700	1,672
Chloride	11,945	11,613	13,438	9,788	9,567	1,106	1,125
Nitrate	10	15	14	16	16	15	16
Total iron	0.68	0.58	0.35	0.32	0.3	0.16	0.12
Manganese	0.05	0.05	0.05	0.52	0.32	0.03	0.03
Reactive silica	21	14	15	19	13	16	11
Strontium	1.4	1.2	1.82	0.8	0.9	1.38	1.48
Fluoride	0.38	0.45	0.45	0.4	0.36	0.37	0.47
Theoretical TDS	23,533	22,837	25,766	19,617	19,155	4,573	4,548
Total ions	23,550	22,849	25,985	19,994	19,518	4,819	4,789
pH Value @ 25°C	4.43	3.86	6.75	6.7	6.77	7.34	7.3
Electrical conductivity, mS/cm @ 25 C	35.5	34.6	38.7	30.6	29.9	6.29	6.3

Table 5
Reject brine quality data, output volumes and indicative annual salt load removal requirements for the RO desalination plants

	Bahja 1 & 2	Rima	Nimr 1 & 2	Marmul 1 & 2
Reject brine average salinity in TDS, g/L	23.1	25.7	19.4	4.5
Reject brine output volume, ML/y	75	45	135	150
Annual salt load discharge, tpa	1730	1160	2600	680
Specific feature	Very low bicarbonate content	Low bicarbonate content	Low bicarbonate content	Low salinity, low magnesium ion content, relatively high bicarbonate content

by processing 405 ML of reject brine per year it would be possible to produce commercial salts worth US $895,000. This is the most optimistic scenario. A detailed cost benefit analysis has not been performed at this stage.

The annual salt load disposal requirement (Table 5) is one of the key parameters in sizing the scale of treatment facility required for the partial or total salt load removal from each site. Despite the relatively larger volume of reject

Table 6
Indicative annual product yield from each RO reject brine source

Treatment options	Bahja 1 & 2	Rima	Nimr 1 & 2	Marmul 1 & 2
1:				
Gypsum, t	350	204	475	
Sodium chloride salt, t	1000	510	1385	
Magnesium hydroxide, t	75	68	97	
Calcium chloride	240	295	385	
2:				
Precipitated calcium carbonate, t	370	320	532	
Sodium sulphate, t	225	130	304	
Sodium chloride salt, t	1100	560	1850	
Magnesium hydroxide, t	35	36	51	
Bittern, ML	1.5	1.0	2.5	
3:				
Gypsum and magnesium carbonate admixture, t				220
Sodium sulphate, t				180
Sodium chloride salt, t				115
Magnesium hydroxide, t				37
Calcium chloride, t				55

brine produced by the Marmul desalination twin plants (Table 5), and hence, larger land area requirement for its pre-concentration, the capacity of the treatment plant itself would be the smallest of all four sites because of a smaller salt load removal requirements.

To make a detailed and comprehensive feasibility study, further data and information are needed, which is discussed in more detail below.

1. Composition and concentration of various chemicals that are added to the feed for pretreatment and/or the chemicals used for RO membrane cleansing. It is understood that most of such chemical additives find their way into the reject brine, and that no attempt has yet been made to assess the impacts of such additives on the reject brine quality, nor to assess the variation in operational conditions at each RO plant site on the reject output. If there are significant variations in the operation conditions, then the effects may need to be assessed in the context of possible effects on the quality and yield of chemicals produced by the treatment plants. However, these effects are expected to be insignificant in the case of conventional SAL-PROC process route (Process Route 1 in Fig. 2), because the bulk of impurities is expected to be removed with the gypsum precipitated in the first step of reaction of reject brine with hydrated lime.

2. Climatic data (primarily temperature, humidity, rainfall and pan evaporation) which are needed for any detailed study, particularly for sizing the operation ponds and related cost estimations for evaporation and crystalliser ponds.

3. The attractiveness of the SAL-PROC technology relates to its use of waste effluent (as a resource) and certain low-value chemicals as the reagents for the recovery of saleable chemical products which collectively offer higher return from their sale, commonly surpassing the cost of the operation. In the case of treatments options proposed for the PDO-generated reject brines, hydrated lime and sodium carbonate (soda ash) are the two main consumables. Fresh water would be needed for washing the magnesium hydroxide and sodium sulphate products

according to product quality requirements by the local and regional markets.

4. In the salt processing plants, the main usage of electricity would for the operation of pumps and agitators in the chemical reactors and fluid transfer circuits. The conventional salt effluent conversion plant is a low electricity user treatment facility. Where the process route involves a cooling circuit for salt crystallisation or a drying circuit to produce powder products for certain market segments, then access to local availability of waste heat could provide significant economic advantage and opportunities for production of other value-added products. This particularly applies to Treatment Options 2 and 3 shown in Fig. 2, which would require an energy source for cooling the liquors to sub-zero temperatures to recover sodium sulphate product.

5. Saline treatment facilities require land for establishing various ponds to pre-concentrate and store the solutions and also to crystallise and harvest the sodium chloride salt. The area requirements vary according to initial concentration and volume of the saline solution, and also the enhancement methods used for pre-concentration (recycle through desalination process or enhanced evaporation techniques).

6. Institutional factors need to be incorporated into the overall design of technical solutions. A robust model for technological development will often include private industry (providing entrepreneurial skills), research organisations such as universities (to provide the latest technological developments) and government agencies (to ensure that "public good" considerations are met and provide some measure of longer term security).

4. Conclusions

A pre-feasibility study, using the available information (for plants in Bahja, Rima, Nimr and Marmul), confirmed the technical feasibility of treating reject brines of inland RO desalination facilities in simple processing routes using the SAL-PROC technology. Based on this analysis, it is clear that various types of salts including gypsum, sodium chloride, magnesium hydroxide, calcium chloride, calcium carbonate, and sodium sulphate can be produced. These chemical products, produced using SAL-PROC technology, are of high quality and are in demand by various industries. A comprehensive feasibility study will be required before a decision can be made with regard to the setting up of salt processing plants using reject brine from desalination plants.

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