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Salt production from brine of desalination plant discharge

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ABSTRACT

Desalination in the Gulf Cooperation Council (GCC) countries is a growing industry to match the requirement of population growth and the high water demand. This activity however, may generate an environmental impact due to discharge of the brine into the sea and to the chemical utilized during the process operation. The brine can potentially affect marine life and ecology in the proximity of the plant discharge. The seawater salinity is increasing due to the high evaporation rate and to the number of desalination plants growth in the region. One possibility is to reuse brine from desalination plants in a salt plant to produce sodium chloride required for exploration as well as in oil refining process; this should be done in order to protect the environment and to produce a commercial and utilizable salt with a competitive price. The paper presents a technical and economic study to reuse the brine to try to reduce the negative impact of the brine discharge.

Keywords: Brine discharge; Desalination plant; Brine reuse; Salt

1. Introduction

Seawater desalination plants, based on either evaporative or membrane processes, produce fresh water that fully meets the drinking water quality standards set by various countries in the world [1]. These technologies are largely used in the Middle East, particularly in the GCC countries where water shortage problems have been increased by the rapidity of the population growth and the expansion of the industrial and agricultural activities. The aim of Gulf countries to meet the present and future water demand has highlighted the importance of desalination technology.

Desalination is now successfully practiced in numerous countries in the Middle East, North Africa, southern and western US, and southern Europe to meet industrial and domestic water requirements. Seawater desalination represents the most relevant supplementary non-conventional water source for countries like United Arab Emirates; it covers 98% of domestic supply [2] in Middle East countries.

All desalination methods are limited by the disposal cost of concentrated brines produced and by the adverse impact of brine composition on the environment. The use of evaporative and/or reactive methods in integrated seawater desalination systems is expected to enhance the recovery of valuable salts in the feed streams, to increase the recovery factor of fresh water, and to reduce the environmental impact of discharged brines on the marine habitat [3].

The characteristic of reject brine is directly related to the quality of the feed water, the technology adopted, the recovery rate and the chemical additives [4]. In particular, the major constituents of reject brine are inorganic salt but different processes technologies generate differences in brine quality; in addition to the inorganic salt, small quantities of chemicals like antiscalant or acid and other reaction products used in pre-treatment, chlorination

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and de-chlorination and other phases of the desalination process can be present in significant concentrations.

In a dry arid–semi-arid regions the rainfall is less that 100 mm/y and the summer shade temperature frequently exceeds 40°C. Several areas in GCC countries have very high evaporation rate equal to 2000–3000 mm/y, a value higher than the Sahara region. In relation to these conditions one of the possibilities to reduce the brine discharge is to reuse it for the production of sodium chloride by means of solar–thermal processes.

2. Objective and methods

Salt is a widespread product obtained from a variety of sources (rock and solution mining, solar evaporation, mechanical processing etc.) and is used for many purposes, including chemical and industrial applications.

Sodium chloride (NaCl) runs around 77% of the total dissolved salt in seawater, therefore an adequate process can recover it from brine reject, preserving the environment. The scope of this paper is to identify a technically and commercially profitable solution, which could be used in industrial processes, for example oil field exploration, boring as well as in oil refining processes.

In particular, the scope of this paper is described herewith:

- Evaluate the possibility of producing NaCl as a by-product of the existing desalination plant, by extraction from brine, at an economical cost and to market the product at a reasonable and profitable price.
- Support environmental protection from the discharge of desalination plant effluent to the sea, and determine the most suitable method for the disposal of bitterns after salt extraction.

This study will assess and evaluate the above and propose the most appropriate and suitable method of achieving the project objectives.

3. Discussion

A brief analysis identified possible methods of disposal for the brine discharge:

- Ocean: it has been the most common brine disposal process until now; several systems have been adopted to decrease the environmental impact of the discharge.
- Ground disposal: such systems often involve the acquisition of land and pipeline construction to deliver the waste streams of large desalination facility. Even in high recovery processes, volumes of highly concentrated discharge streams can be too large to be stocked. Moreover, these systems shall be conformed to regional and federal environmental constraints.
- Deep well injection: this method of brine disposal is considered the most cost-effective as compared to other systems in practice for land based desalination plants [5].
- Recovery of the by-product through processes tailored on the product to be recovered.
- Usage of saline effluent as a culture for bio-processes to obtain by-products in agriculture, forestry, fauna, algae production, minerals and energy production [6].

Processing the brine has the potential of delivering economic benefits like decreasing costs of desalination, producing a marketable by-product and protecting the environment.

All the options related to the reuse of brine for fauna and algae production was discarded: the presence of metals and other contaminants in the desalination plant reject in considerable concentration lead to foresee possible bio-accumulation phenomena. Moreover since no data from long-term pilot plant were available during the present study, different industrial applications were considered.

Salt applications in industry are numerous and include the chlor-alkali industry, water treatment, chemical manufacturing, aluminium smelting and oil drilling. In the latter purified sodium chloride, characterized by high purity, low sulphate and calcium ions, is utilized to lubricate and cool the drilling system during the drilling activities.

One of the first objectives is to identify the type and purity grade of salt to be produced for industrial purposes and commercial drilling operations. The quality of the salt that can be produced by industrial desalination and further crystallisation processes depends on the type of the technology that is adopted.

4. Salt precipitation in seawater

The concentration of dissolved salts in seawater varies with the depth of the water and location, but on average it is about 3.5 wt. % (3.6°Bé). The Baumé scale is a hydrometer scale to measure density of various liquids, unit measure are degrees Baumé or °Bé: it depends on the temperature and it represents the percent by mass of sodium chloride in water at 60°F. Calcium carbonate ($CaCO_3$) is less soluble in concentrated brine and when the brine reaches that point, calcium carbonate precipitates, leaving other solutes dissolved in the brine. Usually, by 13°Bé, soluble iron, calcium and magnesium carbonates are crystallized. Next, calcium sulphate is crystallized between 13 and 25.4°Bé. Crystallization of sodium chloride (NaCl) begins once the concentrated seawater reaches 25.4°Bé. Ideally, sodium chloride precipitation should occur between 26°Bé and 29°Bé. Until above 30°Bé has been reached, the high levels of magnesium in solution reduce the evaporation rate and the deposition process will continue till complete evaporation.

5. Overview of technologies

In order to recover salt from brine discharged from desalination plants several technologies can be considered such as:

- Solar technologies
- Membrane technologies
- Thermal technologies

Several processes are based on them:

- Evaporation pond
- Solar pond
- NF/UF/RO
- MED
- Crystallizer
- Salt washery

The following sections describe those processes in detail and highlight advantages and disadvantages of each.

5.1. Evaporation pond

Evaporation ponds consist of excavated depressions in the ground which often are the final destination of the concentrate if the residual solids are not collected and disposed elsewhere. Previous studies have shown that for sites where environmental conditions present a very high evaporation rate, alt-gradient ponds are less costly than the other solar options.

A good solar salt works consists of a series of ponds with embankments, into the first of which saline water from the sea or brine as in this case, is drawn. The function of these concentrating ponds is to increase the salinity of the brine that is slowly flowing through them, to the point where salt will crystallize. This technology is most favoured in the Gulf countries where the following site conditions prevail [7]:

- Strong solar radiation.
- Low precipitation.
- Low cost desert land.
- Short and easy transport to ports.
- Accessibility to Asian markets, which are large consumers of salt.

The principal environmental concern associated with evaporation pond disposal is pond leakage, which may result in aquifer contamination. All current installations reported in the literature are lined with polyethylene or various other polymeric sheets [8].

5.2. Solar pond

It is a similar process to the evaporation pond but in this case brine does not flow.

Salt gradient established generates different layers. There are three different areas:

- The top zone is the surface zone which is at atmospheric temperature and has little salt content.
- The bottom zone is very hot (80°C) and salty (TDS = 200 g/l). It is in this zone that solar energy is collected and stored in the form of heat.
- The intermediate zone is where the salt content increases from the top to the bottom, thereby creating a salinity or density gradient.

Given that water, salt, solar radiation and flat land are readily available and that there is a valuable use for the thermal energy, a solar pond becomes attractive as a source of renewable energy. The solar pond can be therefore used as a heat exchanger and combined with a thermal process can permit salt concentration, since MED and MSF can operate efficiently at temperatures provided by the solar pond.

This technology produces good quality of salt and produces sustainable energy, however it requires large areas for the plant and high energy consumption for brine piping.

5.3. Membrane technologies (NF/UF/RO)

These technologies require a small area, they have low environmental impact but have a large capital cost and required qualified personnel for operation and maintenance. Membrane with different pore size and different configuration can be used as different steps of salt production:

- Nanofiltration (NF) systems are designed to reduce specific divalent compounds and hardness, including sulphates, calcium and magnesium and to provide an increased NaCl percentage in the concentrate. This results in reduced operating costs per ton of salt in the salt plant. In addition, the overall TDS is reduced, giving a lower osmotic pressure in the SWRO system providing higher recovery and lower energy consumption.
- Ultralow pressure reverse osmosis has become increasingly popular due to the decrease in energy requirements. Although the cost for replacing the membrane is higher than in traditional modules, the ULPRO energy requirements are much lower, making this new advancement more desirable than traditional reverse osmosis.
- The vibrating membrane filtration system known as vibratory shear enhanced process (VSEP) is based on the vibrational oscillation of highly focused shear energy at the membrane surface. The vibrational shear prevents the deposition of colloidal material in proximity to the membrane and maintains them in the vibrational membrane system for further processing

5.4. Thermal technologies

Concentrators (thermal evaporators) produce vapour from boiling the concentrate in a pressurized vapour compressor. The compressed vapour is then recirculated into the heat exchanger until reaching 90–98% evaporation of the concentrate; the salt product has a high grade of purity and is valuable for commercial applications. Vapour compression driven concentrators use about ten times less energy than steam evaporators.

In this process, water is evaporated from purified brine using multiple-effect or vapour recompression evaporators. Multiple-effect (e.g. calandria evaporator) systems typically contain three or four forced circulation evaporating vessels connected together in series. Steam from boilers supplies the heat for evaporators and is fed from one evaporator to the next to increase energy efficiency in the multiple effect system.

The principle of operation of the thermal plants is based on an initial stage consisting of evaporator/concentrator system that collects MSF blowdown brine and produces and concentrated salt solution as feed to the crystallizer and a distillate stream consisting of purified water.

The next stage is crystallisation: the system starts with brine purification step; purified brine is then filtered and sent to the crystallizers for salt production.

The crystallization process is arranged in two stages:

- Stage one is concentrating the purifying brine and crystallizing on concentration limit of $CaSO_4$.
- Stage two uses the purge of stage one, after purifying it in Ion exchangers, to produce pure salt. Its limit of evaporation is the precipitation of potassium. The purge from this crystallizer flows to the plant waste stream.

In the end, advantages of thermal process are a high purity of salt and a small area requirement; on the other side the process is much more power intensive than other ones.

5.5. Salt washery

Salt purification starts by taking the least valuable salt fraction, the fines, and dissolving them in a small amount of water, forming pure saturated brine. Subsequently, the brine flows slowly and upwards, through a layer of downwards moving salt crystals. Each salt crystal is completely encompassed by pure brine so that every soluble solid impurity has the opportunity and time to dissolve. Also the impurities entrapped in the crevices have enough time to leave.

The last step in the salt purification process takes place in a centrifuge. The centrifuge of a vibrating resonance type gives salt with an economical minimum of moisture. Centrifuges produce salt fines by mechanical abrasion. The fines are utilized for production of pure brine in a dissolving vessel. From there the pure brine is returned to the vessel from which the salt and brine flow to the centrifuge.

5.5.1. Salt production process

Different plant configurations can be obtained, combining the different technologies and processes described above. In Fig. 1 there is a resuming scheme of more suitable layouts.

Table 1 summarises the costs, requirements and outputs of the technologies described above.

Each layout may be suitable depending on the constrains and requirements of different scenarios. For example in the Middle East solar technology represent the most economic choice, supported by high solar radiation and easy availability of desert and flat land. However

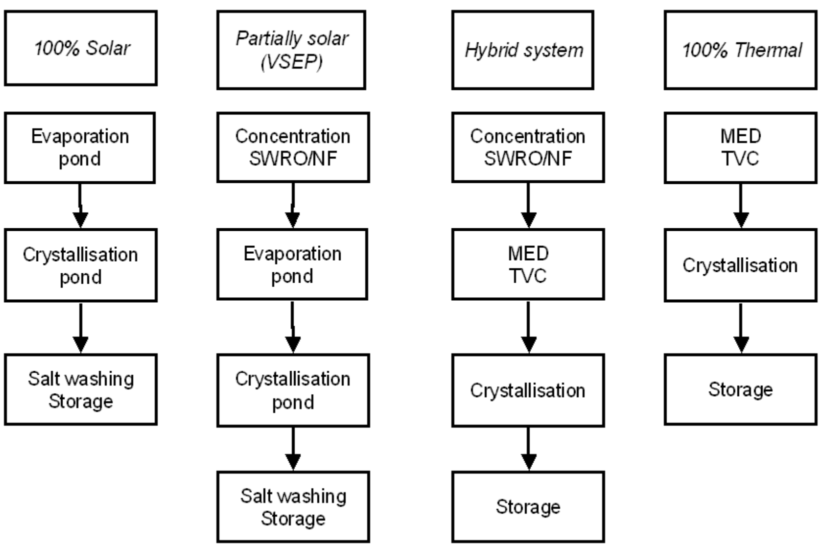

Fig. 1. Layout for salt production process.

Table 1
Operational parameter summary

Parameter	100% Solar	Partially solar	Hybrid	100% Thermal
Land usage	High	High	Medium	Minimal
Electrical energy usage	0(*)	Medium	High	High
Thermal energy usage	No	Medium	High	High
Capital costs (**)	0.7 M$	1.5 M$	2.5 M$	2 M$
Operational costs (**)	$ 10,000/y	$ 40,000/y	$ 70,000/y	$ 60,000/y
Produced salt quality	Bulk type NaCl, could be improved by adding further processing	Bulk type NaCl, could be improved by adding further processing	High purity	High purity
Additional sweet water production	No	Yes	Yes	Yes

(*) excluding the costs of pumping the brine to the evaporation pond
(**) estimations based on a plant with a capacity of 1–2 MIGD treated brine

the salt produced is not a high purity salt therefore an additional step of purification maybe required and this is subject to the industrial process in which the salt shall be utilized.

Wherever additional water production and limited area may be edging parameters, hybrid or thermal option can be the best solution; notwithstanding, giving the increasing cost of energy and steam production, these technologies will be anti-economic.

The environmental advantage of brine discharge reduction given by salt production from desalination plant effluent should be compared with the marketability of the produced salt. If the salt produced will not have a market, unrequested product will be generate and in this case there will be a movement of the pollution instead of a real environmental protection.

In order to evaluate the possibility to have a market for the salt to be produced information related to import market of salt in UAE, as a local sample of world business, has been collected and investigated.

The trend of salt market has been highlighted in Fig. 2.

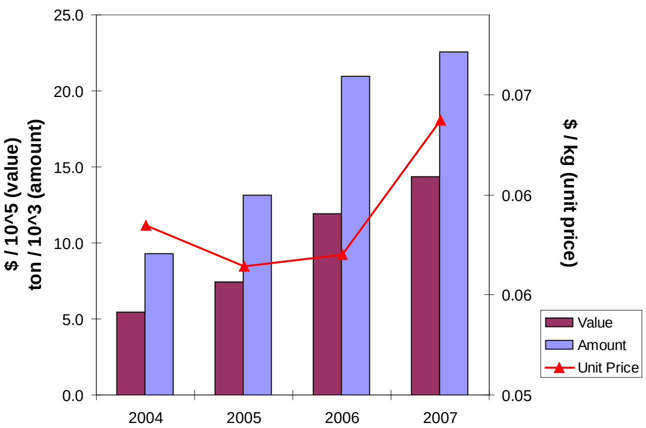

Fig. 2. Sodium chloride UAE import.

Fig. 2 shows that in the last few years there has been a continuous increase of the cost and quantity of salt imported is estimated that 70% of the salt imported utilized for oil and drilling purposes and therefore a brief calculation has been conducted to investigate the real possibility of cost saving by the utilization of salt produced by brine discharge instead of utilising imported salt for drilling purpose.

The premises of salt production have been:

- Feed brine with 6% of salt concentration, which is a typical concentration of MFS blowdown;
- Salt recovery of the overall process around 70%; this includes losses due to bitterns, salt depositions, salt washery, etc.
- A constant feed flow of 1 MIGD.

With above hypothesis, the salt production would be around 197 ton per day of bulk quality salt or either 190 ton per day of high purity salt. Such production is almost three times the present request for high quality salt in a country like UAE.

This calculation lead to conclude that salt production from desalination brine is not likely to find markets that can utilize the entire production; as it is demonstrated a small production can be an economic option to reduce Middle East salt import and can reduce the dependence from a growing market.

6. Conclusion

The quantity of brine discharges from desalination plant has been sensibly increasing for the last 15 years and this trend will be maintained in the near future.

The possibility of brine re-use shall be further investigated starting from the basic processes like salt production till new solutions like utilization of brine as a culture for grow of spirulina or other organisms for the processing of important products in pharmaceutical sector.

However this solution was investigated but not taken in consideration due to the possibility of bio-accumulation.

The idea of using brine to produce by-product for industrial processes shall be considered in a future study for economic feasibility analysis.

The proposed method uses saturated brines at least five times more concentrated than seawater and produces some chemical products of potential value on top of partially desalted water.

In this regard, the method should be considered as a novel approach rather than a competitive one to the traditional thermal, chemical and membrane processes.

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