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Review

A review of sources, effects, disposal methods, and regulations of brine into marine environments

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ABSTRACT

Sources, effects, disposal methods, and environmental regulations of brine are critically reviewed. Desalination is one of the main sources of brine in the world. Other sources of brine include solution mining of salt domes, and oil and potash mining. In addition to high salinity, brine may contain toxic substances such as lead, zinc, copper, arsenic, and naphthalene. Research has shown that small changes in salinity and temperature could have a significant impact on marine ecosystems. Due to their high dilution capabilities, multiport submerged diffusers are nowadays considered the most practical solution to protect marine life from harmful effects of brine and heat. Currently, the discharge of dense brine is usually controlled by allocating large mixing zones around the point of discharge. Mixing zones are, however, not always suitable to be applied in environmentally sensitive areas. In sensitive areas and for the case of brine containing toxic substances, more stringent regulations based on well defined minimum return dilution at the level of the source are recommended.

1. Introduction

Brine (hot salty water) is a main by product of many industrialized and mining processes. During the last few decades, production of brine in the world has increased exponentially due to rapid increase in various industrialized and mining processes. New environmental regulations related to brine have also emerged in various parts of the world due to increased environmental consciousness. Disposal of brine is different than urban effluents as brine is generally not allowed to be discharged into freshwater resources. Selection of a suitable brine disposal method, to satisfy existing environmental regulations, plays an important role in the feasibility of a brine producing industry. Moreover, accommodation to future environmental regulations is also an important issue in the planning of an industry. Review of brine environmental regulations is, therefore, helpful in providing general principles and pertinent information on both current and future regulations trends. Review of brine disposal methods is also helpful in choosing suitable disposal systems based on economy, environment, and technical feasibility at a specific location.

Brine is produced in various quantities by many industrial processes. Understanding the main sources of brine and their impact on the environment are important to develop and implement appropriate environmental policies by environmental protection agencies.

There is a need to clarify misconceptions about the detrimental effects of brine. In particular, the general public often believes that disposal of brine into the sea is not affecting marine life since the sea is already saline. Although brine (in slight quantity) does not appear harmful to marine life in the short term, the long term environmental effects on marine life are well recognized in the scientific community (Einav et al., 2002; NOAA, 1978; Gacia et al., 2007; Matsumoto and Martin, 2008; Talavera and Ruiz, 2001; Pillard et al., 1999; Mabrook, 1994).

An effort is required to inform the general public and policy makers on short and long term environmental impacts of brine when discharged into the sea. This effort would help raise public awareness on environmental issues related to brine disposal and drive the development of new environmental regulations in many countries where they are lacking.

Brine disposal into the sea is certainly the preferred method of managing waste brine when industry is close to the sea. Current brine disposal systems have various layouts and dimensions depending on different constraints, regulations, and design parameters. A review of typical existing marine disposal systems provides some guidelines to design new disposal systems.

The objectives of the present review on management of brine in coastal waters are: (i) raise public and policy makers awareness about detrimental effects of brine on marine life (ii) improve design criteria of diffusers by applying the concept of minimum return

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dilution (iii) develop a foundation for new environmental regulations based on minimum return dilution to protect more effectively the marine environment from brine discharges.

2. Sources of brine

Brine is produced during various industrialized and mining processes. The main industrial processes that produce large quantities of brine are:

2.1. Desalination of seawater

Desalination is a process that separates dissolved salt from seawater for the production of freshwater. According to Global Water Intelligence (2006) report's projection, the world's desalinated installed capacity in 2015 could reach 100 million cubic meters per day (i.e equivalent to 1 157 m3/sec) which is more than half of the Niagara Fall discharge. The two major types of technologies, used around the world for desalination, are Multi Stage Flash (MSF) and Reverse Osmosis (RO). In Reverse Osmosis, brine concentration is 1.3–1.7 times that of the original seawater and in Multi Stage Flash (MSF) brine concentration is 1.1–1.5 times that of the original seawater (Einav, 2003). Desalination is popular in coastal areas and has especially increased in the last decade for three reasons: (i) traditional sources of freshwater such as rivers or artesian wells are becoming scarce in meeting the demands of freshwater; (ii) high population growth rate in coastal areas; (iii) new advancements in Reverse Osmosis have reduced the cost of treatment of desalination. According to the Population Reference Bureau approximately 3 billion people, about half of the world population, live within 200 km of coastline areas (Creel and Liz, 2003). More than 60% of the human population lives in the coastal zone, and around 70% of the big cities are located in this narrow area (Report of 3rd international conference on Coastal processes 2013).

2.2. Solution mining of salt dome for hydrocarbon storage

Large quantities of highly concentrated brine (up to 250 parts per thousand (ppt) are produced during solution mining of salt domes (James et al., 1983). Solution mining of salt dome is a process in which a borehole is first drilled through a salt deposit. Water is then injected to dissolve salt, and the resulting highly concentrated brine solution is pumped to the surface. This process requires large quantity of water, equivalent to 8 to 9 barrels of freshwater for every barrel of space created (Bergman, 1984). Salt domes are large subsurface geological structures that consist of vertical cylinders of salt up to 1 km in diameter and several km deep. If salt is removed from salt dome, the created space can be used for storage of hydrocarbons such as oil and natural gas. The walls of the dome are strong and impermeable to hold hydrocarbons (Evans, 2009).

Storage of oil is considered an important economic security for any country which relies heavily on imported oil. After the oil embargo 1973, the United States implemented the Strategic Petroleum Reserve (SPR) program to store one billion barrel oil in salt domes (Andrews and Pirog, 2012). The large salt domes in Gulf of Mexico along the Gulf Coast were selected and the resulting brine from solution mining of salt domes was disposed off shore through a pipe line and diffuser system (James et al., 1983). Underground storage in salt domes is the most economical, safest, and environmentally friendly option when compared to surface steel tank storage. If good rock conditions are available, underground storage of oil is 50–70% less costly than surface storage (Bergman 1984).

2.3. Mining processes – oil and potash mining

Brine is also produced during many mining processes, including potash mining and oil mining. In mining processes, large quantity of freshwater is pumped into the ground to extract minerals. For example, in oil mining, according to the American Petroleum Institute estimate, nine barrel of water is recovered for each barrel of oil during a typical extraction process. Brine of mines contains high salt content and dangerous chemicals, which could be very dangerous for marine life (Roach et al., 1993; Obire and Amusan, 2003; Andreasen and Spears, 1983; Ahmadun et al., 2009; Vonhof, 1975). Disposing the mining producing brine is, therefore, one of the biggest environmental challenges of Canada since it is the largest potash producer of the world with 46 percent of the total world potash reserves (Natural Resource Canada news release 2012). Most potash production in Canada is from Saskatchewan and Nova Scotia provinces. In Saskatchewan deep-well injection and surface storage in ponds are used to dispose of excess brine, and is considered a major source of contamination of ground water resources (Vonhof, 1975; Water Working Group Report, 2012). In New Brunswick potash mining, the brine produced is disposed into the sea and was shown to be harmful to marine organisms (Hutcheson, 1983).

2.4. Rejected brine from salt ponds

Salt ponds, also known as solar salterns or saltworks, are constructed in arid or semi-arid regions all over the world near an ocean to produce salt from seawater. Salt ponds produce rejected brine, also known as bittern brine, is either disposed into the sea or processed further to make other type of salts such as Kcl, Na_2SO_4. Disposal of bittern brine could be more harmful as it contains high concentration of Mg^{+2}, Cl^{-1}, and SO^{-}_4 ions (Baati et al., 2011). However, disposal of bittern brine is not considered as a serious environmental issue in the literature because bitterns are mostly used to make other products. Salt ponds are generally considered as a good option for brine disposal from desalination plant. For example, Seawater Reverse Osmosis (SWRO) desalination plant in Eilat (Israel), was constructed for dual purpose, for the production of desalination water and also for manufacturing high quality salt. The cost of disposal system was avoided as the brine discharge line and other related facilities were not needed. The salt production in this configuration has increased by 30% compared to the salt production from seawater alone (Ravizky and Nadav, 2007). It may not be possible, however, to rely on salt ponds alone to manage the disposal of brine from large capacity desalination plants.

3. Environmental impacts of brine

Brine can be harmful to the environment due to its salinity, temperature, and toxic substances. Salinity (concentration of salts) and temperature of brine depend upon its production processes. Salinity of brine produced by desalination is around 60 parts per thousand (ppt), potash mining is 350 ppt, oilfield mining is 100 ppt, and solution mining of salt domes is 250 ppt (Tong and Stolzenbach, 1979; Hutcheson, 1983; James et al., 1983; Howe et al., 1982). Temperature of brine produced by evaporation technologies such as Multi Stage Flash (MSF) and Multi Effect Distillation (MED) is very high. In Saudi Arabian desalination plants, operational temperature during MSF process ranges between 90 and 115 °C (Al-Mutaz and Al-Namlah, 2002) and cooling water (usually from electric power generation plants) is mixed with the produced brine to reduce the temperature of the discharged brine to within 10–15° C above ambient (Hoepner, 1999). The brine produced by mining processes may also contain toxic substances.