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Potential use of reject brine waste as a sustainable construction material

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Abstract. In countries near the ocean, the majority of the water used for household, agricultural, and industrial purposes is attained through seawater desalination. Desalination produces highly salty water, commonly known as reject brine, which can have many drastic, negative effects on the environment. The waste results in both an environmental challenge and an opportunity for sustainable resource utilization. This research work is a literature study to investigate the feasibility and potential benefits of utilizing reject brine waste as a sustainable construction material. The results revealed that reject brine has a prodigious possibility to be used as a binder, and in place of water in concrete. The use of reject brine in cementitious composites decreases CO_2 emissions and makes them economical. Also, reject brine is fruitful in the stabilization of soil by increasing the mechanical properties and enhance the strength of soil. In essence, the use of reject brine from water desalination in construction is a sustainable and environment-friendly approach.

Introduction

Water is life. Fresh water is essential for living organisms to survive on earth and is increasingly depleted. The increase in population and industrialization lead to an increase in demand for water. About 1.8 billion people around the world will face water shortage by the end of the year 2025 [1]. The countries near the ocean (e.g., gulf countries) lack fresh water and frequently use desalination techniques to produce drinkable water. The produced water is used by human beings and for construction practices as well. Desalination methods include reverse osmosis, multistage flash evaporation, multi-effect distillation, and electrodialysis [2]. These techniques produce pure water but at the same time result in the production of a by-product waste with a high concentration of salt called reject brine. Only 35-45% of freshwater is recovered from the sea, while the remaining 55-65% of gross feed comes out of the desalination plant as waste brine [3]. It is estimated that Gulf countries produce more than 60% of the world's desalinated water with UAE's contribution alone around 13% [4]. The waste is disposed of in open sea and in valuable lands which is a major threat to aquatic life and sustainable development.

Concrete is the 2nd most widely used material after water on Earth. It is an old material consisting of cement, sand, aggregate, water, and suitable admixtures that have been in use for

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many centuries. The large-scale consumption of ordinary Portland cement (OPC) as a binding agent in concrete results in serious environmental challenges and issues because of the significant CO_2 emissions associated with its production. Every 1kg of cement production results in 0.9kg production of CO_2 to the environment [5-7]. The natural fine and coarse aggregates (sand, gravel, etc.) used in concrete synthesis result in their depletion with time. Concrete is a thirsty behemoth, sucking up almost 1/10th of the total world's industrial water usage. By 2050, 75% of infrastructure water demand is expected to occur in areas expected to experience water stress [8]. Therefore, in the past, various research efforts have been devoted to producing substitute construction materials in place of natural ingredients without compromising the strength, durability, and economy to promote sustainable development. A brief description of some of the studies is given in Table 1.

Table 1: A literature review of the use of different alternatives partially in place of cement, sand, and water in concrete

Material to be replaced	Material replaced with	Procedure	Result	Reference
Cement	Waste brick powder	Prepared concrete specimens using 5% and 10% of WBP in place of cement	Workability and compressive strength increased due to the shape and particle size of WBP	[9]
Cement	Marble dust	Studied the use of marble dust collected from marble blocks in concrete mixtures by 5, 10, 15, and 20%	The mechanical properties of concrete increased significantly compared to the control sample	[10]
Cement	Rice husk ash	Addressed the strength characteristics of cement mortar containing 0, 2.5, 5, 7.5, 10, 12.5, 15% RHA	Compressive strength of hardened concrete decreases with increasing RHA percentage	[11]
Sand	Coal bottom ash	Studied the effect of CBA as a replacement of sand in concrete with dosage at 20, 30, 40, 50, 75, and 100%	Workability and bleeding decreased, compressive and splitting strength of concrete did not change significantly	[12]
Sand	Recycled plastic waste	Evaluated the performance of concrete with RPW as a partial replacement of sand in different proportions	Replacing 10% of sand by volume is the best solution, saving 0.820 billion tons of sand every year	[13]
Sand	Fly ash	Concrete samples containing FA in amounts 20, 40, 60, 80, and 100% were cast and tested	Compressive strength, split tensile strength, and modulus of elasticity increased up to an optimum dosage of 40%	[14]
Water	Polyvinyl acetate resins waste waster	Used the industrial wastewater discharged to replace the water in concrete completely	While compressive strength and density increased slightly, the values of slump decreased	[15]
Water	Treated Water and Waste Water	Assessed the strength of concrete using treated water and wastewater	The strength of concrete samples decreased using wastewater but the value is above the standard requirement	[16]

Desalination of Seawater

The amount of calcium, chloride, magnesium, potassium, sodium, and sulphates in seawater are 412, 19500, 1290, 380, 10770, and 905mg/L as compared to potable water containing these minerals in compositions of 75, 250, 50, 10, 200, and 400mg/L respectively. Also, the amount of total dissolved solids in seawater is 33387pm as compared to 500pm in drinkable water [17]. Desalination is the process of removing minerals from salt water. Saltwater is desalinated in order to produce water suitable for human household consumption or irrigation purposes. The formation of reject brine takes place as a byproduct of desalination. There are different methods used for the desalination process all over the world as shown in Figure 1. They meet the needs of more than 300 million people by producing 87 million cubic meters of clean water every day [18]. The schematic procedure of reject brine formation is shown in Figure 2.

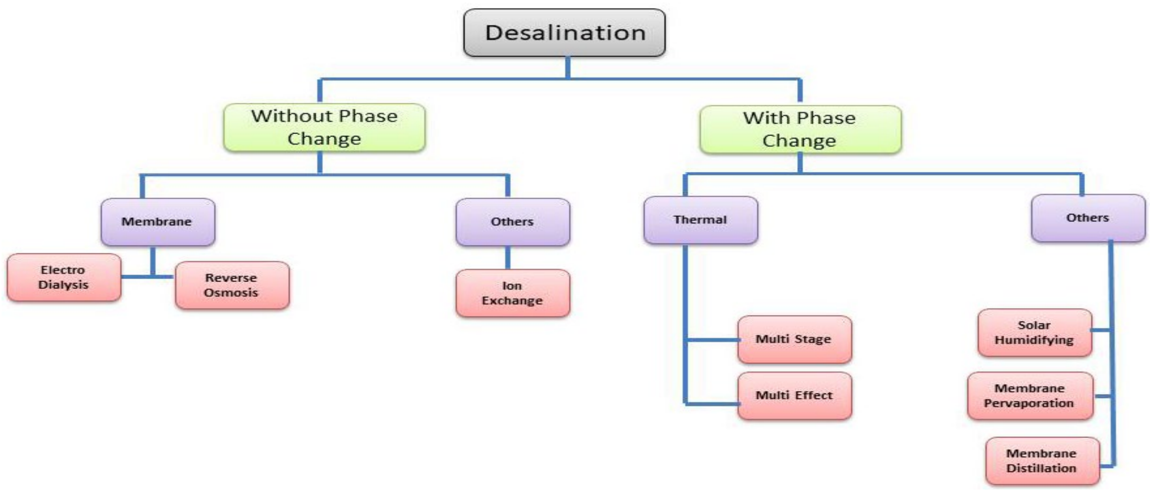

Figure 1: Processes used for desalination [19]

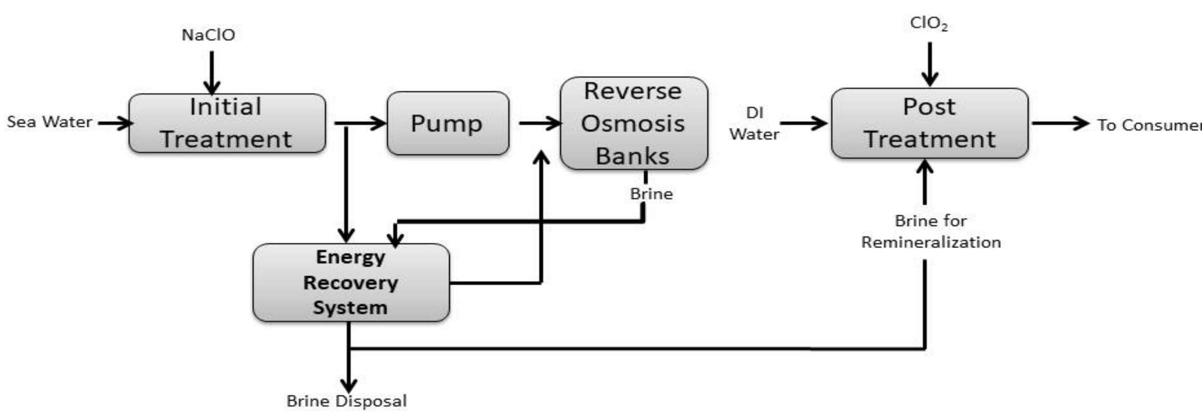

Figure 2: Schematic diagram of reject brine formation [20]

Reject Brine Use in Construction

The study of the feasibility of using desalination reject brine in construction materials has become of growing interest in this modern era. The use of reject brine in making construction materials like concrete, mortar, bricks, blocks, soils, etc. will serve two main purposes. First, natural ingredients consumption in the construction industry will decrease, releasing some pressure on the natural resources which are limited and depleting with time. Second, the brine's harmful ecological and physiochemical influences on the receiving aquatic bodies will be reduced.

Reject Brine as a Binder in Concrete

Cement is the binding agent used in construction projects obtained through the chemical process of limestone, clay, magnesia, silica, alumina, etc. [21]. It gives stability, strength, and durability to materials to guarantee they stay longer. The presence of an optimum percentage of MgO in cement ensures the setting time and strength of the composites [22]. Due to its high magnesium content (Mg^{2+}), waste brine has the character to be used as an eco- friendly and sustainable cause for cement production. S. Ruan et al. (2021) highlighted problems shown with increased emissions of magnesium oxide and carbon dioxide from brine waste. They examined the possibility of producing cement containing MgO (from brine waste) and analyzed its use as a binding agent compared to commercial MgO. The mechanical properties of the specimens were evaluated along with microstructural analysis using X-ray diffraction (XRD), thermogravimetric analysis/differential scanning calorimetry (TGA/DSC), etc. Samples containing higher reactivity magnesium oxide products were found to be stronger than samples containing commercial magnesium oxide products. The increased solubility of synthetic magnesium oxide leads to better hydration and carbonation, leading to a denser structure and structures with improved properties [23].

Reject Brine in Place of Water in Concrete

The process of hydration of cement in cementitious composites is due to the presence of water. Using salt water to prepare concrete is not a new procedure. MS. Islam et al. (2010) emphasized the effect on the setting time of concrete by partially using saline water in place of ordinary portable water [24]. Mori et al. (1981) prepared concrete samples containing fresh water and saline water. They observed a comparatively minor alteration between the mechanical strength of concrete prepared with fresh water and concrete produced with saline water [25]. However, Yamamoto et al. (1980) found that concrete prepared with salty or saline water confirms higher strength compared to concrete containing fresh water [26]. To prevent the chances of metal erosion, V. Kumar et al. (1998) suggested avoiding the use of salty water for reinforced concrete (RC) [27]. However, Dang et al. (2022) studied the long-term concrete exposure to chloride (Cl-) ions and exhibited that the effect of chloride (Cl^{-1}) ions in concrete production from seawater is quite small or insignificant [28]. In another study, F. Qu et al. (2021) determined that corrosion of steel in reinforced concrete (RC) structures is because of sulphate attack occurs not due to the presence of chloride ions (Cl^{-1}) in seawater, but due to the harsh marine environment in which the sample is located [29].

Reject Brine to Minimize CO_2 Emissions from Cementitious Composites

Cement is an important building binding material and its production accounts for 5% of the world's CO2, a powerful greenhouse gas. With the dedication of reducing the carbon footprint of the process of concrete preparation using reject brine, Fattah et al. (2017) conducted research to determine the impact of CO_2 emissions by using brine waste as water and ground- granulated-blast-furnace slag (GGBS) as a cement substitute. Concrete specimens containing different percentages of cement were prepared using ordinary portable water and wastewater containing brine. The results exhibited that the use of reject brine and GGBS enhanced the mechanical strength of concrete formed, because of the high filling character of GGBS. Consuming reject brine as the potential water source and replacing 50% of the cement with GGBS can reduce 3.74–7.5 lbs. of CO_2/cubic meter of concrete, and 388 lbs. of CO_2/cubic meter of concrete respectively. The waste reject brine usage in cementitious composites is an economical approach as it can save about AED 625–1250 per cubic meter of concrete prepared [30].

Reject Brine to Enhance the Strength of Soil

Soil is an important engineering material that serves a major role in the construction of foundations, roadbeds, dams, and buildings [31]. Mathew et al. (2012) studied the effect of increasing brine concentration on soil-bearing capacity. The samples with and without reject brine were prepared and their shear strength parameters were monitored for 364 days. The soil's bearing capacity was calculated using numerical equations. The more the contamination of soil with brine, the more decrease in the bearing capacity [32]. Kuriakose et al. (2022) researched to make use of the brine waste generated from the desalination of water for the steadiness of soil. The brine sludge was mixed with marine clay at various percentages by the dry weight of the moist clay. It was found that brine sludge can be used as a substitute in the stabilization of soft clays as it improves the geotechnical properties of soil [33]. S.L. Barbour et al. (1993) evaluated the geotechnical properties of two Ca-montmorillonite clayey soils having brine adulteration. The changes in mechanical properties (shear strength, bearing capacity, etc.), index properties (liquid limit, plastic limit, etc.), and hydraulic properties by the incorporation of reject brine were determined. A significant increase in shear strength and bearing capacity was reported [34].

Conclusion

In conclusion, this study proved that reject brine has great potential to be used in construction materials, in the formation of cement, mortar, concrete, bricks, soils, etc. It will be a great source to enhance the mechanical and durability properties of cementitious composites and also make them economical. This will in turn reduce the consumption of natural water and get rid of waste brine which is a serious concern in this modern era for the countries near the ocean. The use of reject brine in the construction industry will surely be a sustainable and environment-friendly approach in the future. Future studies by the research team are directed at defining the long-term performances of reinforced cementitious materials through carbonation tests, freeze and thaw tests, sulphate attack tests, rapid chloride ion penetration tests, sorption tests, etc. There is a great possibility of checking the feasibility of reject brine in the manufacture of bricks and also the treatment of soil with brine might enhance its properties.

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