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Feasibility of Reverse Osmosis Desalination Brine as Artificial "Dead Sea" Pool Water

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Abstract

In this paper, a detailed water quality monitoring was conducted on desalination brine according to the basic health requirements for water quality in bathing beaches, swimming pools and other bathing venues. The results showed that desalination brine could fully meet the requirements, so its use as the water source of artificial "Dead Sea" was theoretically feasible. Through further analysis and research, a salt-ozone treatment process was proposed, and optimal process parameters were obtained. Salt dosage could be 100 - 120 g per liter of brine. Ozone input was 5 - 10 g/L for treating 0.5 - 1 h. Average treatment cost was 4.96 - 6.03 $ per ton of water, which was much lower than the conventional artificial "Dead Sea" producing costs.

Subject Areas

Environmental Sciences, Oceanology

Keywords

Seawater Desalination, Brine, Salinity, Artificial Dead Sea

1. Introduction

Seawater desalination, as an advanced water-making, water-saving new technology particularly suitable for island environments, has been widely promoted and applied around the world and in China's coastal regions due to its ability to effectively alleviate the lack of freshwater resources. During seawater desalination, a substantial amount of brine is discharged, whose salinity is much higher than seawater [1]. In addition, large amounts of chemicals are added to the seawater during the desalination process, so if the brine is directly discharged into the sea, it will inevitably cause serious damage to the offshore intertidal ecosystem [2]. China's National Development and Reform Commission issued the

Special Plan for Seawater Utilization in 2005 to strongly support the utilization of seawater resources, not only intending to promote the desalination technologies, but also striving to develop the comprehensive seawater utilization industry. At present, desalination brine is utilized mainly by extraction of various chemical elements, such as solar evaporation salt extraction and extraction of bromine, magnesium, potassium, lithium, etc., while seldom been utilized as an integral whole. In this study, a new idea for brine utilization is investigated around the ever-burgeoning concept of "artificial Dead Sea" in the bath industry through experiments and mathematical calculations.

"Artificial Dead Sea", also known as space float bath, is a new-generation functional float venue integrating bath, fitness and healthcare functions in one, which is artificially prepared using modern technology. According to the relevant UNESCO data, deep bodily relaxation in a holdless state allows rapid replenishment of physical strength; floating in the "artificial Dead Sea" for 1 hour can achieve the effect of eight hours' sleep. "Artificial Dead Sea" can be used in tourist sites, water worlds, bath centers, physiotherapy centers, luxury hotels, nursing homes and other places [3].

Although desalination brine has a higher salinity, its density is sufficient for human body to freely float on water surface. There are two ways to meet salinity requirements close to the "Dead Sea": one way is to evaporate water, so that the brine is further concentrated; and the other way is to add salt to increase salinity. From the perspectives of efficiency and cost, the former is time- and energy-consuming, which is unsuitable for long-term application. The latter, in comparison, is more feasible. Experiments have demonstrated that in addition to elements like Ca, Mg, Na, Cl and S, other major components of desalination brine are trace elements, which do not cause harm to humans. To increase salinity, all that is needed is to add coarse salt into the desalination brine.

On the basis of understanding the quality of desalination brine, this study attempted possibly suitable water treatment processes according to the basic requirements for artificial "Dead Sea" pool water and ultimately identified economic, feasible approach through comparison. The study could provide reliable scientific theoretical and factual bases for large-scale implementation of brine as artificial "Dead Sea" pool water.

2. Materials and Methods

2.1. Experimental Materials

Brine used in this study was collected from the brine outfall at the Lvyuan Desalination Plant in Daishan, Zhejiang province of China. The plant had a daily freshwater production capacity of 2500 t, which used reverse osmosis desalination process. Its basic water quality conditions are shown in **Table 1**.

2.2. Experimental Methods

There were two issues to be solved for application of desalination brine as the

Table 1. Water quality of desalination brine.

Parameter	Range (unit)
pH	7.3 - 7.7
Salinity	36.3 - 37.1 (‰)
DO	5.2 - 5.6 (mg/L)
COD_{Mn}	0.015 - 0.018 (mg/L)
Ca^{2+}	451.3 - 482.1 (mg/L)
Mg^{2+}	1930.7 - 2020.9 (mg/L)
SO_4^{2-}	3213.6 - 3323.4 (mg/L)
Cl^-	21.655 - 21.864 (g/L)
Bacterium coli	Not determined
Total bacteria	1542 - 1839 (cell/mL)

artificial "Dead Sea" pool water: one was to increase salinity to the extent that human body could float; the other was to ensure the water quality to comply with the safety and health standards for bathing, swimming pool water.

Although desalination brine had salinity higher than original seawater, it was still not enough to make human body float. Coarse salt was added to the desalination brine and mixed until completely dissolved, until human body can float. Then, ozone was passed through the desalination brine, and changes in the number of bacteria were observed over time. Meanwhile, residual ozone concentration was determined, and optimal ozone treatment time was identified.

Parameters like pH, DO, total alkalinity, residual ozone concentration and salinity were determined directly with HACH multi-parameter analyzer. COD was determined by alkaline potassium permanganate method (HJ132-2003, China) [4]. Other parameters were determined according to the methods in the China's National Standards of GB17378.4-2007 [5].

3. Results and Discussions

3.1. Salt Addition to Desalination Brine

3.1.1. Estimation of Minimum Density of "Artificial Dead Sea" Water

As mentioned in the introduction, when floating in the "artificial Dead Sea", human body was not completely submerged in water. At least the head and neck must be exposed above the water, and in most cases, other parts were also exposed above the water surface. Therefore, buoyancy acted on human body was less than the gravity of water drained by total volume of human body. Assuming that the height of a normal people was H and head was a sphere, the average proportion of human body is roughly shown in **Figure 1** [6].

"*H*" represents length of human body, and every part of the body was labeled with "*H*".

Accoding to the model of **Figure 1**, we can calculate the volume of body part as follows:

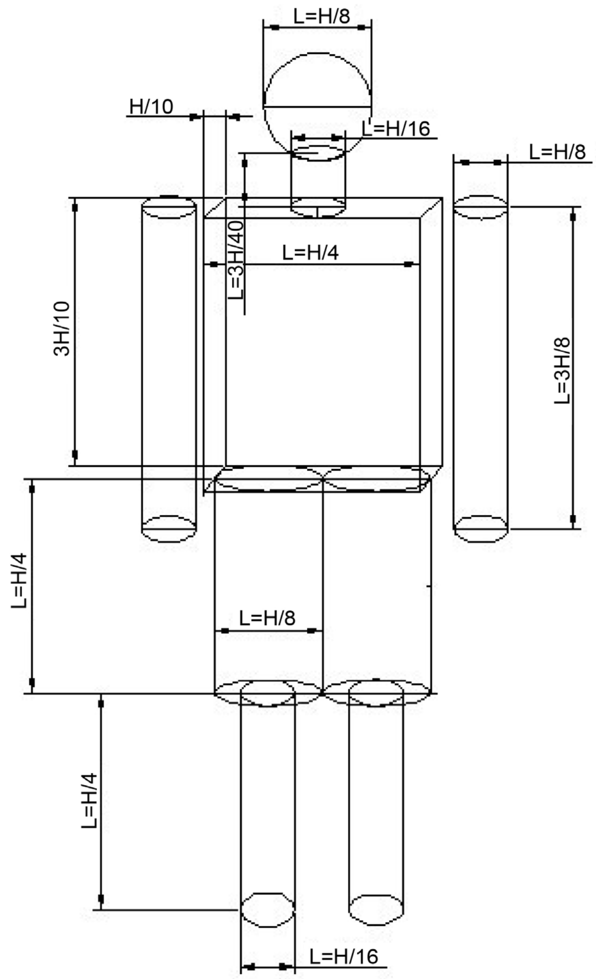

Figure 1. Human body model.

$$V_{head} = \frac{4}{3}\pi\left(\frac{H}{16}\right)^3 = \frac{\pi H^3}{3072} = \frac{H^3}{978.344}$$

$$V_{neck} = \pi\left(\frac{H}{32}\right)^2\left(\frac{3H}{40}\right) = \frac{H^3}{4348.195}$$

$$V_{torso} = \left(\frac{H}{4}\right)\left(\frac{3H}{10}\right)\left(\frac{H}{10}\right) = \frac{H^3}{133.334}$$

$$V_{arms} = 2\pi\left(\frac{H}{32}\right)^2\left(\frac{3H}{8}\right) = \frac{H^3}{434.820}$$

$$V_{thighs} = 2\pi\left(\frac{H}{16}\right)^2\left(\frac{H}{4}\right) = \frac{H^3}{163.057}$$

$$V_{Lower\ legs} = 2\pi\left(\frac{H}{32}\right)^2\left(\frac{H}{4}\right) = \frac{H^3}{652.229}$$

$$V_{body} = \frac{H^3}{978.344} + \frac{H^3}{4348.195} + \frac{H^3}{133.34} + \frac{H^3}{434.820} + \frac{H^3}{163.057} + \frac{H^3}{652.229} = 0.018717908H^3$$

$$V_{immersed} = V_{body} - V_{head} - V_{neck} = 0.017465793H^3$$

The critical condition that body can float on the brine is gravity equals buoyancy, *i.e.*

$$\rho_{body} V_{body} g = \rho_{brine} g V_{immersed}$$

The average density of human body is 1.1 g/cm^3, so we can calculate the result:

$$\rho_{brine} = \rho_{body} V_{body} / V_{immersed} = 1.1829\ \text{g/cm}^3$$

If standard distilled water was used as a reference, the specific gravity of "artificial Dead Sea" pool water should exceed 1.1829 in order to make the human body float.

3.1.2. Salt Solubilization Experiment

1000 mL of desalination brine was added into a 2 L beaker, added successively with coarse salt (50 g/group), then stirred slowly to allow quick and complete dissolution, followed by measurement of density with Baumé hydrometer.

As can be seen from Table 2, density of the desalination brine studied was 1.2085˚Bé when the total salt addition reached 120 g, density no longer changed. Thus, it was ascertainable that the density of solution reached the maximum when the salt addition was between 100 - 120 g. Further addition of salt into the solution was unable to increase the density, as the solution had already been in a saturated state.

3.2. Ozone Treatment of Artificial "Dead Sea" Water

After salt treatment, brine could meet the free-floating requirements of human body. But to meet the basic requirements for swimming pool water, sterilization with disinfectant was also needed. If higher removal efficiency within a short time was desired, ozone could be a good choice to rapidly kill bacteria in the water. Moreover, metabolite of ozone was oxygen, which was beneficial to human body. Characterized by good water quality and low bacterial levels, desalination brine was easier to treat than normal water source. Thus, ozone was more suitable than chlorine.

Figure 2 shows changes in the number of bacteria over reaction time during ozone treatment of the salt-treated brine. As can be seen, after reaction of ozone with water, bacterial number could be reduced from 1788 cell/l to 789 cell/l within 0.5 h and dropped to 459 cell/l after1 hr. With the prolongation of reaction time, bacterial number further reduced, and 2 h later, ammonia nitrogen-degrading bacteria basically did not change significantly. According to China's requirements for general pool water, total bacterial content should be less

Table 2. Change of beaume density with salt delivery.

Salt Delivery (g)	0	20	40	60	80	100	120	140
Beaume Density (˚Bé)	1.0275	1.0750	1.1090	1.1417	1.1723	1.2018	1.2085	1.2085

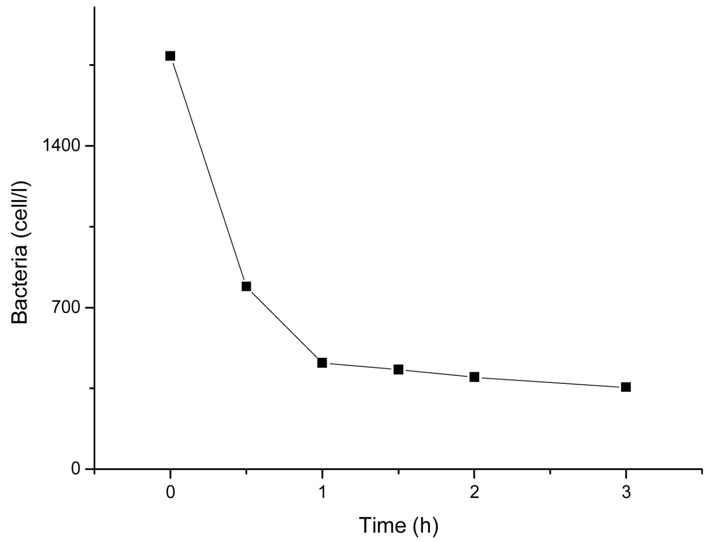

Figure 2. Effect of different ozone reaction time on the removal of bacteria.

than 1000 cell/l. Thus, treatment time should be between 0.5 - 1 h.

Figure 3 shows the correlation between ammonia nitrogen removal rate and ozone dosage for a reaction time of 0.5 h. As can be seen, when ozone exceeded 10 mg/L, increase in the ozone dosage had no significant effect on promoting the bacterial removal. Ozone is a gas, whose solubility in water is limited. Too much ozone would escape from the water, resulting in waste. In the present experiment, appropriate ozone dosage was determined to be 5 - 10 mg/L, while treatment time should not exceed 1 h.

3.3. Quality of Desalination Brine after Treatments

Table 3 shows the quality of brine after an aforementioned series of treatments. As can be seen, after treatment, salinity reached the level at which human body could freely float. Turbidity and COD decreased, so the water was clearer. Dissolved oxygen increased, and residual ozone met the requirements for residual disinfectant in swimming pool water (≤0.5 mg/L). Total number of bacteria was less than1000/ml, where no E. coli was detected. Water quality could fully meet the industrial standards [7].

3.4. Cost Analysis

Cost of treatments presented herein came mainly from the salt treatment cost and power consumption by ozone treatment.

In comparison, currently common artificial "Dead Sea" water preparation is achieved generally by salt dissolution into normal freshwater. Kang Pingyu and Liu Wenyuan disclosed a method for preparing artificial Dead Sea water, where the ratio (by weight) of raw materials was water 67 - 85; salt 15 - 33; bluing agent 0.008 - 0.015; and scenting agent 0.003 - 0.005. Preparation method was as follows: salt dosage was adjusted to allow the salinity of water to reach the standard

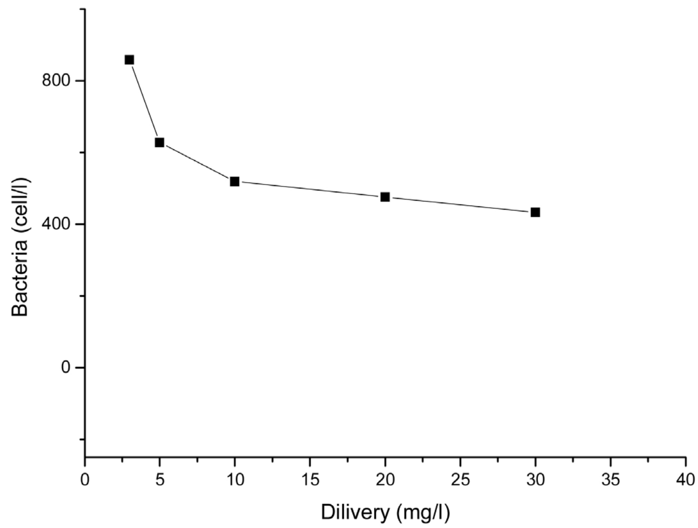

Figure 3. Effect of different ozone dosages on removal of bacteria.

Table 3. Quality of desalination brine after treatments.

Parameter	Range (unit)
pH	7.2 - 7.5
Salinity	287 - 296 (‰)
DO	6.1 - 6.6 (mg/l)
COD_{Mn}	not detected
Bacterium coli	not detected
Total bacteria	435 - 487 cell/ml
ozone	0.34 - 0.41 (mg/l)

(15% - 33%) equivalent to the Dead Sea; impurities were filtered; bluing agent was added at 0.008% - 0.015%; and finally, scenting agent was added at 0.003% - 0.005% [8].

Taking preparation of 1 t of artificial "Dead Sea" water as an example, the two methods were compared for cost input where manpower, winter heating and other costs were not considered. The results are shown in **Table 4**.

Power consumption of ozone generator: ozone consumption was 5 - 10 g for treating per ton of water. Assuming that the power consumed for generating 10 g of ozone was 1700 W, treatment time was 1 h, and commercial power rate was 0.12 $/kwh, then the cost for treating 1 t of water was 0.10 - 0.20 $, which totaled 4.96 - 6.03 $. Comparison found that the use of desalination brine as the artificial "Dead Sea" water source allowed treatment cost to be lower than any other existing method. To put into practical use, brine conveyance or transportation remains to be resolved.

4. Conclusions and Outlook

In this paper, the feasibility of desalination brine as the artificial "Dead Sea"

Table 4. Cost analysis ($).

The method of Kang and Liu				Our method			
Resource	Quantity	Price	Cost	Resource	Quantity	Price	Cost
Salt	0.15 - 0.33 t	48.6/t	7.29 - 16.04	Salt	0.10 - 0.12	48.6 $/t	4.86 - 5.83
bluing agent	0.08 - 0.15 kg	60.8/kg	4.86 - 9.12	Electricity	0.85 - 1.7 kwh	0.12/kwh	0.10 - 0.20
scenting agent	0.03 - 0.05 kg	91.1/kg	2.73 - 4.55				
Total	14.88 - 29.71			Total	4.96 - 6.03		

water is preliminarily investigated, and the basic process flow for water treatment is presented. In this paper, a detailed water quality monitoring was conducted on desalination brine according to the basic health requirements for water quality in bathing beaches, swimming pools and other bathing venues. The results showed that desalination brine could fully meet the requirements, so its use as the water source of artificial "Dead Sea" was theoretically feasible. Through further analysis and research, a salt-ozone treatment process was proposed, and optimal process parameters were obtained. Salt dosage could be 100 - 120 g per liter of brine. Ozone input was 5 - 10 g/L for treating 0.5 - 1 h. Average treatment cost was 4.96 - 6.03 $ per ton of water, which was much lower than the conventional artificial "Dead Sea" producing costs.

However, factors involved in the study are not detailed enough, and some parameters remain to be optimized. Impact of the quality of water obtained on human health and its healthcare effect need further study. Maintenance of water quality, countermeasures for quality problems and water treatment processes under long-term operation and use conditions remain to be studied further. Desalination plants are widely distributed in the coastal areas, so brine supply is guaranteed. Implementation of artificial "Dead Sea" water preparation project by fully utilizing desalination brine has advantages such as low cost and simple treatment, which has a very good application prospect. This technique will surely be widely promoted and applied after perfection.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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