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Ocean Salt Basins Energy Harvesting

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In this paper, consideration is given to the harnessing of the energy contained in ocean salt basins. These deep ocean depressions which host thick salts deposits whose salinities could be up to 5-10 times higher than normal seawater open an interesting -and so far, unexplored possibility to harvest energy from the oceans. It is known that upon mixing two solutions of different concentrations spontaneous energy can be released, and then, if the upper waters surrounding the basin are deliberately brought and mixed with the hypersaline brine pool and using a semipermeable membrane, osmotic energy can be obtained. If it is considered that typical osmotic energy stored per unit of volume could be around 1 kWh/m^3 , then the energy stored in ocean basins -which can be several kilometers broad, translate into a vast amount of energy. This energy could be steadily extracted without interruption from the basin and then avoiding the intermittence problem besetting traditional renewable energies. In addition, and owing to the huge dimensions of the ocean, an adapted version for an *osmotic pool engine* is feasible in which brackish streams can be gravitationally pumped out by buoyancy eliminating in this way the need for pressure exchangers as required in traditional approaches. The economical viability for an ocean brine pool power station could be in any case higher or at least similar than that from Ocean Thermal Energy Conversion (OTEC) considering that for OTEC given the much less pronounced thermal gradient the cold water must be transported from the deep cold waters to the surface by the use of very large and expensive pipeline systems, but for an ocean brine pool power station, and owing to the strong abrupt change in salinity between the pool and the surrounding water the mixing can be in situ, and then only the electrical energy must be transported. Additional R&D is required in order to arrive at a reliable practical design and to explore this yet untapped new source of ocean energy.

Keywords. *Ocean brine pool; Osmotic energy; Ocean power*

I. INTRODUCTION

Deep hypersaline anoxic basin or DHABs are deep ocean depressions which host thick salts deposits with the formation of local brine pools whose salinities could be up to 5-10 times higher than normal seawater and they have been created essentially by salt tectonics when thick layers of salt -up to 8 km thick in some places, come into contact with seawater in rims around active brine vents, they dissolve, and form the pool. For more thorough discussion of the physical aspects of ocean brine pools, the reader is referred to the review [1]. Ocean brine pools vary greatly in extension across the oceans and then the technical exploitation of ocean brine pools must be evaluated for the specific pool, but in common, all of them are in extreme conditions of elevated salinity (up to 10 times higher than normal seawater) and relatively high hydrostatic pressure (≈ 2000 meters deep) required to generate the abrupt stratification. Ocean pool brine could form veritable big salt-bubbles which enclose 200 m column of highly hypersalinity as is the case for the Orca basin, northern Gulf of Mexico with several kilometers of ex-

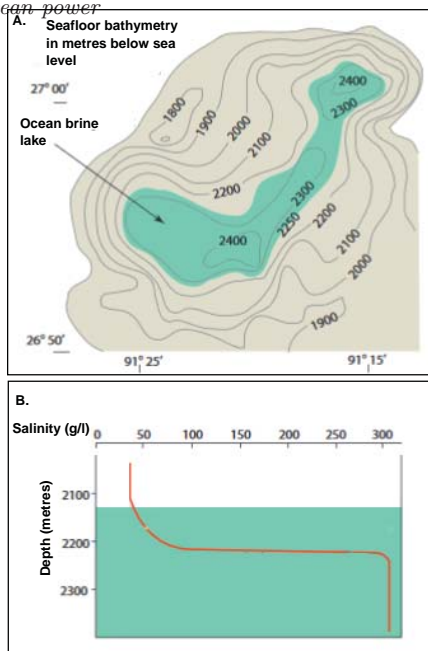


FIG. 1: Bathymetric profile (in metres below sealevel). Grey area outlines the extent of deep highly saline anoxic bottom waters (DHAB) created by the dissolution of nearby allochthonous salt. B) Salinity profile in the basin, [2]

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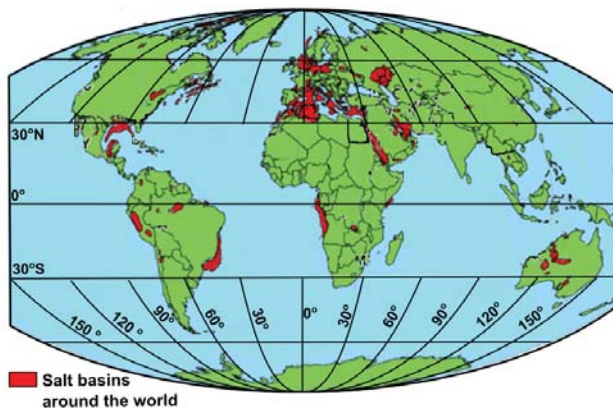


FIG. 2: Salt basins around the world. From [3]

tension as shown in Fig. 1. [1].

Since the 1980s these ocean systems has been documented on the deep seafloor below normal marine salinity water column around the world,[3] (see Fig. 2). Referring to this figure, it is seen that ocean basins could be specially interesting for places as Europe which so far other kind of ocean energy as Ocean Thermal Energy Conversion (OTEC) has been prevented and restricted to more warm tropical and subtropical seas.

Although the main purpose of this preliminary work is to give some figure on the extractable power density from an ocean brine pool power station, nevertheless the economical viability of such a station could, in any case, be higher or at least similar than that from Ocean Thermal Energy Conversion (OTEC) stations which can be envisaged by looking at Fig. 3 in which the ocean salinity-temperature profile is depicted. In this figure, we can see that owing to the mild thermal gradient of the ocean, in OTEC technology it is required that cold waters be transported from the deep to the surface which translate into the the use of a very large pipeline system -pipelines could be around 2000 meters long and with 3 meters diameter or thereabouts. This fact besides to reduce the economical attractiveness on the OTEC technology also limit its application to warm tropical and subtropical seas. However, for the case of an ocean pool brine power station because the very strong and definitive boundary of salinity between the brine pool and the upper water (see Fig. 3, right side), the mixing can be performed locally -as pictorially depicted in Fig. 4, and then a very small pipeline with only a few meters long is required to bring the near upper waters inside the pool and as a result only the cable for carrying the electricity to the surface is required which can reduce substantially the cost, the repair and maintenance of the station.

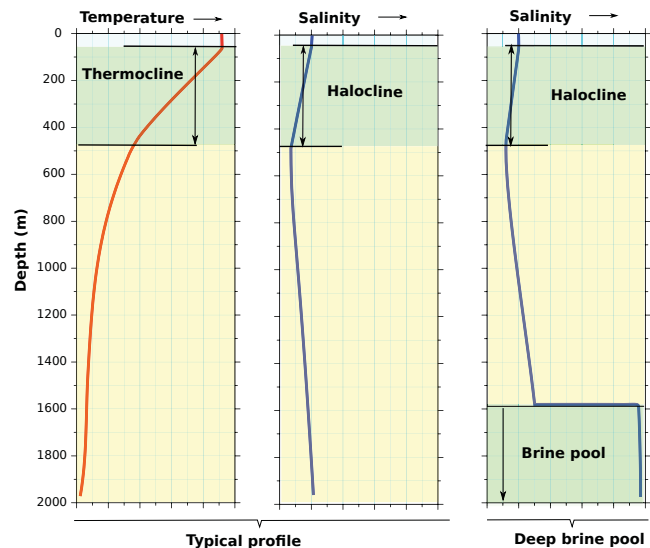


FIG. 3: Salinity- temperature depth profile showing the typical thermocline (zone of the most rapid temperature decline), and the halocline (zone of the most rapid salinity change). DHAB (right side) is evidenced as a deep ocean abrupt change in salinity.

As regard the osmotic energy technology, the idea of extracting energy from salinity gradients back to the year 1954, [5] and the first technology proposed for harnessing salinity gradients called as Pressure Retarded Osmosis (PRO) process was invented in 1973, [6], and has been improved over the years , particularly after the opening of the first osmotic power plant prototype in Norway in 2009. There are a vast literature available on the theory, performance and design of PRO process, but the interested reader the recent review of the state-of-the-art, [7] which includes a technical, economical, environmental and other aspect of PRO as well as the latest research achievements in the last few years for t osmotic power production on a commercial scale is recommended.

II. MATERIALS AND METHODS

In this section some first estimation for the extractable power density attainable from a hypothetical ocean brine pool power station is derived. However, the reader must to keep in mind that the maximum theoretical power density reported result from unavoidable idealizations which are necessary in order to obtain analytical expressions and therefore are not intended to typify estimates. This should not misconstrued as an attempt to produce a definitive mechanistic analysis. However, this will provide important guidance in future efforts to analyze the problem.

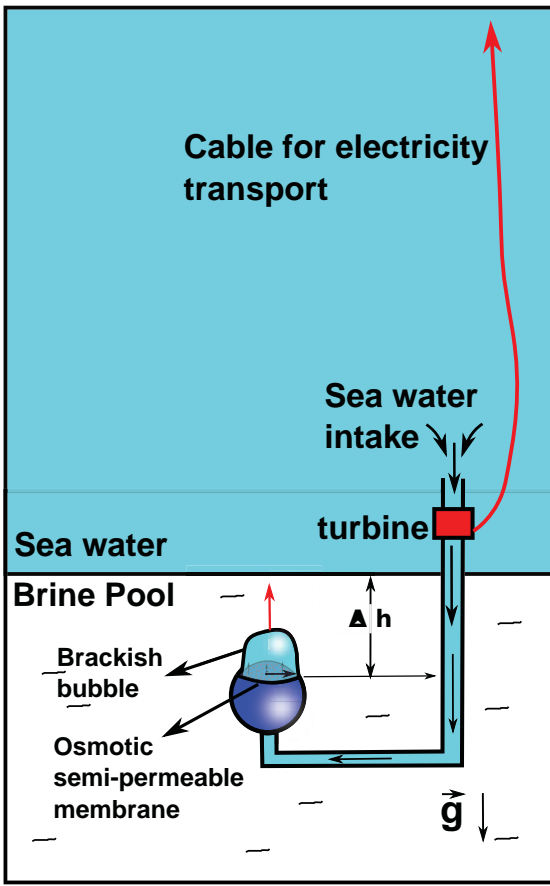


FIG. 4: Sketch of a brine pool power station. Because the abrupt change in salinity it is not required a large pipeline system to transport deep waters as is the case for OTEC, and then the mixing can be promoted locally which means that only a cable is needed to transport electricity to surface.

A. Maximum extractable energy from ocean brine pools

To begin with, in a thermodynamically reversible process the maximum extractable energy from the mixing could be estimated using the specific Gibbs free energy of mixing ΔG_v which is defined as the energy per volume of mixed solution generated from mixing two solutions of different salinities in an isobaric and isothermal process. The theoretical maximum volumetric Gibbs energy ΔG_v from an ideal (diluted) mixture is given by [8]

$$-\Delta G_v = \nu RT c_F \left[\frac{x}{x-1} \ln(x) - \exp\left(\frac{x \ln(x)}{x-1} - 1\right) \right] \quad (1)$$

where ν is the van't Hoff factor for strong electrolytes (e.g., $\nu = 2$ for NaCl) R is the ideal gas constant; T is the absolute temperature; c_F is the molar concentration of the feed and x is the ratio between the concentration of the draw c_D and the feed, i.e., $x = \frac{c_D}{c_F}$.

Fig. 5 shows the specific Gibbs free energy of mixing for seawater as feed $c_F = 0.6\text{M}$ and $T = 294\text{ K}$ as a

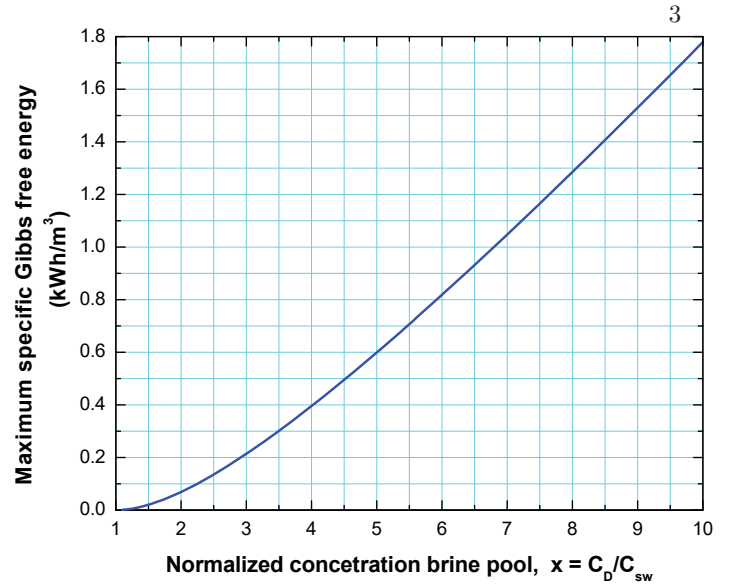


FIG. 5: Specific Gibbs free energy of mixing for the mixing of seawater $c_F = 0.6\text{M}$ as a function of the concentration of draw.

function of the concentration ratio of the draw x . It is seen that the osmotic extractable energy from ocean brine pools whose salinities could be up to 5-10 times higher than normal seawater may be in the range of 0.6 kWh/m^3 to 1.8 kWh/m^3 , respectively. In addition, if one considers that hypersaline oceanic pools can be as large as 20 km long with hypersalinity columns 60 meters as in the Gulf of Mexico, we obtain a storable energy in the pool in the order of $\sim 12\text{ GWh}$, i.e., an ocean brine pool power station delivering a power output of 100 kW could operate day and night for up to 14 years.

B. Power density

Finally, a parameter important is the density of power which in osmotic energy is limited mostly by the area of the semi-permeable membrane. As first estimation it can be calculated as follows:

The maximum power density per area of membrane, W_s can be calculated by multiplying the maximum extractable energy per unit of volume given by Eq.(1) by the water flux across the membrane, J_w ,

$$W_s \approx J_w \Delta G_{v,max} \quad (2)$$

The water flux across the membrane, J_w ($\text{m}^3/(\text{sm}^2)$) can be defined in terms of the membrane water permeability coefficient A ; the osmotic pressure at the draw side on the membrane active layer, Π_D ; the osmotic pressure at the feed side of the membrane active layer, Π_F ;

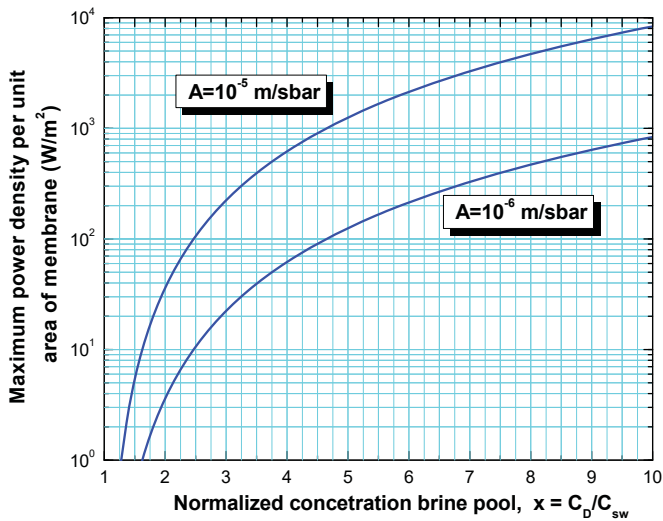


FIG. 6: Power density per unit of area of membrane as a function of the concentration of draw.

the hydrostatic pressure difference between the column of hypersaline brine and the feed,

$$J_w = A [(\Pi_D - \Pi_F) - g(\rho_D - \rho_F)\Delta h] \quad (3)$$

where ρ_D and ρ_F are the densities of the brine pool (the draw) and the seawater (the feed), respectively, and Δh is the difference in level between the osmotic engine and the interface seawater-brine pool as depicted in Fig. 4. On the other hand the difference of osmotic pressure between the sides of the membrane is related with concentrations as

$$\Pi_D - \Pi_F = \nu RT c_F (x - 1) \quad (4)$$

Further, as mentioned in preceding sections, because the strong salinity gradient with a definitive salinity boundary, it is not required to bring upper waters from far a way and then Δh could be around 10 meters or so, and with the difference of concentrations we are dealing the hydrostatic term can be neglected in comparison with the pressure from the difference of concentrations. Thus, the water flux across the membrane, simplifies as

$$J_w = A(x - 1)\nu RT c_F \quad (5)$$

With current commercial technology, membrane water permeability coefficients can be found between 10^{-6} $\text{m}^3/(\text{m}^2 \text{ s bar})$ to 10^{-5} $\text{m}^3/(\text{m}^2 \text{ s bar})$ which translate into power densities as a function of the concentration of the draw as shown in Fig. 6. Depending on the specific design PRO process can yield about 70-90% of the specific Gibbs free energy of mixing, or around 50-60% for a co-current flow PRO process,[8]. Then to stay in the

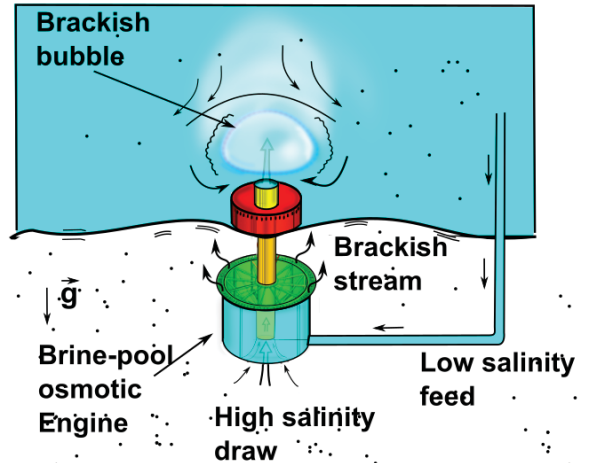


FIG. 7: Sketch of an osmotic pool engine.

conservative side, if we assume efficiency around 50%, then the power density attainable from a brine pool with 8 times the salinity of seawater will be between 50 W/m^2 to 500 W/m^2 depending of the water permeability of the membrane. This power density is higher than solar energy $\sim 20 \text{ W/m}^2$ (as the the Cestas Solar Park in France photovoltaic power station) and or even more in comparison with wind energy $\sim 4 \text{ W/m}^2$,[9]. In addition, it must be stressed that this energy can be extracted day and night without interruption and then avoiding the intermittence problem besetting those renewable energies. Changes in cell length, membrane resistance and the use of nanotubes could increase power density closer to the maximum extractable energy.

C. The osmotic pool engine

Besides the attractiveness in terms of power density and uninterrupted production in comparison with other renewable energies, or the elimination of an expensive pipeline system in comparison with OTEC, there is another point in comparison with traditional osmotic power itself. Indeed, traditional osmotic engines designed for extraction of mixing energy require the use of pressure exchangers (PEXs) in order to increase the operating pressure in the system and pumping the draw, the feed or both solutions through the system, [8]. However, for the specific case of an oceanic brine pool osmotic engine because the huge dimensions of the ocean the use of PEXs are no longer necessary. In fact the buoyancy force acting on the resulting mixed solution (due to its lower density in comparison with the surrounding brine) can induce the formation of a *brackish bubble* as pictorially shown in Fig. 4 and Fig. 7. The motion of this convective bubble will continuously remove the brackish stream

and then PEX is not longer necessary for this application.

Finally, although conceptually the exploitation of hypersaline ocean salt basins seems practical, nevertheless it will encompass engineering challenges. The main challenge, perhaps, is related with the need to descend to depths of up to 1600 meters or thereabouts (see Fig. 3). Indeed, although the absolute pressure at that depth cannot be a concern (considering that the osmotic engine is surrounding by the same pressure and the only hydrostatic pressure gradient is due to the depth of penetration Δh of the osmotic engine starting from the interface basin-environment as depicted in Fig. 4) and also considering that in addition the osmotic engine has not any movable parts (pressure exchanger are not necessary as discussed previously), nevertheless anchoring and mooring an osmotic plant at that ocean depths would be an issue. Such a moored structure will require a high resistance to stretching and great rigidity and to absorb shocks and control the position of the platform (displacement) which without doubt will be a key criteria to be considered.

III. SUMMARY OF RESULTS AND CONCLUSIONS

The demonstrated existence of vast brine pools in a number of places in the ocean basin around the world offers an interesting alternative to the production of power from ocean so far unexplored. The attractiveness of these vast deposits of brine lie in the fact that can be readily dissolved with the surrounding top waters and then by using an osmotic engine extracting the spontaneous mixing energy released. It was demonstrated that the extractable power density -assuming a conservative 50% of efficiency, lies between 50 W/m^2 to 500 W/m^2 if it is considered the performance of current commercial membranes. This power density is higher than those from solar energy ($\sim 20 \text{ W/m}^2$) and significantly higher than wind energy ($\sim 4 \text{ W/m}^2$), which in addition, can be extracted day and night without interruption and then avoiding the intermittence problem besetting those renewable energies. Furthermore, owing to the huge dimension of the ocean basin, the brackish streams can be pumped out by buoyancy using a kind of *osmotic pool en-*

gine and then eliminating the need of pressure exchangers as is needed with traditional pressure retarded osmosis process. Changes in cell length, membrane resistance and the use of nanotubes could increase power density closer to the maximum extractable energy. Because this kind of power stations don't need water from rivers, they can be specially interesting for power stations or outpost in the middle of ocean. Additional R&D is required in order to arrive at a reliable practical design and to explore this yet untapped new source of ocean energy.

NOMENCLATURE

A = membrane water permeability coefficient
 c = concentration
 g = gravity
 ΔG_v = volume free energy of mixing
 Δh = difference of level
 J = water flux across the membrane
 R = ideal gas constant
 T = absolute temperature
 x = ratio concentration brine pool to feed

Greek symbols

ρ = density
 ν = van 't Hoff factor
 ϕ = feed volume fraction
 Π = osmotic pressure

subscripts

D = draw
 F = feed
 M = mixture
 w = water

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