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SALINITY GRADIENT ENERGY RESOURCE IN TROPICAL HYPERSALINE COASTAL LAGOONS: PERSPECTIVES FOR SUSTAINABLE USE.

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ABSTRACT

Renewable energy resources are now of growing interest and so is the technology to use them. From the available ocean energy resources, salinity gradients are the least studied. The natural coastal processes in countries within the tropics, like Mexico, generously provide the essentials for the development of intense salinity gradients: abundant rainfall and intense solar radiation (high rates of evaporation). A salinity gradient research project at the Mexican Center for Innovation in Renewable Energies of the Ocean aims to quantify and evaluate this natural resource in Mexico, to understand the processes controlling the resource, to characterize the environments at selected sites with potential, to investigate the existing techniques to obtain energy from salinity gradients and to promote new studies to improve the existing technologies. Mexico has numerous rivers discharging to micro-tidal basins and low-inflow coastal lagoons, some of which develop hyper saline conditions during dry seasons. Theoretical estimates of the available energy in one of these sites through one year measurements, revealed higher potential (2-3 times more) than existing estimates at river mouths in the world. Intensive field campaigns are revealing new biological and physical findings together with information providing clues to understand the overall behavior of this delicate and extreme site.

Keywords: ocean energy, Mexico, Yucatan

1 INTRODUCTION

The entire planet is suffering from the effects of the modern human life, which include numerous negative environmental trends, in which several energy related issues are important contributors to the problem. Most countries are somehow committed to attend planetary issues related to climate change and one approach is to search for healthier ways to obtain energy. The interest to study renewable energy resources (including the ocean), and to optimize the technology to use them is increasingly growing. Countries like Mexico, which are bordered with oceans, have additional opportunities for energy that must be carefully and responsibly evaluated.

From the different ocean energy resources, the salinity gradients are the least studied. Mexico has a great potential for harvesting this resource, since abundant precipitation discharge through numerous rivers both in the Pacific and in the Gulf of Mexico. Additionally, several coastal water bodies of the country generate hyper saline characteristics due to an excess of evaporation over precipitation.

A large amount of energy is released when two water masses with different salinity concentrations are in contact. In coastal regions where continental waters reach the marine environment, salinity gradients develop controlled by the combined geographical, atmospheric and oceanographic characteristics at the site: locations with high evaporation rates and substantial inland rainfall promote salinity gradients while mixing processes (tides, wind, etc.) act against them. Mexico has numerous rivers discharging to micro-tidal basins and low-inflow coastal lagoons, some of which develop hiperhaline conditions during dry seasons. Sites with these characteristics are not very common in the world and their natural presence in Mexico suggest that salinity gradients might be an energy resource worth investigating. But the coastal environments where salinity gradients are developed are of huge ecological wealth, being home and nursing grounds of a great number of coastal and marine species.

One aim of the Mexican Center for Innovation in Renewable Energies of the Ocean (CEMIE-Ocean) is to study salinity gradients of the country as an energy resource. In coastal sites with salinity gradients (i.e. estuaries and negative estuaries), where the different water masses meet, the salinity concentration is highly variable at different time scales (from hours to years) due to tides, climatic seasons, and atmospheric events. It is also foreseen that additional changes will arise at coastal sites due to climate change, with salinity decrease at high latitudes and increase in the tropics and subtropics at both hemispheres. Three sites were selected within the project to be intensively monitored to quantify the salinity spatial and temporal variability, and the local hydrodynamics. At the same time, an environmental base line of these selected sites is being constructed to provide the solid information basis required to understand and to protect and preserve the natural environments where these resources exist.

Even though the existing technology to obtain energy from salinity gradients is not costly effective at the present time, it is also true that the technology design has not targeted this process as one with potential. One reason might be that salinity gradients are invisible and not evident energetic processes such as those linked with hydroelectric plants, waves or ocean currents; however, the remarkable amount of energy contained in the salinity difference between sea water and fresh water when they mix was described decades ago by Pattle [1], who mentioned that in theory, the energy per cubic metre of fresh water discharging at the sea is equivalent to the energy generated from water falling over a dam of approximately 280 meters high (up to 0.8 kilowatts per cubic metre). Due to the delicate balance that allows the existence of salinity gradients, it is not pretended that the energy extraction from this resource could be massive, but in contrast, this could possibly be a clean renewable and sustainable option of micro-generation in coastal sites. This contribution presents results from existing salinity measurements (time series) at one site and preliminary results of the four-year project at one year from the start.

2 METHODOLOGY

A working group, including academics from different national and international academic centres, was gathered to initiate and promote the research in salinity gradients and the energy provided by them. The first job was to provide an understanding of the temporal and/or spatial variations of salinity with a literature review, excluding those studies with only point measurement or sporadic salinity values (most studies were discarded for this reason). The existing useful information was gathered in a database, and was used to select the sites to be intensively studied within the CEMIE-Ocean salinity gradient project.

Existing data from La Carbonera coastal lagoon, covering one year from September 2014, were used to evaluate the temporal and spatial variability of the thermohaline characteristics of the site. The theoretical

potential energy, which is the maximum usable energy if ideal efficiency could be achieved independently of harnessing the technology [2], was calculated from these data.
When two waters with different salt concentration are in contact, they can be mixed to form a homogenous mixture in a process driven by the difference in chemical potential between both solutions where Gibbs' free energy is released [3]. The free energy of mixing a concentrated and a diluted solution (G_{mix}) can be expressed as:

$$\Delta G_{mix} = G_b - (G_c + G_d) \quad (1)$$

where G is the free energy (J) subscript [c] represents the concentrated solution; [d] represents the dilute solution; and [b] represents the brackish solution that results from the mixing. For ideal dilute solutions (i.e. no change in the enthalpy, ΔH= 0), it can be shown that the Gibbs free energy of each electrolyte solution (diluted, concentrated or brackish) is given by:

$$G_i = -T_i \Delta S_i \quad (2)$$

with *i* = c, d, b; [T] is the absolute temperature (K). The entropy increase of each solution [ΔS_i] is calculated using the equation:

$$\Delta S_i = -V_i m R [x_i \ln(x_i) + y_i \ln(y_i)] \quad (3)$$

where [V_i] are the water flow rates (m^3) in the mixing ($V_i = V_c + V_d$), [m] is the total number of moles of water solution (mol/m^3), (it can be assumed constant for all solutions), [R], is the universal gas constant (8.314 J/mol K), and [x] and [y] are the molar fractions of ions (Na^+ and Cl^-) and water respectively.

3 RESULTS

3.1 Selection of sites for salinity gradient monitoring

Mexico has a large variety of coastal environments, but from the salinity gradients point of view, it has three different types of coastal sites and one of each were chosen to be intensively monitored: a) one river discharging to a microtidal sea, the Jamapa River in the state of Veracruz, discharging to the Gulf of Mexico. b) one coastal lagoon situated close to a river that discharges to the Pacific Ocean in the state of Oaxaca; this region provides in a relatively small distance, fresh water from the river and water from the coastal lagoon with higher salinity concentration than the sea water. c) One coastal lagoon located in a region of high evaporation rates and karst geology that prevents the existence of rivers; the Yucatan Peninsula has important precipitation rates but the fresh water is rapidly filtered to the underground providing a rich freshwater reservoir with preferential paths of discharge to the sea. Hence most coastal lagoons in this region have areas with hipersaline characteristics during some periods along the year.
The field campaigns at the coastal lagoon of Rio Lagartos, in the Yucatan Peninsula began in May, 2017. Since then, CTD moorings are collecting temperature, salinity and water level data at four different sites and two intensive field campaigns have been performed during two of the three climatic seasons (rainy season and winter season, characterized by strong northerly winds). During these campaigns, spatial and temporal variations of physical, chemical and biological data are obtained in spatial stations throughout the lagoon and during entire tidal cycles at two selected cross-lagoon transects (mouth and inside).
The moored data will provide temporal variations of the salinity gradients and their theoretical energy potential. The physical variables measured during the field campaigns will provide hydrodynamical information, salinity variations, rates of exchange (of salt, properties, materials, organisms) between the lagoon and the sea and the eastern and western sides of the lagoon. The environmental monitoring is revealing the characteristics of the ecosystem, its health state and its relation with the physical processes of the lagoon.

3.2 Salinity gradients in La Carbonera, Yucatan

Existing data from CTD measurements at 5 mooring sites in La Carbonera coastal lagoon in the Yucatan Peninsula (Figure 1) revealed that the salinity gradients in the region can be up to 3 times greater than those in river mouths around the world. The lagoon is connected to sea by a channel formed in 1988 by Hurricane Gilbert, is very shallow (average depth 0.5 m) and covers an area of ~16.5 km^2.

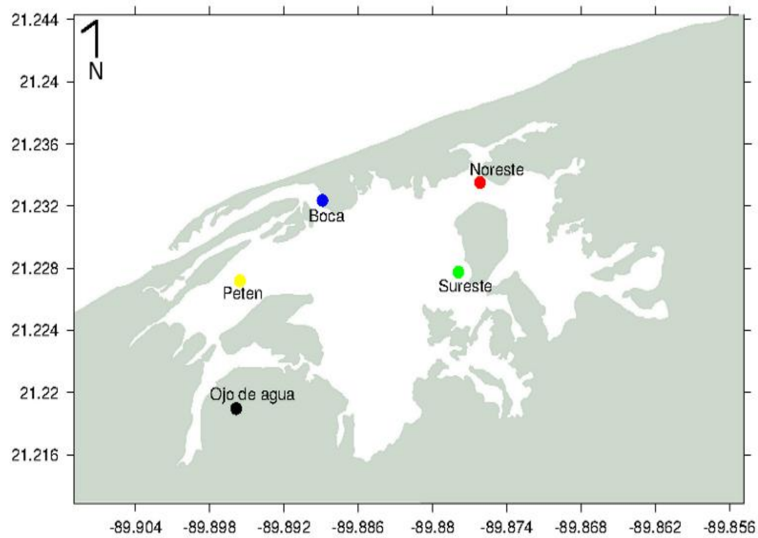

Figure 1. Lagoon "La Carbonera" in Yucatan, Mexico showing the CTD locations. The CTD located at the spring of SGD is shown with the black dot.

In the southwestern side, it has an intense point-source submarine groundwater discharge (SGD) through a "cenote" (sinkhole), and toward the east the lagoon develops hyper-saline characteristics [4].
The thermohaline measurements at the site (Figure 2) reveal pronounced salinity gradients with very small spatial variations in temperature at the site. The SGD measured at the spring (black line-Figure 2) has nearly uniform temperature and salinity throughout the year while the rest of the lagoon has very high diurnal variations that exceed the seasonal temperature variations (gray lines behind the bold lines in the top panel-Figure 2) but very little spatial variability.
In contrast, it is notorious that the eastern sites reach salinity values that can be twice and sometimes three times (around 80 psu) higher than those of the sea (around 30 psu), particularly during the dry season (approximately from January to May).

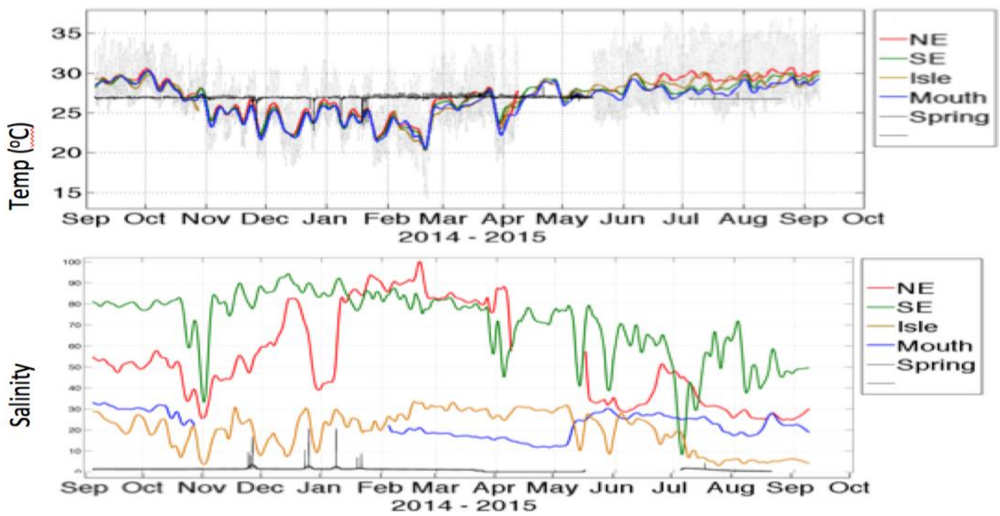

Figure 2. High pass filtered temperature (bold lines in the top pannel) and salinity (bottom) variations in the mooring sites at La Carbonera (Figure 1). The black lines correspond to the CTD located at the spring of SGD.

3.3 Theoretical salinity gradient potential

With the measured data and using the SGD as the diluted water and the mouth and the southeastern measured characteristics as the concentrated water respectively, the theoretical energy potential was calculated. Only the Chlorine and Sodium ions were used for the calculations and the water flow rates were assumed as 1 m^3/s constantly, as if there were no availability limitations.

The theoretical potential, as expected, shows high temporal variability with maximum values obtained from the calculations between the freshwater spring and the southeastern site (hypersaline) during the dry months (mean during those months 4.13 MJ reaching moments of 7.18 MJ). The lowest potential was obtained from the calculation between the freshwater spring and the mouth of the lagoon during winter and spring (0.76 MJ). This result shows that during this year, at this lagoon, the rainy season was less effective to dilute the lagoon than the winter season. During the rainy season, tropical weather results in intense precipitation events where large volumes of water rain over small areas; in winter, the precipitation events are less intense but of larger spatial scale and sometimes also of longer duration. These characteristics may determine the dilution of a coastal lagoon due to rain falling directly into it, with higher probabilities during winter.

4 CONCLUSIONS

Mexico may have a very important energy resource in salinity gradients around the coastal regions of the country. Particularly in coastal sites where evaporation promotes the development of hypersaline characteristics, the theoretical energy available is much higher than the one at river discharges. However, most of these sites are rare environments with the perfect characteristics that make them habitat for a wide biodiversity. It is therefore our responsibility to assess the potential of salinity gradient resources hand by hand with a comprehensive evaluation of the overall physical, chemical and biological processes of the sites with potential so that the desired sustainable and proper use of natural environments can be achieved if this resource proves to be a good option and if the technology development allows its extraction in the future.

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