Conceptual design of a salinity gradient energy demonstration unit at the Magdalena River mouth

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I. INTRODUCTION

Colombia has one of the most significant potentials worldwide for harnessing Salinity Gradient energy (SGE), specifically at the Magdalena River, whose mouth at the north of Colombia has 15 GW and 0.8 GW of theoretical and technical potential, respectively [1], [2].

In previous research, we built a device that generates electricity from SG through Reverse Electrodialysis (RED) principles. We also investigated the technical and financial feasibility and the possible environmental and social impact of implementing SGE in this system.

Given this context, we are developing a project to implement the first demonstration unit (150 Watts of installed capacity) of SGE in Latin America, which will be deployed in a place of new urban development for the city of Barranquilla that will bring together tourism, sustainability, and new green technologies [3].

In this work, we present the advances in constructing the SG demonstration unit at the mouth of the Magdalena River and the conceptual design of further scaling up toward the demonstration plant. We mainly study RED technology and emphasize operating conditions and stack arrangements; in this regard, technology efficiency has an important effect on environmental impacts at large scales since low-efficiency technologies imply more considerable water extraction to meet a fixed installed capacity.

II. METHODS

The location of the SG unit is at the mouth of the Magdalena River, in the area known as "Bocas de Ceniza," a place widely studied in the SGE literature [1], [4], [5] due to its ideal configuration for harnessing SGE – given for the artificial barrier that separates the sea from the river (see Fig. 1). The demonstration unit will be located at the far right of the artificial wall, targeting the shortest distance between the seawater and river water.

Fig. 1. Location of the demonstration unit at the Magdalena River mouth - north of Colombia (left). Zoom in on the beach "Puerto Mocho", where we intend to deploy the SG demonstration unit (right).

Our design involved three studies: an analysis of the river and the sea's hydrodynamic conditions to evaluate the amount of energy available, the pre-treatment of the water, and the installation of RED technology.

We set the plant's operating flow based on the targeted installed capacity and according to the energy density found in the salinities of the Caribbean Sea and the Magdalena River, which vary yearly according to the season (high or low river discharge) and was reported in our previous study [2]. We estimated the operating flow using (1) for the theoretical and specific site potential.

$$P = \Delta G_{mix}\dot{V} \tag{1}$$

Where P [W] is the power output, ΔG_{mix} [J.m^{-3}] is the volumetric energy density, and $\dot{V}$ [m^{3}.s^{-1}] is the volumetric flow, which we assumed is equal for the river and the seawater.

We considered both potentials to comprehensively understand the energy available and design according to the worst possible scenario. With this, we can ensure the installed capacity of the demonstration unit regardless of the season.

Pretreatment consists of multimedia filters whose main objective is to reduce the turbidity of the water to acceptable limits before entering the membrane modules.

We then fixed specific sizes for the RED stacks. From the operating flow, we deemed that three stacks with different sizes would be enough to build the unit and have more possibilities in experimentation and operation of diverse multi-stage arrays in series and parallel, analyze the scaling-up, vary the number of cells, and many other configurations and applications that might be worthy of study in the future. Our modules use up to 500 cell pairs (1000 membranes) each and have active areas of 13 cm x 13 cm, 9.5 cm x 9.5 cm, and 5 cm x 5 cm.

To analyze the operating conditions, we used a standard model for RED based on those published in the literature [6], [7]. The model input conditions correspond to typical salinities for the Caribbean Sea and the Magdalena River (36 g/kg and 0. 06 g/kg) at a standard temperature of 25 °C. For ease of calculation, we consider that the feeding waters are synthetic solutions of NaCl. We used the preset dimensions for the three RED units operating at a channel speed of 1 cm/s for commercial 254 μm spacers and Fujifilm® Type 10 membranes. In this way, we obtained power density curves.

III. RESULTS

Table 1 shows the different types of potential, theoretical and site-specific, and their estimation according to the year's season, i.e., river discharge (high or low). The volumetric energy density is the Gibbs-free energy of mixing calculated from the salinities and temperatures of the water in each season; from these data and the target installed capacity, the results of the eq. 1 indicates the demonstration plant's sizing, which is the same for river and sea.

TABLE I
SEASONAL VARIATION OF SGE POTENTIAL AT THE MAGDALENA RIVER MOUTH. ESTIMATIONS FOR 150 W AND VOLUMETRIC ENERGY DENSITIES WERE REPORTED IN [2]

Potential Type	Season (Discharge)	Volumetric Energy Density (MJ.m^{-3})	River Flow (m^{3}.h^{-1}) [m^{3}.day^{-1}]
Theoretical	High	2.20	0.2 [5.9]
	Low	1.86	0.3 [7.0]
Specific of the site	High	1.2	0.5 [10.8]
	Low	0.9	0.6 [14.4]

We based our demonstration plant configuration on similar facilities reported for SGE [8], [9]. The typical layout (Fig. 2) consists of water capture tanks for both the sea and the river with their respective pumps; it also has a pre-treatment area and storage tanks for the pre-treated water. Two pumps drive the treated water toward the RED module, and one additional pump circulates the electrode rinse solution.

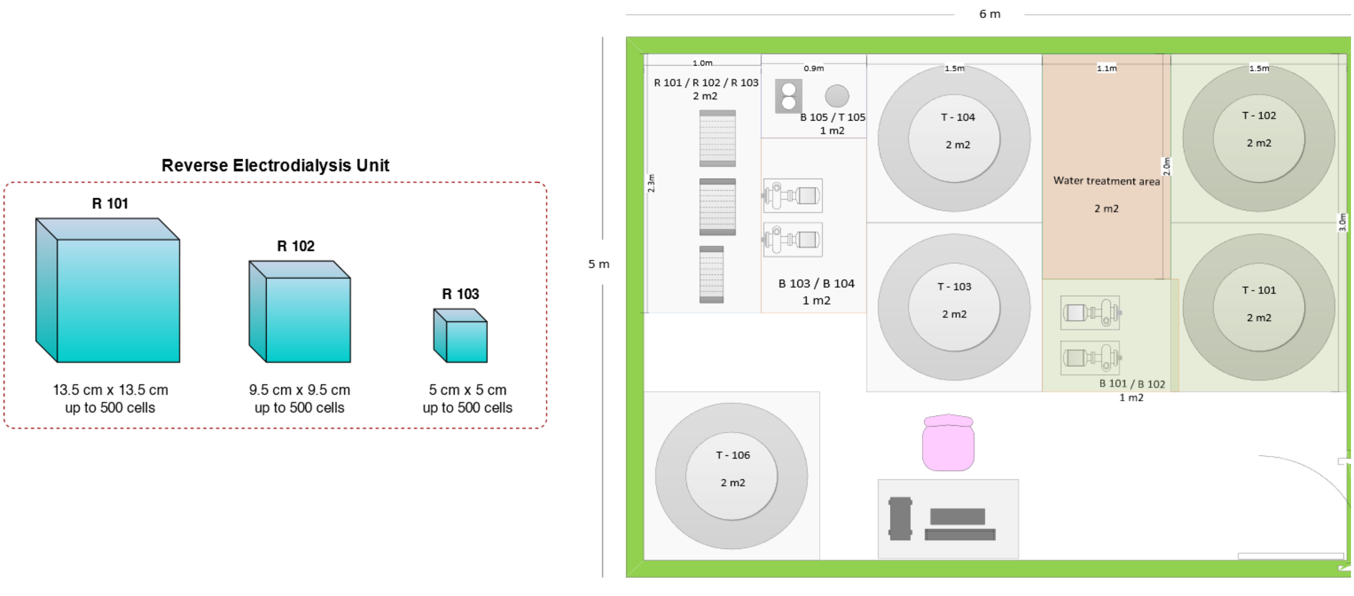

Fig. 2. Sketch of the RED module comparing the sizes of the three stacks (Left). Layout for the demonstration unit enclosed in a 6x5 m space (Right).

Once the electricity is obtained, the resulting water from the RED module is returned to the sea or the river — this is a subject of study once the demonstration unit is operating.

Fig. 3 shows the power density curves obtained from the simulations. Although the model should be validated with the experimental data of 500 cells (in the literature, there are validations only up to 50 cells), the variation between the maximum values for each stack is striking since it would be expected that the scaling would not present such significant differences in power densities. Such behavior could be associated with some phenomena missing in the modeling to anticipate the behavior of devices with large numbers of cell pairs. Most of the models available in the literature only predict the phenomena of one cell pair and replicate them for more cell pairs. In this case, the model omits the interaction phenomena between the cell pairs, which could affect the overall predictive capacities.

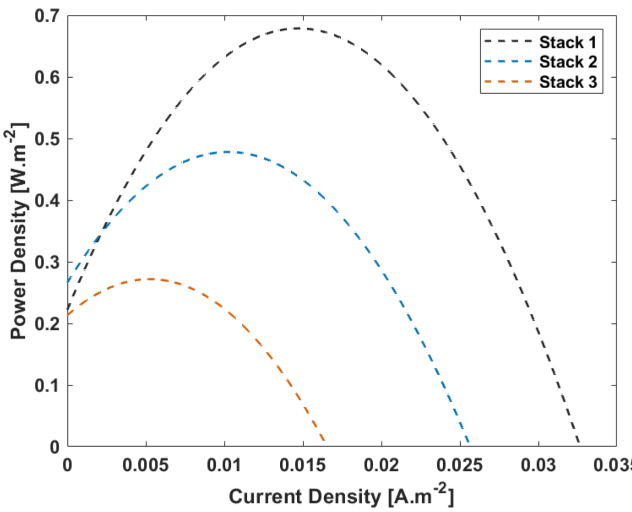

Fig. 3. Power density curves for the three stacks devised for the demonstration unit operating with NaCl solutions with typical Magdalena River and Caribbean Sea salinities.

IV. Conclusions

This work presented the first ideas and conceptual designs of the first demonstration unit of SGE in Colombia at the mouth of the Magdalena River. Although the installed capacity is fixed (150 W), it was found that the flow required to reach it varies according to the season of the year. In this sense, natural hydrodynamic conditions may affect the plant's behavior throughout the year, not only in terms of the pumping power required but also in the quality and pretreatment of the water.

The RED stacks to be used in the demonstration unit are of different sizes, as we aim to study the upscaling of the technology. In addition, having several units will allow exploring different configurations between series and parallel (multi-stage operation).

The simulation of the stacks from models published in the literature must be validated and calibrated according to the challenges encountered when operating in a relevant environment with natural water at a larger scale than the laboratory.

The results of this study will be the input for the analysis of salinity gradient technologies in Colombia. The demonstration unit primarily aims to generate insights in a relevant environment on the environmental and economic viability of harnessing SGE at the Magdalena River mouth. In addition, the structure and assembly with sensors, pipes, and pumps will help strengthen the study of marine resources in the country and develop more projects involving salinity gradient technology, e.g., coupled systems with desalination or hydrogen production from ocean resources.

V. References

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