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Performance evaluation of a wave energy converter that produces potable water.

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***Abstract** – The electrical power performance of a wave energy converter (WEC) has been standardised; however, recent interest in wave-driven desalinization systems (WDDS) has given rise to standard metrics to evaluate the performance of a WEC for water desalination. The efficiency of water production should consider the quantity and quality of desalinated water. In this paper, water production was investigated by quantifying the salinity concentration and permeate flow using reverse-osmosis membrane laboratory data and industry-accepted empirical formulas. The evaluation indicates that WDDS sea-trials critical measurements are pressure, flow, salinity, temperature, and salinity of the feed flow and the permeate flow.*

***Keywords** – Ocean wave energy, Desalination, Reverse osmosis membrane, Renewable energy, Water production metrics*

I. INTRODUCTION

Producing potable water from seawater is an energy-intensive process; however, the use of marine renewables such as WEC could make this practice more sustainable. In terms of WEC's electrical power performance, the capture length is a standard metric for wave power production per wave energy flux [1]. However, such an indicator has not been established for water desalination. The objective of the present work is to identify the parameters required to evaluate the performance of a WDDS. An example of a new WDDS design is DUO-DS, the device captures wave energy to pump pressurised water through a reverse osmosis (RO) membrane to produce drinkable water. DUO-DS provides an ideal test case to identify the additional parameters required to evaluate the overall performance of a WDDS. Future DUO-DS sea-trial testing will provide the opportunity to identify the role of the parameters measured and would allow the adaptation of IEC/TS 62600 standards to wave-powered desalination and potable water generation.

II. METHOD

Assessment of a WDDS performance and thereof identification of the modifications needed in the IEC/TS should consider the 1) wave resource characterisation, and 2) water production evaluation. In terms of water production, numerical modelling of WEC hydrodynamics and RO desalination process [2] [3] indicate the relation between the driving pressure of the feed water on both salinity concentration and permeate water, where driving pressure is an indicator of wave sea states. However, [2] relied on constant feed water to satisfy the RO operating conditions and [4] pointed out the relevance of considering the variability of incident wave power. To address this gap [3] and [5] investigated the performance of SWRO membrane under time-varying wave conditions which produce the variation of the feed water. Figure 1a illustrates the experimental set up of a wave-powered SWRO desalination unit, it shows key components such as feed water, permeate water, RO module, and pressure sensors. As an example of WDDS operation Figure 1b shows DUO-DS 2021 deployment on Strangford Lough Northern Ireland. To appreciate the parameters required for water production the evaluation of datasets obtained by [5] and the relation for the concentration coefficient C_p derived by [2] numerically are used. The data correspond to a RO FILMTEC SW30-2540 laboratory experiment under steady flow and steady pressure with a constat feed water rate of approximately 12 L/min.

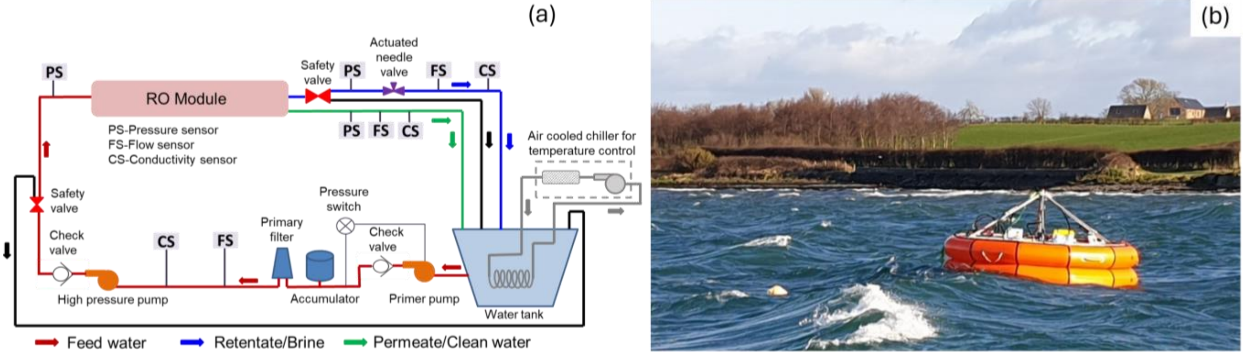

Figure 1. (a) Schematic of experimental set up of a wave-powered RO desalination unit from [2] and (b) DUO-DS wave power desalination system.

III. RESULTS

The permeate water and permeate salinity obtained for a feed pressure from 35 to 60 bar obtained by [5] were used to estimate proportionality constants: initial water permeability coefficient (A_w) and the salt permeability coefficient (B_s), which characterise the performance of a RO membrane [7]. A_w and B_s were used to calculate the concentration coefficient C_p (Equation 3), which is an indicator of salinity concentration, and the permeate flow rate Q_p (Equation 4). These relations are a function of the seawater salt concentration C_s, active membrane surface area S, net driving pressure and osmotic pressure of seawater (ΔP - Δπ). Performance of the wave-powered desalination unit as a function of feed pressure is shown in Figure 2a for the feed flow rate of 12 L/min. The plot indicates that permeate flow and salinity concentration are a function of the driving pressure, where higher pressures are related to higher permeate flow and smaller salinity concentration. In this case, the salinity concentration is used as a proxy for the total dissolved solids concentration (TDS). Drinking water requires TDS concentrations lower than 600 ppm. In terms of palatability levels within 300-600 ppm are considered good. Figure 2a indicates the production of permeate flow at an excellent rate for drinking water [8]. As C_p and Q_p are a function of the driving pressure, for a constant feed water rate C_p and Q_p match the laboratory data (Figure 2a). However, a WDDS will operate with time-varying feed water, and in this regard [5] used rectified sinusoidal flow to investigate fluctuations in the feed flow and feed pressure. [5] indicates that a rectified sinusoidal flow increases the permeate water recovered and produces a significant increase in permeate salinity concentration, further investigation by [5] also found RO membrane performance degradation. Nevertheless, C_p exemplify the salinity concentration, which is an indicator of water quality, and Q_p can be used to estimate the volume of water produced. Both C_p and Q_p can be use as inputs in wave-powered desalination metric (Equation 3) reported by [8] and presented in Figure 2b. This empirical equation gives a higher score to the device that produces a larger volume of water with lower C_p, and indicates that assessment of water production requires the quantification of the volume and salinity concentration of the water desalinated.

$$C_p = \frac{C_s}{\frac{A_w}{B_s} * (\Delta P - \Delta \pi) + 1} \tag{1}$$

$$Q_p = S * A_w * (\Delta P - \Delta \pi) \tag{2}$$

$$Score = \frac{2800 + \left(\frac{6{,}500{,}000{,}000}{1 + \frac{{C_p}^{1.26}}{0.002}} \right)}{1{,}300{,}000} * (Q_p * 60) \tag{3}$$

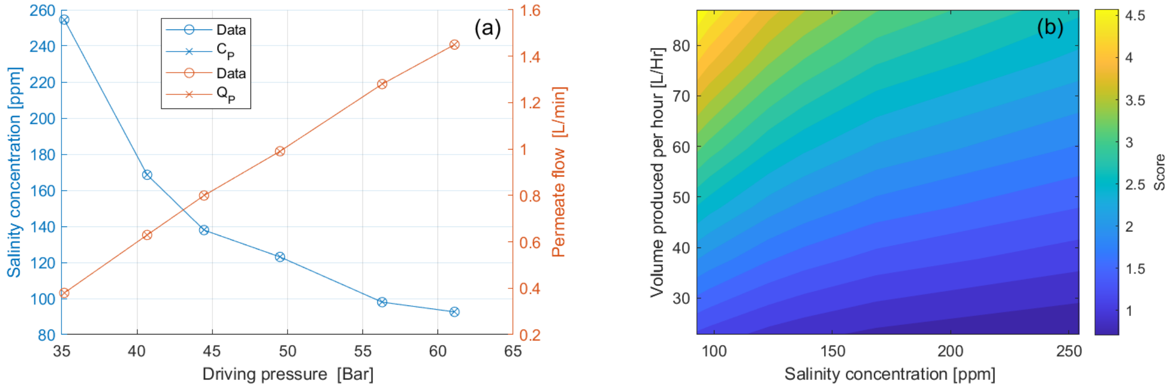

Figure 2. Key indicators for evaluating water production. (a) Driving pressure versus salinity concentration and permeate flow; and (b) wave-powered desalination metric.

IV. CONCLUSION

To identify the modifications needed by the IEC/TS to incorporate the evaluation of WDDS performance the volume and salinity concentration of the permeate flow are key parameters to measure. Laboratory RO experiments with variable flow indicate the relevance of measuring the feed water conditions and optimizing the RO operation. Furthermore, seawater characterisation in terms of total dissolved concentration requires the monitoring of additional measurements such as temperature, turbidity and pH. A list of key parameters to measure to evaluate water production is presented in Table 1. These parameters together with wave resource characterisation would provide the evidence to evaluate a WDDS performance. Upcoming DUO-DS sea trials will provide a good opportunity to investigate its performance at a particular site.

Parameter [units]	**Measurement**	**Sensor**
Pressure [bar]	Feed pressure	Hydraulic pressure transducer
	Permeate pressure	
Flow [L/min]	Feed flow in hydraulic circuit between pistons and RO membranes	Hydraulic flow meter
	Permeate flow at outlet of RO membrane	Hydraulic flow meter
Seawater salt concentration [ppm]	Feed flow	Salinity sensor
	Permeate flow	
Turbidity [NTU], temperature [℃], pH	Feed flow	Temperature, pH, and turbidity sensors
	Permeate flow	

Table 1. Key measurements collection during WDDS sea-trial

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