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Production of Fertilizer from Seawater with a Remote Control System †

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Abstract: Seawater is abundant and full of nutrients known as ORMUS. Inorganic fertilizers have become scarce and expensive, so alternatives to feed plants are being studied. An automatic tank on a fishing boat was designed to extract salts from seawater, as follows: Sodium hydroxide is applied to seawater and agitated within a tank until its pH reaches 10.78. Salts begin to deposit, and the sodium mixed with the water stays at the surface. Water with sodium is removed after 3 h with a low-pressure pump. Clean water is added to the salty solution at the bottom of the tank to remove more sodium. Water at the top is sucked by the pump again, and the process is repeated once more. After the white salt (ORMUS) lying at the bottom of the tank is removed, the fertilization extraction process can start again. The automatic system regulates the agitator speed, pump filling and suction timing, and bottom valve opening.

Keywords: fertilizer extraction; sodium hydroxide; ORMUS; remote control

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1. Introduction

Water scarcity is expected to increase as water needs intensify, due to population growth, climate change, and agricultural demands [1]. Spain has invested large amounts of capital to increase the availability of water over the course of this century. Desalination consumes high amounts of energy, and may cause deleterious effects on marine ecosystems [1]. The amount of water available for irrigation is limited, and treated seawater can be used for tree plantations close to the sea. Water for irrigation can mix seawater with fresh water at a 1:30 dilution [2], which is known as diluted seawater (DSW). Soil ammonium concentration in wetlands increases with salinization caused by saltwater incursion. Long-term saltwater exposure of intact soil shows an exchange of salt cations that increases the reactive N being released.

The existence of inorganic fertilizers is decreasing. Cover cropping provides plant-available nitrogen in organic systems economically, as well as manure-based compost [3]. Dry organic fertilizers such as fishery waste and guano are widely used, but their quantity is limited, and mineralization of their N can take between four and eight weeks [3]. Sea salt has been applied as a source of sea mineral solids for foliar and soil treatments [4,5]. In a total replacement scenario, the increase in water cost EUR ha^{-1}) with respect to production costs is far more relevant than fertilizer cost for all crops; water cost ranges from 2.6% for lettuce to 35.1% for lemons [5]. Fertilizer increase represents less than 1% of the production costs for all crops. Irrigation of faba bean plants with diluted seawater (3.13 to 6.25 dS m^{-1}) led to significant reductions in shoot length, shoot dry weight, number of leaves per plant, and photosynthetic pigments [6]. A bittern solution, which is a byproduct of a solar salt production process, can be used as a reliable source of Mg and other nutrients required for plants; 390 ppm is the ideal bittern dosage [7].

A fertilizer extraction system on a canoe, with process control, was implemented. The control system is managed remotely through a LoRa system, and the main actions are controlled within a loop at the boat. Monitored data are transmitted to the shore to keep track of the process and the amount of fertilizer obtained.

2. Equipment Design

The fertilizer extraction system uses a stainless steel tank fixed over the boat base, with an output cone at the bottom (Figure 1a). The closed tank presents an injection/extraction pump, a powder dosifier, and an agitator fixed at its surface. The injection pump sucks water from the sea, filling the tank with seawater, and when it turns in the opposite direction it extracts the salt water produced by the chemical reaction and returns it to the sea. The 0.5 kg h^{-1} volumetric dosifier (model Kö 2-1, Werner Koch Maschinentechnik GMBH, Germany) feeds the powder to the tank during each event. The chamber of the dosing roll is filled equally before it is emptied at a constant speed. The agitator is composed of a two-pitched-blade turbine that is fixed to the motor blade. This turbine produces axial and radial flows with an intermediate shearing effect, and its flow can be controlled with a speed controller.

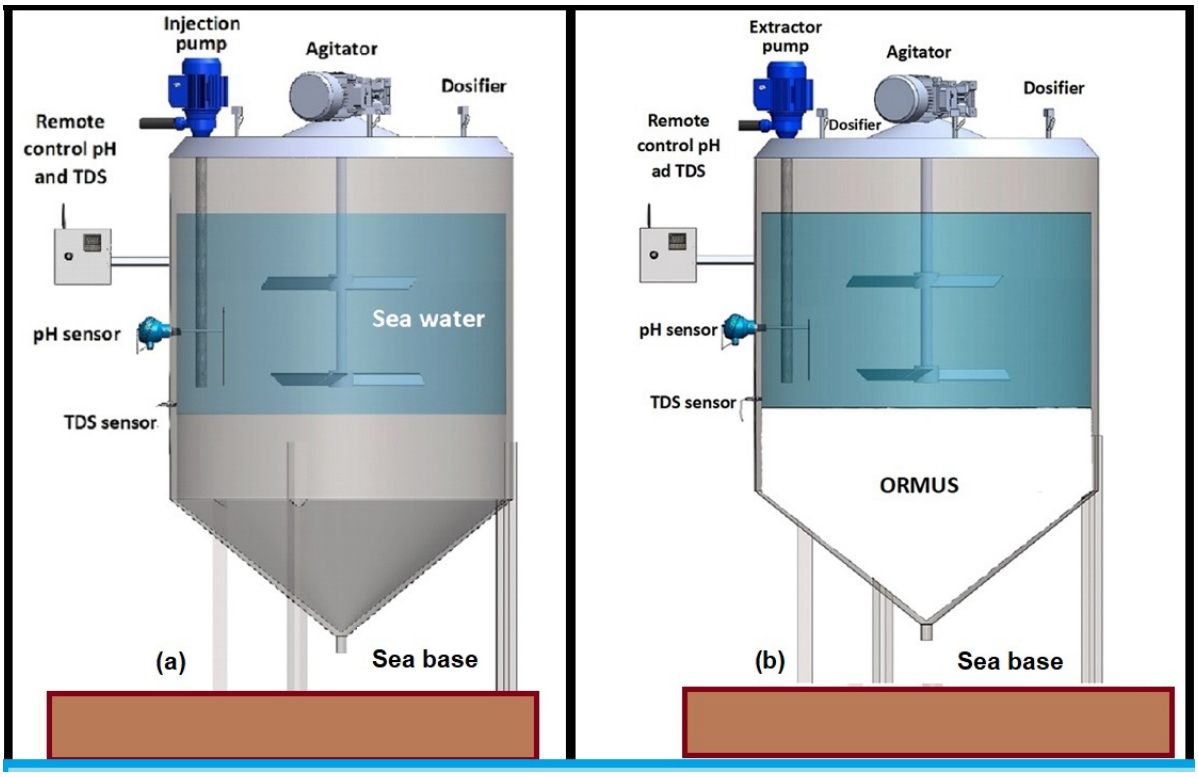

Figure 1. Process equipment (**a**) when seawater is injected, and (**b**) after ORMUS is produced.

3. Instrumental Equipment

The monitoring equipment for the processing tank uses pH (HI-11310, Hanna, Woonsocket, RI, USA) and TDS (HI-7634-00, Hanna Instruments, Woonsocket, RI, USA) sensors (Figure 1b). A pH controller (BL 931700, Hanna, Woonsocket, RI, USA) with a set point fixed at 10.78 controls the sodium hydroxide dosage. Measurements are directly acquired from a pH electrode in the range from 2 to 16, with a resolution of 0.01; the cable of the glass probe is 1 m long. A two-point calibration is performed daily and calibrated through trimmers on the front panel. The TDS sensor is calibrated by the HI-70030 solution at 12880 µS cm^{-1}, and by the HI-70038 reference at 6.44 µS cm^{-1}.

Total dissolved solids (TDS) combine the sum of all ion particles that are smaller than 2 microns. Freshwater can have a maximum conductivity of 2000 mg L^{-1}, while saline

water conductivity is always over 3700 mg L^{-1}. A TDS controller (model BL-983319-0, Hanna Instruments, USA) is employed with a 0.5 conversion factor and temperature compensation. Water TDS increase when seawater is injected. Once the sodium hydroxide is applied, pH increases up to 10.78. Salts separate from the sodium water, and the salts gravimetrically deposit due to their higher density. Once the higher TDS value is reached, the pump at the top extracts the salty water with sodium and returns it to the sea. As the electrical conductivity at the top of the tank becomes 0 as it is full of air, it is refilled with purified water and agitated again. This process is repeated 3 times.

An ESP32-WROOM-32 microcontroller board (Espressif, China) controls the data acquisition and transmits the values through the LoRa transmitter. Controllers for pH and TDS are used in real time to turn off the dosifier and start removing the sodium-concentrated water.

4. Results and Discussion

Dosing of powder implies that it is homogeneous and does not carry small stones. The sodium hydroxide powder was dry, and its diameter was smaller than 1 mm. When the dosifier applied the powder over the tank water surface, it was too light to mix. Therefore, powder was introduced using a metallic screw and mixed with the water 20 cm above the bottom of the tank. Three different pH probes were installed at that height within the periphery of the tank, and their values varied considerably. The pH at the place where sodium hydroxide left the screw increased instantly, and was higher than on the opposite side. For example, seawater pH increased to 8.5 at the output of the screw, but on the opposite side pH was only 7. The closed loop was difficult to implement until another two dosifiers were added.

In the first experiment, a remote controller turned on the pump and filled the tank with 100 L of seawater. The dosifier added sodium hydroxide until the seawater pH reached 10.78 near the dosifier screw. The agitator turned slowly, and heating was noted within the tank, with an endothermic reaction taking place. The pH controller turned off the dosifier and, after three minutes, the temperature became constant within the tank. Under constant temperature, the agitator was stopped for a period of three hours.

With continuous agitation at 150 rpm, pH quickly reached 10.78 (Figure 2). If timers were used with the agitators at 150 rpm (purple line Figure 2), pH remained constant until the dosifier worked again. It is better to provide 2 kg of NaOH and wait until pH reaches 10, and then slowly add the powder until it reaches 10.78, reducing overheating of the sensors. A fuzzy algorithm was used to implement the dosage.

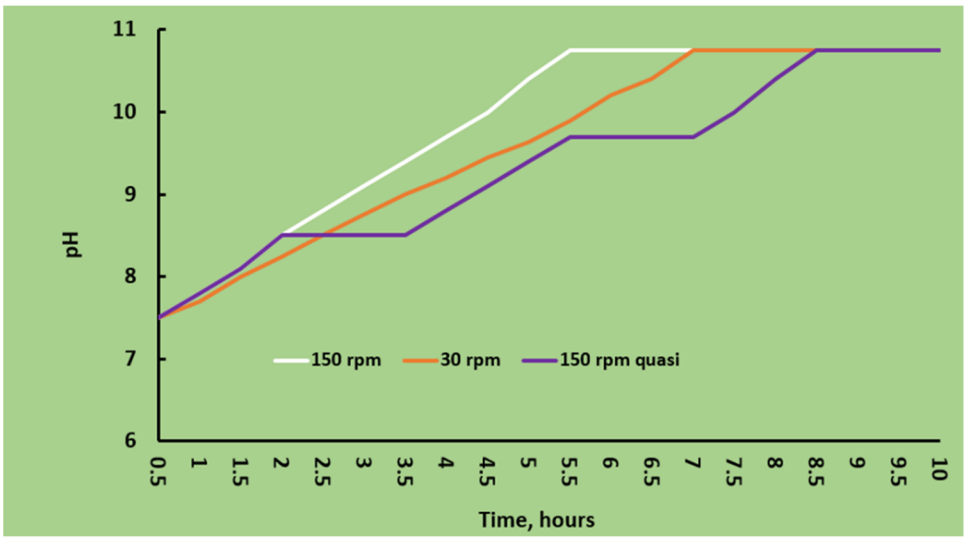

Figure 2. pH monitoring at different agitator speeds.

An event-driven controller was used instead a time-driven one, as fewer events took place at times when the controlled process did not require high accuracy [8]. Event-driven controllers can achieve a compromise between processor load and control performance. Three classes of control algorithms can occur according to the way in which actions take place in time. These classes can be classified as synchronous, semi-synchronous, and asynchronous. In this process, TDS and pH are measured synchronously within the tank, but the activation of different actuators is asynchronous [8]. At a distance of 5 km from where the boat was located, the wireless system with LoRa worked properly. A spreading factor of 12, a frequency of 915 MHz, and a coding rate of 4/6 were used, obtaining an RSSI of −75 at 5 km. This result is consistent with LoRa experiments using normal antennas, where 22 km receptions over seawater were reported [9].

Large desalination plants using reverse osmosis in Spain, processing more than 100,000 m^3 day^{-1}, can obtain freshwater from seawater at a cost of EUR 0.36–0.53 m^{-3} [1]. Nutritional deficiencies (mainly $Ca_2{}^+$ and $Mg_2{}^+$) when using diluted seawater (DSW) can be fixed by blending DSW with other hard water sources [7]. The combined use of desalinated seawater and brackish water reduces the salinization of underground water, enabling the reclamation contaminated aquifers [10]. The water obtained from our prototype can also yield other interesting byproducts. Although fertilizer costs with respect to production only account for 1%, fertilizers are scarce in Mexico, and must be imported.

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References

1. March, H.; Saurí, D.; Rico-Amorós, A.M. The End of Scarcity? Water Desalination as The New Cornucopia for Mediterranean Spain. *J. Hydrol.* **2014**, *519*, 2367–2660. [CrossRef]
2. Sgherri, C.; Kadlecova, Z.; Pardossi, A.; Navari-Izzo, F.; Izzo, R. Irrigation with diluted sea water improves the nutritional value of cherry tomatoes. *J. Agric. Food Chem.* **2008**, *56*, 3391–3397. [CrossRef] [PubMed]
3. Hartz, T.K.; Smith, R.; Gaskell, M. Nitrogen Availability from Liquid Organic Fertilizers. *HortTechnology* **2010**, *20*, 169–172. [CrossRef]
4. Mekki, B.B.; Orabi, S.A. Response of prickly lettuce to uniconazole and irrigation with diluted seawater. *Am. Eurasian J. Agric. Environ. Sci.* **2007**, *2*, 611–618.
5. Álvarez, V.; Gallego-Elvira, B.; Maestre-Valero, J.F.; Martin-Gorriz, B.; Soto-Garcia, M. Assessing concerns about fertigation costs with desalinated seawater in south-eastern Spain. *Agric. Water Manag.* **2020**, *239*, 106257. [CrossRef]
6. Sadak, S.H.; Abdelhamid, M.T.; Schmidhalter, U. Effect of foliar application of aminoacids on plant yield and physiological parameters in bean plants irrigated with seawater. *Acta Biol. Colomb.* **2015**, *20*, 141–152.
7. Wijayarathne, U.; Wasalathilake, K.; Vidanage, P. Development of a Multi-Nutrient Fertilizer from Liquid Waste of Solar Salt Manufacturing Process. In Proceedings of the 2015 Moratuwa Engineering Research Conference (MERCon), Moratuwa, Sri Lanka, 7–8 April 2015; pp. 24–28.
8. Sandee, J.H.; Heemels, W.P.; van den Bosch, P.P. Event driven control as an opportunity in the multidisciplinary development of embedded controllers. In Proceedings of the American Control Conference, Portland, OR, USA, 8–10 June 2005; Volume 3, pp. 1776–1781.
9. Jovalekic, N.; Drndarevic, V.; Pietrosemoli, E.; Zennaro, I. Experimental Study of LoRa Transmission over Seawater. *Sensors* **2018**, *18*, 2853. [CrossRef] [PubMed]
10. Reca, J.; Trillo, C.; Sánchez, J.A.; Martínez, J.; Valera, D. Optimization model for on-farm irrigation management of Mediterranean greenhouse crops using desalinated and saline water from different sources. *Agric. Syst.* **2018**, *166*, 173–183. [CrossRef]