



2-21-2017

Oceanus: Autonomous Wave-Powered Desalination

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OCEANUS

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Autonomous Wave-Powered Desalination

1.17 billion people—nearly one-sixth of the world’s population—live in areas currently experiencing water scarcity.

Another 500 million are in danger due to this situation.¹ The problem of water scarcity has grown steadily over recent decades, and is predicted to increase in severity in the future. Many of those who lack access to potable water live in remote or underdeveloped areas, and are therefore susceptible to severe health risks as a result of water scarcity. One way to address this water crisis is to utilize reverse osmosis technology.

Reverse osmosis desalination is a process that can extract clean water from salt water by forcing that salt water through a thin, permeable membrane. The salt molecules are too large to fit through the small pores of the membrane, so pure fresh water can be collected from this process. However, most reverse osmosis solutions that are implemented today are done so on an industrial scale. These are large plants that contain hundreds of reverse osmosis membranes and require large amounts of electricity, powered by the burning of fossil fuels, to provide them with the amount of energy they need. This type of solution is not attainable for all geographical areas, yet it is the only option for Los Angeles, Israel, and Saudi Arabia, where the high density requires very intensive forms of desalination. Places that are remote often do not have the well established electricity grid infrastructure necessary to support reverse osmosis on an industrial scale. They need an alternate solution.

One possibility for providing these areas with the energy they need to drive reverse osmosis desalination is to harness that energy from the ocean waves through the implementation of a Wave Energy Converter, or WEC. WECs range in shape and size. The type of WEC that is pertinent to this project is known as an oscillating wave surge converter, as shown in Figure 1. As ocean waves pass by the WEC, its flange pitches from side to side and harnesses the kinetic energy of those ocean waves.

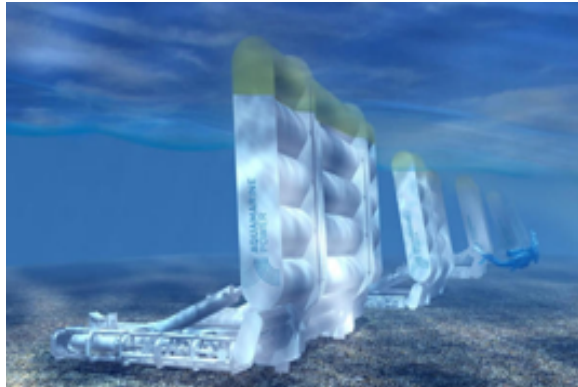


Figure 1: Oscillating wave surge converter via Aquamarine Power

“**While Oceanus is just a prototype, innovations like this are a critical part of alleviating world water scarcity.**”

While the direct integration of WECs with reverse osmosis (RO) desalination seems like a convenient pairing, there is a problem associated with doing this. If an RO membrane were directly attached to an oscillating wave surge converter, it would experience cyclic, rapid pressure variations due to the periodic motion of the WEC. However, the industry standard for RO membranes is that they are to be exposed to only very small pressure fluctuations, or else they may experience fatigue over time and be subject to damage.

We have created a novel, compact pressure vessel, known as Oceanus, that is meant to modulate the fluctuating pressure profiles created by ocean waves to allow the direct integration of WECs with RO desalination.

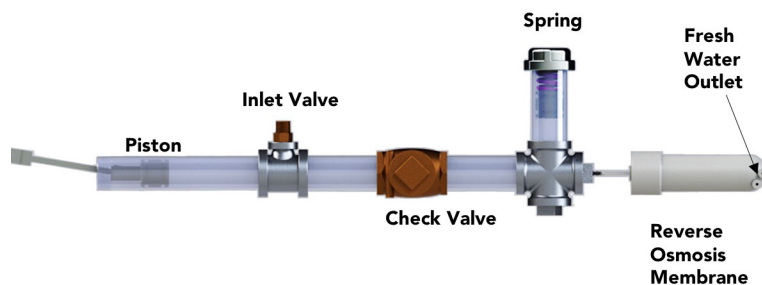
Oceanus is a mechanical system that uses a spring to capture and modulate the rapidly varying pressure of ocean waves. It contains a series of check valves that allow the system to push seawater through a reverse osmosis membrane at a nearly constant pressure. At the end of

each wave cycle, it allows new salt water into the system to replace that which has been lost.

Imagine a wave rolls in towards the WEC. The WEC will pivot in relation to the wave, driving our piston forward and increasing the pressure in the whole system. This pressure causes our spring to compress, and store a substantial portion of the energy for later in the cycle, while some clean water is pushed through the RO membrane, and extra-salty brine is ejected from the system. It is worth noting the size of the systems means there are negligible environmental impacts of the salt disposal.

When the wave recedes, the WEC will start to return to its normal position, due to natural buoyancy. This means the piston begins to retract and the pressure in the system will fall rapidly, an unacceptable outcome. Thus, our check valve will close, and isolate the left side of the system from the right. This means the spring-membrane portion will remain pressurized, while the piston-inlet valve section will refill. When the next wave comes by, the piston will drive forwards again, re-pressurizing the system, and causing the check valve to open.

However, the real magic happens while the spring is isolated from the piston. The spring was previously compressed, but now starts to expand again, keeping the pressure in the right hand side high, and continuing to push water

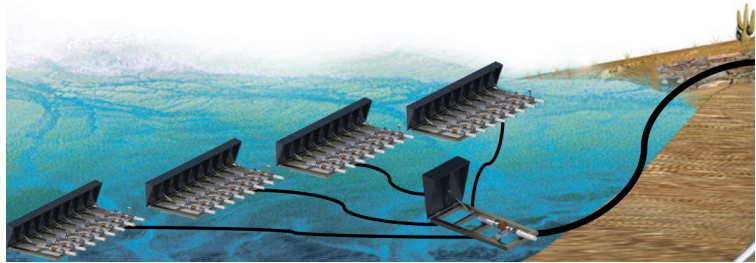


through the membrane. This means the membrane never sees substantial pressure variation, and fresh water is continually being produced.

Sadly, the Oceanus system has yet to be tested in water (though planning is ongoing for May 2017 deployment off Florida). Due to time, logistical, and funding constraints, the final prototype underwent thousands of tests on an MTS, or tension-compression machine at Penn. The machine was programmed to realistically simulate the impact of waves of various speeds and periods on the piston. This was more than sufficient to prove the effectiveness of the device and collect meaningful data.

At its best performance, the Oceanus system is able to produce about five liters of potable water per hour and reduce pressure fluctuations on the membrane to under 30%. It can take feed water that has been laced with salt, dye, or other particulates (tested up to 1700 ppm) and reduce that particulate content down to 350 ppm, which is better than medical grade quality water.

To ensure that this novel system's pressure fluctuations would not damage the membrane, the team performed Scanning Electron Microscopy as well as methyl blue porosity testing on samples of membranes that had undergone thousands of simulated wave cycles. These membranes were designed to never see more than a 5% variation of pressure, and had performed hundreds of tests with 50% pressure drops in only a few seconds—far more challenging conditions than any to be faced in the ocean. These test samples were compared against control samples, and no damage was visible. There was also no long term, observable, degradation in performance on pressure tests, so the team believes that reverse osmosis membranes are capable of handling the pressure fluctuations seen in the Oceanus system.



Though the Oceanus system is currently only a prototype, there are promising possibilities for deployment in the future. A full installation would consist of four WECs each driving eight Oceanus systems, along with a WEC pumping station, which could provide up to 64 gallons of clean water per hour, enough to alleviate the water scarcity problem for as many as 128 people.

While Oceanus is just a prototype, innovations like this are a critical part of alleviating world water scarcity. A simple, low cost system like Oceanus can provide water for an entire village, and help to alleviate water scarcity, improve productivity and reduce illness. Installation of the Oceanus system could cost under \$100,000, as opposed to the tens of millions that are often spent on industrial desalination plants. Furthermore, Oceanus does not require electricity nor complicated engineering to install. The ocean is a massive source of energy and water. It seems foolish not to tap into it!

Oceanus was created in 2016 as a Mechanical Engineering Senior Design Project by Sasha Klebnikov, Christina Springer, Chevona Walcott, William Cheng and advised by Dr. Jennifer Lukes. It won the John Couloucoundis Prize, the Naval Academy Science and Engineering Conference Best Poster Award, and came in First Place in the UPenn SEAS Senior Design Competition. The system is currently patent pending, but anyone interested in taking the project further is strongly encouraged to reach out to the team.

CITATIONS

¹ "Water." World Resources Institute. N.p., n.d. Web. 08 May 2016.