Sustainable Desalinator – An EPS@ISEP 2016 Project

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ABSTRACT

The European Project Semester (EPS) is a one semester capstone project/internship framework offered by the EPS providers to engineering, product design and business undergraduates. While a student-centred project-based learning offer, EPS proposes a unique multidisciplinary and multicultural teamwork set up to promote soft, technical and scientific competencies. In the spring of 2016, the EPS at the Instituto Superior de Engenharia do Porto (ISEP) welcomed a team of engineering students who chose to develop a sustainable water desalinator, the working principle relying on solar energy and natural temperature differences to convert saline water into fresh water. This paper describes the team's journey, including the motivation, the solution design process, considering the technical & scientific state of the art as well as the potential impact in terms of ethics, sustainability and marketing, and the development and testing of the prototype. The results obtained validate the purpose of the developed system since a significant reduction of the salt water conductivity, to values of the same order of magnitude of tap water, were observed. Although improvements can be made, the desalinator prototype produced 70 ml/d of distilled water in late spring and 7 ml/d in midwinter atmospheric conditions.

Conference Key Areas: Sustainability and Engineering Education, Engineering Skills.

Keywords: EPS, Project-based Learning, Multicultural and Multidisciplinary Teamwork, Water Desalination.

INTRODUCTION

The European Project Semester is a one-semester engineering capstone project/internship programme offered by a group of 18 engineering schools from 12

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countries – the EPS providers. The EPS defines a common structure composed of a multidisciplinary project module together with a set of project supportive modules devoted to soft skills, aiming to prepare students for international collaboration. The EPS providers implement the programme in accordance to a set of core rules, the “10 Golden Rules of EPS[2]”. These rules specify, among other features, that English is the working language, teams must be formed by students from different countries, and it is worth 30 ECTS credit units (ECTU). Despite this common structure, each institution enjoys some freedom in the implementation of EPS. The programme is addressed mainly to incoming exchange students so that the class becomes a truly international setting. The goal of the EPS is to expose participants to diversity, both cultural and scientific, teamwork and multidisciplinary problem-solving [1].

ISEP offers EPS to 3rd and 4th year engineering, business and product design students every spring semester since 2011. The EPS@ISEP assigns 20 ECTU to the project module and 10 ECTU to complementary project supportive modules: Project Management and Team Work; Marketing and Communication; Foreign Language; Energy and Sustainable Development; and Ethics and Deontology. EPS@ISEP has been challenging students from multiple educational backgrounds and nationalities to join their competences to solve multidisciplinary real life problems in close collaboration with industrial partners and research institutes. This approach stimulates students to contribute with and apply their specific knowledge and develop transversal skills, namely social and communicative skills, during the different stages of the team collaboration process [2].

In the spring of 2016, a team of civil, packaging, mechanical, electrical and logistics engineering students chose to develop a sustainable water desalination module. The team embraced this challenge motivated by the idea of providing a sustainable source of drinkable water to populations located in coastal areas where water is scarce and/or contaminated. The team, driven by this opportunity, decided to design, build and test a sustainable desalination system using solar energy. Solar distillation involves direct absorption of solar energy in the saline water and its evaporation (at a temperature substantially below the normal boiling point) in an enclosed space. In contrast to the fossil fuel powered desalination, solar desalination is a sustainable process. This process removes impurities, such as salts and heavy metals, as well as eliminates microbiological organisms. The purified water can be used for human and animal consumption, farming, gardening, etc. The team decided that their system was intended for human and defined as their main marketing target governmental institutions, non-governmental organisations (NGO) and environmentally aware individuals. The team first conducted a state of the art review together with sustainability, ethical and marketing studies in order to define the use cases and requirements of their system. Based on these requirements, the team designed the structure and control system, chose and procured the materials and components and, finally, built, tested and determined the average daily volume of distilled water obtained with their solar powered desalination prototype.

This paper is organised in six sections. Section 1 presents existing desalination methodologies and describes the team own approach. Section 2 presents the complementary analysis performed by the team in terms of sustainability, marketing and ethics. Section 3 describes the proposed solution, whereas Section 4 reports the functional tests as well as its results and Section 5 draws the main conclusions.

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[2] http://www.europeanprojectsemester.eu

1 WATER DESALINATION

The most common chemical-free water desalination processes are Vapour Compression, Reverse Osmosis, Direct Contact Membrane Distillation and Water Desalination Powered by Renewable Energy Sources [3].

Vapour Compression process evaporates the salt water by using heat delivered by compressed vapour, as shown in *Fig. 1*. This type of desalination requires a mechanical driven compressor or a blower connected to the mains. The team rejected this technique for its expensiveness and high consumption of energy.

Reverse osmosis, relies on high pressure to overcome the osmotic pressure of a membrane, forcing the water through the membrane while retaining salt and other minerals (*Fig. 2*) [4]. Although an efficient technology, the team rejected it for being complex, difficult to downscale, expensive and susceptible to membrane fouling [5].

The direct contact membrane distillation process relies on a membrane dividing a container in two parts, at distinct temperatures (*Fig. 3*). The vapour flows from the heated tank, through the membrane, into the lower temperature tank, where the vapour condenses into drinkable water [6]. Although compatible with downscaling, this approach suffers from high energy consumption [5] and a cost incompatible with the available budget.

Sustainable water desalination systems are powered by renewable energy sources. As an example, solar power desalination relies on the Sun to convert saline water into fresh water [7]. The Sun heats the salt water, which evaporates and, then, condensates on the transparent cover. Finally, drinkable water can be collected (*Fig. 4*).

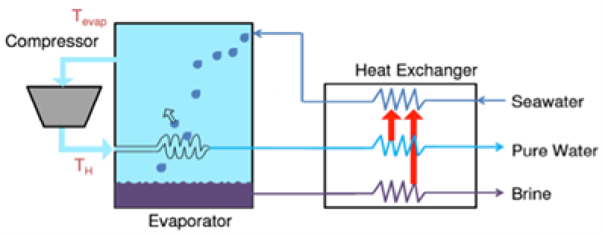

Fig. 1. Vapour Compression [4]

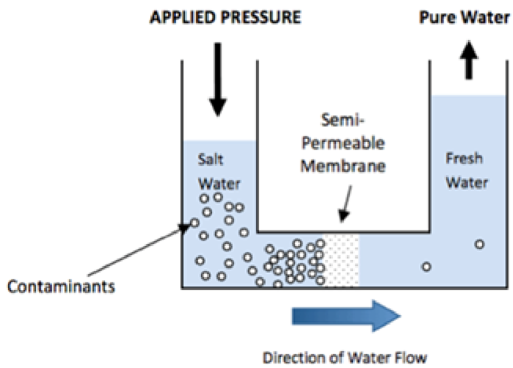

Fig. 2. Reverse Osmosis [8]

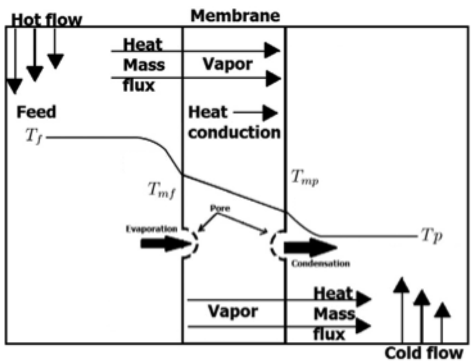

Fig. 3. Direct Contact Membrane Distillation [6]

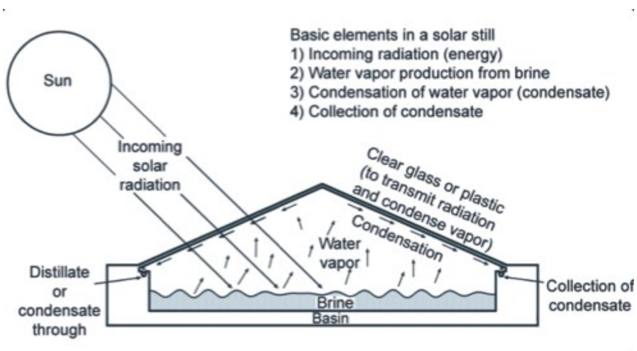

Fig. 4. Solar powered water desalination [7]

The team, under the motto "You don't need to be a fish to drink seawater", chose to develop a modular solar powered desalination system named "Water Pyramid".

Furthermore, the Water Pyramid should be modular, scalable and low cost.

2 COMPLEMENTARY STUDIES

The goal of this project was not just to build a working prototype, but to adopt a comprehensive approach considering the distinct relevant perspectives when developing a product like the Water Pyramid, namely, Marketing, Sustainability and Ethics. The idea is to make the team consider the development of a product, rather than just a technical proof of concept prototype, including the eventual creation of a company.

2.1 Marketing

The team defined as their target governmental institutions, NGO and environmentally aware individuals. Governments and NGO could provide the desalination module at reduced or no cost to dislocated or low-income people living close to the coast. Eco-friendly individuals, *e.g.*, nature lovers or outdoor sports practitioners, could also buy and use the product while exploring remote coastal areas. In addition, the module could also be marketed as an educational tool to: (*i*) promote environmental education by raising the awareness for the need to preserve, save and share existing water resources; and (*ii*) enrich the learning experience in the field of thermodynamics, *e.g.*, by performing experiences involving unpredictable factors such as the meteorological conditions, as well as in the field of data acquisition and automation, by providing a stimulating set up covering different areas such as sensor selection, Internet of Things and cloud based computing (sharing the data available).

2.2 Sustainability

Sustainability is a holistic concept involving economic, social and environmental perspectives. In this project, the resulting product – an affordable solar powered desalination module for households – is expected to have a good market acceptance and pay itself, considering there will be no further need to buy bottled water.

The team envisioned the creation of a company to develop and market an eco-friendly domestic water desalination product. The company is not just focussed on selling and making profits, but above all in meeting the users' needs and expectations. Based on these ideas, the team decided to use raw materials and sustainable energy sources (sunlight rather than fossil fuels) to minimise the generation of environmental pollution. On the one hand, a domestic scale system places the burden of the operation know how on the customer side. On the other hand, it can also mean a strong personal customer service where a company instructor will demonstrate how to operate and explain the relevance of the desalinator from a sustainable development perspective.

2.3 Ethics

In terms of code of ethics, the team chose the American Academy of Water Resources Engineers (AAWRE) code for the Water Pyramid. This code specifies a set of good practices standards regarding water resources for engineers [9], *i.e.*, helps engineers to adopt a professional practice and individual behaviour conducive to the preservation and respect towards existing water resources. The objectives of the AAWRE are the: (*i*) identification and certification of engineers with specialized knowledge in water resources for the benefit of the public; (*ii*) recognition of the ethical practice of water resources engineering at the expert level; (*iii*) enhancement of the practice of water resources engineering; (*iv*) support and promotion of positions on water resources issues important to the public health, safety and welfare; and (*v*) encouragement of life-long learning and continued professional development. In particular, the team decided to focus on objectives *ii* and *iii*.

3 WATER PYRAMID

Standard strategies to provide fresh water to human populations imply typically high energy costs. The challenge of this project was to design, build and test a sustainable water desalinator module for a multifunctional dome with minimum energy consumption. The Water Pyramid was designed to be placed on top of a modular wooden dome described in [10], *i.e.*, to become the top module of the dome.

3.1 Structure

The Water Pyramid (*Fig. 5*) includes fresh and salt water containers for desalination, a transparent cover to allow the passage of the sunlight in and to condensate the evaporated water as well as external fresh, salt water and leftovers storage tanks. Three pipes connect the pyramid with the different storage tanks. The fresh water container is the white pentagonal base, with a 3º slope to ensure the drinkable water flows into the fresh water storage tank. The black salt water container, with a 1000 ml capacity, is centred in respect to the white base and placed horizontally to optimize evaporation. The transparent cover is made of five triangles with an inclination of approximately 30º. The resulting pyramidal cover is easier and more economical to build than the intended bowl shape. *Fig. 6* shows a general view of the structure and a cross section. For the cover, the team chose transparent polymethylmethacrylate (PMMA) instead of glass because: (*i*) typical PMMA grades allow the passage of 92 % of the sunlight, including ultraviolet (UV), which speeds up the process; (*ii*) the thickness does not affect the transparency; (*iii*) the lightness and hardness of the material; and (*iv*) the manufacturing process does not involve toxic materials or heavy metals. The salt container is made of black plastic – a flowerpot coaster – to absorb heat and increase the distillation process efficiency.

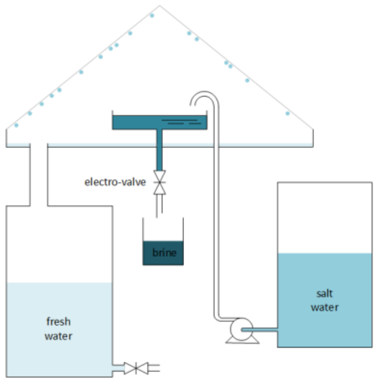

Fig. 5. Water Pyramid system

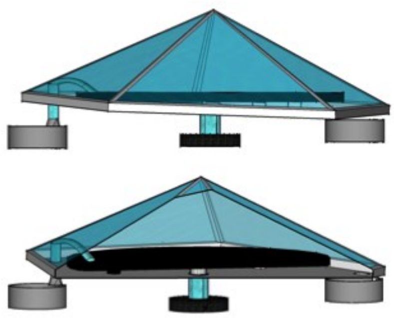

Fig. 6. General view of the structure and cross section

3.2 Working Principle

The desalination starts with the pumping of salt water from the external storage tank into the black container. As the sunlight passes through the transparent cover, it heats the inside of the pyramid, raising the inside temperature – greenhouse effect – and, consequently, decreasing the relative humidity and increasing the ability to evaporate the salt water. Due to the temperature difference between the inner and outer sides of the PMMA cover, the water vapour condensates on the inner side and runs down into the white base container. Finally, the drinkable water flows through the sloping surface of the white container into the external fresh water tank.

The black container needs to be periodically emptied of the process leftovers. In order to remove the highly concentrated brine remaining in the black container, the system opens the electro-valve, which connects the black container with the leftovers tank, and turns on the salt water pump to help draining the brine from the black container into the leftovers tank, and, finally, closes the electro-valve.

3.3 Control System

The team designed an electronic control system to make the Water Pyramid autonomous. The system comprises a micro-controller, a pump (output), an electro-valve (output) and four ultrasonic sensors (inputs). To prevent overflows, two ultrasonic sensors measure the maximum level of the water in the internal salt water container and in the external fresh water storage tank. The remaining two ultrasonic sensors measure the minimum level of water in the internal salt water container and in the external fresh water storage tank. These sensors are responsible for the removal of the leftovers from the black container and for the restart of the process when the fresh water tank is below its capacity. To prevent salt deposition in the black container, the system refills the black salt water container whenever the low level sensor detects a level corresponding to approximately 100 ml of salt water by opening the electro-valve (*Fig. 5*). The micro-controller, based on the measurements of the level sensors, operates the pump – to fill the black container with salt water – and the electro-valve – to remove the leftovers from the black container.

4 EXPERIMENTS AND RESULTS

To evaluate the performance of the prototype, two experiments were carried out. The first was focussed on proving the concept and detecting problems in the prototype (late spring) and the second on establishing the performance of the system in a worst case situation (midwinter). While the late spring experiment lasted one day, the midwinter one took 27 days. All experiments were performed using a 1 to 5 scaled prototype of the real structure to reduce costs and improve transportability, while achieving the same functionality.

The initial experiment took place on June 2016 (late spring) in an obstacle free area (the terrace of building F). Specifically, the prototype was placed at N 41º10'45.26'', W 08º36'29.21'' and data was collected from 8th June 2016 till 9th June 2016. In this 24-hour period, the prototype collected 70 ml of fresh water. In terms of average temperature values, the brine and the inside of the pyramid were 15 % and 13 % warmer than the outside, respectively. Concerning the average relative humidity, the value inside of the pyramid was 35 % higher than outside. *Fig. 7* illustrates the evaporated water conduction under the cover. The condensed fresh water flows down the cover inner walls into the white container as shown in *Fig. 8*.

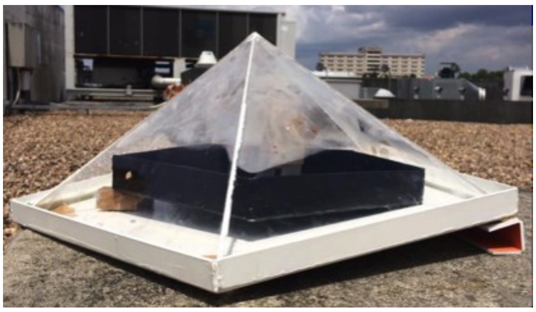

Fig. 7. Conduction on the cover

Fig. 8. Condensation process

The second experiment was conducted during the winter from 8th December 2016 to 4th January 2017. The prototype was positioned on an obstacle free horizontal surface located at N 41º13'39.67'', W 8º36'53.96''. *Fig. 9* displays the daily temperature and relative humidity conditions, including the outside air temperature (navy blue), inside air temperature (light blue) and brine temperature (red), outside air relative humidity (orange) and inside air relative humidity (green). Considering the average values, the brine solution was 7 % warmer than the outside air, whereas the average inside air temperature was 6 % higher than the average outside air temperature. In terms of the average relative humidity, the relative humidity inside the device was 14 % higher than outside.

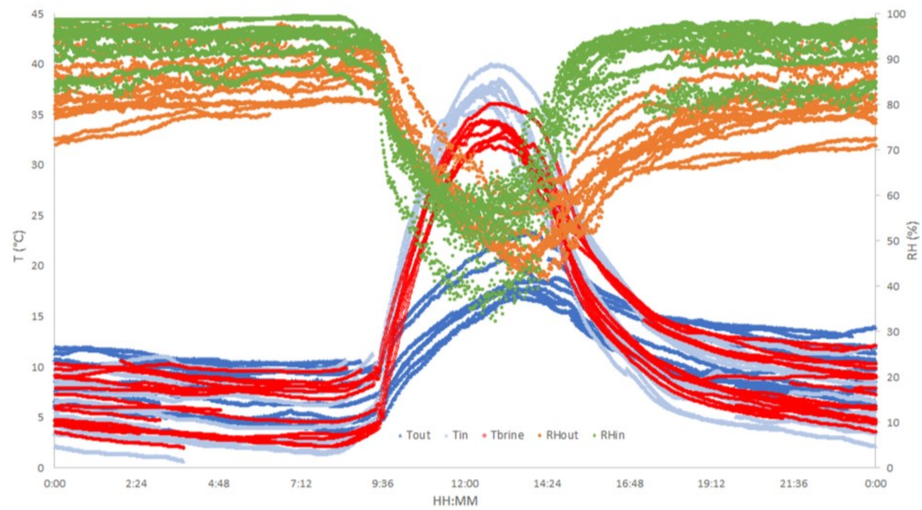

Fig. 9. Daily temperature (outside, inside and brine) and relative humidity (outside and inside) during the midwinter test

Table 1 summarises the results of both experiments concerning the average, minimum and maximum values of the temperature (T) in ºC of the (B)rine, (I)nside and (O)utside the pyramid, the minimum and maximum relative humidity (RH) in % (I)nside and (O)utside the pyramid and the daily volume of distilled water (DW) in ml. As expected, the late spring temperature and relative humidity were, respectively, higher and lower than the corresponding midwinter values. The average daily volume of distilled water in late spring was 70 ml and in midwinter 7 ml.

Table 1 Spring and winter results

		T (ºC)			RH (%)		DW/d (ml)
		B	I	O	I	O	
Spring	Avg	25.5	24.7	22.1	83.7	62.0	70
	Min	17.9	16.6	15.9	31.4	15.0	
	Max	49.9	61.2	43.6	95,7	83.7	
Winter	Avg	11.0	10.9	10.2	88.9	78.3	7
	Min	02.0	00.6	03.3	32.5	41.5	
	Max	36.1	40.0	23.3	99.7	98.5	

The electrical conductivity (EC) of the salt water and of the fresh water obtained after desalination was evaluated using a WTW LF 538 Conductivity Meter. EC decreased from 5.05 S/m to 0.154 S/m, indicating that a significant reduction in the salt water concentration occurred as a consequence of the desalination process.

5 CONCLUSIONS AND ACKNOWLEDGEMENTS

The EPS@ISEP framework provided a holistic, multicultural and multidisciplinary learning environment. First, the team specified and justified the requirements of their design solution – the Solar Pyramid – based on multiple team studies, brainstorming and coaching. These studies involved marketing, sustainability, ethics and deontology, as well as water desalination principles. After, the students selected, procured and acquired the materials and components from local suppliers. Next, they developed and tested a scaled model. The tests allowed the team to: (*i*) identify and correct assembling problems; and (*ii*) verify experimentally that the yield of the process depends on the atmospheric conditions, enabling the team to confirm the Solar Pyramid potential for regions with high atmospheric temperature range even in low relative humidity conditions. In terms of the learning experience, the team considered that the "*European Project Semester enriched all team members with culture, teamwork and team bonding*".

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