Learning Sustainability with EPS@ISEP – Development of a Water Disinfection System

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Abstract

The European Project Semester (EPS) is a one-semester capstone project/internship programme offered to engineering, product design and business undergraduates by 18 European engineering schools. EPS aims to prepare future engineers to think and act globally by adopting project-based learning and teamwork methodologies. The EPS@ISEP programme – the EPS programme provided by ISEP – the School of Engineering of the Polytechnic Institute of Porto – started in 2011 and has since welcomed 3rd and 4th year mobility students during the spring semester. In particular, sustainable development is a pervasive concern within EPS projects. It was in this context that, in 2012, a team of EPS@ISEP students decided to develop a water disinfection system. While the technical goal of the project was to design and develop a fluid disinfection system for removing bacteria, viruses and seaweeds, the overall objective was far more ambitious: to help students learn, develop and adopt sustainable practices for their future professional life. The system was intended to be a simple and effective solution for water treatment and recycling. At a larger scale, the project contributes to the preservation of the planet's fresh water resources and to the improvement of the population's health by eliminating harmful microorganisms from the water. This challenge was, by itself, motivational and exposed the team to new learning experiences. The team found several approaches for water treatment and, after a detailed analysis, decided to adopt Ultraviolet (UV) irradiation for the removal of microorganisms. This multidisciplinary real world problem drove the team during the semester. The team surveyed and compared different methods for water cleansing and recycling, chose one approach and, then, designed, built and tested the prototype. In addition, the students also addressed marketing, sustainability as well as the ethic and deontological issues regarding the proposed solution while developing cross-cultural understanding, teamwork and communication skills. The project provided an excellent opportunity to foster the concept of sustainable development amongst students.

Keywords: Engineering Education; Sustainable Development; European Project Semester; Water Disinfection.

1 Introduction

The European Project Semester (EPS) is a one-semester capstone project/internship programme offered to engineering, product design and business undergraduates by 18 European engineering schools. EPS aims to prepare future engineers to think and act globally (Andersen, 2004), by adopting project-based learning and teamwork methodologies, fostering the development of complementary skills and addressing sustainability and multiculturalism. In particular, sustainable development is a pervasive concern within EPS projects.

The EPS@ISEP programme – the EPS programme provided by the School of Engineering – Instituto Superior the Engenharia do Porto (ISEP) – of the Polytechnics of Porto – welcomes engineering, business and product design students and includes six modules: Project (20 ECTU), Project Management and Team Work (2 ECTU), Marketing and Communication (2 ECTU), Foreign Language (2 ECTU), Energy and Sustainable Development (2 ECTU) and Ethics and Deontology (2 ECTU). These 2 ECTU modules are project supportive seminars oriented towards the specificities of each team project (Malheiro et al., 2015).

Every spring, EPS@ISEP proposes a set of projects (each one with a specific client, responsible for defining the project requirements and checking its compliance) with a strong focus on sustainability, to raise the students awareness to the problem. In the spring of 2012, a team choose to develop a Water Disinfection System, which was proposed by the Chemical Engineering Department of ISEP. In accordance with the EPS 10

Golden Rules, the team was composed of four students with different nationalities and backgrounds (Malheiro et al., 2015). The goal of the disinfection system was to produce clean water (with no microorganisms) to be used in research experiments, using an automated system. The cleaned water was NOT intended for drinking. In the students' opinion, this project was an opportunity to contribute to clean / recycle already used water. Before building the product, the students studied and compared different solutions regarding water disinfection, developed a marketing plan with competitor and SWOT analyses and a marketing programme. Subsequently, they designed a solution, analysed its sustainability and specified a list of the materials, which they used to build and assemble the system. Finally, they carried out the necessary electrical simulations and experimental tests to verify the full operational capability.

Several approaches can be found nowadays for purifying water, such as using chemicals (chlorine, ozone), Ultraviolet (UV) lamps, reverse osmosis and filtering. The team decided to use UV radiation for removing microorganisms since they found it to be the most advantageous method to achieve the goal. As a result, the project's technical goal became to build and develop a disinfection system to remove bacteria, viruses and seaweeds from water using UV radiation, taking into consideration the requirements defined by the client: (*i*) the system should be able to provide 72 l/h continuous flow-rate; (*ii*) the treated water should not contain any viable cells of pathogenic (in particular bacteria, viruses, seaweeds, microalgae); (*iii*) the cleanness of water should be such that sun light can pass through the water layer, and reach about 15 cm depth of water with microalgae; (*iv*) the system should be controlled by a Programmable Logic Controller (PLC); and (*v*) the budget for developing the entire system is 400 €.

This paper presents in Section 2 a brief state of the art on methods for water treatment. Then, Section 3 introduces the system architecture proposed and Section 4 describes the implementation of the system and the tests performed in order to check the correct functioning of the device. Finally, in Section 5 the discussion and conclusions are presented.

2 Water Treatment

Water treatment is presently a very important topic since the world's fresh water resources are becoming limited (Water Facts, 2016). Every year millions of people die from water related diseases and others due to lack of access to clean water. Several companies and institutions are increasingly seeking different ways for disinfecting and cleaning contaminated water in order to re-use it. There are several applications and approaches for cleaning wastewater, namely using chemicals (chlorine, ozone), UV lamps and filtering. In the following subsections the main methods commonly used for water disinfection will be presented as well as some companies that sell products for this purpose.

Besides disinfection, which aims at reducing or eliminating the contents in pathogens, the water can also be submitted to several other different physical-chemical treatments, such as mechanical filtration, carbon filtration, removal of nitrates, decarbonisation and demineralisation, removal of iron and manganese, water softening (removal of components causing water hardness, involving the conversion of calcium and magnesium ions, responsible for hardness of water, into sodium ions), and the correction of pH. None of these treatments was addressed in this project.

2.1 Methods for Water Disinfection

2.1.1 Chlorination

Chlorination is the cheapest and most popular way to eliminate pathogens and disinfect water. The bacteria and viruses are destroyed by the action of chloride or pure chlorine gas to the water. Chlorine gas is the least expensive form of chlorine available, being the typical amount of chlorine gas required for water treatment ranges from 1 mg to 16 mg per litre of water. However, the most popular means of disinfection consists of using a solution of sodium hypochlorite (NaOCl), which is also the most efficient of the chlorinated disinfectants, with a recommended dosage from 0.2 mg to 2 mg of NaOCl per litre of water (SDWF, 2016).

The dose of chlorine should be selected according to the water quality. For the preparation and dosage of the solution, chlorinators are used (a chlorinator is typically composed of a diaphragm pump/suction-pumping engine, a polyethylene tank for the sodium hypochlorite solution, a suction pipe in the tank that contains the solution of disinfectant and a duct). The chlorinator must be installed in a separate room equipped with ventilation and as close to the receiver as possible. Sodium hypochlorite disinfection presents the disadvantage of deterioration of water odour and taste by chlorine. Despite its popularity, chlorine disinfection has gained several opponents since, not only, it is unable to kill some protozoan cysts, but produces trihalomethanes, a carcinogenic disinfection by-product (SDWF, 2016).

2.1.2 Ozonation

Ozonation consists of injecting oxygen enriched with ozone (O_3, triatomic oxygen) through the water. Ozone production is a local instant process generated by a silent, electric discharge in a high voltage alternating field, which affects the flow of clean, dry oxygen or air from the environment. Water ozonation stations consist of equipment for the production of ozone (ozonators) and contact tanks for dissolving ozone into the contaminated water.

Ozone has many advantages, which make it appropriate for application in water treatment: (*i*) ozone application improves the colour and taste of water; (*ii*) ozone oxidation trace contaminants such as pesticides and surfactants are destroyed; (*iii*) ozone is a powerful oxidizing agent that reacts directly with organic double bonds; (*iv*) ozone causes the biological disintegration of organic substances in wastewater which, in turn, when applied to a biologically active filter are further broken down to CO_2 and water; and (*v*) ozone causes the destruction of microorganisms contained in the water.

The disinfection of water by ozonation is most often used in swimming pool water, as well as in the case of large aquaria and fisheries. Ozone is also used for wastewater treatment such as surfactants and detergents from the laundry. As a basic principle widely applicable, the following requirement is applied: to get the highest degree of disinfection of drinking water, a residual ozone concentration of 0.4 mg/dm^3 must be maintained for a period of 4 min (Ozonia, 2009). However, although ozonation is an effective water treatment for aquaculture systems, ozone is also very dangerous and 5 ppm can be immediately life-threatening to personnel, which poses serious restrictions to its use (Summerfelt at al., 2009).

2.1.3 Ultraviolet Radiation

Solar disinfection takes advantage of UV radiation. However, only UV-A (400–315 nm) and UV-B (315–280 nm) reaches the Earth surface since the UV-C (280-100 nm) fraction of this radiation is almost totally absorbed by the atmosphere (WHO, 2016). Solar disinfection systems have long been used for water treatment (Kalt et al., 2014).

The fact that the UV-C light spectrum (280-100 μm) is absorbed through the structure of the DNA of microorganisms, stops their replication and constitutes a powerful chemical free bactericidal. By using a properly selected time and intensity, UV radiation can completely destroy microorganisms (Abbaszadegan et al., 1997) through the destruction of their DNA. Different organisms have different resistance to UV. In order to destroy a certain type of microorganism specific UV doses (mJ/cm^2) are applied (ClorDiSys, 2013).

The effectiveness of disinfection depends on the extent of the microbial contamination of the water. Usually it is defined for indicator bacteria, namely *Escherichia coli*. For the purpose of drinking water, disinfection in waterworks usually is taken to be effective for *Escherichia coli* at the level of 99.9 %, requiring a UV dose of 40 mJ/cm^2. The dose is adjusted depending on the application.

UV sterilization lamps are widely used to disinfect water without using heat or chemicals. UV lamps can replace pasteurizers in breweries, mineral water bottling plants, food processing plants at a fraction of operating costs. These devices provide a safe sterilizing system, disinfecting water in conventional greenhouses and closed loops with drainage. UV disinfection of water can be done at the location. Ultraviolet sterilization in the swimming pools results in the reduction of the amount of chlorine or even the total abandonment of chlorination. UV use in ponds and fountains protects water from organic matter rotting. UV lamps are also used for the destruction of ozone in ozone water.

The use of UV sterilization lamps presents the following advantages: (*i*) UV radiation of wavelength 254 nm damages DNA, which is lethal to microorganisms (Timmermann et al., 2015); (*ii*) does not alter the chemical composition of water; (*iii*) is overdose free; (*iv*) has low operating costs; (*v*) is free from the problems related with the use of chlorine (or other chemicals) and corrosion; and (*vi*) breaks down some pathogens such as *Cryptosporidium*, which are resistant to chlorination (Agrawal and Bhalwar, 2009).

Although UV irradiation provides a chemical free method of disinfecting soundproofing materials that are traditionally chemically incompatible and an effective method for inactivating pathogens resistant to chemicals, it presents the disadvantage of not being effective if the water has too many suspended particles that block the access of UV radiation, impeding its action (ClordiSys, 2013).

Solar water disinfection (SODIS) can be used both in bench-top facilities and in direct systems over the roof, is simple to use and inexpensive. This method of water sterilization has spread all over the developing world and is being used daily in more than 50 countries in Asia, Latin America, and Africa, where more than 5 million people get disinfected drinking water with SODIS technique (McGuigan et al., 2012).

2.2 UV-based Fluid Disinfection Products

There are several companies around the world that provide fluid disinfection services using UV technology. Those companies are mainly focused on worldwide service in industry and municipal environment. They provide services on an extremely big scale intended for different applications, mainly divided in two major areas: (*i*) industry: medical, pharmaceutical, industrial wastewater, aquaculture; and (*ii*) municipal: drinking water, beverage industry, swimming pool water treatment.

Examples of worldwide companies which provide UV technology are Atlantic Ultraviolet Corporation (Ultraviolet.com, 2016), Aquionics (Aquionics, 2016), Enaqua (Enaqua, 2016), Hanovia (Hanovia, 2016), and WEDECO (Wedeco, 2016). Each of these companies patented their own UV technology and method of application. Most of them use not only fluid disinfection by UV technology but also other methods like ozone systems or reverse osmosis. They provide different products for numerous different applications. Those companies, which are typically focused on mass production and distribution, have large budgets and broad teams of specialists and workers.

The problem of water disinfection for travellers has been addressed by a commercial device using UV-C radiation, the SteriPEN (SteriPEN.com, 2016), which was tested under different operating conditions. The device is able to sterilize water provided that the adequate bottle is used and that the device is conveniently applied (Timmermann et al., 2015).

3 System Architecture

Before defining the system architecture, EPS students have to study and define the environment in which their product will fit and the required restrictions that apply.

With this purpose, the team elaborated their marketing plan and analysed the sustainability issues of their solution. These topics are described in the next two subsections, after which, in the following subsection, is described the architecture the team proposed for the product.

3.1 Marketing Plan

After analysing the market for identical products and doing a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, the team performed a costumer segmentation, analysed the most relevant client's needs and defined the market positioning, objective and planning for the product to develop. In the sequel, they elaborated the marketing programme and the marketing mix.

According to this detailed marketing plan, they proposed the development of a product focused only on one specific area: fluid disinfection using a germicidal UV lamp. According to the students, their idea is not to create their own UV technology, but build a system with equipment available on the market and sell the service. This way, the parts can be defined and ordered for each client, allowing clients the possibility to choose the best materials and technology depending on their budget and needs. They also propose targeting individual clients, such as chemical laboratories or small companies, keeping in mind that the clients can always count on their technical support to maintain the system. In comparison to larger companies, the price of such a company service would be lower.

3.2 Sustainability Issues

The students analysed, in the next stage, the eco-efficiency measures regarding the sustainability of the proposed product. The advantages of UV radiation for water disinfection were proven when compared with the use of chemicals and heat (energy consumption). The option for a modular system also presents advantages since it is only needed to replace the broken part in case of the malfunction or breakdown of a component.

3.3 Proposed Architecture

As verified during the state of the art research, there are several systems on the market for purifying contaminated water. Most of them are designed for industrial use, i.e., have large dimensions, process large fluid volumes and are expensive. There are also systems for cleaning the water in pools and ponds as well as systems for aquariums.

Based on these ideas, the team proposed to build a system differing from the existing commercial solutions in the sense that it should be compact, simple, small and modular. The idea to build a modular system implies that every part of the system can be changed easily and extra devices or equipment can be easily added, if needed (e.g., a chemical cleaning/filtering). The fact that the system is based on UV radiation is because this technology is sufficient, fast, environmentally safe and effective. Due to the small water volumes involved, the system should be small and compact to fit in laboratories. Besides that, it should be built according to the needs of the client. Furthermore, the system must be automated, meaning that the whole system should be controlled by a PLC. It should include an ON/OFF button, a START button and water level sensors, which will allow shutting down the system if the water level rises/drops above/below pre-defined levels.

Given these specifications, the team designed the UV-based water disinfection solution depicted in Figure 1 (left). The water is pumped from the container with contaminated water, pre-filtered, exposed to the UV radiation and is collected in the clean water recipient. As required, the entire system is controlled by a PLC.

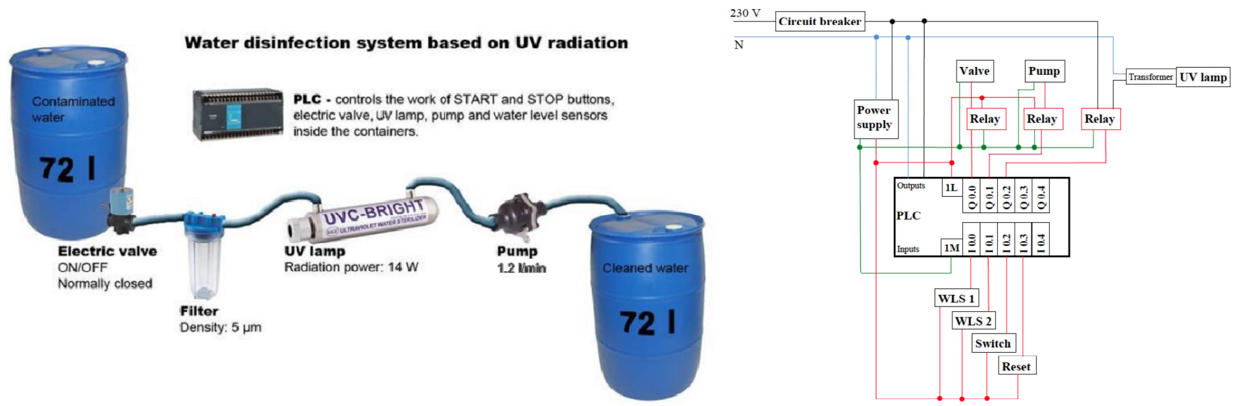

Figure 1. Project sketch of the water disinfection system based on UV radiation (left) and schematic of the water disinfection system electrical circuit (right).

This proposed architecture differs from the existing solutions in the sense that it is compact, simple, small and modular. Besides that, it is built according to the needs of the client. In this case the system is also automated, which means that the whole system is controlled by a PLC. To operate it, the system has an ON/OFF and a START button. The PLC will, based on the water level sensors, shut off the system if the water level rises above or drops below the pre-defined levels.

4 Implementation and Testing

4.1 System Main Components

For implementing the system depicted in Figure 1, the team performed the selection of materials and solutions while looking for a balance between quality, economy and ecology. The main principle adopted was to reuse resources which were already available at the client. In cases where it was possible, the team chose recyclable and environmentally friendly materials such as wood and metals. Whenever the technical requirements required purchasing plastic materials, long lifetime plastics were chosen.

The UV water sterilizer is the most important component of the system. It was chosen taking into consideration the specified water flow rate. Since the capacity of the pump is 1.2 l/min, the capacity of the water sterilizer should be higher to ensure proper sterilization. As a result, the team chose the 2G UV Water Sterilizer (220 V) Model A-140-6. There are cheaper UV systems with identical capacity on the market, but this sterilizer is more reliable and sustainable due to its stainless steel housing.

The team included an electrical valve (Solenoid Valve YCWS1) to control the water flow and a filter, placed before the UV lamp, to remove particles bigger than 5 μm from the water and improve the efficiency of the UV sterilizer.

To provide the adequate water flow through the UV sterilizer, the team selected a mini diaphragm pump. The pump's task is to extract the water from the first container (contaminated water), through the mechanical filter and the UV sterilizer, into the second container. Mini diaphragm pumps operate using two opposing floating discs with seats that respond to the diaphragm motion. This process results in a quiet and reliable pumping action and presents high efficiency, which results in longer life for the motor pump unit. Since, in these pumps, no metal parts come in contact with the materials being pumped, they have a good chemical resistance. Furthermore, the pump body contains no machinery parts, so it can be in dry running condition for a short while. The team chose the 6088 Aqua-Win pump Model C-152-6 because its low throughput matches the nominal capacity of the filter and of the UV sterilizer. A higher throughput implies higher capacity and robustness from the parts and, therefore, a higher price.

To control the system, and according to the client specifications, the proposed solution uses a Programmable Logic Controller. A PLC is an industrial digital computer typically used to control electromechanical devices such as industrial machinery, pumps, lighting, etc. The PLC, which is connected to the system sensors and switches, processes in real time the inputs and controls the outputs based on the defined logic (the user program). In this system, the PLC (SIMATIC S7-200, CPU 212) is used to read the ON/OFF and START buttons (inputs) together with two water level sensors (inputs) and to control 3 relays (outputs) connected to the main modules (pump, UV lamp and electrical valve). The user activates the system by pressing the ON/OFF button (power up), followed by the START button (startup). Once the system is activated, the electrical valve opens and the pump and UV light are turned on. The system shuts down automatically (when the water level sensors detect the pre-defined values) or at the user request (the user presses the ON/OFF button). After an automatic shutdown, once the water levels in the containers have been restored to appropriate values, the user may restart the system by pressing the START button.

As stated, the pump, UV lamp, and electrical valve are connected to the PLC through relays. A relay is an electrically operated switch where a low-power signal is used to control a circuit or several circuits, ensuring complete electrical isolation between control and controlled circuits. In this system, the relays are used to allow the outputs of the PLC to drive the power components. Finally, the system includes a 24 V DC power supply for the PLC, relays, level sensors, electrical valve and pump. Figure 1 (right) presents the schematic of the electrical circuit for this system.

4.2 Simulation Tests

In order to check if the electrical system works, two software applications were used: Simulador_S7_200_V2 Esp and MFC PC_Simu, version 1.0. The results of these simulations allowed concluding that the electrical schematics, including the components and circuitry, were correct and that the PLC logic was fully functional.

4.3 System Implementation

The final assembled prototype is presented in Figure 2 (left), including the water containers, the pump, filter, UV lamp and the control box. Figure 2 (right) illustrates the operation of the system.

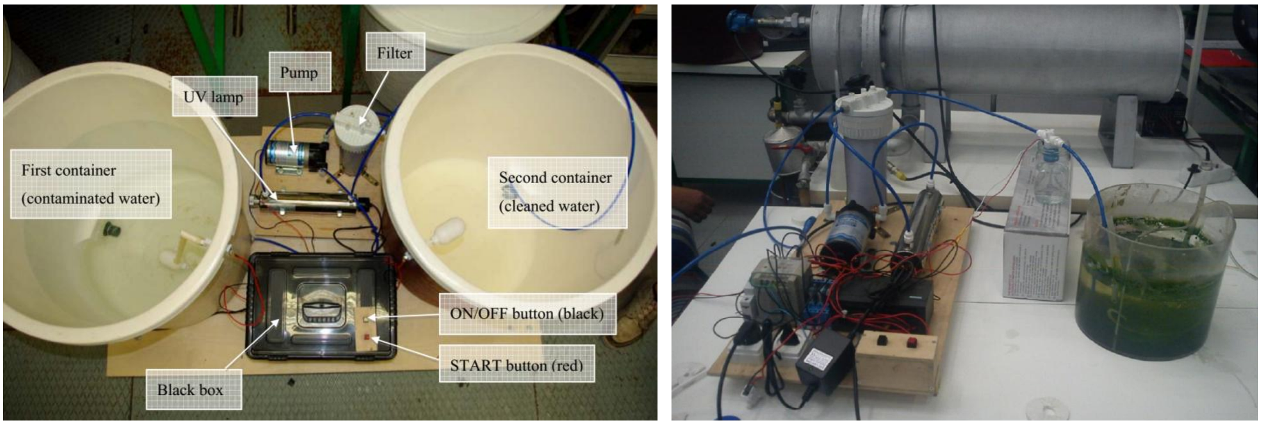

Figure 2. Assembled water disinfection system based on UV radiation (left) and water disinfection system tests (right).

Finally, after verifying that the system works in accordance with the pre-defined user requirements, the team developed an operating manual for the UV Fluid Disinfection System (Bazylinska et al., 2012b). This user manual, to be supplied to the client and to the system users, contains the system specifications, all components used (with their detailed specifications for component maintenance or repair) and the operating instructions. These instructions include the system operation as well the replacement of the relays and of the UV lamp.

5 Discussion and Conclusion

This paper presents the development process of the "Fluid Disinfection System Based on UV Radiation" prototype by a multinational team of students during the EPS@ISEP Spring 2012 edition. The objective of the prototype is to clean water, which has been used in the ISEP's chemical laboratory, based on UV technology. The whole system, which is controlled by a PLC, filters, exposes to UV radiation and drives the water using a small diaphragm pump. The mechanical and control parts of the system were successfully tested. The team was able to develop a fully functional prototype fulfilling the specifications.

The adopted learning methodology was project based learning with a strong emphasis on multicultural and multidisciplinary teamwork. A pro-active autonomous learning attitude was promoted among students as well as the development of critical thinking, collaboration, communication and creativity/innovation. During the project development, students had to define a work plan, identify and distribute the tasks, and autonomously decide the approach, the design and the technologies to use according to a budget previously specified as well as investigate alternative solutions for the proposed problem. The panel of supervisors with different fields of expertise acted not as directors but as a consulting committee. For each weekly supervision meeting the team had to specify the topics to be discussed.

The fact that the project was multidisciplinary together with the joint supervision provided students with the opportunity to develop solid scientific and technical competences, as well as transversal skills, as stated by the team members: "According to the team members, "*during these four months of work we have learnt many different aspects connected, not only, with mechanical, electrical and chemical knowledge but also teamwork. We improved our cooperation and communication as a team. Moreover, we dealt with the conflicts, restrictions and limitations we encountered on our way, namely, time, budget and knowledge limitations. To sum up, thanks to this project we improved our teamwork skills and got new knowledge, which can be useful in our future career. (...) We now can provide a service for different clients, taking into consideration low cost, good quality and sustainability.*" This testimony supports the idea that the challenge was, by itself, motivational and exposed the team to new learning experiences, namely, contributed to foster the concept of sustainable development amongst the students.

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6 References

Abbaszadegan, M., Hasan, M.N., Gerba, C.P., Roessler, P.F., Wilson, B.R., Kuennen, R., Van Dellen, E. (1997). The disinfection efficacy of a point-of-use water treatment system against bacterial, viral and protozoan waterborne pathogens, Water Research, 31 (3), pp. 574-582.

Agrawal, VK., Bhalwar, R. (2009). Household water purification: Low-cost interventions, Medical Journal Armed Forces India, 65 (3), pp. 260-263.

Andersen, A. (2004). Preparing engineering students to work in a global environment to co-operate, to communicate and to compete, European Journal of Engineering Education 29 (4) pp. 549–558, doi:10.1080/03043790410001711243.

Aquionics (2016). "Aquionics – UV that works" [Online]. http://www.aquionics.com/main/ [Accessed: 5-February-2016].

Bazylinska, A., Jenei, A., Walczak, J., Küttis, S. (2012a). "Fluid Disinfection System Based On UV Radiation – Final Report" [Online]. Available: http://www.eps2012-wiki2.dee.isep.ipp.pt/lib/exe/fetch.php?media=t2_final_report.pdf [Accessed: 5-February-2016].

Bazylinska, A., Jenei, A., Walczak, J., Küttis, S. (2012b). "Fluid Disinfection System Based On UV Radiation – User Manual" [Online]. Available: http://www.eps2012-wiki2.dee.isep.ipp.pt/lib/exe/fetch.php?media=t2_user_manual.pdf [Accessed: 5-February-2016].

ClorDiSys (2013). Ultraviolet Light Disinfection Data Sheet [Online], Available: http://www.clordisys.com/pdfs/misc/UV%20Data%20Sheet.pdf [Accessed: 3 March 2016.

Enaqua (2016). "Enaqua" [Online]. Available: http://www.enaqua.com/ [Accessed: 5-February-2016].

Hanovia (2016). "Hanovia UV – the power in UV technology" [Online]. http://www.hanovia.com/ [Accessed: 5-February-2016].

Kalt, P., Birzer, C., Evans, H., Liew, A., Padovan, M., Watchman, M. (2014). A Solar Disinfection Water Treatment System for Remote Communities, Procedia Engineering, 78, pp. 250-258.

Malheiro, B., Silva, M., Ribeiro, M. C., Guedes, P., Ferreira, P. (2015) The European Project Semester at ISEP: the challenge of educating global engineers, European Journal of Engineering Education 40 (3) (2015) 328–346, doi:10.1080/03043797.2014.960509.

McGuigan, K.G., Conroy, R.M., Mosler, J.-J., du Preez, M., Ubomba-Jaswa, E., Fernandez-Ibañez, P. (2012). Solar water disinfection (SODIS): A review from bench-top to roof-top, Journal of Hazardous Materials, 235–236, pp. 29-46.

Ozonia (2009). Ozonia North America Inc., Degremont Technologies. Application Brochure: Drinking Water Treatment Municipal Drinking Water – DIS02302EN-V2-02/2009

SDWF, Safe Drinking Water Foundation (2016). "Fact sheet: What is Chlorination?" [Online]. Available: http://www.safewater.org/PDFS/resourcesknowthefacts/WhatisChlorination.pdf [Accessed: 4-March-2016].

SteriPEN.com (2016). "SteriPEN" [Online]. Available: http://www.steripen.com/ [Accessed: 3-March-2016].

Summerfelt, S.T., Sharrer, M.J., Tsukuda, S.M., Gearheart, M. (2009), Process requirements for achieving full-flow disinfection of recirculating water using ozonation and UV irradiation, Aquacultural Engineering, 40 (1) pp. 17-27, doi:10.1016/j.aquaeng.2008.10.002.

Timmermann, L.F., Ritter, K., Hillebrandt, D., Küpper, T. (2015). Drinking water treatment with ultraviolet light for travelers – Evaluation of a mobile lightweight system, Travel Medicine and Infectious Disease, 13 (6), pp. 466-474.

Ultraviolet.com (2016). "Atlantic Ultraviolet Germicidal UV Equipment and Lamps" [Online]. Available: http://ultraviolet.com/ [Accessed: 5-February-2016].

Water Facts (2016). "Water Facts: Facts About Water and Sanitation - Water.org" [Online]. Available: http://water.org/water-crisis/water-sanitation-facts/ [Accessed: 5-February-2016].

Wedeco (2016). "Water purification" [Online]. Available: http://www.xylem.com/treatment/us/brands/wedeco [Accessed: 5-February-2016].

WHO (2016). World Health Organization, "Ultraviolet Radiation and Health". [Online]. Available: http://www.who.int/uv/uv_and_health/en/. [Accessed: 3-March-2016].