Design, Implementation, and Validation of Compact Surface Water Purification Plant with Independent Power Source

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***Abstract*: The "Design, Implementation, and Validation of Compact Surface Water Purification Plant with Independent Power" project has been carried out based on Agreement No. 008-FIDECOM-INNOVATE PERU-PIMEN-2017, in partnership between the Universidad de Piura, Embonor del Norte EIRL, and Innovate Perú.**

The project's main objective is to provide a compact, mobile, flexible, easy-to-assemble system with low maintenance costs and an independent power supply, that provides high-quality water from surface water sources in isolated areas.

The plant was designed with nine filters to eliminate any pathogens that may be found in the source water. The disinfection system uses a UV reactor. The support structures were digitally simulated to optimize spaces, while the power supply uses a stand-alone photovoltaic system.

To validate the results, water quality tests were performed in an INACAL-accredited laboratory, according to the Water Quality for Human Consumption Regulations contained in DS 031-2010-SA, as well as product testing with consumers.

It is important to note that this compact plant is ideal for avoiding drinking water shortages caused by natural disasters, such as the Coastal El Niño phenomenon of 2017, that periodically affect the region of Piura.

***Index Terms:* Purification, surface water, solar power, compact plant.**

I. Introduction

This document describes the design, implementation, and validation of a compact water purification plant with independent power source, carried out under Agreement No. 008 - FIDECOM - INNOVATE PERU-PIMEN-2017, in partnership between the Universidad de Piura, Embonor del Norte EIRL, and Innovate Perú.

In recent years, few to no authorities have offered an efficient and long-lasting solution to water shortages in the region. Some parts of the provinces of Talara and Paita have just two hours of drinking water supply per day (Ogallo, 2008). Meanwhile, the percentage of basic sanitation coverage is extremely low in peripheral urban areas of Piura. According to the Peruvian Institute of Statistics (INEI), for example, in 2010, out of nearly 73,000 homes that lacked indoor plumbing, 72% were located in urban areas, and 28% in rural areas.

On the other hand, EPS GRAU, the company responsible for drinking water distribution in Piura, often conducts unscheduled service outages, leaving different parts of the region without a water supply for excessive lengths of time (Diario Correo, 2016). Furthermore, this "pseudo-potable" water that EPS GRAU offers to Piura's residents is not apt for human consumption (El Comercio, 2009). For such reasons, users are forced to resort to other alternatives to meet their drinking water needs, such as buying bottled water. However, given the lack of oversight by the competent authorities in the sector, bottled water producers who fail to meet the applicable minimum quality standards have proliferated in the market with deliberately misleading products at extremely low prices. Not only do such products have an outsized impact on the environment, but they also lead to unfair competition that it is practically impossible to fight against.

According to figures from the INEI, updated as of March 2018, access to water via public networks in the Piura region is available to 85.9% of residents. This situates our region in a disgraceful lower third. The supply crisis is further aggravated if we consider that this number conceals the reality faced by *asentamientos humanos* and *pueblos jóvenes*, as shantytowns are referred to locally. Here, the population must resort to alternative channels with no guarantee that the water is apt for human consumption, making them even more costly (El Comercio, 2009).

In recent years, studies have been performed on how to supply drinking water to the Piura region. Caminati (2013) proposes a water treatment system for human consumption, distributing this water on the Piura campus of the Universidad de Piura. At this same university, Seminario (2015) documents the production of table water by reverse osmosis for self-supply. Elsewhere, Lossio (2012) has designed a drinking water supply system for four rural inhabitants, implemented in the district of Lancones, Sullana.

While some progress has been made, there is still a clear lag in the investigation of new water purification

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technologies. Accordingly, this projects represents a boost to this field, promoting the virtuous triangle between government, enterprise, and university.

This project includes the sanitary, mechanical, and power design of a compact surface water purification plant. As a starting point, prior to the sanitary design, a full analysis was performed on the source water, helping to define its physicochemical and microbiological parameters. These analyses were conducted in the sanitary laboratory, accredited by INACAL, of the Hydraulics Institute of the Universidad de Piura. For the mechanical design, digital simulation was performed using the Solidworks program to assess different filter support layouts, optimizing the space required by the plant. For the power supply, based on a solar power of 6.5 kWh/m^2 reported by the Peruvian National Weather Service (SENAMHI-MEM) [1] in the region, renewable photovoltaic solar power is used, thus reducing the environmental impact and increasing the sustainability of the company's operations.

The water volume obtained from the compact plant totals 1.6 m^3/h, and the water's physicochemical and microbiological characteristics meet the water quality regulations for human consumption established in Supreme Executive Order (DS) 031-2010-SA. Furthermore, the compact plant—including the photovoltaic power supply—can be transported by a lightweight vehicle with a wagon, and installed by a team of two or three people in approximately three hours.

II. MATERIALS AND METHODS

A. *Project Location*

The project was conducted in the area of influence of the company Embotelladora del Norte E.I.R.L., located in the district of Marcavelica, province of Sullana, in the department of Piura, in the north of Peru.

The Biaggio Arbulu Canal, which is the surface water source used, runs for a length of 57.39 km and irrigates the Bajo Piura Basin.

B. *Source Water Characteristics*

The source water characterization is an important analysis that must be conducted at the start of the project, given that its results are used to define the water treatment processes to be implemented.

This analysis helps identify the size of the microorganisms and solids present. This, in turn, determines the type and number of membranes or filters needed to treat the water.

The water quality characterization analysis was performed on the Biaggio Arbulú Canal during the dry season. The methodology used for the analysis involved the collection of samples at the same spot in the canal during July and August 2017, on different days between 8 a.m. and 12 p.m.

Field parameters such as residual chlorine, pH, and electrical conductivity were analyzed at the sampling site itself using standard methodology for field parameters. For their part, total coliforms, thermotolerant coliforms, Escherichia coli, and heterotrophic bacteria, among others, were sampled and analyzed in the laboratory using standard methodology.

The parameters analyzed in the field and those analyzed in the laboratory were performed by trained, experienced, and technically competent personnel from the Sanitary Engineering Laboratory of the Institute of Hydraulics, Hydrology, and Sanitary Engineering of the Universidad de Piura.

According to the interpretation of the lab results and DS-004-2017-MINAM – Sub-Category A2 "Waters able to be purified using conventional treatment," the physicochemical parameters of the source water meet all of the parameters required under DS-004-2017-MINMAN.

Likewise, the microbiological and parasitological parameters meet the Environmental Quality Standards (ECAs) for Water for purposes of purification using conventional treatment, while the inorganic parameters (dissolved metals) also meet all applicable requirements. Thus, the water from the Biaggio Arbulú Canal exhibits no significant values of heavy metals such as arsenic, lead, mercury, or cadmium.

C. *Compact Plant Design*

The design of the compact plant involves three components: sanitary and hydraulic; mechanical; and power.

The sanitary design includes three stages: pretreatment (sedimentation), filtration, and sterilization. During pretreatment, the suspended solids in the water are allowed to settle for approximately four (4) hours.

The filtration stage uses 50-micron filters to eliminate any suspended solids remaining in the water after sedimentation; 10-micron filters to eliminate nematode larvae, rotifer eggs, copepods, protozoan parasites, pathogens, and algae; 5-micron filters to eliminate bacteria, fungi, and yeast; 1-micron filters to eliminate smaller microorganisms such as Cryptosporidium sp., ciliates, flagellates, and amoeboids; and finally, 0.2-micron filters to guarantee that the water is free from any contaminant of microbial origin.

Additionally, an activated carbon filter has been included to eliminate any odor or flavor that the water may have. The sterilization stage uses a short-wave 254 nm UV lamp.

With regard to the hydraulic design, it was determined that the circulation of water during the process requires the installation of a 0.5 HP pump system.

For the mechanical design, digital modeling was performed using the *Solidworks* program in order to evaluate several options for the final layout of the filtering and disinfection equipment, thus successfully optimizing space and materials.

The design sought to facilitate assembly in the field and structural stability.

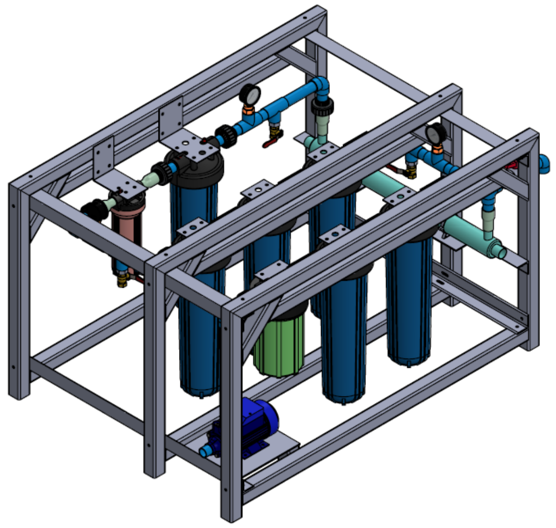

Fig. 1. 3D model of the filter support structure performed using the Solidworks program

For the power design, taking into account the system's mobility requirements, it was decided to use a photovoltaic power supply system with a lightweight yet robust support.

The photovoltaic system consists of five (5) 140 Wp photovoltaic panels; one (1) 1kw inverter; three (3) 12V 150 AH batteries; one (1) 0.75 kW variable speed drive; and one (1) control and protection panel. To support the panel system, two structures were built, one trapezoidal on which the panels can rest, which also serves to cover the system; and the other to position the panels at greater height.

Fig. 2. Trapezoidal support system for polycrystalline photovoltaic solar panels.

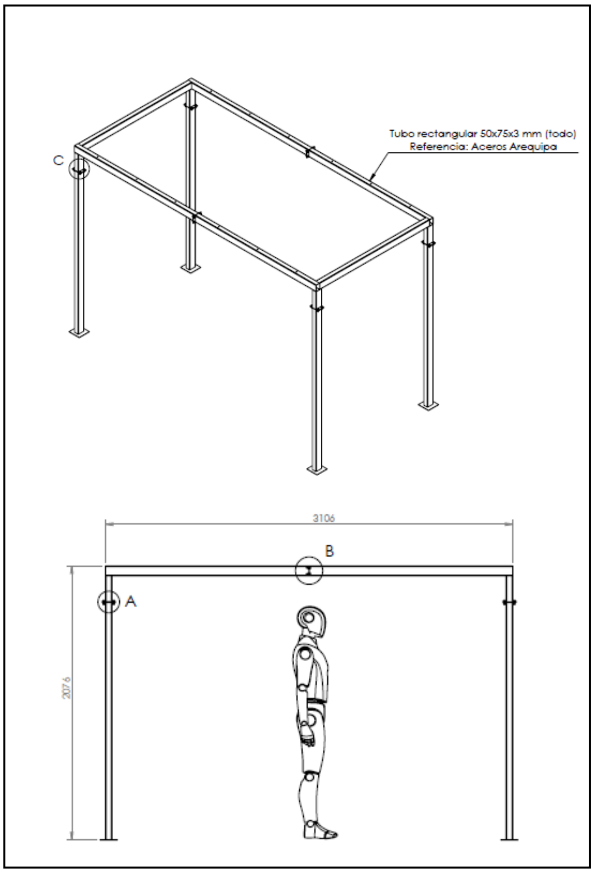

Fig. 3. Support structure for added height.

D. Compact Plant Attributes

The novel part of the compact surface water treatment plant lies in its primary attributes: mobility, ease of maintenance, independent power supply, and operating flexibility.

Mobility: The structure's design allows for the possibility of hoisting it, with dimensions calculated to facilitate its transport on the bed of a pickup truck. The structure is lightweight yet robust, allowing it to support the filtering and disinfection equipment.

Maintenance: The structure's design and the hookup to the equipment is based on ease of maintenance, including universal joints between the filtering and disinfection equipment to make it easier to remove them for maintenance or replacement.

Independent power supply: In view of the potential of photovoltaic solar power systems in northern Peru, the power supply system was developed using photovoltaic solar panels. The supply system includes a bank of batteries, given the constant need for electrical power for the pumping system.

Operating flexibility: The system uses an electrical control panel that includes the corresponding electrical enclosures and a variable speed drive to allow for the flexible operation of the pumping system.

III. Results

The final dimensions of the compact plant are 1.3x1.0x0.8 m, occupying an area of 1.3 m^2 and a volume of 1.04 m^3. This represents savings of over 90% compared to the conventional processes currently being implemented by Embonor E.I.R.L.

The compact plant's process flow volume is 1.6 m^3/h, while the marginal power cost of operation is zero.

As for the quality of water obtained, Table I presents a comparison between the input water quality and the output water quality from the compact plant, providing evidence of its efficiency.

IV. Conclusions

The results of the analysis conducted in accordance with the Water Quality Regulations for Human Consumption – DS 031-2010-SA guarantee that the water obtained from the compact plant is apt for human consumption.

For its part, the design makes clear that the digital simulation helped optimize such design, including the resources and space required for the plant's implementation. The design of a modular structure and the ease of coupling among its components makes it highly mobile and easy to maintain.

The use of photovoltaic solar power in the process guarantees the prototype plant's independent power, while the use of a variable speed drive to control the pumping system offers flexibility and energy efficiency during operation.

TABLE I
WATER QUALITY ANALYSIS RESULT BEFORE ENTERING AND AFTER EXISTING THE COMPACT PLANT

Parameter	Before DS-004-2017	After DS-031-2010	Result
Conductivity (µS/cm)	404	317	Yes
PH	7.81	8.5	Yes
Cyanide	0.005	--	NA
Chlorides	18	20	Yes
Biochemical Oxygen Demand	2	--	NA
Total Hardness	146	94	Yes
Nitrates	0.6	0.7	Yes
Nitrites	0.091	--	NA
Ammonia nitrogen	< 0.1	--	NA
Sediment solids	< 0.1	--	NA
Total solids	285	--	NA
Total dissolved solids	273	185	Yes
Total suspended solids	5	--	NA
Sulfates	40	36	Yes
Turbidity	14.7	0.3	Yes
Heterotrophic bacteria	1200	< 1	Yes
Heat-resistant coliforms	46	< 1.1	Yes
Escherichia coli	46	< 1.1	Yes
Helminth eggs	< 1	< 1	Yes
Cyst and oocysts of pathogenic protozoa	< 1	< 1	Yes
Free-living organism			
Algae	3007	< 1	Yes
Copepods	< 1	< 1	Yes
Rotifers	2	< 1	Yes
Nematodes	< 1	< 1	Yes
Protozoans	397	< 1	Yes

The result is determined based on the Regulation of Water Quality for Human Consumption DS N° 031-2010-SA from the General Secretariat of the Environmental Health from the Health Ministry. Lima – Perú, 2011.

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