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Techno-economic assessment of a multi-effect distillation plant installed for the production of irrigation water in Arica (Chile)

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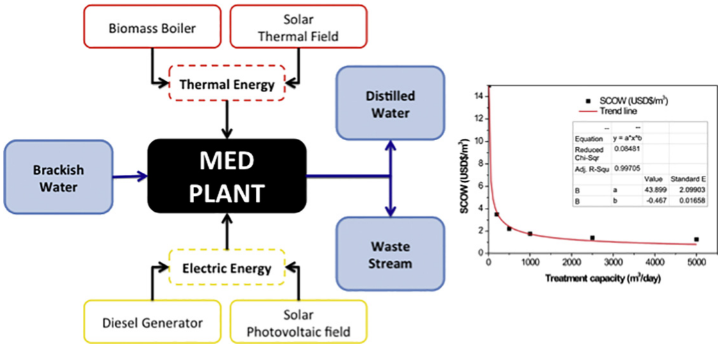
HIGHLIGHTS

- Techno-economic assessment of a solar MED plant located in a Chilean community
- The characterization of the feed water and effluents from MED has been performed.
- The plant has proved its feasibility to remove toxic elements as As and B.
- Annual simulation model predicts the behavior of the MED plant with solar energy.
- Economic assessment determines water costs of the MED plant for several capacities.

GRAPHICAL ABSTRACT



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ABSTRACT

In the context of a regional Chilean project (FIC Taltape project, BIP code 30158422-0), a multi-effect distillation (MED) pilot plant has been built and installed in a small community in the north of Chile (Taltape, Arica) in order to supply treated water for agricultural and domestic purposes. The aim of this paper is to assess the techno-economic feasibility of this system for supplying water with the required quality to the population. The characterization of the feed water and the effluents from the MED pilot plant (distillate and brine), obtained during five months of operation, has been firstly performed. Then, the prediction of the operation of the water treatment system with solar energy has been carried out using a typical meteorological year and the design of a static solar field that cover the thermal energy needs of the water treatment plant.

The annual simulations of the MED pilot plant operating with solar energy showed that the water needs can be mostly covered using a static solar thermal field with a total area of 113.2 m^2, which would generate roughly 46% of the total heat required by the water treatment plant. The technical analysis has been completed with an exhaustive economic assessment. The specific water costs have been determined for the MED pilot plant and the scale factor when the productivity is increased up to 5000 m^3/day has been evaluated. The cost of distilled water produced by the MED plant varied from 15.0 USD$/$m^3$ for the 10 m^3/day production capacity to 1.25 USD$/$m^3$ when this variable is increased to 5000 m^3/day.

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Nomenclature

R	Retention percentage (%)
C_{BFW}	Concentration of the element in the brackish feed water (mg/L)
C_D	Concentration of the element in the distillate (mg/L)
$\Delta T_{eff,\ i}$	Temperature difference between effects (°C)
T_v	Vapor temperature inside the effect (°C)
N	Number of effects
Q_s	Heat transfer rate provided to the first effect (kW)
T_s	Temperature of the heating energy source supplied to the first effect
M_s	Steam mass flow rate supplied as the heating energy source to the first effect (kg/s)
λ_s	Change in enthalpy related to the condensation of the steam supplied to the first effect (kJ/kg)
U_e	Overall heat transfer coefficient (kW/m^2·°C)
M_f	Feedwater mass flow rate (kg/s)
M_{gb}	Total vapor generated inside the effect (kg/s)
λ_{gb}	Latent heat of vaporization (kJ/kg)
C_p	Specific heat (kJ/kg·°C)
T_f	Temperature of the feedwater that reaches the first effect (°C)
M_{prod}	Total distillate obtained from the water treatment plant (kg/s)
RR	Recovery Ratio
sA	Specific area (kg/m^3/day)
STC	Specific thermal consumption (kWh/m^3)
GOR	Gain Output Ratio
θ	Incidence angle (°)
η_{opt}	Optical efficiency (%)
G_k	Global irradiation over tilted plane (W/m^2)
T_{amb}	Ambient temperature (°C)
$\dot{m}$	Mass flow rate through the solar collector (kg/s)
T_{col}	Average between the inlet and outlet temperatures of the collector (°C)
T_{in}	Inlet water temperature in the solar collector (°C)
T_{out}	Outlet water temperature in the solar collector (°C)
$K_{\tau\alpha}$	Incident angle modifier
A_a	Aperture area of the collector (m^2)
C_B	Approximate cost of equipment (USD\$)
C_A	Known cost of equipment (USD\$)
S_B/S_A	Ratio known as the size factor
n	Size factor's exponent
SCOW	Simplified Cost of Water (\$USD/m^3)
M_W	Annual volume of water produced (m^3)
C_F	Annual fixed costs (\$USD)
C_v	Operating cost (\$USD)
I_o	Initial capital investment (\$USD)
α	Amortization factor
i	Discount rate
t	Depreciation period (year)
	$C_{consumables}$ Consumables costs (\$USD)
C_{staff}	Staff costs (\$USD)
	$C_{maintenance}$ Maintenance costs (\$USD)
P_e	Total electric power consumed by the MED plant (kW)
	N_{col_series} Number of collectors in series in a row
N_{rows}	Number of rows
N_{total}	Total number of collectors
A_T	Total aperture area (m^2)

1. Introduction

Water is a vital resource for both human and economic development, so it is not surprising that the absence or scarcity of water resources is directly related to poverty. Humanity faces a water scarcity problem that grows in a sustained and almost exponential way. According to the World Health Organization (WHO), 844 million people do not have easy access to an improved source of drinking water; furthermore, this number exceeds two billion people if this includes the access to enough water volume (WHO and UNICEF, 2017). This problem is related to governments and institutions around the world, so there are national policies in many countries which aim to achieve universal access to safe water. Two-thirds of the 94 countries of the United Nations recognize drinking water and hygiene services as a universal human right and 80% of them have approved national policies in this regard. However, only a quarter of them are carried out as they were established. Despite the remarkable efforts being made worldwide in the field of water, the United Nations institution highlights the fundamental need to increase investment, build human capital and obtain reliable data on which to base global actions (GLAAS Report, 2014).

Atacama Desert, which is considered the most arid one in the world, has annually less than 10 mm of precipitation per year, presenting isolated areas that only have water coming from rivers and groundwater. Nevertheless, these waters have in many cases a high content of salts, arsenic and boron and, therefore, they are neither suitable for human consumption nor for agricultural and aviculture purposes. This fact limits the development of many locations in the region which only economic resources are selling agricultural products (Bundschuh et al., 2012).

The presence of arsenic and heavy metals in the environment is a very acute problem in Latin America (Bundschuh et al., 2010). Arsenic is highly toxic in its inorganic form and its presence is mainly associated with altiplanic quaternary volcanism in the north of Chile. According to the WHO-2016 (WHO, 2016) over 226 million people worldwide are estimated to be drinking contaminated water, with an arsenic contaminant level above the 10 μg/L that WHO establishes as a maximum. This situation can lead to chronic arsenic poisoning (arsenicosis) of which skin lesions and skin cancer are the most characteristic effects (Bhattacharjeea et al., 2013; Hong-Jie et al., 2014; López et al., 2012; Yunus et al., 2011). According to the FONDECYT REGULAR 2011 project results, (FONDECYT REGULAR 2011, "An evaluation of the distribution, mobility and bioavailability of the arsenic present in soil and water in the Valley of Camarones, Chile: study of the levels of transference and the accumulation of arsenical species in native plants and crops" Code: 1120881) where an evaluation of the distribution and mobility of the arsenic present in soil and water was performed, the water in the Arica and Parinacota Region presents different levels of arsenic, both As(III) and As(V) species. The highest levels, more than 100 times higher than the levels established by national and international institutions (Decreto Supremo 143/2009; Decreto Supremo 144/2009; Directive 98/83/EC, 1998), are found in the Valley of Camarones. This problem presents a difficult solution, as the arsenic cannot be easily destroyed and can only be converted into different forms or transformed into insoluble compounds in combination with other elements, such as iron (Choong et al., 2007).

One of the most affected areas in the valley of Camarones is the Taltape community, where the inhabitants economy is mainly based on the exploitation of small agricultural estates, with low-valuable products such as alfalfa, and the production of meat, milk and cheese (mainly from cattle and goats). Due to the above mentioned situation, the generated products contain As and, consequently, these cannot be introduced in the legal markets, which affects the local development. For this reason, there is an important need to solve the water quality problem in a sustainable way so that this location can be established