SDGC, Method and Plant for the Continuous Desalinization of Water: Technical Dimensioning, Analysis of Economic Convenience and Innovative Aspects Compared to Current Technologies

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ABSTRACT

The SDGC system, a patented invention presented in two previous articles by the same author, is further described in the present paper. In particular, the possible critical operating states of the system and the devices foreseen to respond effectively and resume optimal operation are treated. On the basis of the mathematical model developed in previous articles, a simulation of the construction and of the operating of the SDGC is then presented. This simulation allows an assessment of profitability and a technical-economic comparison with existing technologies. The innovative aspects of SDGC are then highlighted with respect to comparable plants. The results of these comparisons are positive and encourage to further develop the SDGC system and to proceed with a detailed design, in order to promote a technology based mainly on the use of renewable energy.

Keywords: Water, Desalinization, Purification, Distillation, Renewable energy.

1. SDGC system

The SDGC process (Solar Desalination Geoassisted Continuous) is an innovative thermal distillation process that is essentially based on a first humidification phase and a second phase of air dehumidification, exploiting, at steady state, only solar thermal energy.

Fig. 1

As explained in two previous papers (Farné S. (2020) Theoretical Setting, Mathematical Model and Operating Principles of an Innovative System, Based on Natural Evaporation Processes, for Salty and Brackish Water Purification, Asian Journal of Applied Science and Technology (AJAST), Volume 4, Issue 3, Pages 183-209 and Farné S. (2020) Development and Sizing of an Innovative System, Based on Natural Evaporation Processes and Convective Motions, for Salty and Brackish Water Depuration, Asian Journal of Applied Science and Technology (AJAST), Volume 4, Issue 4, Pages 102-126), the patented invention SDGC refers to a method and to a device to

desalinize sea water, brackish water or from industrial processes, in a continuous and self-supported mode. In particular, the invention is described with reference to the accompanying figures, in which: Figure 1 is a perspective view of the device according to the invention; Figure 2 is a view in section, obtained by a transverse plane, of the device according to invention.

Fig.3 shows a diagram of layout of SDGC plant with heat generators.

Fig.3. SDGC simplified plant layout

2. Critical Operation

Despite its simple construction, the system is not exempt from possible anomalies. The operation is based on the tight maintenance of well-defined thermal gradients; in the absence of such temperature differences, the system can drastically reduce the production of condensation up to the complete shutdown of the system itself. The worst condition is reached when the thermal gradients are reset and the tank is all at the same temperature: the

evaporation stops (due to having the same saturation pressure at each point) and the heat cannot circulate through the thermal tunnel. In this case it is necessary to break the thermal equilibrium, re-establishing the right gradients so that the system resumes operation. To this end, auxiliary safety exchangers are installed in order to transfer the thermal energy from one area of the tank to another or transfer it to the thermocouple in the event of excess. These exchangers must be able to restart the system as soon as possible, so they must be able to transfer a large amount of heat in a short time.

2.1 Upper/lower heat exchangers

The thermal tunnel represents a possible bottleneck for the plant. This element, in fact, must guarantee the passage of all the thermal energy absorbed by the expanded sheets during the condensation process; if this function could not be carried out efficiently, these would gradually increase to the same temperature as the humid air, thus slowing down the process until it stops. To compensate for this drawback, in a first analysis it was assumed to install a piping circuit (made of corrugated material) passing between the upper and the lower part of the tank, filled with a heat-carrying fluid (water or other better performing fluid). By the aid of a hydraulic pump, the movement of the fluid would allow the absorption of thermal energy from the humidified air to transfer it to the colder water at the bottom of the tank. In this way, the thermal tunnel would be able to dispose of the remaining thermal energy without the risk of reaching the thermal equilibrium between the humidified air and the expanded sheets. The dimensioning of these pipes was carried out in the light of the fact that, should the need arise, this exchanger must be able to absorb a large amount of thermal energy in a short time. The results shown in Table 1 follows the calculation principles of the technical physics (Magrini & Magnani, 2009, p. 173), in which some parameters have been set: (1) The temperature of the thermal fluid inlet and outlet from the pipeline, on which the thermophysical parameters necessary for the calculation depend; (2) The dimensions and material of the piping, referred to standardized industrial products. (3) The internal speed in the piping.

The calculation provided for the determination of the conductive and convective thermal resistance (internal and external side) of the piping, for which it was necessary to calculate the convective heat exchange coefficients on the inside and outside according to the commonly used calculation models (Moran et al., 2011; Magrini & Magnani, 2009). The dimensioning of the exchanger was carried out considering the exchange with air. Achieving a satisfactory degree of absorption in this area, we are sure that this will be just as good for the salty water exchange zone, by virtue of its greater thermal conductivity. Furthermore, for this exchanger the calculation was conservative.

<i>Fresh water data</i>		
Delivery temperature	°C	20.00
Minimum return temperature	°C	50.00
Average temperature	°C	35.00

Thermal conductivity at average temperature	W/mK	0.62
Kinematic viscosity at average temperature	m ² /s	7.52E-07
<i>Piping data</i>		
Estimated length	m	9.30
Outer diameter	mm	50.00
Thickness	mm	1.00
Internal fluid speed	m/s	2.50
Material conductivity	W/mK	390.00
Conductive resistance	K/W	1.79E-06
<i>Internal convective heat resistance</i>		
Prandtl	//	5.04
Reynolds	//	159,574.47
Nusselt - turbulent flux in heating	//	638.57
Internal convective coefficient	W/m ² K	8242.88
Internal convective heat resistance	K/W	8.65E-05
<i>External convective heat resistance</i>		
Film temperature	K	320.5
Kinematic air viscosity at the film temperature	m ² /s	1.77E-05
Thermal conductivity at the film temperature	W/mK	0.02754
Reynolds	//	25,359.26
Prandtl	//	0.7099
		102.070670
Nusselt - laminar flow	//	1
External convective coefficient	W/m ² K	56.22
External convective thermal resistance	K/W	1.22E-02
<i>Power</i>		

Total thermal resistance	K/W	1.23E-02
Thermal power absorbed	kW	3.26
Number of installations	exchangers	15.00
Potential for total exchange	kW	48.92

Table 1. Secondary heat exchanger (upper/lower)

By installing 15 pipes connected in parallel through a suitable collector, the system is able to absorb a quantity of heat equal to about 40% of the total to be disposed of through the thermal tunnel, enough to restart the process in the event of a system stall.

2.2 Side heat exchangers

As stated in the previous pages, the worst criticality for the operation of the system is represented by the zeroing of the thermal gradients. This situation can occur for two main reasons:

- in the system, insufficient thermal energy was introduced to compensate for losses through the enclosure and to guarantee the formation of thermal gradients suitable for making the system work efficiently;
- too much thermal energy was introduced into the system, saturating it and bringing the tank to the same temperature at each point.

While in the first case it is sufficient to introduce further thermal energy, the second case certainly deserves more attention. It may be due to malfunctions or to unsuitable control systems. If these situations occur, the tank being well insulated and therefore with limited losses, it is necessary to withdraw a portion of this thermal energy and transfer it outside the system in order to restore the thermal gradients necessary to restart the process.

For this purpose, it was decided to install a series of pipes along the side walls of the tank, similar to the solution adopted in the previous paragraph, in which a heat-carrying fluid is circulated to absorb thermal energy from the salty water and transport it outwards, to be dissipated in the environment or stored in a thermal storage system. In this way, the cooling of the salty water will allow the thermal tunnel to start the condensation process again. Table 2 shows the calculations performed for sizing, which require the selection of some parameters.

<i>Fresh water data</i>		
Delivery temperature	°C	20.00
Minimum return temperature	°C	50.00
Average temperature	°C	35.00
Thermal conductivity at average temperature	W/mK	0.62
Kinematic viscosity at average temperature	m ² /s	7.52E-07

Piping data

Estimated length	m	18.60
Outer diameter	mm	50.00
Thickness	mm	1.00
Internal fluid speed	m/s	2.50
Thermal conductivity	W/mK	390.00
Conductive resistance	K/W	8.96E-07

Internal convective heat resistance

Prandtl	//	5.04
		159,574.4
Reynolds	//	7
Nusselt - turbulent flux	//	638.57
Internal convective coefficient	W/m ² K	8242.88
Internal convective heat resistance	K/W	4.33E-05

External convective heat resistance

Film temperature	K	320.50
Kinematic air viscosity at the film temperature	m ² /s	5.86E-07
Thermal conductivity at the film temperature	W/mK	0.64
Cubic expansion coefficient	1/K	4.37E-04
Grashoff	//	3.90E+07
Prandtl	//	3.76
Rayleigh	//	1.47E+08
Nusselt	//	76.48
External convective coefficient	W/m ² K	975.20
External convective thermal resistance	K/W	3.51E-04

Power

Total thermal resistance	K/W	3.95E-04
Thermal power absorbed	kW	63.27
Number of installations	exchangers	6.00
Potential for total exchange	kW	379.63

Table 2. Secondary heat exchanger (left/right)

By installing six exchangers in parallel, close to the sidewalls of the tank, they will be able to absorb about 380 kW of thermal power. This power will be sufficient to break the thermal equilibrium by bringing the system to work again in a time of about 3 h. Table 3 gives a verification of the mathematical calculation.

Table 3. Secondary heat exchanger - validation

Balance temperature	°C	60.00
Operating recovery temperature	°C	20.00
Total mass of water	kg	33,617.95
Mass of water to be cooled	kg	23,532.57
Energy spent on cooling	MJ	3940.29
	MWh	1.09
Time spent cooling	h	2.88

Fig.4. SDGC heat exchangers simplified layout

Once the sizing of the main elements of the system has been completed, Figure 4 shows the dimensioned drawing of the SDGC system.

2.3 Auxiliary plants

For the correct and efficient operation of the system it is necessary that the tank remains closed most of the time, allocating the opening and therefore the shutdown of the system only in case of scheduled maintenance or in cases of overtime. This makes it necessary to design a series of auxiliary service systems able to maintain the adiabaticity of the tank, the vacuum of the tank and, at the same time, to guarantee the continuity of the process. The plants covered by this paragraph are:

- ✎ Brine removal plant;
- ✎ Salty water intake system;
- ✎ Condensate extraction system;
- ✎ Control and regulation system;
- ✎ Vacuum system of the tank.

The study and design of these plant portions will be the subject of future developments of the SDGC system. The following is a construction concept in order to justify the purchase and installation costs reported in the economic analysis of the next section.

2.3.1 Brine removal system

During the process of the evaporation of the salty water, the chemical reaction of the separation of water from the salts takes place. As a result of this separation, during the process the salty water that remains inside the tank will be increasingly enriched in salts, increasing their concentration up to a maximum limit beyond which the water will no longer be able to dissolve them, causing them to sink to the bottom of the tank. To guarantee the efficient removal of the brine (where this term refers to salty water which has undergone a partial increase in the concentration in salts), it will be necessary to provide for its partial replacement with a reintegration of salty water before the limit of concentration. For a first evaluation it was decided to arrange, homogeneously on the bottom of the tank, a perforated pipe connected to a hydraulic pump able to effectively suck out the brine deposited on the bottom. The machine can be connected to a level sensor, which measures the position of the free surface when it falls below a certain value, or to a sensor that detects the degree of concentration of salts in the solution.

2.3.2 Salty water intake system

During operation and as stated in the previous paragraph, the water evaporation process and the brine removal must correspond to a simultaneous reintegration of the salty water, in order to maintain the level of the free surface above the pipes of the main heat exchanger. This operation can be carried out simply by connecting a pipe to one or more nozzles located on the side walls of the tank and connected to a hydraulic pump connected to an external storage tank that guarantees certain autonomy. The system must also be able to provide rapid filling of the tank during start-up or at the end of the scheduled maintenance.

2.3.3 Condensate extraction system

The water is condensed by the cooling process. To avoid this energy being dissipated in the external environment, a possible solution that will be the subject of future study could be to preheat the salty water using energy contained in the condensate. To accomplish this, double-walled piping could be used to inject the salty water into the tank, so that the condensate during the outlet travels through the innermost pipeline, yielding thermal energy to the salty water entering through the outer piping. To collect the condensate, a possible evaluated solution consists in the installation of a collection tank at the base of the thermal tunnel with a certain slope, so as to allow the condensate to exit from the gravity tank until it flows into an external tank. From there, a hydraulic pump would send it for the final use through the double-walled pipe described above.

2.3.4 Control and regulation system

Monitoring and control of the system parameters is the crucial point of the whole system. As explained in the previous sections, good operation is based on the strict maintenance of thermal gradients and established operating conditions. This can only be achieved if upstream there is an effective control system that allows the total management of the entire system, from heat generators to safety exchangers, in order to obtain the reintegration of the salty water and to maintain the speed of the indoor air. All this can be achieved through a series of appropriate sensors. Pressure, level, temperature, speed, concentration and weather sensors to manage the solar thermal system are just some of the possible devices that can be used by the system to work properly.

2.3.5 Vacuum system for the tank

Natural water evaporation is a rather slow process. An open container filled with water and left in the environment needs a few hours before it empties. To speed up this transformation we can use different strategies, all exploited within the SDGC system: air acceleration in order to promote convective motions, increase of the water temperature to increase molecular agitation and promote diffusion, and finally vacuuming the environment in which the water must evaporate. By reducing the total pressure inside the tank, the evaporation is greatly facilitated; as shown by the formula

$$N_{Az} = \frac{p_{tot} D_{AB}}{RTL} \ln \left(\frac{p_{tot} - p_{sat}(T_L)}{p_{tot} - p_{sat}(T_0)} \right) \quad \left[\frac{kmol}{m^2s} \right]$$

decreasing the value of the total pressure increases the value of the natural logarithm and, consequently, the molar flow of evaporated water. To evacuate a tank, it is necessary to establish a pressure difference between the tank to be emptied and another region of the space. To obtain this condition, vacuum pumps are used, suction devices capable of emptying closed containers containing liquids, sucking out part of the air inside. The suction system of the tank must be able to maintain the degree of vacuum expected during the sizing phase for a sufficiently long time in order to assure the continuous operation of the machine. For this reason, it will be necessary to provide adequate sealing systems both for the air extraction system and for the connections of the other auxiliary systems for the entry and removal of salty water and for the extraction of condensation.

3. Economic Analysis

This section presents the economic results obtainable by using the SDGC system as a desalination system. The analysis was carried out taking into account the main costs and estimating all the elements that, at present, have not yet been designed in detail. This makes it possible to derive a first evaluation of the costs connected to the construction and operation of the plant during the prototyping phase and allows a first comparison to be made with existing technologies. The cost analysis was performed considering the cost of the SDGC module only, without considering any pre-treatment systems for salty water or post-treatment of fresh water.

It is recalled that the standard module of the previous sizing can easily be replicated in parallel to cover the required fresh water requirement. Thanks to scale effects and to design revaluation on auxiliary and generating systems, as the production size increases, the cost of specific plants will decrease considerably.

3.1 Cost of the investment

The cost of the plant represents the total costs incurred for its construction. The total represents the initial capital needed for the plant to be ready to produce. Table 4 shows the evaluation of the plant cost, considering the materials needed and the implementation of a single SDGC module.

<i>Description of cost items</i>	<i>Price [€]</i>
Reinforced concrete tank 53 m ³	7000.00
Insulation panel 100 mm	3840.00
Corrugated tube CU 32x1.5 mm	1674.00
Corrugated tube CU 50x1 mm	5070.00
Rhomboidal expanded sheet Al 62x20 sp.2 vp.30%	6750.00
Solar collectors Sky Pro 18 + Mechanical support	4000.00
Heat pump W/W 301.A21	7000.00
Auxiliary plants - machines - control and regulation systems	6000.00
Civil works (foundation + machine room)	5000.00
Installation - total workforce	7000.00
Total	53,334.00

Table 4. Unit module cost

The table shows that the implementation of the system involves an estimated initial outlay of about 53,000.00€, which for the current level of development can be considered sufficiently reliable based on the fact that the materials used in the construction are all standardized products used in the industrial sector.

3.2 Operating cost

The operating cost represents the sum of all the costs to be incurred in a given period (the year is considered) to operate the plant correctly, so as to maintain its performance characteristics at the project conditions. At present, the operating cost of the SDGC system represents a difficult point of analysis, since there is not yet a prototype that allows reference values to be considered. The determination, therefore, was carried out on the basis of a careful critical analysis of the operation over the reference period, assuming what could be the possible costs to be taken into account and to what extent. The operating costs considered in the calculation are shown below:

- **Management:** the system has been designed to be able to operate autonomously through an appropriate control and regulation system, not requiring the presence of permanent personnel. In this first phase it is considered opportune that the system can be monitored remotely, even if, as we will see below, as the size increases, it may be more convenient to hire staff.
- **Electricity:** at present, the possibility of installing a photovoltaic system capable of supplying the total amount of electricity required has not yet been assessed, therefore the connection to the electricity grid is assumed with a contract at an industrial price. For the reasons stated above, the evaluation of the electrical consumption of the plant is difficult to determine; for a first analysis it was assumed to set the utilization coefficients that would allow an estimate of the number of equivalent operating hours on the total shown in Table 5.
- **Ordinary maintenance:** scheduled maintenance interventions are expected to be limited to cleaning the tank from possible encrustations and, where necessary, to the treatment of the elements in contact with salty water with anti-corrosion products.

<i>Factor of use of main pumps</i>	0.2	The pump serving the solar thermal system works for approximately 1600 h/year equivalent.
<i>Use of secondary/ auxiliary pumps</i>	0.013	The pumps serving the safety and in / out salty water systems work for approximately 104 h/year equivalent.
<i>Heat pump utilization factor</i>	0.01	The heat pump works for around 80 h/year equivalent.

Table 5. Electric power usage factors

Table 6 shows the estimated costs necessary to maintain the SDGC system in the operating conditions established in the design phase.

<i>Global data</i>		
Annual operation	h/year	8000.00
Industrial electricity price	€/kWh	0.12

Rated power for solar thermal pumps	kW	0.75
Rated power for auxiliary pumps	kW	1.10
<i>Estimated energy consumption</i>		
Heat pump energy consumption	kWh/year	541.74
Solar thermal pump energy consumption	kWh/year	1200.00
Power consumption of auxiliary pumps	kWh/year	686.40
Total electricity consumption	kWh/year	2428.14
<i>Operating cost</i>		
Electric energy	€/year	291.38
Routine maintenance	€/year	550.00
Remote management contract	€/year	1000.00
Total	€/year	1841.38

Table 6. Unit module operating cost

From a first estimate, it is therefore clear that the order of magnitude of the annual operating costs of a unit can be evaluated as approximately 1800.00 €/year.

3.3 Production cost

From what has been described in the previous paragraphs, it is possible to evaluate a first estimate of the production cost of desalinated water through the SDGC system. By fixing the operating period of the system as 8000 h/year, it is possible to obtain the quantity of water produced through an SDGC module. By dividing this amount by the operating costs, the unit production cost of desalinated water is obtained. Table 7 shows the results.

Annual production of desalinated water	m ³ /year	1337.36
Specific consumption	kWh/m ³	1.82
Specific production cost	€/m³	1.38

Table 7. Fresh water specific production cost

Therefore, for an SDGC plant made up of only one operating module, the specific cost of producing desalinated water is equal to 1.38 €/m³ compared to an energy consumption of 1.82 kWh/m³. This cost has been assessed without considering any contributions due to the operation of water treatment systems, which may be necessary in relation to the occurrence of particular conditions of the supply water (presence of disturbing elements that could clog or damage hydraulic machines at the service of the plant) or in relation to the particular use of desalinated water. Moreover, the easy modularity of the plant allows its production to be increased against a less than proportional increase in operating costs.

3.4 Comparison with existing technologies

The following section shows a comparison, in terms of distillate production and specific consumption, between the SDGC plant and the existing technologies supplied with traditional sources. In Table 8, a comparison has been made (de la Cruz & Cynthia, 2015):

Technology		Typical capacity	Specific consumption		Cost
		m^3/d	kWh_e/m^3	kWh_r/m^3	$€/m^3$
Processes of renewable sources	Solar still	< 0.1	//	//	1 – 6
	Solar MEH	1 – 100	1.5	100	2 – 6
	Solar MD	0.15 – 10	//	150 – 200	8 – 15
	Solar MED	> 5000	1.4 – 2	60 – 70	1.8 – 2.2
	PV-RO	< 100	0.5 – 1.5	//	5 – 7
	PV-EDR	< 100	3 – 4	//	8 – 9
	WIND -				
	RO	50 – 2000	0.5 – 5	//	3 – 7
Conventional sources processes	MSF	6 – 500	3 – 5	70 – 90	1 - 4
	MED	10 – 200	2 – 4	70 – 90	3 – 10
	RO	10 – 120	3 – 5	//	3 – 7
SDGC		> 4	1 – 3	//	< 3

Table 8. Comparison between SDGC plant and existing desalination technologies

From Table 8 it can be seen that the SDGC system can compete with traditional systems by virtue of its low operating costs, exploiting the modularity of the plant and the economies of scale on materials.

3.5 Comparison with traditional technologies

At present it is very difficult to compare in detail the SDGC technology with the traditional ones, as the plant is at a stage of development that makes it difficult to quantify costs in addition to what is already reported in the previous paragraphs. However, it can be expected that the system will be more suitable for medium and low capacity applications (possibly up to $200/300 m^3/d$) given the production density that can be obtained with the current configuration. Table 9 shows some values on the cost of desalinated water related to MSF and reverse osmosis

plants. These costs were obtained by analyzing the material present in the literature and extrapolating average values; in fact, they are subject to significant variation depending on the size, the place of installation and the characteristics of the water to be treated.

<i>Process</i>	<i>MSF</i>	<i>RO</i>
	€/m ³	€/m ³
Capital costs and plant construction	3500.00	2600.00
Operating costs	1.80	2.20
Production cost of desalinated water	1.32	1.25

Table 9. Orders of magnitude of plant and operating costs, MSF and RO

From these values, it is possible to make a comparison assuming the construction of a plant capable of producing 150 m³/d of desalinated water. To meet this production target, it is necessary to install 38 SDGC modules. For the analysis of plant and operating costs, it is assumed that, thanks to the modularity of the plant, the economies of scale on the materials allow a considerable reduction of costs of building materials and civil works, as shown in Table 10.

<i>Description of cost items</i>	<i>Price [€]</i>
Reinforced concrete tank 53 m ³	7000.00
Insulation panel 100 mm	3840.00
Corrugated tube CU 32x1.5 mm	1674.00
Corrugated tube CU 50x1 mm	5070.00
Rhomboidal expanded sheet Al 62x20 sp.2 vp.30%	6750.00
Civil works (foundations + machine room)	5000.00
Sub-total for single module	29,334.00
Scale effect	45.00%
Sub-total discounted for each module	16,133.70
Total construction and civil works for 38 SDGC modules	613,080.60

Table 10. Cost variation for building and civil works

As for the heat generation system, with the use of multiple SDGC modules, one might reconfigure the layout of the system to make it more efficient (for example, using a higher power generator to serve more tanks and managing starting in sequence, rather than many low-power generators). This is thought likely to lead to significant economic benefits on the costs of heat generation systems, as shown in Table 11.

<i>Description of cost items</i>	<i>Price [€]</i>
Sub-total for single module	11,000.00
Scale effect	70.00%
Subtotal discounted for each module	3300.00
Total heat generators for 38 SDGC modules	125,400.00

Table 11. Cost variation for heat generators

As regards the auxiliary systems, the devices and the control and regulation system, it is believed that this cost cannot be reduced particularly, due to the increasing complexity of the plant and the management that generally characterize a large plant. On the other hand, as regards the cost of labor, better management of the number of technicians and workers could lead to cost savings. Table 12 shows the result of the hypotheses made so far.

<i>Auxiliaries plants - machines – regulation and control systems</i>	
<i>Description of cost items</i>	<i>Price [€]</i>
Auxiliary plants - machines - control and regulation system	6000.00
Scale effect	40.00%
Subtotal discounted for each module	3600.00
Total auxiliary plants - machines - control and regulation for 38 SDGC modules	136,800.00
<i>Installation</i>	
<i>Description of cost items</i>	<i>Price [€]</i>
Installation - total workforce	8000.00
Scale effect	65.00%
Subtotal discounted for each module	2800.00
Total installation - labour for 38 SDGC modules	106,400.00

Table 12. Change in costs for auxiliaries, installation, labour

From these calculation estimates, based on critical evaluations, the total cost of the plant can be calculated, corresponding to approximately 980,000 €. With regard to the running costs, these can also be evaluated through a

critical assessment of the situation. As far as electricity costs are concerned, they can be considered essentially invariable with the size of the plant, as the energy requirement increases proportionately with the size, while a reduction of 30% of the ordinary maintenance cost can be assumed thanks to the economy of scale. As regards the cost of monitoring and management of the plant, it is possible to consider hiring a person in charge of this task, abandoning the hypothesis of remote management. Table 13 shows the summary of the calculations.

Electric energy	€/year	11,072.31
Ordinary maintenance	€/year	14,630.00
Staff (one worker)	€/year	20,000.00

Table 13. Operating costs considering the staff

From this it is deduced that the operating cost of the plant is about 45,000.00 €/year. From this analysis we can deduce that the specific cost in terms of the production of water is equal to 0.90 €/m³.

Table 14 shows the result of the comparison between the SDGC plant and the traditional technologies of the same dimensions shown previously in Table 8.

<i>Process</i>	<i>MSF</i>	<i>RO</i>	<i>SDGC</i>
Capital costs and plant construction [€]	525,000.00	390,000.00	981,680.60
Operating costs [€/year]	90,000.00	110,000.00	45,702.31
Desalinated water production cost [€/m ³]	1.77	2.16	0.90

Table 14. Comparison of the same size of SDGC – MSF - RO

From this initial analysis, it emerges that, at the current state of development, the initial investment on the SDGC plant is much higher than traditional technologies. However, the cost of the plant can certainly be reduced given a design aimed at reducing costs and optimization, which has not yet been taken into account. Furthermore, the possibility of access to government grants or incentives, which could certainly result in a reduced charge for the client, cannot be ruled out. From this analysis it is also possible to see how the use of the SDGC system leads to a significant reduction in operating costs and consequently to a reduction in the cost of producing desalinated water compared to traditional technologies.

The data shown in Table 13 it allows to compare the break-even time of the SDGC system with the traditional small-scale MSF and RO systems. The comparison is made on the basis of savings on operating costs, which, compared to the extra cost of building the plant, returns the minimum time that the SDGC plant will have to operate to repay the investment. The summary of the calculations is shown in Table 15:

<i>Plants compared</i>	<i>MSF-SDGC</i>	<i>RO-SDGC</i>	<i>U.M.</i>
Difference in operating costs	44,297.69	64,297.69	€/year
Difference with SDGC	456,680.60	591,680.60	€
Break-even time	10.31	9.20	year

Table 15. Economic analysis of SDGC - MSF - RO

As it can be seen from the table, the extra cost of realizing the SDGC plant compared to the traditional ones is paid back, by virtue of lower operating costs, in a period of 9 – 11 years based on the technology. Strictly speaking, in order to evaluate the comparison between investments more precisely, cash flows should be discounted. However, the current economic situation shows that interest rates are almost zero; in a first approximation, therefore, the results obtained in Table 15 can be considered sufficiently reliable.

Considering that the average life of systems of this type is between 20 and 30 years, the use of an SDGC plant can allow a considerable economic saving starting from the break-even point of costs.

3.6 System innovation

The SDGC system was found to be a potential alternative to traditional plants. The main innovative aspect of the system consists in reproducing, in a restricted environment, the water cycle that commonly occurs in nature. In fact, through the solar thermal energy, part of the water present in the seas and oceans evaporates according to the relationship presented in the calculation model, returning towards the atmosphere. Thanks to the convective motions, the mass of water in the aeriform state is pushed up to an environment in which it condenses, thanks to the low pressures and temperatures, precipitating successively to the ground.

<i>Technology</i>	<i>Size</i>	<i>Investment</i>	<i>O & M</i>	<i>Water cost</i>	<i>Energy req</i>
<i>Installation</i>	<i>m³/d</i>	<i>€</i>	<i>€/year</i>	<i>€/m³</i>	<i>kWh/m³</i>
Solar - HDH*	0.022	1400.00	270.00	0.04–0.089	nd**
Solar - HDH*	0.02	10,775.00	1200.00	156.00	nd**
Solar - HDH*	0.5	11,440.00	80.00	4.15	nd**
ST - MED - Abu Dhabi	120	2,037,783.00	nd**	6.58	50.91
⁸ ST - MED - Almeria	73	nd**	nd**	nd**	3.3 – 5

⁸ PV - RO - Lampedusa	120	nd**	nd**	6.5	5.5 - 6
⁸ PV - RO - BW - Ceara	8	11,300.00	654.00	10.32	4.7
⁸ PV - RO-Pozo Izquierdo	3.2	nd**	nd**	9	5.5
45,702.3					
SDGC - Case Study	150	1,087,160.24	1	0.90	1.82
*prototype; **undeclared					

Table 16. Technical-economic data of installed systems

The SDGC system exploits and accelerates this process: solar energy is used to heat the heat-carrying fluid which, by means of a heat exchanger, heats the surface of the mass of water present in the tank, making it evaporate in a closed environment in vacuum and with artificially accelerated moist air. All this allows a faster process and the almost total recovery of latent heat thanks to the presence of the thermal tunnel. In Table 7 there was already a first positive comparison between the unit module and the orders of magnitude of the current technology park. In this section, we want to show the comparison between the system sized in the case study and some plants, operational and experimental, set up for the exclusive operation of solar energy, with the aim of highlighting the additional innovative and technological features of the SDGC system. Table 16 shows the declared data of the plants under examination, obtained from the analysis of the scientific literature.

From this comparison, it can be deduced that the SDGC system, with a production level comparable to MED and RO plants powered by solar energy, investment costs, presents significantly lower production costs and specific consumption. This is due to the simplicity of construction that characterizes the SDGC system; exploiting standard commonly used products reduces the costs associated with the development of new elements, which would certainly lead to an increase in the total investment cost. The modular nature of the system also allows the system to be rescaled according to the production size without completely redesigning the system, thus guaranteeing a reduced design cost. The operation of the system allows the recovery and continuous reuse of the latent heat, making the SDGC a practically self-supplying system, since the thermal energy supplied during the start-up phase is continuously reused thanks to the presence of the thermal tunnel, unless lost through the envelope, which is reintegrated through solar collectors. This element represents the heart of the whole system and at the same time its most delicate part. In fact, it plays a dual role of equal importance: acting as a condensation and condensate collection surface and at the same time recovering the latent heat to reuse it within the system itself, allowing it to self-feed. This second function is implemented by realizing a communication path, using the procedure described in the previous sections, between the condensation zone and the exchange zone at the bottom of the tank, passing through the portion of water heated to the free surface. This solution actually represents a great innovation, since it allows the complete recovery of the latent heat to feed the main process and not, as often happens in traditional

systems, for secondary pre-heating functions. This allows a drastic reduction of the energy to be supplied to the system and, consequently, the related costs.

Thanks to these technological solutions, a specific consumption of energy is obtained that is much lower than that of the plants shown in Table 16 and allows a much lower production cost compared to alternative plants. This makes the SDGC system competitive, even with a higher investment cost, because, as shown in Table 15, it allows a return of the investment cost in a sufficiently short time, relative to the average life of this type of plant.

4. Conclusions and Future Developments

This paper has presented the development of the Solar Desalination Geoassisted Continuous system, a new and innovative type of system for desalinating marine or brackish waters through a sustainable use of energy. The analysis and the calculation models, presented in the previous articles of the same author (Farné S. (2020) Theoretical Setting, Mathematical Model and Operating Principles of an Innovative System, Based on Natural Evaporation Processes, for Salty and Brackish Water Purification, Asian Journal of Applied Science and Technology (AJAST), Volume 4, Issue 3, Pages 183-209 and Farné S. (2020) Development and Sizing of an Innovative System, Based on Natural Evaporation Processes and Convective Motions, for Salty and Brackish Water Depuration, Asian Journal of Applied Science and Technology (AJAST), Volume 4, Issue 4, Pages 102-126), make it possible to relate the geometrical and thermophysical parameters to the operating conditions of the plant, allowing a formulation to be obtained for calculating the producibility of the plant. Following the sizing, an effort was made to estimate the potential costs related to the construction and operation of the plant, producing a comparison with conventional technologies, being aware that in this phase of development the results are estimated on the basis of a model. What was achieved, however, was encouraging:

- [1] the investment the investment to build the plant was far higher than traditional plants of the same size fed through conventional energy sources. This is due to the non-optimization of the system according to the modularity of the SDGC system, as explained in the previous paragraphs. With continued development, it is expected that this cost may fall significantly until it reaches levels comparable with conventional technologies. Furthermore, the possibility of a configuration change, aimed at obtaining a higher level of productivity than the standard model, is a precondition for achieving the desired productivity level by installing a smaller number of SDGC modules;
- [2] operating costs were relatively low, due to the simplicity of the plant and to the use of renewable energy. By purchasing electricity at an industrial price, the annual cost was relatively low. Some of the operating costs were reserved for scheduled maintenance, which consists of a total cleaning of the tanks and the removal of any salt deposits and the management of the system. Due to the small size of the plant, it was considered appropriate the stipulation of contracts for external management, instead of hiring personnel to supervise the plant itself, while the increase in size required the possibility of hiring a supervisor. All this made it possible to obtain much lower operating costs compared to traditional systems of the same size, and this led to a significantly lower production cost.

- [3] The results obtained have therefore found in the SDGC system a possible alternative to the desalination methods present on the market today, setting the starting point that will allow planning the future development of the system, as summarized below:
- [4] optimization of the analysis model: the model presented in the previous papers of the same author represents the first reliable method to describe the functioning and allow a preliminary sizing. Precisely because of its newness, it is subject to analysis and changes that will increase the accuracy and the precision, in the direction of its final validation;
- [5] technical-economic optimization of the construction elements: as explained in the previous paragraphs and relevant papers, for the preliminary sizing only the effectiveness and standardization of the inserted elements was taken into consideration. Future development will necessarily have to focus on optimizing all the elements, so as to significantly reduce the cost of installation;
- [6] design of the plant auxiliaries: it will be necessary to provide a detailed sizing of the auxiliaries, mentioned in the project concept and of which an estimate has been made in the economic analysis. To these is added the final choice of the type of system for moving the air and for creating the vacuum inside the system;
- [7] Complete sizing of the plant: the sizing carried out in the previous paragraphs and relevant papers did not consider elements that could be complementary to the operation, such as salty water pre-treatment systems and fresh water after-treatment systems. These processes must necessarily be sized leading to a more detailed and reliable technical and economic analysis.

The problem of the scarcity of fresh water is incredibly pressing and constantly increasing due to population growth and consumption. Studying new and more environment-friendly plants and investing in the development of sustainable systems for salty water desalination remains one of the key points on which it is worthwhile to concentrate our efforts to solve this problem.

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Patents

Lavanga Vito, Farné Stefano - Method for the Continuous Desalinization and Device for the Implementation of SAID Method; Publication Number WO/2016/162896 - Publication Date 13.10.2016 SDGC

<https://patentscope.wipo.int/search/en/detail.jsf?docId= WO2016162896> (sea and process water solar desalination)

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Consent to participate

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We declare that we consented for the publication of this research work.

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Authors are willing to share data and material according to the relevant needs.

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