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WIND-SOLAR DESILTER WITH AUTONOMOUS RENEWABLE ENERGY SUPPLY

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***Abstract.** Silting is a phenomenon which occurs in every waterbody and can affect the sustainability of many human facilities and activities. The current strategy to remedy it is through corrective dredging operations, employing large pumps or excavation devices, which end up polluting the surrounding waters. This paper introduces a desilting system designed to operate at lower rates for longer periods, harnessing renewable energies from the environment instead of burning fuels or depending on the electrical network. A few assemblies were estimated with standard market components, and their theoretical performances were compared with the solid particle inflow of a facultative pond and a consumption water reservoir. As expected, the proposed technology seems promising to perform preventive maintenance, keeping the sediment levels low, but would not be as practical in attempting to revert the already accumulated sediments from decades of unattended siltation. This system may also be seen as an introduction to a sustainable strategy of utilizing renewable energies to perform long term tasks with enough complacency to incorporate the sources' fluctuations without compromising the overall functionality.*

Keywords: *Silting, Desilting, Windpower, Photovoltaic*

1. INTRODUCTION

Liquid streams tend to carry a certain amount of solids in suspension, for example, dust, sand, organic matter, particles detached from pipes, etc. Then, when the stream reaches a wider space, where the flow speed decreases, the suspension may decant and the solid particles may accumulate in the bottom. As a result, the effective volume of the receiving fluid space is altered. This phenomenon is called sedimentation, silting or siltation, which can be seen as the other end of the erosion process (Brown et al., 2006).

In some cases, sedimentation may be perceived as a natural and harmless occurrence. However, when the phenomenon is accelerated as a result of human activities, or when it decreases the effective volume of reservoirs and dams, it causes a series of problems such as disturbing ecosystems and contributing to shortages in water supply or hydroelectricity.

The usual method to revert the situation in already silted water bodies is to dredge the waterbed, either by excavation or by employing high capacity slurry pumps (Wilson et al., 2006). Such response is usually triggered when the siltation has reached levels high enough to cause perceptible changes, and thus demands an immediate solution. Therefore, high capacity equipment is employed to hasten the process. This approach follows the corrective maintenance method, with some of its most prominent disadvantages, such as faulty planning and significant interference in the maintained system or environment. Depending on the technology applied and the site conditions, dredging operations may significantly increase the suspended solids concentration for kilometers downstream, which can affect turbidity, biochemical oxygen demand, disperse toxic contaminants, among other effects (Elsaeed, 2011).

In face of that, an idea for a solution came to mind: a system designed to preventively counterbalance silting, in a more sustainable and environment friendly way. Such is the philosophy behind the wind-solar desilter, hereby presented.

2. OBJECTIVE

This paper's objective is to estimate the performance of a wind-solar desilter assembly with commercial parts available in the market, designed to work as a preventive maintenance system. Then, by comparing the estimated quantities with the needs of known reservoirs, evaluate its applicability and viability. It may also serve as an

introduction to a sustainable strategy of utilizing renewable energies to perform long term tasks with enough complacency to incorporate the sources' fluctuations without compromising the overall functionality

3. METHOD

The proposed solution, simply put, comprises a floating platform equipped with a pumping system able to reach the reservoir's bed and collect water along with the accumulated sediments, like a regular pump dredge. However, instead of taking energy from the local electrical network, or burning fuels in generators, the desilter counts on photovoltaic panels and wind turbines to harvest the energy needed. This feature allows it to be employed in remote spaces without energy infrastructure facilities, and may reduce its carbon footprint.

Also, it would be designed to work for long periods with lower extraction rates when compared to traditional dredges. The equipment would be sized to maintain the silting levels permanently under control, instead of performing sporadic emergency operations. Figure 1 presents a schematic diagram which synthesizes how the desilter works.

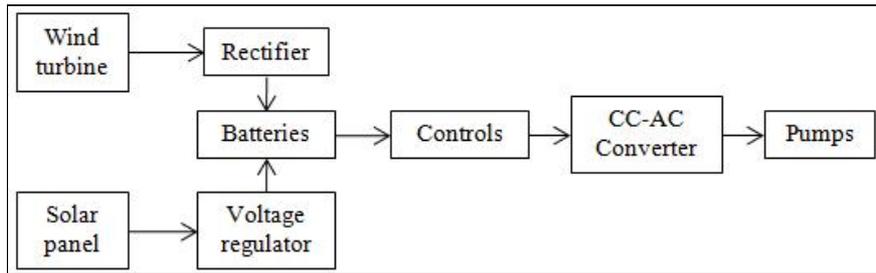


Figure 1. Schematic diagram of the desilter

To design the assemblies, predictions about how much energy can be captured are needed. The wind speed can be modeled as a Weibull probability distribution, as described by Eq.(1), where p is the occurrence probability of a velocity V , k is called the shape factor and c is called the scale factor. The factors k and c are determined by statistical treatment of measurements taken for a location at a reference height above the ground (Moreira, 2017).

$$p(V) = \frac{k}{c} \cdot \left(\frac{V}{c}\right)^{k-1} \cdot \exp\left[-\left(\frac{V}{c}\right)^k\right] \quad (1)$$

The wind speed varies with the height above ground. The velocity profile is assumed to follow a power law, as described by Eq.(2), where V_H is the corrected velocity for height H ; V_0 is the velocity estimated or measured at the reference height H_0 ; and n is an empirical exponent, which varies with the surrounding surfaces' roughness (Moreira, 2017).

$$V_H = V_0 \left(\frac{H}{H_0}\right)^n \quad (2)$$

Therefore, by accessing wind regimen registers, such as the ones available at Cresesb wind databases (2015a), and combining them with wind turbine power curves given by their manufacturers and distributors, one can estimate the average energy harnessed in a day.

The meteorological institutes provide data about solar incidence as well (Cresesb, 2015b). The values given represent the power per area hitting a plane with a specific inclination and orientation, such that one can estimate the energy harvested in an average day as described by Eq(3). E is the energy collected, I is the daily solar incidence estimated by local measurements for a set of installation parameters, A is the sum of solar panel surface area installed as specified, and η_p is the average photovoltaic efficiency for the chosen panels (Moreira, 2017).

$$E = I \cdot A \cdot \eta_p \quad (3)$$

Wind and solar energies are by default variable sources, which may fluctuate from one minute to the next. Meanwhile, rotative machines, such as motors and pumps, work more efficiently under steady regimens, preferably close to the conditions they were designed for (for example, a pump's best efficiency point). Their parts also tend to have a longer work life when submitted to steady regimens.

Moreover, wind turbines usually work with alternate current (AC), while most photovoltaic panels discharge continuous current (CC). Therefore, between the energy harvesters and the pumps one should install some element to

accommodate different types of current and also provide a steady power level during working shifts. The preliminary assemblies shall use batteries, for they are the most widely available technology for electrical energy accumulation. In future stages, this option may be substituted by a more efficient device.

The pump inlet shall be positioned close to the waterbed, so that the inflow agitates the sediments and suspends the solid particles, suctioning a mixture of water and solids. The tubulation would then transport the suspension to a separation system, whose selection or design may be studied in future opportunities. For the time being, the separators considered shall be hydrocyclones, passive devices which rely on flow speed and density difference between the liquid and the solid phases.

The head increase or loss from pumps, hoses and separators were modelled as quadratic functions of the flow, as presented by Eq(4), where H is the head increase for the pump, or loss for the other components; i is the index identifying the component considered; Q is the flow passing through the component; a , b and c are the curve coefficients, calculated to fit the equation to the data informed in catalogues.

$$H_i = a_i \cdot Q^2 + b_i \cdot Q + c_i \quad (4)$$

The head increase given by the pump should equal the head losses due to the hose and the separator, and elevate the column up to the discharge outlet. That is translated in Eq.(5), where H is the head; h is the height of the discharge outlet, measured above the reservoir surface; the underscore p indicates the pump, t indicates the tubulation (hose), and s indicates the separator.

$$H_p = H_t + H_s + h \quad (5)$$

By expanding and reordering the terms on Eq.(5), one can find the theoretical equilibrium flow as shown in Eq.(6). The plus or minus sign comes from the quadratic equation solution, but only the positive value of Q is applicable for this analysis.

$$Q = \left[\left(-b_p + b_t + b_s \pm \sqrt{(-b_p + b_t + b_s)^2 - 4(a_p - a_t - a_s)(c_p - c_t - c_s - h)} \right) \right] / [2(a_p - a_t - a_s)] \quad (6)$$

Figure 2 shows a representation of a possible assembly, to better illustrate the concept. It presents an assembly with floaters, electric motor and a propeller, parts related to the system's navigability, whose studies are not part of this paper's scope.

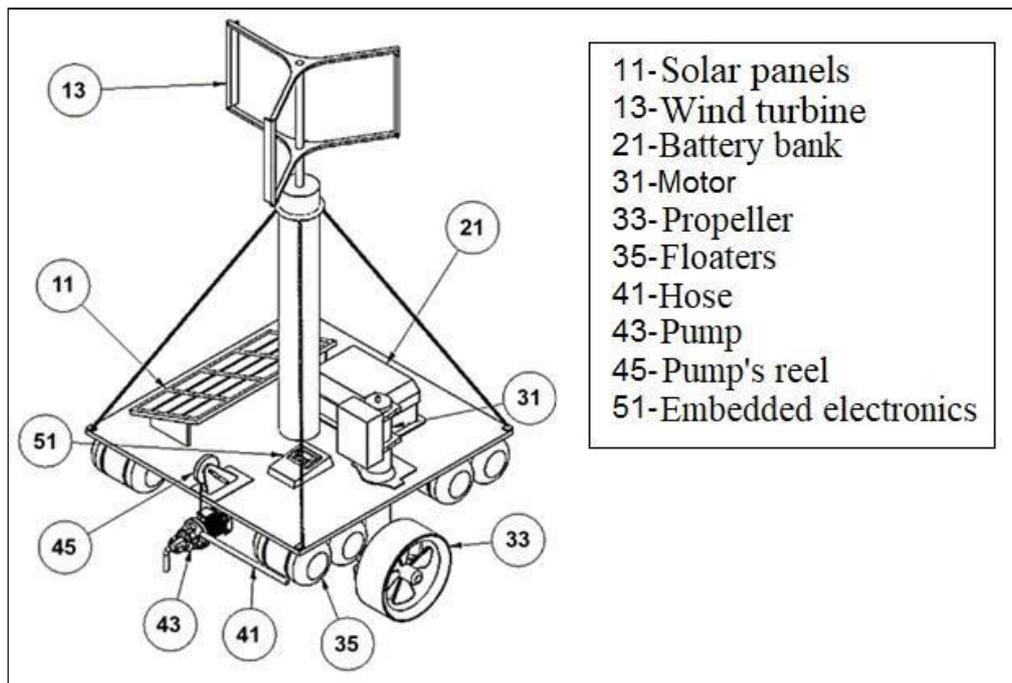


Figure 2. Assembly illustrative representation (Kiyohara, Zachariadis and Imamura Junior, 2020)

4. RESULTS

In order to compare a comprehensible variety of assemblies, the scope has been restricted. The analysis adopted the following directives:

- solar regimen from Cidade Universitária de São Paulo region, 23,55° S 46,72° W, for which CRESESB solar atlas informs an average of 16.2 MJ/(m².day) (or 4.5 kWh/(m².day)) for horizontal panels. The horizontal installation, although less efficient than using the proper inclination, was selected to simplify the operation, such that one doesn't need to adjust the vessel orientation;
- wind regimen from Cidade Universitária de São Paulo region, 23,55° S 46,72° W, for which CRESESB Wind map informs a Weibull distribution at 50 meters height with factor k of 2.26 and a c factor of 4.23. The exponential roughness factor n was assumed as 0.12, attributed to grass and low vegetation surroundings;
- BCS series pumps (submersible centrifugal) from Schneider Pumps;
- hoses with diameters suited to the pump, and varying lengths connecting the pump to hydrocyclones installed at the shore. To sweep wider reservoirs, the desilter needs longer hoses;
- cylindrical hydrocyclones, whose models were selected to suit the pump's flow range;
- discharge outlet height h 3 meters above the water level;
- about 6 hours of operation per day, to reflect a regular work shift minus repositioning time and other adjustments;
- vertical axis wind turbine SD0117 (Cosmos Energia) mounted 5 meters above the deck. This model has a cut-in wind speed of 1.5m/s and a rated speed 12 m/s at which it reaches 500 W, with a power curve nearly linear from between those points. In the simulated conditions, this would harness an average power of 91.6 W, or about 6.73 MJ (1.87kWh) per day, after accounting for the 85% efficiency in the AC-CC converter;
- 2 m² solar panels with 15% efficiency, in horizontal position in a quantity enough to feed the pump for the daily shifts. In the simulated conditions, each panel would collect about 4.7MJ (1.3kWh) per day;
- 2.88 kVAh (10.37MJ) batteries, in a number enough to accumulate the energy needed with a 20% discharge depth. The limited discharge depth is a way of prolonging the battery work life;
- conversion from AC to CC, and vice versa, with average efficiency of 85%.

Following these directives, some assemblies were estimated. Table 1 and Table 2 present the values for the ones designed with BCS 220 series pumps, which range between 368 and 2206 W (½ and 3 cv) in rated power. Those models are compatible with 50.8mm (2") diameter hoses, as described in the catalogues.

Table 1. Estimated operation for assemblies with BCS 220 series pumps.

Pump model	Hydrocyclone model	Hose diameter [mm]	Hose length [m]	Average Operation power [kW]	Flow [m ³ /h]	Flow per power [m ³ /MJ]
BCS 220 1/2 cv	SV 9	50.8	15	0.54	8.76	4.51
		50.8	30	0.53	8.25	4.29
BCS 220 1 cv	SV 13	50.8	50	0.90	12.83	3.98
		50.8	100	0.85	10.33	3.36
		50.8	150	0.82	8.51	2.87
BCS 220 2 cv	SV 13	50.8	50	1.44	15.84	3.06
		50.8	100	1.37	12.98	2.63
		50.8	150	1.33	10.92	2.29
		50.8	200	1.29	9.34	2.01
BCS 220 3 cv	SV 13	50.8	100	1.43	15.41	3.00
		50.8	200	1.34	11.50	2.39
		50.8	300	1.28	9.02	1.95

Table 2. Project features for assemblies with BCS 220 series pumps.

Pump model	Hydrocyclone model	Hose length [m]	Number of solar panels	Number of batteries	Work shift [h/day]	Max. Pumped volume [m ³ /day]	% wind power
BCS 220 1/2 cv	SV 9	15	1	6	4.98	43.6	59%
		30	1	6	5.03	41.5	59%
BCS 220 1 cv	SV 13	50	3	11	5.48	70.3	32%
		100	3	11	5.75	59.4	32%
		150	3	11	5.96	50.8	32%
BCS 220 2 cv	SV 13	50	6	17	5.73	90.8	19%
		100	6	17	6.00	77.9	19%
		150	6	17	6.21	67.8	19%
BCS 220 3 cv	SV 13	200	5	15	5.52	51.6	22%
		100	6	17	5.77	88.9	19%
		200	6	17	6.15	70.7	19%
		300	5	15	5.55	50.1	22%

Next, the same proceedings were repeated for assemblies with BCS 475 series pumps, which range from 2.2 to 7.3 kW (3 to 10 cv) in rated power. Those models are compatible with 101.6 mm (4") diameter hoses, and are able to operate higher heads, allowing assemblies with longer hoses. The results are shown in Table 3 and Table 4.

Table 3. Estimated operation for assemblies with BCS 475 series pumps.

Pump model	Hydrocyclone model	Hose diameter [mm]	Hose length [m]	Average Operation power [kW]	Flow[m ³ /h]	Flow per power [m ³ /MJ]
BCS475 3 cv	SI 85	101.6	100	2.96	61.3	5.75
		101.6	200	2.78	51.3	5.14
BCS475 5 cv	SI 85	101.6	100	3.83	68.9	5.00
		101.6	200	3.57	57.5	4.47
		101.6	300	3.41	50.3	4.11
BCS475 7.5 cv	SI 85	101.6	200	4.63	64.6	3.89
		101.6	350	4.31	53.1	3.42
		101.6	500	4.11	45.9	3.11
BCS475 10 cv	SI 85	101.6	200	5.66	71.5	3.50
		101.6	400	5.14	55.8	3.03
		101.6	600	4.84	47.0	2.69

Depending on the local conditions and specific needs of a reservoir, the design can be reviewed to change, for example, pump models, number of solar panels, height and number of wind turbines, separation method.

Table 4. Project features for assemblies with BCS 475 series pumps

Pump model	Hydrocyclone model	Hose length [m]	Number of solar panels	Number of batteries	Work shift [h/day]	Max. Pumped volume [m ³ /day]	% wind power
BCS475 3cv	SI 85	100	14	35	5.77	354	9.3%
		200	14	35	6.15	316	9.3%
BCS475 5cv	SI 85	100	19	47	5.91	407	7.0%
		200	18	44	6.03	347	7.4%
		300	17	42	6.00	301	7.8%
BCS475 7.5cv	SI 85	200	24	58	6.08	393	5.6%
		350	22	54	6.02	320	6.1%
		500	21	51	6.04	277	6.4%
BCS475 10cv	SI 85	200	29	69	5.95	426	4.7%
		400	26	63	5.91	330	5.2%
		600	25	60	6.05	284	5.4%

These numbers allow estimations on how many units of a given assembly would be necessary to compensate for the silting rate of a certain reservoir. However, the maximum pumped value is calculated based on charts for clear water. The effective solids removal rate is a function of the particle concentration in the suspended mixture, which may also affect the pump performance by changing the mixture's density and the head loss due to viscosity (Wilson et al., 2006).

Pumps' catalogues may inform the maximum particle concentration, over which the equipment malfunctions, but the actual value obtained when pumping would be better determined experimentally, as it depends on local factors such as sediment composition and particle size and cohesion. Initial calculations may consider an arbitrary concentration below operation limits to direct the experiment's equipment selection, and the final selection would consider the actual results.

According to Leite França et al. (2010), while studying the dredging costs on the primary facultative pond Coronel Macedo, in São Paulo State, the reservoir has an area of about 6642 m², and an accumulation rate of about 234 m³ of humid sludge per year. The sludge contained 12% of solids, which means an average of 28 m³ of solid particles per year. If the pond had a roughly square shape, it would have a side of 81.5m, which means that a desilter might need a hose of about 100 m to reach most of the pond.

The maximum concentration allowed for BCS pumps is 15% (Schneider, 2006). Assuming that, when using a BCS 220 1 cv with a 100 meters long hose to pump sludge from a facultative pond, the pump mixture would have a concentration of about 1.5% (one tenth of the maximum allowed), and a work regimen of 230 days per year (excluding weekends, vacations, holidays, maintenance stops), the desilter would extract up to 205 m³ of solid particles per year, more than 7 times the estimated solids inflow for the Coronel Macedo facultative pond. Therefore, if there are more similar ponds nearby, one could establish a rotation system, so one desilter would be serving more than one pond along the year, preventing the sedimentation.

Taking the measures for a larger reservoir, the Quixeramobim dam (DNOCS, 2015) has a volume of 54 million m³, and lost about 85% of it due to siltation over 55 years. Assuming its sediments have a similar concentration to the one found in the facultative pond, 12%, this indicates 100145 m³ of solid particles intake per year. It would require a desilter with more capacity and longer hoses than the previous example.

Considering BCS 475 10 cv assemblies with 600 m long hoses, in a work regimen of 330 days per year, and supposing that the higher flow would create a suspension with 3% particle concentration, each unit would extract 2812 m³ of solid particles per year. To balance the solid particles intake of a dam like Quixeramobim, 36 of such assemblies would have to work simultaneously.

However, in the case of a corrective dredging operation, longer periods and more units would be needed. In the Coronel Macedo example, the extraction of 2000 m³ was performed in about 80 days. One desilter equipped with a BCS 220 1 cv pump would take about 12 years to complete the same task. As for the Quixeramobim dam, in order to revert the 55 years accumulation, it would take 108 units equipped with BCS 475 10 cv working in parallel for 27 years.

5. DISCUSSION AND CONCLUSIONS

According to data on Table 2 and Table 4, as the model nominal power increases, the assembly can pump a larger amount of water, which may be the first option to cope with silting on large reservoirs. However, for the conditions presented in this case, related to wind and solar regimen, models of high nominal power also demand more photovoltaic panels and batteries in order to provide the electrical energy for the whole system during its operation. This augment on the number of features clearly impacts the cost of implementation. Hence, not only the pumped volume capacity defines the optimum solution, but also the total cost that may lead to an infeasibility of some assemblies. For this situation, a set of smaller pump assemblies would promote the same pumped volume capacity.

The hose length must also be considered. The wider the reservoir, the longer hoses are needed to sweep its entire extension, even if the suspension receptor is reallocated from time to time. Longer hoses mean higher head losses and the need for pumps with higher power.

Figure 3 and Figure 4 below present the set of data about number of components and maximum pumped volume estimation in each pump model according to their nominal power. In both cases, the number of solar panels and batteries increase as the pump power requirement augments. The water volume collected by the system may not show any clear behaviour tendency for the same BCS series, due to the hose length variation. But the threshold of average pumped volume in BCS 475 series is about five times higher than in BCS 220.

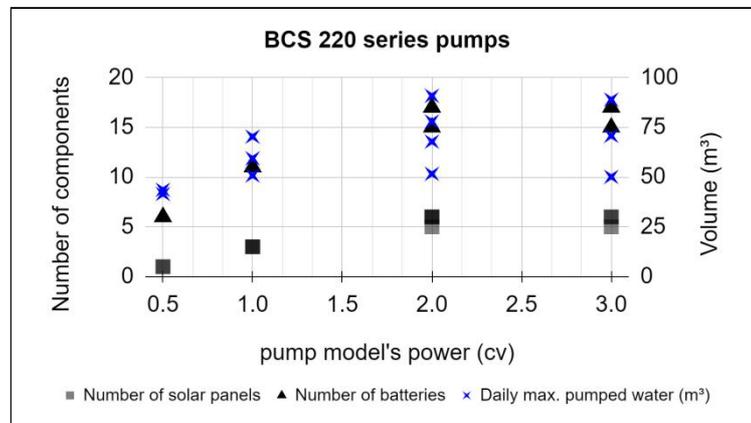


Figure 3. Number of components and max. pumped volume of BCS220 model assemblies.

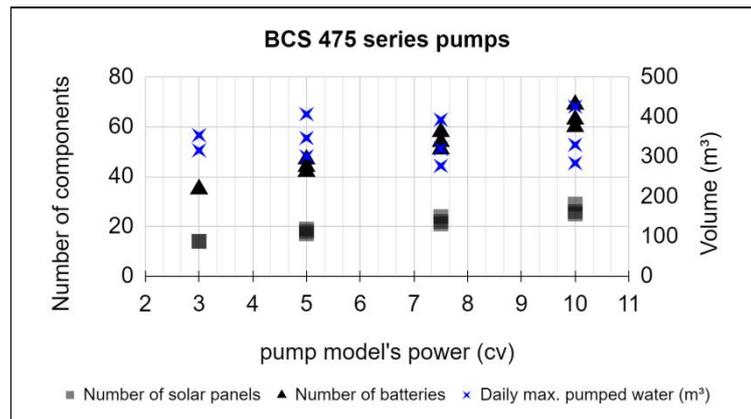


Figure 4. Number of components and max. pumped volume of BCS475 model assemblies.

The presented estimation method is preliminary, since it considers solar and wind data from maps based on interpolation of measurements. It also lacks the corrections concerning solids concentration and composition in the pumped suspension, which would be determined experimentally for each specific case or, eventually, in an experimental database customized for this application.

As for the expected effectiveness, the estimated numbers show that desilter assemblies might provide a satisfactory preventive maintenance to reservoirs with sizes ranging from a facultative pond with less than 10 thousand m³ up to a

water dam of 50 million m³. With some adaptations, it could attend rivers, lakes or shores, but those applications demand a careful environmental impacts study before being considered.

However, the desilters would need many years and numerous units to extract the sediments accumulated over decades of unattended siltation, which means they do not immediately substitute the traditional dredges, but can be introduced in a transitional initiative, achieving a more sustainable methodology.

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