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Aqua Solaris – an optimized small scale desalination system with 40 litres output per square meter based upon solar-thermal distillation

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Abstract

Classical small scale solar distillers (flat collector solar stills) have been in use especially in remote tropical locations for more than a century, but they only utilize a fraction of the available solar energy flux per area. Our aim was to develop a system that optimizes the energy efficiency and approaches the physical limit of freshwater output as close as possible. The construction takes into consideration the general principles of thermodynamics. The evaporation and (cooled) condensation chambers were separated, the evaporation chamber and surface increasing material were expanded into the third dimension (a collector cubicle instead of flat collector), additional mirrors are applied to increase the solar energy input and for wind protection, and the necessary electronic microcontroller that controls the airflow rhythm was empirically optimized by a long series of test runs and measurements. A prototype on the Island of Bonaire currently produces 40 l of freshwater per square meter surface area at an ambient temperature of 30°C for an estimated life cycle of 20 years. The applications are broad. Each unit can supply a large family with freshwater at low costs, and the water source can be anything from sea water to water polluted with heavy metals and mineral poisons (e.g. arsenic polluted wells in Bangladesh). The concept builds upon readily available low-cost standard materials and parts and can help to alleviate numerous social and environmental problems, including local dependence on bottled water import, the related garbage build-up on islands and adjacent coral reefs, water borne diseases as well as desertification, deforestation and even unemployment. In addition to scientific and technical details various project proposals, participatory approaches with local end-users and business models are presented.

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1. Background

The general situation regarding distribution and availability of safe drinking water in developing- and even in developed-countries is well known, and the situation is likely to worsen in the future as a result of population pressure, intensive agriculture and climate change, which are a part of the multi factorial scenario that leads to overuse of land and water resources. In addition numerous regions of the world are not inhabited or can only be inhabited by small populations due to very limited freshwater resources. Desalination generally is a wide spread solution, but currently most systems are capital and energy intensive steam distillation and reverse osmosis facilities or small and reliable but relatively unproductive solar stills. However, in face of the world wide peaking of total oil production, the importance of solar energy also in this sector cannot be overvalued. Increasing fuel prices will result in dramatically rising costs for freshwater produced from facilities based upon fossil fuels and also in increased prices for bottled drinking water imports around the world. 'Especially in the field of drinking water and food supply it must be assured that also the costs for meeting these basic needs necessary for survival does not exceed the financial abilities of also the poorest members of the population' [1].

Drinking water related problems especially in the tropics and sub-tropics include but are not limited to:

- Water borne diseases through microbial and parasite contamination.
- Water borne diseases through mineral contamination (arsenic in wells, residues from mines etc.).
- Deforestation & desertification (additional wood as fuel for water sterilization).
- Additional garbage accumulation (plastic bottles/containers – a pressing problem on small islands).
- Decrease of carbon sinks and additional CO_2 release (see above, the latter also due to long distance mass-transportation of imported water).
- Steady capital drain from already impoverished populations (continuous bottled water import).

The above and other factors are responsible for hundreds of thousands of deaths each year and lead to immense suffering and growing dependencies of local populations on paid outside supply that is beyond their control.

2. The technological goal

The classic solar still is a means to ease the situation, but in many settings it is of limited use due its low yield of approximately one cubic meter of product water per year and square meter collector area for tropical locations [2]. Our goal was to develop an optimized solar still with substantially increased yield without sacrificing the benefits of the classical solar still: reliability, utilization of often locally available low cost material and ease of use. The vision was to develop a simple to use, modular system that can be scaled as needed and operate with little maintenance in remote locations for a long period of time.

The approach was a purely empirical whole-system-approach, almost entirely based upon field- and laboratory experimentation and optimization. The following factors were considered:

- Optimal use of the available solar energy.
- Concentration of solar energy by means of additional side mirrors (which, depending on location, also act as wind shields).
- Expansion of the main collector into the third dimension (a cube instead of a flat collector).
- Dramatic expansion of the evaporation surface inside the collector cube using all-natural materials.

- Separation of evaporation and condensing chambers (two stage system, see Figs. 1 and 2).
- The ideal gas law and thermodynamics.
- Basic astronomy.
- Utilization of excess process waste heat for pre-heating the input water.
- Utilization of locally available wind/soil/shadow/water as thermal sink to cool the condenser chamber.

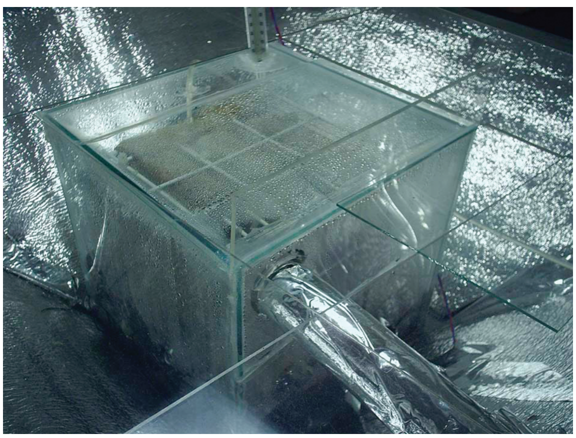

Fig. 1. Evaporator and surrounding mirrors (working laboratory demonstration version).

Fig. 2. Cooled condenser (working laboratory demonstration version).

The only compromise where modern equipment and moving parts had to be introduced came in the form of a simple solar powered controllable ventilator, which is an extremely durable low cost and mass produced part as found in standard electronic equipment such as personal computers, and a simple, low cost microcontroller. These components would have been considered high technology only a generation ago, but factually they now are penny products.

Having no support from scientific institutions and only private funds available, it was not possible to conduct thorough theoretical modelling and planning. Instead an ad-hoc approach was applied.

Once set up, the system was modified and optimized along the way. In the beginning, additional collectors were used (still seen in the form of the two rectangular structures on Fig. 1), but this approach later was abandoned in favour of the more effective- and simpler- waste heat recycling, which further reduced complexity and costs.

During the developmental phase, Hygrotec [3] humidity, temperature and condensation point sensors were deployed in the different parts of the systems, to determine the internal temperature and humidity parameters in different air flow situations. The system was continuously modified, and the airflow control optimized by experiment. The logged data were then compared to the systems output to determine the optimal flow control, a clever feedback mechanism forming the base of the microcontroller's software – one of the main elements of the Aqua Solaris system.

All in all 15 different patented interconnected elements that enhance each other's performance contribute to the systems productivity.

The amount of energy that is necessary to evaporate 1 l of water under norm conditions is just under 2260 kJ/kg. In a tropical

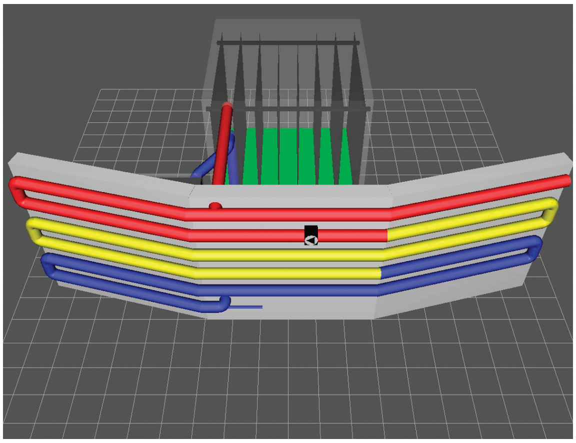

Fig. 3. Schematic representation of the Bonaire Prototype; the wall protects the system from the cooling trade winds, which at the same time are utilized to enhance the condensation process.

Fig. 4. Real world look of the working prototype producing 40 l freshwater per day; the industrial design will include all components in one compact cubicle.

location like Bonaire, (Fig. 3), the sun delivers a total energy of approximate 28,000 KJ per square meter surface area and day, which would then allow for a total evaporation and distillation of ca. 12 l of water. The Aqua Solaris prototype (Figs. 4, 5) however in its current optimized version reliably produces 40 l of product water, day in day out, and the final industrial design will not cover more than one square meter of surface area. The system can be fed via sophisticated electronic feeding or entirely manually.

3. Economics and practical issues

Ultimately the value of a solar desalination system depends on its ability to function under real world conditions. These include physical and geographical conditions as well as social and economic realities. It must be low cost, easy to use, durable and it must be accepted by the population.

Our current estimate is that in its most basic version Aqua Solaris can be produced at less than 200 Euro per unit, including all components, and it has an estimated life cycle of 20 years. Allowing for some production variation this still results in the production of 14,000 l of highest quality drinking water per year – even after only one year, this would mean 1.4 ct per litre – about 1/10th of the price of imported bottled water even in the cheapest cases. An example from the Island of Ebaye in the Republic of the Marshall Islands showed that during water shortages and power down of the local water treatment plant prices according to

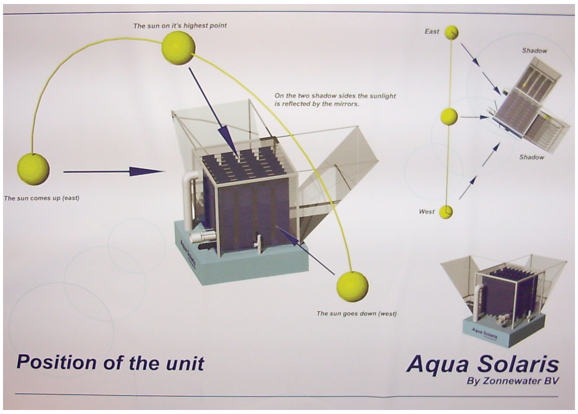

Fig. 5. Possible industrial design scheme and relation of the unit to the sun.

some local reports went up to US$ 3 per gallon of potable water, which then had to be imported via the US military base on neighbouring Kwajalein Atoll [4]. This seems to be an extreme case, but the laws of supply and demand are merciless. With one billion people on Earth having less than $1 available per day, even much lower water prices can pose a life threatening risk [5].

If the estimated total lifetime of the system is taken into consideration, in a subsistence setting the price per cubic meter of freshwater will be at or below the tap water costs in Western Europe.

The system is particularly well suited as a decentralized solution for families, meeting the immediate drinking water demand of ten to twelve people per day. In addition it is feasible to build a variety of small business schemes around the system. It could be possible to finance two or three systems as part of a micro credit scheme and start a small scale water delivery service. With a revenue of only five cents per litre a realistic total revenue of 700 Euro annually could be achieved, an amount substantially above the per capita GDP of many developing countries. Since the system is modular in nature and technically there is no limit as to the number of units that can be combined, village or community water farms also are a possibility, even in challenging environments. The system already has proven its durability during Hurricane seasons on Bonaire. Such water farms could be operated commercially or as a service to community members. The latter could work particularly well in small traditional and well organized communities.

For development projects involving new technology a participatory approach is absolutely essential. The new technology cannot simply be inflicted on a given community, since it may severely disrupt the social fabric in unforeseen ways.

An example has been reported about a water facility in Africa. Anthony Maslin, founder of the Australian solar company SES/SOLCO reported: 'I heard about a solar pump installed in Africa, which kept breaking down. After some investigation, it was found that it was the women of the village sabotaging the pump – the very same people they were trying to 'help'. No one had bothered to ask any questions, and the end result was that they had taken away the women's only social outing of the day – and the only chance to get away from the men!' Such is not an isolated incident, therefore any development 'aid' must not only include but built upon participation of the local population.

SOLCO has initiated a business model in the Maldive Islands which could also form a role model for Zonnewater/Aqua Solaris or similar ventures. Not the systems (in the case of SOLCO photovoltaic powered reverse osmosis systems) are sold, but the water, and the entire business from maintaining the systems over marketing and distribution of the locally produced water is in the hands of the local population, hence creating jobs and income where it is needed most and at the same time benefiting the environment [6].

Although the technological approach of SOLCO is very well suited for the production of larger water volumes, we are convinced, that families in developing countries can benefit even more from the Aqua Solaris concept, which also has been given the by-name 'Family Well'. In addition to allowing water production at lower costs than with reverse osmosis, the main parts of the system are simple and in many cases locally available. Although a ready made professional industrial design is under preparation, we plan to launch a licensing scheme, that will allow most components of the systems to be produced locally, which will help to create more regional income. Other than the low cost microcontroller, a small solar cell for the fan and the fan itself there are no products involved that cannot be made available in most countries. Even if they are not available, the raw material, e.g. standard piping and flat glass etc., could be delivered and assembled locally. Approaches like SOLCOs Solar Flow and Aqua Solaris are not competing but should be considered as supplementing each other to meet varying needs in varying locations and social settings and on different dimensions.

Another aspect is a division of the markets. High tech versions of Aqua Solaris are in the planning for consumer level markets in the first worlds. Applications are diverse and range from fully automated 'pool refillers' to portable drinking water production for yachts. The division of the market into a high price high tech and a low price segment will make it possible to support the production and marketing in developing countries with funds obtained through marketing in the higher price segment. It must also be taken into account that water shortage is not only a problem of developing countries. Australia, for example, is one of the countries that is hit hardest and faces severe mid-term water supply difficulties.

4. Vision

It is our vision to contribute to the betterment of the environment and the human condition. Solar thermal water desalination and purification has a positive impact on a large number of health and environmental problems. A severe oil crisis is just beyond the horizon, and when it comes, it will get ever worse because the global oil supply eventually will not keep up with ever growing demand. Fuel costs will skyrocket, and especially remote communities in developing countries and on isolated islands which often rely on diesel power for both electricity production and water treatment, will be hit hard. Besides the recent technological advances in the field, this background is the main reason why solar energy will rapidly become competitive. Within ten years of time there simply will be no other alternatives in many situations. If necessary, it is possible to live without electricity, but not without safe drinking water. In our view Aqua Solaris is a solution to one of the most pressing problems of some of the poorest people on Earth. The benefits of industrial mass production could be fully utilized, and a remote dream might be to see long and previously uninhabited desert coastlines with row after row of Aqua Solaris systems silently doing their work of slowly greening the desert, e.g. in North-Western Australia, Namibia or Peru.

In combination with other new developments, such as halophytic agriculture that makes use of edible salt loving plants, entire new branches of economy could blossom within practically self sufficient communities. It is a dream, but not an impossible one.

In addition to water purification there are two additional spin off applications which also are patented: the production of highest quality sea salt and an economic way of industrial waste water treatment based upon the all-natural fibres of the surface expander in the evaporation chamber.

At this time we are in the planning phase of a first larger pilot project. Suitable locations in India are under survey, where the technology of solar thermal desalination already is relatively well accepted. We are convinced that as soon as the industrial design is ready for mass production and a larger pilot project is under way, the Aqua Solaris concept can rapidly spread around the globe. To achieve this we are still looking for investment and industrial partners who share our vision of a humane, environmentally friendly and sustainable business style.

5. The authors

Jan de Koning, founder of Zonnewater, worked as a manager at DuPont Chemicals near Rotterdam for 25 years before opting for an early retirement scheme. He then used his private funds to almost single-handedly develop the Aqua Solaris system and deploy a field prototype on the Island of Bonaire. His vision is to develop a new ethical business model that takes into account human values and environmental aspects.

Dr Stefan Thiesen is a multi disciplinary scientist working as a freelance science writer and consultant as well as activist. In addition to his Ph.D. in Astronomy (Münster, Germany, and Hawaii) and MA in Geography (University of London) he also holds a BS from the University of the State of New York and post graduate qualifications in water management and energy consulting from the Fraunhofer Institute. He is author of several books and numerous articles.

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