

Solar Thermal Water Disinfection¹

Development and implementation of a flow through solar pasteurizer for small communities that produces 500 liter drinking water per day for a 500\$ initial investment

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Abstract

Worldwide five million people die each year due to lack of clean drinking water (WHO, 2000). To combat this SPF is developing a solar thermal device for water disinfection in small communities of emerging and developing countries. The targeted device has an output capacity of 500 liters per day at an initial cost of 500\$. The project is divided into three main working areas:

- Technical system development
- Fundamentals of thermal inactivation of pathogen microorganisms
- Implementation approaches in developing countries

For each of the three listed working groups suitable methods were chosen. For the microbiology and implementation part specialized organizations were involved.

A preliminary study showed that solar thermal approach for water disinfection can be cost comparative to other water disinfection technologies like PV-UV or filters. Being a very safe and self-sustaining technology, solar thermal water disinfection can play a major role in improving the drinking water situation in developing and emerging countries. As other water treatment projects have shown, the social acceptance remains to be one of the major challenges. Therefore different approaches for the implementation of the device are tested in several developing countries (s.a. Fig. 1).



Fig. 1: The solar thermal water disinfection system installed at a testing site in rural Mocambique.

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1. BACKGROUND AND OBJECTIVES

Water quality and water shortage is becoming one of the world's biggest challenges for this millennium. At the same time solar thermal technology has grown by now to a strong industry with decades of experience. With an economy of scale the cost of solar thermal products have sunk considerably over the last years. Having proved that microbiologically contaminated water only needs to be heated up to pasteurization temperature for disinfection, solar thermal technology can become cost comparative to other technologies. In a preliminary survey conducted at SPF (Rechsteiner, 2007) the highest potential for solar thermal water disinfection has been identified for the small communal sector with a daily output between 100 and 1000 liters. The comparison between the approach presented in this paper and other water treatment methods confirms this potential, as shown in Fig. 2 based on (Burch, 1998). For higher daily water outputs other methods seem to be more appropriate, mostly due to lower costs. But also on the lower household level there are other suitable methods like the pet-bottle approach SoDis (2009), that uses a combination of UV-radiation and heat for disinfection. However, applications on a household level depend strongly on the motivation and discipline of each individual. As experiences show this is a challenge that is often hard to overcome. The communal approach is less confronted with this problem.

In Fig. 2 different water treatment methods are compared regarding their capacity and treatment costs. Capacity costs are defined as the initial costs divided by the daily water output. On the other hand the treatment costs (or life-cycle-costs) are representing the costs of investment and operation divided by the total assumed lifetime water output. For emerging and developing nations the initial costs play a very important role since they are often an entry-barrier. So even if a product has very low life cycle costs, it may never be purchased due to high initial costs. Therefore capacity costs are an important indicator for technologies in development.

On the very right hand side of the graph the costs for the newly developed device are shown and compared to other technologies. Summarized it can be stated that the developed pasteurization device lies within the same cost range like other technologies in the home/community-scale, such as UV-PV or home-filtration. Apart from costs other important aspects influence the success or failure of a method. E.g. chlorine adds a taste to the drinking water that is often disliked by the local users. Or the turbidity of the water can reduce the effectivity drastically when using UV-radiation. For home filters the necessary regular cleaning can be an issue. For chlorine also limited storage time under specific conditions and the need for constant supply can be problematic in many environments. Taking all this aspects into account it can be concluded that the cost factor is not deciding alone for one or the other technology, but an overall view of the situation has to be taken in any case. With this background solar thermal water disinfection becomes an interesting option among other technologies, being a very safe and sustainable method, also suitable for remote areas with low infrastructure.

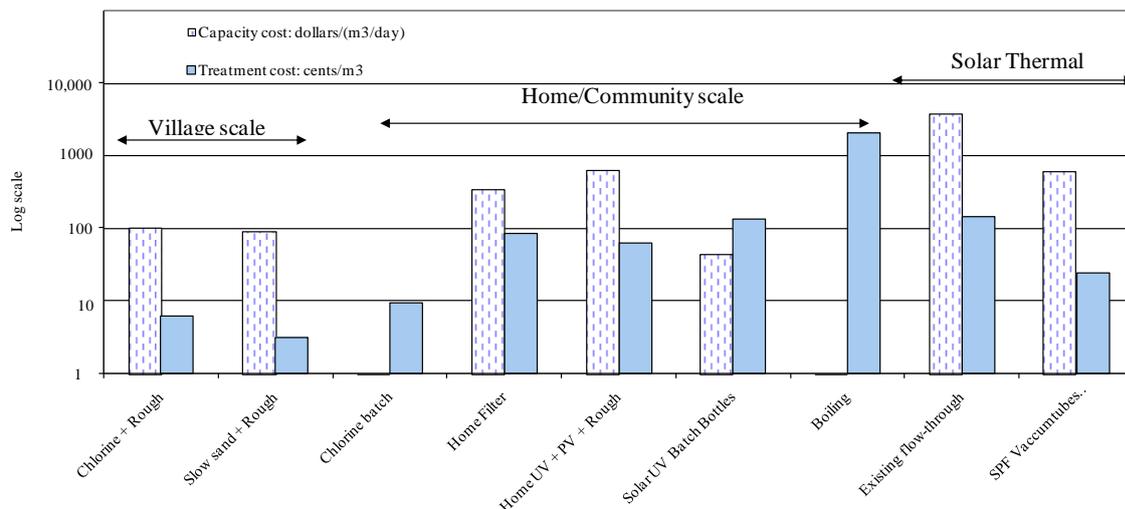


Fig. 2: Cost comparison for different water disinfection methods, on the very right hand side the costs for the newly developed device are displayed. The shown figure is based on (Burch, 1998) and extended by the authors.

2. METHODOLOGY

According to the project structure this chapter is divided into the three main working areas, namely technical system development, microbiology and implementation.

Technical system development

Initially a market survey on solar thermal water disinfection methods was carried out. A flow-through system presented by SafeWaterSystems (2009) was identified as the most promising available solution on the market according to the requirements defined as: Low cost, simple maintenance and operation, no parasitic energy, output capacity for small communities (100 up to 1000 l/d). The concept of the system mentioned was analyzed and used as a starting point used for further optimization.

The general concept is shown in Fig. 3. It consists of three main components: Collector, thermostatic valve and heat-exchanger. A catalogue of criteria was defined to assess different options for components and system assembly. This catalogue was developed with feedback from different experts coming from different fields, mainly solar technology, microbiology and development cooperation. The most important criteria were: Low initial costs, low treatment costs, high effectivity, simple operation and very low maintenance.

Further criteria are listed as follows: Scaling, freezing, high stagnation temperatures, corrosion, need for (non)-qualified maintenance, expected lifetime, social acceptance, suitability for transportation, operation security, risk of theft, need for supply, need for additional energy, possibility for local production and distribution.

The defined criteria were weighted in order to assess the various possibilities for each of the three main components and finally for the overall system.

For the development and optimization of the systems main components (valve and heat-exchanger) specific test facilities were installed. The overall system was tested and optimized on the SPF-roof. The monitoring equipment consisted of four temperature sensors, a radiometer, and an impeller flow control unit.

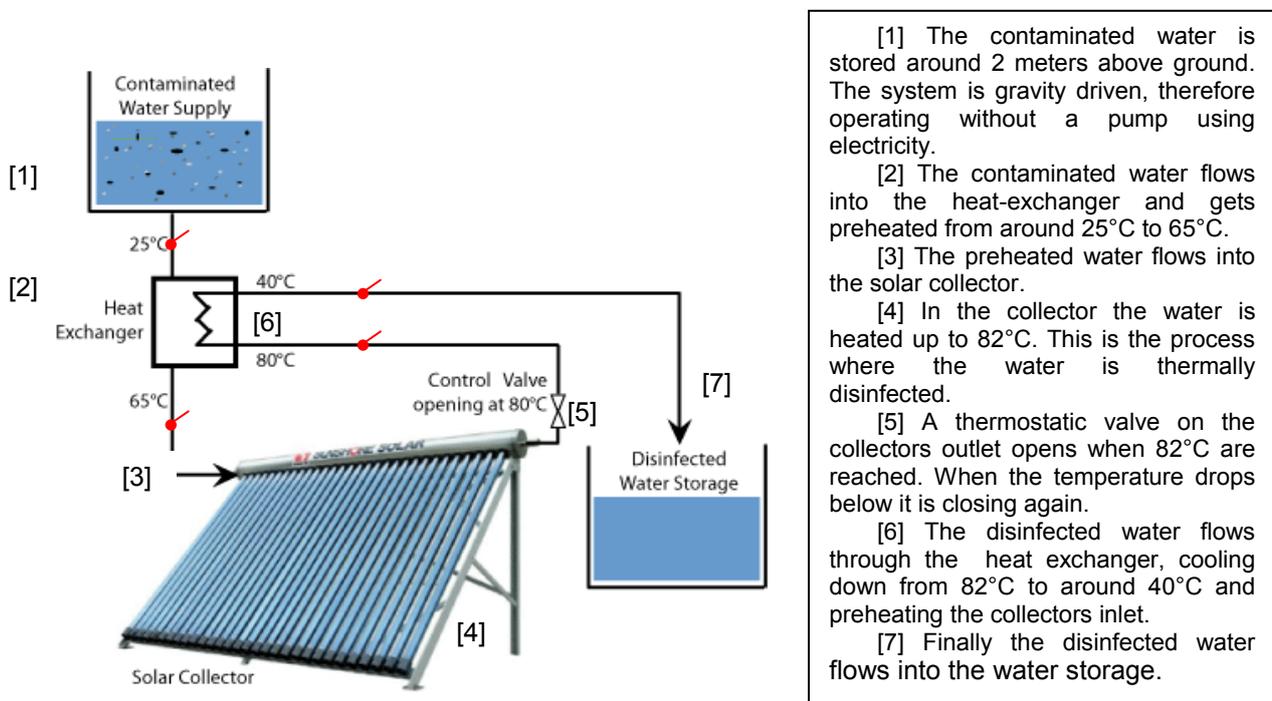


Fig. 3: Scheme of the solar thermal pasteurization plant with its main components heat-exchanger, collector and thermostatic valve. General functionality is indicated in the text box on the right.

Microbiology

The product development of the solar thermal disinfection plant was accompanied by a detailed study on inactivation on pathogen microorganisms in function of temperature and exposure time. This study was commissioned to EAWAG in Switzerland, which is among the world's leading aquatic research institutes. The broad study was divided in different work-packages:

- Fundamentals of thermal disinfection: The thermal inactivation of microorganisms in function of temperature and time exposure was tested in the laboratory. This research was conducted by the institution EAWAG for a selection of eight different types of microorganisms, which were considered as most importantly effecting drinking water quality in developing countries. Previously a literature study was conducted. The testing was done by different microbiological methods, such as non-selective TSA-plate counting and flow-cytometry/live-dead-staining.
- Prototype testing: different setups of the developed device were tested on their inactivation-effectivity in operation on the roof at SPF. For this purpose the water tank was spiked with E.Coli bacteria.
- Assessment of different microbiological methods for the analysis of the system's effectivity: This included methods like traditional selective plate counting, newly applied methods of flow-cytometry/live-dead-staining, and also low-cost methods that are easy to handle in the field.
- Regrowth potential: In the laboratory it was tested if and after what duration a potential recontamination of the treated water could occur.

Implementation in developing countries

A group of experts working in development cooperation were involved in the project to guide the product development according to the needs of the targeted users of the system in emerging and developing nations. Additionally it was decided to extend the project by including field-tests in developing countries to evaluate functionality and social acceptance in the target environment of the application.

First field tests were initiated in October 2009 with a duration of around six months. Existing experiences from projects on water disinfection and hygiene in developing countries have shown that affordability and effectivity of a method alone do not necessarily lead to the successful implementation of a technology. Therefore it is projected to test different approaches of implementation in order to find out under which conditions the system proves its assumed potential.

3. RESULTS AND DISCUSSION

Again, according to the project structure this chapter is divided into the three main working areas: technical system development, microbiology and implementation in developing countries.

Technical System Development

The general concept of the system with its three main components is shown in Fig. 3. Detailed research and development on each of these three components has been conducted. After having identified a promising solution for each component the complete solar thermal disinfection system was assembled, tested and optimized. In the following sections the research and development work accomplished regarding the three main components and the overall system is described.

Collector

Detailed theoretical research on different types of collectors has been carried out. Initially it was differentiated between three general types of collectors : vacuum tube-, glazed flat plate with copper absorber and polymer collectors. Due to expected scaling problems the option of using a standard flat plate collector was not followed upon any further.

In accordance to Burch (1998) and Beikirchner (2008) originally a high potential was estimated for a polymer solution, mainly due to low costs of raw materials. A detailed investigation on different

polymer-materials was conducted and several prototype concepts were developed. The investigation finally showed that fluorinated polymers which fulfill the required properties (stagnation temperature, lifetime and UV resistance) are too expensive with regard to the scopes of the project. Stabilized polymers remained the only type of material identified to theoretically meet the requirements of low costs and technical feasibility. Limited lifetime for stabilized polymers could become a problem though. Finally, it was concluded that the development of a polymer collector that can compete with the low cost-benefit ratio of fully flooded vacuum tube collector would have exceeded the frame of the current research project (see Table 1).

Based on the originally defined criteria and the analyzed options finally the fully flooded vacuum tube collector was selected for further system development. This selection was mainly due to the excellent cost-benefit ratio, the high efficiency and the technology being approved over decades. Furthermore scaling and other residues can be removed manually.

Table 1: Area and power specific costs of different collector concepts.

	Costs per collector area [\$/m ²]	Costs per power [Cts/W]
Vacuum Tube	29.3	4.5
fluorinated polymer film, no coating	23.0	8.2
fluorinated polymer film, with coating	28.6	8.3
stabilized polymer film, no coating	2.2	0.8
stabilized polymer film, with coating	7.8	2.3

Heat-exchanger

Different types of heat-exchangers have been tested in a facility that has been built specifically for this purpose (Fig. 4). The test facility was used to determine general functionality and effectiveness (see eq. 1) of the heat-exchangers at different flow speeds. Apart from the cost criterion also for the heat exchanger scaling was a major issue. Therefore the option of using a plate-heat-exchanger was not considered as an appropriate solution, whereas counter-flow coaxial heat-exchangers with sufficient diameters can be used. Different variations with copper and polymer components have been analyzed, developed and tested. In Fig. 5 the effectiveness for three different heat-exchangers are illustrated at different volume-flows. Apart from the temperatures to determine the effectiveness, also pressure drop has been measured. Since the system is gravity driven with a very limited maximum pressure difference of around 0.5bar (5m difference in height), low pressure drop was an important requirement.

Again, the polymer approach was assumed to have a high potential due to low material costs. A coaxial heat exchanger completely made out of polymer (corrugated tube in tube) was built. A corrugated tube was taken because it guarantees stability despite thin wall thickness which is important for the heat transfer, because polymers have a low thermal conductivity compared to metal. The polymer prototype was compared to another coaxial counter-flow heat-exchanger built with two copper pipes. A 15 meter long polymer version was built to reach the corresponding effectiveness that is achieved with a copper-copper version of a length of 5 meter. The costs of both prototypes were ended up to be around the same, the effectiveness of the copper-version proved to be a bit higher though. Higher lifetime and better security during operation were further assets clearly speaking for the copper- version. Therefore the corrugated tube-in-tube solution wasn't followed upon any further.

In a next step it was investigated how the heat exchangers length has to be dimensioned related to the collector's area in order to achieve as low water costs as possible. With the given measurements to determine the effectiveness at different flow speeds it was possible to calculate the collector's area corresponding to the power supplied in the testing facility by the electric heater. With the assumed costs for the heat-exchanger and the collector it was possible to calculate the final costs per liter disinfected water for different system setups. To verify these calculations several combinations were tested on the SPF-roof as an overall system (Fig. 8). Based on these calculations and measurements it was possible to determine the heat-exchanger's optimized length in function of the collector-area.

After having identified the copper-copper-heat-exchanger as a well working solution that is simple, has relatively low specific costs and ensures high operation safety, it was tried to optimize this favored type of heat exchanger. The inner tube made out of copper has a high thermal conductivity and is ensuring a high heat exchange rate. For the outside tube this wasn't a requirement though. Having

this in mind the outside tube was replaced by a polymer hose, which is significantly lower in costs than the corresponding copper tube. Measurements in the testing facility confirmed that both versions have a similar effectiveness, which makes the polymer-copper combined version more cost-effective compared to the pure copper version. The overall costs of the heat exchanger were lowered by around 40% with this new approach. For the upcoming field tests the copper-copper-version will be used though, since long-term tests on the polymer combined heat exchanger have to be completed before implementation in the field can take place.

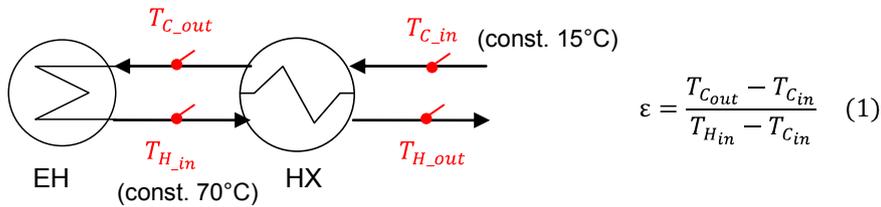


Fig. 4: Simplified scheme of the heat-exchanger's testing facility. The tap water with constant temperature of around 15°C is entering the heat-exchanger (HX) with a defined flow. Temperature (Tc_in) and volume flow are measured. After having passed the cold side of the HX, temperature is measured again (Tc_out). Then the water is heated by an electric heating rod (EH) up to a constant value of 70°C (collector emulation). Having measured the temperature (Th_in) the water is flowing to the hot side of the HX. Finally the temperature is detected from the volume flow leaving the heat-exchangers hot side (Th_out).

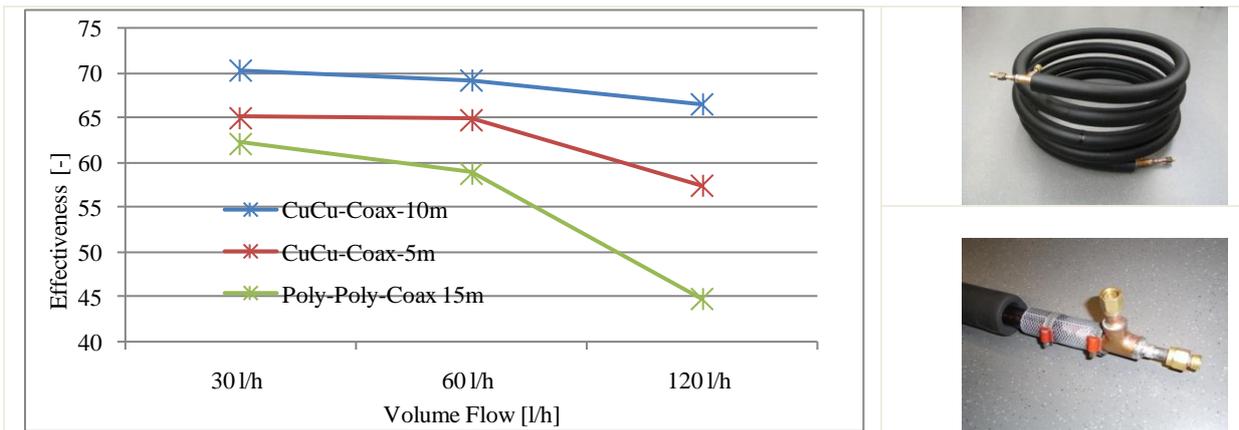


Fig. 5: Effectiveness for different typical volume-flows for three different coaxial counter-flow heat-exchangers: Copper tube in copper tube with a length of 10 meters (CuCu-Coax-10m), Copper tube in copper tube with a length of 5 meters (CuCu-Coax-5m), corrugated polymer tube in corrugated polymer tube with a length of 15 meters. The values presented are based on measurements done in the testing facility. On the right two pictures from some of the developed prototypes are shown.

Automatic Valve

In order to find an optimal solution for the valve, a set of around ten different products were identified, modified and tested. Again it was aimed in a first step to find a product that was available in mass industry, e.g. in the automotive sector. From the investigations a well working low-cost thermostatic valve was identified to meet the originally defined requirements. After slight modification it is functioning without leakage and is opening and closing within the desired temperature-range, allowing smooth operation with reduced stop-and-go behavior. In Fig. 6 one of the tested valve-types is shown that is not regulating the volume flow as desired to reach a constant outlet temperature. In contrary Fig. 9 shows how the finally chosen valve is regulating the volume flow. The opening-closing temperature of the valve was set to 82°C, which is well above the theoretically needed 65°C for 5 minutes shown in the laboratory tests. This temperature was chosen to guarantee a maximum safety for the developed system.

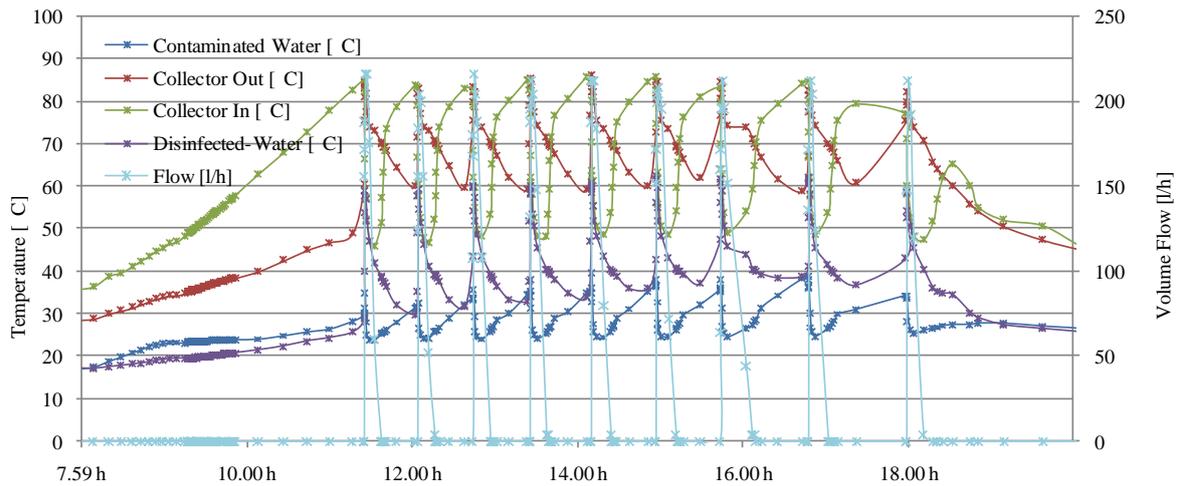


Fig. 6: Cycling operation of the pasteurization plant with a valve that turned out not to be suitable. The volume flow is not regulated in time by the valve to reach a stationary operation. The result is a stop-and-go behaviour, that is reducing efficiency and effectiveness of the plant.

Overall System

The selection of the three main components was an iterative process as all technologies depend upon another. After the identification of a suitable set of main components the overall solar thermal disinfection system was assembled. By now tests over more than two years have been conducted on the system. Many different setups have been tested regarding their functionality, efficiency and effectivity. Also inputs from non-technical sectors had a strong influence on the current design of the device, as described later on.

The general concept of the system is shown in Fig. 3. In Fig. 7 the completed prototype of the overall system is shown. The general principle of the developed device is still similar to the system from Hawaii (Sunray1000) which had been taken as an initial point for the development. Nevertheless, the detailed research on each of the three main components identified various modifications to improve the system's performance and functionality. Most importantly some technical features had to be added for ensuring complete inactivation of microorganisms. Furthermore the system developed has much lower initial costs since it comes in smaller dimensions.

One of the tasks on the system level was the optimization of the collector area in relation to the length of the heat exchanger aiming at an optimal cost-benefit ratio. For this purpose different setups have been installed on the roof at SPF in Rapperswil (Switzerland). Selected results are presented in Fig. 8. In this graph it is also shown that the maximum system output on a sunny day for a standard 24-tube collector is in the range of 300l/d and for a standard 48-tube-collector in the range of 600l/d. The daily integrated energy per area indicated in Fig. 8 is not determining alone the daily disinfected water volume, because the fluctuation of the radiation power is having an influence too.

In Fig. 9 the system operation on a sunny day is illustrated. Due to the relative high thermal mass of the system (fully flooded vacuum tubes) the system slowly reaches the minimal temperature to open the thermostatic valve. Then, the thermostatic valve regulates the volume flow, therefore the outlet temperature almost stays constant. The disinfected water leaving the collector header with around 80°C is cooled down in the heat exchanger to around 40°C before being stored into the drinking water tank.

The long-term testing of the system on the SPF roof showed a basically maintenance free operation. It was limited to occasional cleaning of the mesh filter, that was installed after the source tank to prevent particles from blocking the volume-flow or from inducing possible malfunction of the valve. Limestone precipitation was found in the system, since temperatures are ideal and the used water source was very calciferous. With the concept presented these scaling residues can be removed manually, without need for chemical treatment.



Fig. 7: The left picture shows the overall system installed on the roof at SPF, on the right the system is shown in field-operation in a village in rural Mocambique.

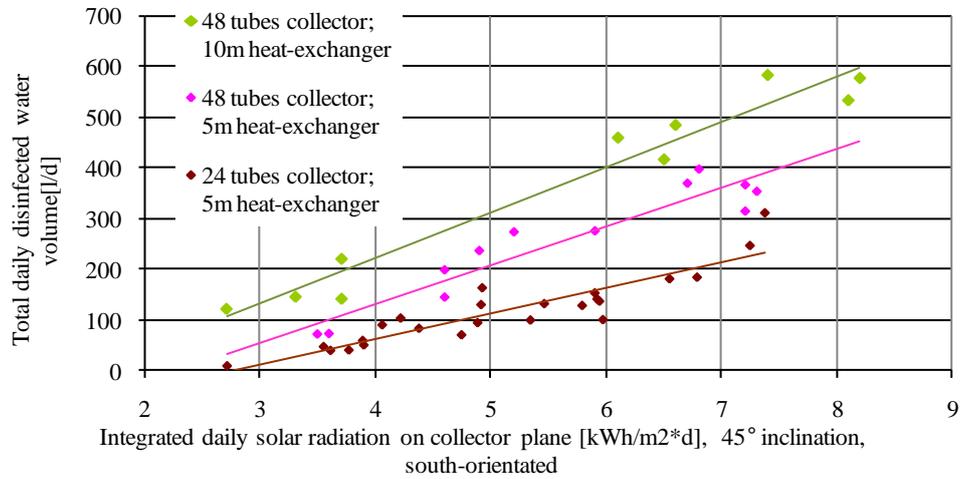


Fig. 8: Daily disinfected water output in function the daily solar energy for different tested system setups. Every point stands for one day of measurement. The heat-exchanger indicated are all coaxial-copper-copper-types.

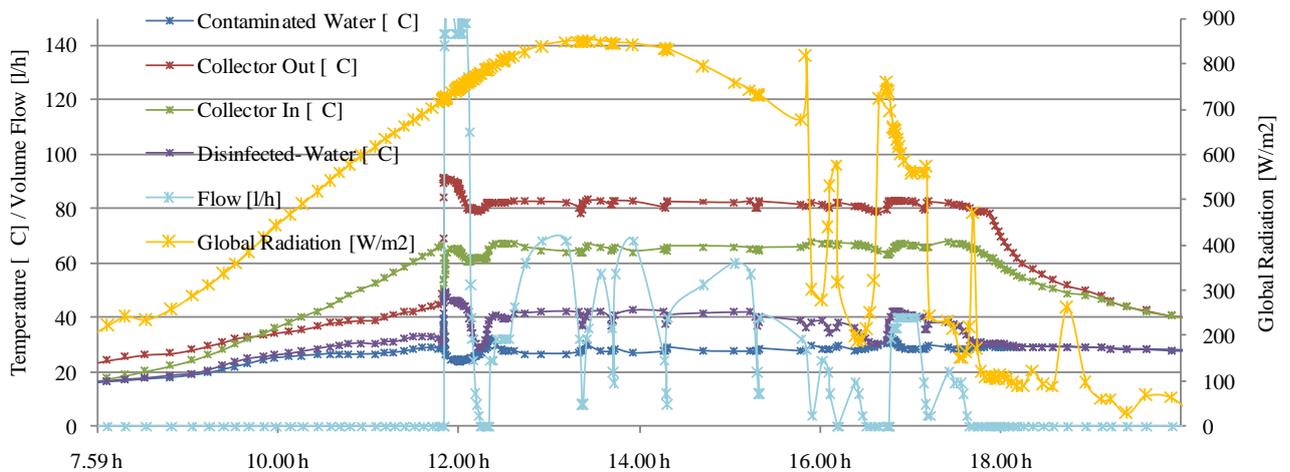


Fig. 9: Illustration of the system operation on sunny day (27.7.2009). The graph shows the parameters global radiation (45° inclination, south-orientated, likewise collector plane), the temperatures and the volume flow. The thermostatic valve is regulating the volume flow to keep the collector outlet temperature constantly at around 82°C.

Microbiology

The microbiological study on thermal inactivation of pathogen microorganisms has confirmed that water does not need to be heated up to 100°C for disinfection from pathogen bacteria. The results showed that 70°C for 1 minute or 65°C for 5 minutes are a sufficient thermal exposure to reach inactivation of the most common and resistant pathogen bacteria species. Similar results have also been published by (Anthony, 2006)

Within the laboratory studies carried out at EAWAG the following eight species were analyzed: *E. coli* O157, *E. coli* K12, *Salmonella* Typhimurium, *Shigella flexneri*, *Enterococcus faecalis*, *Vibrio cholera*, *Pseudomonas aeruginosa*, MS2 Phages (as a virus-indicator). In Table 2 the inactivation rates for these microorganisms in function of temperature and exposure time are summarized in increasing order of resistance. MS2 Phage and *Enterococcus faecalis* were identified as the two most resistant species out of the tested selection. In Fig. 10 the inactivation-curves for two of the examined species are exemplarily illustrated. The results presented are based on traditional plate counting methods. Additionally an alternative method (FCM/life-dead-staining) was applied. The complete extensive results of the microbiological study will be published in a separate paper. There, also results on regrowth-potential and the assessment of easy-to-use and low-cost methods to analyze water quality in the field will be included.

The testing of the inactivation effectivity of the developed prototypes is still ongoing. These tests are carried out on the testing roof at SPF. By now the prototype tests already revealed interesting results that show a high sensitivity on different system setups and also on the analytic methods used. The alternatively applied microbiological methods (FCM/Live-Dead-Staining) proved to be much more sensitive compared to the traditional methods that are commonly accredited by law or the World Health Organization (WHO). Tested with the selective plate counting methods basically all system setups were reaching total inactivation, which wasn't always the case when testing with the alternatively applied methods. This sensitivity allowed for the exact assessment on the effectivity of different technical modifications in order to make the overall-apparatus as safe as possible.

Table 2: Overview heat-resistance of different tested microorganisms. Analysed by plate-counting on Trypton-Soy-Agar in triplicates.

(X = inactivation below detection limit; (X) = inactivation-rate below 10⁻⁴; - = not tested)

	Negativ-Control												
Temperature	20°C	55°C	60°C	65°C	70°C	55°C	60°C	65°C	70°C	55°C	60°C	65°C	70°C
Exposure-Time	5 min	1 min				2 min				5 min			
<i>V. cholerae</i> O1			X	X	X	X	X	X	X	X	X	X	X
<i>P. aeruginosa</i>				X	X		X	X	X		X	X	X
<i>S. typhimurium</i>				(X)	X		(X)	X	X		X	X	X
<i>S. flexneri</i>				(X)	X			(X)	X		X	X	X
<i>E. coli</i> K12		-	-	-	-			X	X		X	X	X
<i>E. coli</i> O157					X			X	X			X	X
<i>E. faecalis</i>					X			(X)	X			X	X
MS2 Phage					(X)			(X)	X			(X)	X

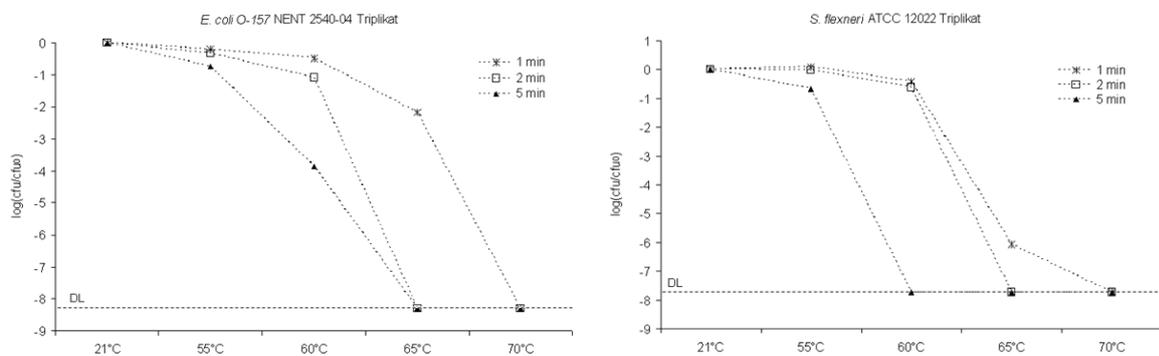


Fig. 10: Thermal inactivation of Escherichia coli O-157 and Shigella Flexneri in function of exposure time.

Implementation in developing countries

In a preliminary survey conducted at SPF (Rechsteiner, 2007) the highest potential for solar thermal water disinfection has been identified for the small communal sector with a daily output between 100 and 1000 liters. Taking this as a starting point, the process of product development was initiated. Experts from development cooperation were involved into this process from the very beginning in order to ensure that the product was developed according to the needs of the end-users. Among a variety of criteria one of the main argument was to have as low initial investment costs as possible (Heierli, 2008). Thus, the initial costs of the device have been set to 500\$.

After having approved the prototypes effectivity and functionality on the roof at SPF in Switzerland it was planned to implement the solar thermal disinfection system in several developing countries starting by the end of 2009. In total four testing-sites were determined, each test lasting up to 6 months. For each location a collaboration with a local partner organization for operation and maintenance was established. The aim of these tests is to approve the newly developed technical solution for water disinfection in the field. Apart from the technical aspects these field-test also aim to monitor different social factors. For installation and initiation an SPF-team is locally assisting. At each location the local authorities are integrated in the process of implementation.

The four selected locations are located in Sub-Saharan Africa and South-Asia. Different approaches of implementation were chosen in order to find out in which type of environments the system can prove its assumed potential best. The environments chosen for implementation vary from a downtown market place, to a technical college, to a rural primary school and finally to urban slums. In two cases the water will be sold by a "waterkiosk" or "flying water vendors", in the other cases the water will be distributed without charge (school/college).

During the 6-months period the tests will be monitored from a technical and social point of view. The technical monitoring consists of a customized system that is logging different parameters, such as radiation, temperature or volume-flow. These parameters will allow to assess the system's performance and to indicate how the system is operated. In Fig. 12 the different components of the monitoring system are illustrated.

For the assessment of the social aspects a journal will be filled out on a daily basis by the operator of the system. The process of water distribution will be under supervision by the partner NGO and the local authorities. Well defined responsibilities for the different tasks (such as technical maintenance and operation, water distribution, in some cases also sales and accounting) will be allocated. For each location it is planned to conduct a final workshop to assess the gained experiences for further development and distribution strategies.

As further element of the field-tests the water quality (before and after treatment) will be analyzed on the site by the previously assessed methods (s.a. Fig. 13). In most locations the quality of the water will additionally tested by a local laboratory that is approved by the local health ministry, aiming to strengthen the credibility of the implemented technology.

It is assumed that the acceptance of the here described system strongly depends on the awareness of the potential consumers about the risks of drinking untreated water. First experiences in the field have shown, that the thermal disinfection approach is advantageous, because people can easily comprehend the effect of water-disinfection by water-heating, same as it is well known from traditional water-boiling by burning wood. As many other water treatment projects have shown though, the social acceptance is often the major challenge because it is not depending only on affordability and effectivity. Social aspects like status or tradition often play a major role when implementing new technologies in developing countries (Heierli, 2008; Novogratz 2009). By applying different approaches of implementation it is aimed to find out in which conditions the solar water disinfection system can become a success story.



Fig. 11: One of four different system-implementation sites (here in rural Mocambique). Left picture: a local team is trained for the installation, maintenance and operation. Right picture, background: information campaign about water-hygiene and the water disinfection system.

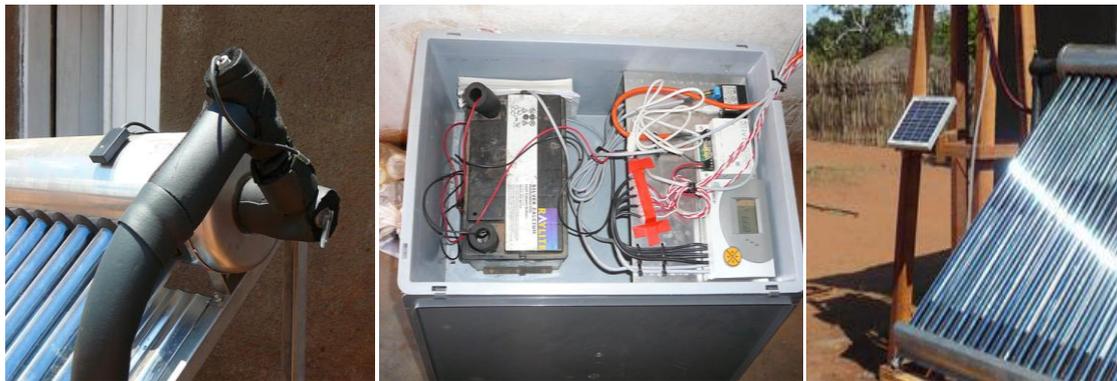


Fig. 12 The technical monitoring system of the solar water disinfection plant is shown in the pictures above (from left to right): temperature and radiation sensors, logging equipment powered by a car batterie, pv-panel for keeping the battery charged over the 6 months testing period.

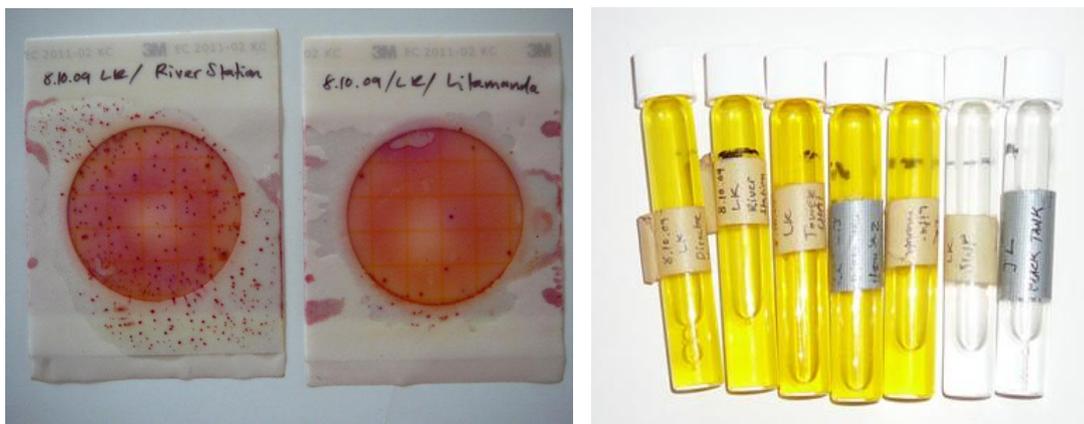


Fig. 13: Two different methods to determine the water-quality in the field. The left picture shows a test-result from 3M-Petrifilm (E.coli/Coliform Count Plate) and the right picture shows a presence/absence-test with Colilert by IDEXX (also E.Coli / Coliform). Both methods are easy to handle in the field because no additional equipment is required. The results are ready after an incubation time of 24 hours.

4. CONCLUSIONS AND OUTLOOK

The project presented in this paper aims to develop a water disinfection device, that is thermally inactivating pathogen microorganisms and is appropriate for the implementation in smaller communities in developing and emerging nations. At the current stage of the project a well functioning prototype has been elaborated and first tests in developing countries were initiated. The main criteria for this water treatment method are low initial costs, simple operation and low maintenance efforts. The system and its components were tested at the SPF outdoor facilities on a long term basis. It is shown that with a number of technical developments complemented with detailed microbiological investigations, the initially defined target of producing 500 liters of drinking water daily for an initial investment of 500\$ can be reached. Since the flow-through system is operated by gravity and the valve works thermostatically, no external energy such as electricity or combustibles is needed. Therefore the system works totally independent and is very low in maintenance. With the assets described it is assumed that the system has a high potential for a application in developing and emerging communities worldwide.

Within a subtask of the project a detailed microbiological investigation on the systems inactivation effectivity was carried out. First tests on the prototype have shown that with some technical solutions added complete inactivation can be reached like it was shown under laboratory conditions before. The alternative microbiological methods (flowcytometry/live-dead-staining) used to test effectivity proved to be much more sensitive compared to the traditional methods that are accredited by national law or WHO. This sensitivity allowed to assess technical modifications in order to further increase the output water quality of the system.

Apart from the challenging technical and economical aspects of the presented pasteurization device it is expected that the ongoing implementation in the field will be the biggest challenge for the developed system. The different approaches of social implementation aim to reveal in which type of environment the developed device proves its assumed potential. Further results including first experiences from the field tests will be reported in near future.

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6. REFERENCES

- Anthony T., Spinks, R.H. Dunstan (2006): *Thermal inactivation of water-borne pathogenic and indicator bacteria at sub-boiling temperatures*, School of Environmental & Life Sciences, The University of Newcastle, Australia
- Beikirchner T. (2008): *Evaluation Polymerkolektor*, ZAE Bayern
- Burch J. (1998): *An Overview of Water Disinfection Technologies in Developing Countries and the Potential for Solar Thermal Water Pasteurization*, National Renewable Energy Laboratory
- Heierli U. (2008): *Why is it so hard to bring safe water to the poor – and so profitable to sell it to the rich? The marketing challenges for point of use water treatment devices*, msd consulting, SDC
- Novogratz J. (2009): *The blue sweater: bridging the gap between rich and poor in an interconnected world*, published by Rodale, New York, ISBN-13 978-1-59486-915-0
- Rechsteiner F. (2007): *Solares Pasteurisieren – Entkeimung von Trinkwasser*, Bericht Studienarbeit, SPF / Hochschule für Technik Rapperswil
- SafeWatersSystems (2009): *Technical brochure*, <http://safewatersystems.com>, July 31 2009.
- SoDis (2009): *SoDis Pamphlet English*, http://www.sodis.ch/files/SODIS_pamphlet_e.pdf
- WHO (2000): *The world health report: Making a difference*. Geneva, World Health Organization