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Swiss Federal Insitute for Environmental Science & Technology

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SODIS at the Turning Point - A Technology Ready for Use

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Abstract

Solar water disinfection (SODIS) makes use of solar energy to inactivate pathogenic microorganisms present in the water. In 1991, SANDEC embarked on an extensive laboratory and field test project which assesses the potential of SODIS and develops this sustainable and low-cost method for treatment of small quantities of drinking water at household level. The potential of SODIS is substantially increased by exposing polluted water to both solar radiation and heat treatment. The use of half-blackened plastic bottles or plastic bags is the simplest way of applying this treatment method. Field studies, carried out in seven developing countries in Asia, Africa and Latin America, indicate a promising socio-cultural acceptance of this low-cost water treatment method. National workshops are now planned to launch SODIS application on a larger scale.

Exposure of SODIS plastic bottle on corrugated iron roof in Indonesia

Introduction

An important section of the population in developing countries is compelled to use surface water or polluted water drawn from rivers, irrigation canals, ponds or lakes. Since these waters carry many infectious and tropical diseases, they generally have to be treated prior to consumption. The main objective of water treatment is the removal or inactivation of disease-causing organisms (pathogens), such as harmful bacteria, viruses, protozoal cysts, and worm eggs. The addition of chlorine and use of slow sand filters are the two most widely applied treatment processes for bacteriological water quality improvement.

Since the chemicals are often inappropriately used or unavailable in rural water supply schemes, reliable and adequate water treatment processes, such as flocculation and chlorination, are generally beyond the capacity of local skill and resources. The supplied public water is, therefore, often contaminated and has to be boiled prior to consumption. This is, however, quite unrealistic owing to the limited supply of firewood or kerosene primarily used for cooking. Consequently, new and individual water treatment methods, applicable in low-income areas, have to be developed and promoted.

As described hereafter, solar water disinfection could provide such a simple, efficient and sustainable water treatment option to produce small quantities of drinking water at household level.

Solar Water Disinfection (SODIS)

Microorganisms are vulnerable to light and heat. Solar energy, universally available and free of charge, is used in the water treatment process termed as solar water disinfection (SODIS). As shown in Fig. 1, transparent containers filled with water and exposed to full sunlight for several hours constitutes the basic concept of this treatment process. SODIS may be used as batch process at household level to treat small quantities of drinking water in bottles or plastic bags. However, since the daily capacity of the batch process is limited by the volume of water stored in the sun-exposed bottles, SODIS can also be used in continuous-flow systems, comprising solar collectors and heat exchangers, to significantly increase the daily drinking water output. Hence, SODIS continuous-flow reactors can be used to disinfect the water supply of institutions (e.g. hospitals or schools). The design of SODIS reactors is still in progress and respective field experience will not be reported here.

The SODIS Project

In 1991, EAWAG/SANDEC embarked on an extensive laboratory and field test project to assess the potential of SODIS and to develop an effective, sustainable and low-cost water treatment method. The SODIS project has been subdivided into the three following phases:

Phase 1: comprehensive laboratory and field tests to determine the potential and limitations of the process

Phase 2: field tests to develop equipment and operating guidelines for the water treatment method

Phase 3: demonstration projects to study socio-cultural acceptance and affordability of SODIS.

A project team, composed of sanitary engineers, photochemists, bacteriologists, and virologists, conducted the comprehensive laboratory tests at EAWAG, and studied the inactivation of bacteria (E.coli, Str. faecalis, Enterococci), viruses (EMC virus, rotavirus) and bacteriophages (f2) by irradiation under different operating conditions (at differ-

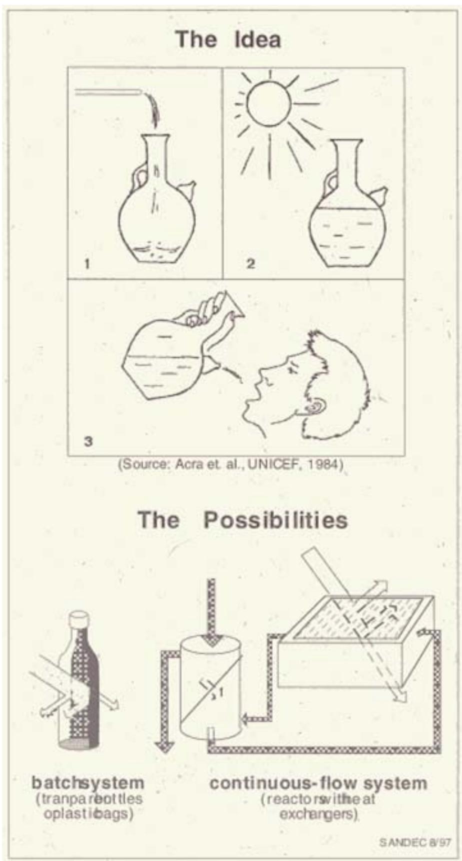

Figure 1 Application of Solar Water Disinfection

ent wavelengths, turbidities, temperatures, organic matter, and methylene blue concentrations) [1]. Field tests carried out in cooperation with CINARA in Cali, Colombia [2], supplemented EAWAG's research in the laboratory. These tests, run under real field conditions, were conducted with natural bacteria mixtures from highly polluted river water.

The second phase of the SODIS project aimed at developing and field testing adequate containers and reactors for the water treatment process. The small diameter quartz tubes used in Phase 1 were replaced by locally available material such as glass and plastic bottles as well as plastic bags. The field tests were performed in cooperation with local institutions in Colombia, Jordan and Thailand [3]. However, since the daily output of treated water is limited to the stored and exposed water volume of these containers, EAWAG designed and constructed prototypes of continuous-flow systems which were field tested by the same institutions. The design of the SODIS reactor was further developed in cooperation with Swisscontact, and field tested with AyA in San José, Costa Rica.

EAWAG's SODIS project has currently reached Phase 3 - the most decisive of the project. The preceding phases focused on scientific and technical aspects, and the water produced was drained off unconsumed. The current stage of the SODIS project includes the target population; i.e., the future users of this water treatment method. Sociocultural acceptance, applicability and financial aspects of the water treatment method are currently studied in demonstration projects conducted by local partners in Colombia, Bolivia, Burkina Faso, Togo, Indonesia, Thailand, and China. The selected sites comprise a large range of different sociocultural backgrounds, as well as climatic and living conditions. The ongoing projects are expected to produce valuable information on acceptance and affordability of SODIS to be promoted on a large scale after thorough evaluation.

A Milestone in Process Development

In the past, two different water treatment processes using solar energy were developed to improve the microbiological water quality. The first method, using predominantly UV-A radiation, is known to have a bactericidal effect. The second method, utilising infrared radiation to raise the water temperature to over 70 °C, is known as pasteurisation. However, the climatic conditions are often far from optimal. Since a cloudy sky reduces sunlight radiation, the necessary UV-A radiation dose or the required water temperature of 70 °C cannot be reached to disinfect the water.

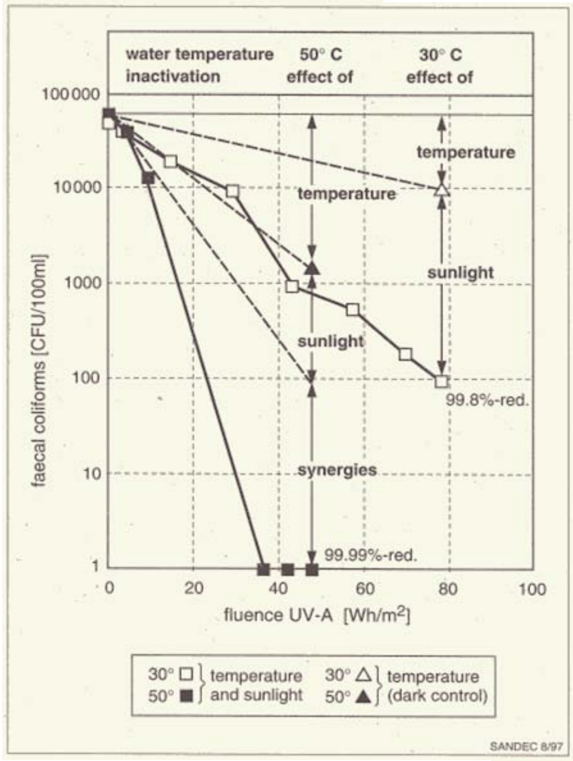

Figure 2
Effect of Solar Radiation and Water Temperature on the Inactivation of Faecal Coliforms

Under these conditions, simultaneous use of both solar energy sources - UV-A light and infrared radiation - seems a good idea. The two processes were assumed to complement each other and, thus, compensate for the partly unfavourable climatic conditions. EAWAG's research programme focused, therefore, also on these combined effects and discovered synergies between solar radiation and temperature. This recorded phenomenon constitutes a breakthrough in the development of the technology, and significantly enhances the potential of SODIS application.

Fig. 2 illustrates the synergies produced by the combined use of radiation and thermal treatment on the inactivation of faecal coliforms. Two different faecal coliform inactivation tests were carried out at constant water temperatures of 30 °C and 50 °C, respectively. The results, marked as points, of the dark control samples wrapped in aluminium foil show the inactivation effect of temperature (and time) only. The combined effect of solar radiation and water temperature is shown by the two curves for water temperatures of 30 °C and 50 °C, respectively. A series of parameter tests at water temperatures between 20 and 55 °C revealed that the inactivation rate of faecal coliforms remains constant within a 20 - 40 °C temperature range. However, at a threshold water temperature of 50 °C, the required fluence of UV-A light is about four times smaller than at 30 °C. The fluence of solar radiation required for a 3 log reduction of faecal coliforms can be estimated at:

30 °C: 100 Wh/m² UV-A
50 °C: 25 Wh/m² UV-A

As indicated by the graph, inactivation of bacteria at 50 °C can be attributed to three different factors: heat effect, sunlight exposure and synergies caused by the combined application of temperature and radiation. Hence, since the combined use of the two treatment processes - water disinfection by solar radiation and thermal treatment by solar energy - can substantially enhance the potential of SODIS, its application is thus certainly worthwhile.

Equipment

SODIS requires sunlight, exposure time and adequate containers to produce drinking water. The required containers (glass or plastic bottles used for mineral water or soft drinks) are available everywhere. Since glass bottles are heavier and more fragile than plastic bottles, the plastic progressively replaced the glass material. Plastic bottles are either made of PET (polyethylene terephtalate) or PVC (polyvinyl chloride), the latter may contain some additives to increase its elasticity. However, high concentrations of these additives could diffuse into the water and pose a health risk. PET bottles are inert and, therefore, recommended for SODIS use.

The polluted water is bottled and exposed to sunlight, which has to travel through the wall of the bottle into the water. UV-A light (wavelength 320 - 400 nm), the most bactericidal sunlight spectrum, should have a high light transmittance through the material of the bottle.

Water temperature development is the second most important process parameter. Temperature increase is dependent on container type and support material used. To improve water heating, transparent plastic bottles should be half-blackened to enhance infrared light absorption. Furthermore, the ratio between exposed surface area and stored water volume greatly influences temperature development. Flat plastic bags filled with a water layer depth of 2 - 6 cm yield a far better area/volume ratio than normal round shaped bottles. Therefore, significantly higher water temperatures can be reached by the bags. Finally, type and shape of support material used to carry the plastic bottles or bags directly influence water temperature development. Half-blackened plastic bottles placed on a corrugated iron roof offer the best configuration for SODIS batch process application. The water in such bottles is heated by the infrared light which is absorbed by the black paint. The convective heat is, in turn, absorbed and conveyed to the bottle by the metal sheet.

Results

Laboratory Tests at EAWAG

The photochemical and microbiological laboratory tests at EAWAG assessed the potential of solar water disinfection and can be summarised as follows [1]:

- Of the terrestrial solar radiation UV-A light (320 - 400 nm) is mainly responsible for the inactivation of microorganisms. Violet light (400 - 450 nm) alone is hardly bactericidal. However, due to synergetic effects with UV-A light, its inactivation rate of E.coli increased by a factor three.

- A fluence (dose of solar radiation integrated in the 350 - 450 nm wavelength range) of 2000 kJ/m² or 555 Wh/m² is required to achieve a 3 - log reduction of E.coli at water temperatures between 20 °C and 40°C. The same amount of fluence reduces the bacteriophage f2 and a strain of rotavirus to a similar order of magnitude when exposed to solar radiation at 30 °C water temperature. The comparison of the required fluences for the inactivation of different micro-organisms indicates that E.coli and bacteriophage f2 may be used as indicator organisms to monitor the efficiency of solar water disinfection as regards the inactivation of bacteria and viruses.

- Water temperatures between 20 and 40 °C do not affect the inactivation of bacteria by UV-A and visible light radiation. Synergetic effects were observed above a threshold water temperature of 50 °C. Compared to lower water temperatures, the fluence required to inactivate E.coli is more than three times smaller at this temperature. Viruses are, however, more sensitive to water temperature changes. The inactivation rate for the bacteriophage f2 increased by a factor 1.8 when the water temperature was raised from 20 to 40 °C. Enteroviruses and rotaviruses are even more sensitive to the same water temperature change. Their inactivation rates increased by a factor 2.4 and 3.6 respectively.

The tested bacteria showed no photosensitisation to natural organic matter (NOM). Instead, a decrease in efficiency was observed with increased NOM concentrations as a result of reduced light transmittance of the cell suspensions.

The efficiency of light in killing bacteria is considerably increased by methylene blue.

Field Test Results

The EAWAG's research work with SODIS was conducted under strictly controlled laboratory conditions. To assess the inactivation rates of faecal coliform, and, in one case, of Vibrio cholerae, under different climatic, physical, chemical, and microbiological conditions, the laboratory tests were complemented with field tests [3]. They were run at CINARA (Instituto de Investigación y Desarrollo en Agua Potable, Saneamiento Básico y Conservación del Recurso Hídrico) Cali, Colombia [2, 4], at AyA (Instituto Costarricense de Acueductos y Alcantarillados) San José, Costa Rica [5, 6], at the Renewable Energy Research Centre of the Royal Scientific Society in Amman, Jordan [7, 8], and at the Khon Kaen University in Khon Kaen, Thailand [9, 10].

Physical Tests

The experiments revealed that UV-A intensity decreases rapidly with increasing water depth.

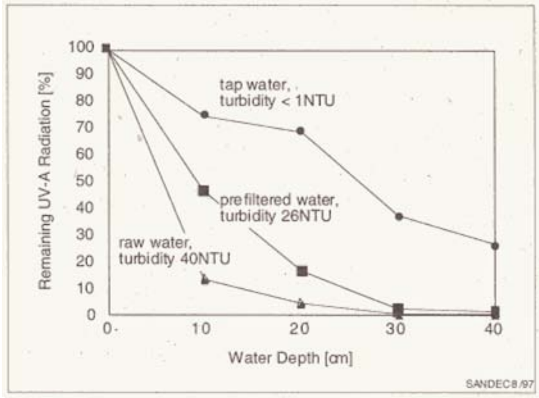

Figure 3
Reduction of UV-A Radiation as a Function of Water Depth and Turbidity, Assessed with a Measuring Tube, (●) Tap Water (NTU < 1), (■) Prefiltered Water (26 NTU), (▲) Raw Water (40 NTU), NTU = Nephelometric Turbidity Unit.

This effect is amplified by increasing turbidity. Fig. 3 shows the remaining UV-A light plotted as a function of water depth and turbidity measured in a 3-cm diameter tube. Compared to the conditions in a translucent bag or an irradiation reactor, this decrease occurs relatively fast.

Average UV-A transmission losses (spectrum 320 - 400 nm) of the used transparent container material were the following: plastic bottles: ~ 30 %, glass bottles: ~ 25 %, plastic bags: ~ 10 %. The losses for coloured bags are at least six times higher than for transparent bags.

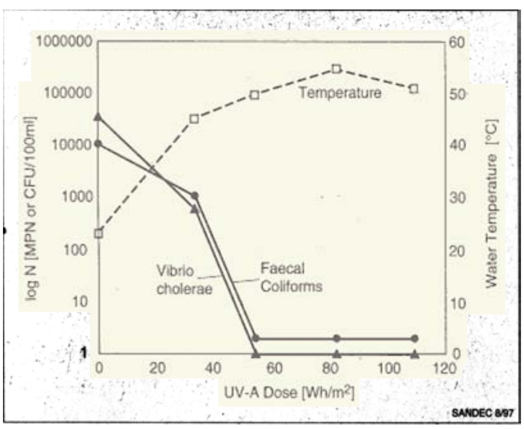

Figure 4
Inactivation Curves of (▲) Faecal Coliforms and (●) Vibrio Cholerae in Plastic Bags, Water Turbidity 14 NTU, (□) Water Temperature (> 50 °C), N = Number of cells (Faecal Coliforms in Colony Forming Units (CFU), Vibrio Cholerae in Most Probable Numbers (MPN)).

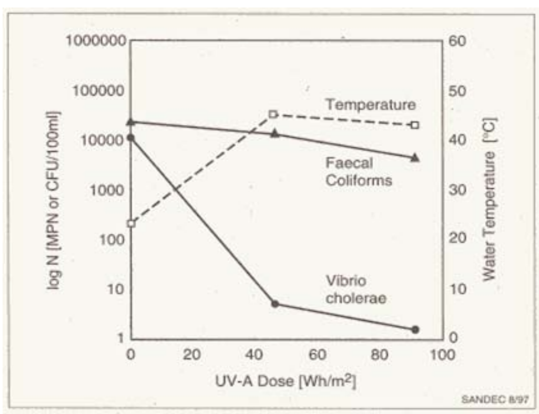

Figure 5
Inactivation Curves of (▲) Faecal Coliforms and (●) Vibrio Cholerae in Glass Bottles, Water Turbidity 23 NTU, (□) Water Temperature (< 50 °C).

Table 1 Best Test Result achieved in Bottles and in Bags for Faecal Coliforms (fco) and Vibrio cholerae (Vch), exp. time = exposure time

container	organism	max. temp.	turbidity	exp.time	UV-A	reduction
		[C°]	[NTU]	[min]	[Wh/m2]	[%]
bottle	fco	57	17	330	85	100
bottle	fco	48	40	270	105	99.56
bottle	Vch	45	23	130	52	99.98
bag	fco	52	50	90	19	100
bag	fco	55	14	140	54	100
bag	Vch	55	14	140	54	99.98

Microbiological Tests

The field tests confirmed the results obtained by the laboratory tests. As soon as the water temperature reaches 50 °C, the inactivation process is accelerated. This often leads to a complete disinfection of the water. Fig. 4 shows the inactivation curves of faecal coliforms and Vibrio cholerae. It also indicates clearly an increased inactivation of both microorganisms beyond a water temperature threshold of 50 °C. The difference in temperature resistance of the microorganisms is shown in Fig. 5. The plotted curves show the inactivation process during an experiment with water temperatures below 50 °C. The figure shows a lack of sharp increase in the inactivation rate beyond a certain temperature and the inexistence of two parallel curves. Since the inactivation rate of faecal coliforms is much slower than that of Vibrio cholerae, Vibrio cholerae are assumed to be more vulnerable to temperature than faecal coliforms.

A comparison of the temperature curves between Fig. 4 and 5 indicates that a rise in temperature is generally faster and higher in plastic bags than in bottles. This can be attributed to the shape of the bag resembling a small solar collector with a relatively large energy collecting surface. The solar collecting surface of a two-litre bottle is about three times smaller than that of the bag. Furthermore, the bag can be filled at a small water depth. This not only enhances water heating but also irradiation of the microorganisms as the intensity of UV-A radiation is neither significantly reduced by turbidity nor by water depth. Consequently, fast and complete inactivation is more easily achieved with bags than with bottles. The fastest 100% faecal coliform reduction in a plastic bag occurred within 90 minutes at an UV-A dose of 19 Wh/m^2 and a water temperature of 52 °C. Table 1 contains the best test result obtained in bottles and in bags with faecal coliforms (fco) and Vibrio cholerae (Vco).

Demonstration Projects

Potential and limitations of SODIS were studied in Phase 1, and application possibilities and procedures developed in Phase 2. The ongoing Phase 3 is now focusing on the following aspects:

- **will the SODIS process be accepted** by potential consumers? What are the most important criteria for such an acceptance?

  can the SODIS process be integrated into traditional water collection, transport, storage, and use? How should the application be designed for easy integration into existing water handling schemes?

- **can the SODIS process be afforded** by potential consumers? What price are the consumers willing to pay for water quality improvement? What are the investment and operating costs for different SODIS systems?

The answers to these questions are studied in demonstration projects conducted in seven different developing countries (Colombia, Bolivia, Burkina Faso, Togo, Indonesia, Thailand, and China).

Changing Water Treatment Habits

SODIS will only be used and applied if the beneficiaries are convinced of its advantages over the traditional ways of treating and handling drinking water. The new water treatment method will find acceptance if:

- it requires less firewood for the preparation of food and beverage (SODIS-treated water does not require boiling, and the preheated water can also be used in the kitchen)
- preparation of drinking water is less cumbersome (water boiling may be tedious, dangerous and annoying as it requires a fire, careful handling of the hot pots and exposure to smoke)
- SODIS containers can also be used for water transport (e.g. plastic bottles can be taken to the field for water consumption during field work).

Changing Water Handling Habits

Consumers will only fully benefit from SODIS if they understand the importance associated with the bacteriological water quality transmission routes of water-borne diseases and methods to reduce or avoid these risks. Beneficiaries may change their water handling habits if they are willing and able to:

change or complement their traditional water containers by more adequate containers for SODIS application

protect good quality water from in-house contamination, and preferably consume SODIS treated water directly from the sun-exposed container

separate and adequately use water of different quality.

Paying for Water Quality Improvement

Private users will only invest in water treatment if they perceive direct benefits. Health benefits are often indirect and may only have a long-term effect. SODIS will, therefore, only be sustainable if:

consumers recognise the health benefits from water quality improvement and are willing to pay for them

investment and operating costs are low

equipment can be provided and replaced by locally available material.

Field Experience

SODIS Efficiency

The efficiency of SODIS on the inactivation of microorganisms has been studied extensively in laboratory and field tests [1,3]. The initial faecal coliform concentration used in the experiments was often much higher (>10,000/100 ml up to more than one million/100 ml) than commonly encountered in rivers and ponds (1000/100 ml or less). Although an efficient reduction of faecal coliform has been observed, the SODIS treated water has never been used for consumption in the experiments.

Table 2 Faecal Coliform Reduction with Different Containers in China

1st Test Period: August - November '96	Untreated Water	SODIS Treated Water with **2500 ml Glass Bottles**
Polluted Samples	161 (74.5%) (2-1600 MPN/100 ml, Ø 78 MPN/100 ml)	60 (27.8%) (2-220 MPN/100 ml, Ø 23 MPN/100 ml)
Unpolluted Samples (MPN/100 ml = 0)	55 (25.5%)	156 (72.2%)
2nd Test Period: May - August '97	**Untreated Water**	**SODIS Treated Water with SODIS Bags and 1250ml Plastic Bottles**
Polluted Samples	99 (82.5%) (2 - 1600 MPN/100 ml, Ø 312 MPN/100 ml)	1 (0.8%) (23 MPN/100 ml)
Unpolluted Samples (MPN/100 ml = 0)	21 (17.5%)	119 (99.2%)

The conditions in the SODIS demonstration projects differ from the ones in the previous experiments. The process is not applied under strictly controlled conditions, the material and methods used are often not optimal, the raw water pollution is generally much lower and the handling of the treated water frequently inadequate.

Therefore, the preliminary results of faecal coliform reduction have to be evaluated with caution. The available data is also limited as some partner organisations decided for instance not to analyse water samples during their initial project phase in order not to disturb the users. The taking of periodic samples at this point in time may be perceived as too much external intrusion.

Some of the available field results of faecal coliform reduction can be summarised as follows:

- Ningxia Sanitation and Antiepidemic Station (NSAS) in Yinchuan, China, analysed the raw water drawn from wells partly equipped with handpumps. Some of the wells are probably polluted via infiltration (animals in the yard, onsite sanitation facilities), and by inadequate water withdrawal practices (polluted buckets and ropes). Table 2 summarises the results obtained from a total of 336 raw and treated water samples analysed for faecal coliforms. The faecal coliform concentration was reduced in all polluted samples, however, the high Chinese water quality standard (MPN/100 ml = 0) was not always met. This was probably due to the large (2500 ml) glass bottle volume used in which the water could only reach a temperature of 35 - 47 °C. NSAS then started using SODIS plastic bags and locally available plastic bottles (1250 ml) and could thereby significantly improve the efficiency of SODIS. All but one of the analysed 120 treated water samples complied with the high Chinese water quality standard as shown in Table 2 for the 2nd period.

NSAS carried out two series of SODIS field tests in February and March 1997 to study the inactivation of faecal coliforms at low ambient temperatures. The air temperature varied between -2.2 and -14.8 °C during the experiments. The groundwater stored in 2,500 ml glass bottles rose from about 12 °C to 30 °C after five hours of sun exposure. The faecal coliform concentrations ranged between 5 and 49 (average 17) MPN/100 ml in eight polluted raw water samples. Apart from one sample, which was only partially disinfected (reduction of faecal coliforms from 17 to 2 MPN/100 ml), no faecal coliforms were detected in the SODIS treated water. These field tests reveal that SODIS is not only a "hot climate technology", but also appropriate for temperatures below 0 °C provided sufficient sunlight radiation is available (required radiation intensity 500 W/m^2).

Environmental Concern (EC) in Khon Kaen, Thailand, selected two villages using rainwater as raw water source. The rainwater is collected from the roof of the houses and channelled to 1.5 m^3 collection jars. A total of 22 raw water and 55 treated water samples were analysed for faecal coliforms in the first test period. The sporadically high concentration of faecal coliforms is surprising. Secondary contamination caused by poor handling is the most likely cause for this high concentration. The villagers were advised not to use contaminated containers for drinking water storage when transferring the treated water during the second test period. A comparison of the results of the two test periods shows, on the one hand, that the number of polluted raw water samples increased in the second field test period. This may be explained by a secondary contamination caused by the extended and inadequate withdrawal of rainwater stored in jars. On the other hand, treatment efficiency in terms of samples with 0 CFU/100 ml increased from 78 to 98%, and is certainly attributed to the continued training of the users in improved SODIS application.

- Yayasan Dian Desa (YDD) in Yogyakarta, Indonesia, studied the effects of inappropriate water handling by the users through own parallel tests. Table 3 indicates that peri-urban dwellers (Dobalan) are more careful in applying the SODIS method than the rural population (Melikan). Nevertheless, both communities can further improve the SODIS water treatment efficiency through correct use as revealed by the results of the YDD staff.

Table 3 Effects on Faecal Coliform [CFU/100 ml] Reduction by Different Users in Indonesia

Community (Raw Water Source)	Raw Water	Treated by the Community		Treated by the YDD Staff	
		In Bottles	In Bags	In Bottles	In Bags
Dobalan	220	0	0	0	0
(Open Dug Well)	2,400	5	0	0	0
Melikan	1,800	70	170	-	-
(Untreated Lake Water)	2,400	1,000	400	0	0
	2,400	110	130	0	0

SODIS Acceptance

The SODIS water treatment method was introduced in the demonstration project villages less than a year ago. The project staff visited the demonstration projects once a week during the first month, and every two weeks over the next three months. The field visits were subsequently reduced to once a month in order to reduce external intervention and study individual application of the propagated treatment method. During the numerous field visits, the following observations were made:

An overall positive response of the households participating in the SODIS demonstration projects was observed. The users find the treatment method very practical and helpful, easy to handle, as well as time and fuel saving. The consumers also appreciate the good taste of the water compared to the undesirable taste of chlorinated or boiled water.

- In some projects (e.g. in Indonesia), SODIS is not applied predominantly for water quality reasons, but to temperate drinking water. Traditionally, the women had to heat the water early in the morning before it was carried to the fields by the men in cooking pans (caldors). SODIS makes life easier for them as only water-filled bottles have to be carried to the fields and merely exposed to sunlight during field work.

The local community health workers and the more educated inhabitants, such as the teachers, still seem to question the SODIS technology and continue to emphasise the need for boiling drinking water. They currently neither support nor condemn the new treatment method, but just seem to have adopted the "wait and see" approach.

The consumers generally prefer the SODIS plastic bottles since they are more robust, easier to fill and more practical to carry than the SODIS plastic bags. In contrast to plastic bags which require an additional glass, the users also favour the plastic bottles as the water can be drunk directly from the bottle.

The commercial benefit from SODIS is starting to spread. For instance, the owner of a restaurant in Colombia safes money by using SODIS treated water instead of expensive bottled mineral water. The cook of a pancake shop in Indonesia serves SODIS treated water to his clients. Apart from becoming more competitive, they promote the new water treatment method as SODIS might be copied by their customers.

SODIS plastic bags and bottles were initially distributed free of charge to the participating households by the local partner organisations. However, EAWAG's partners are now promoting self-help projects due to the increasing need for new or additional bottles in the demonstration projects. Production of SODIS bottles on a village level has to be discussed, and marketing of the products organised. These projects will determine the actual interest of the customers for SODIS plastic bottles and their willingness to pay for an improved drinking water quality. This experience will be significant for future dissemination of the SODIS technology.

Planned Activities

Evaluation of Demonstration Projects

The development and experience gained by the demonstration projects are presented in two progress reports. The results and conclusions drawn from the projects will be summarised in a final report by the local project partners. EAWAG/SANDEC has developed different questionnaires for the progress reports, as well as a list of ten questions with standard answers for the final report. This final survey will assess the specific water supply situation of the households participating in the SODIS project, users' opinion about SODIS and their willingness to continue using the SODIS method. Furthermore, interviews will be conducted with project staff and local leaders to obtain a comprehensive assessment of the general acceptance of SODIS, as well as to review the experience gained from the demonstration projects with the project partners.

SODIS Workshops

Once the demonstration projects are evaluated by internal review teams, national workshops will be organised in the seven developing countries participating in the SODIS project. The objectives of the planned workshops comprise a general introduction of the SODIS water treatment method, presentation and review of the results and experience gained from the demonstration projects, as well as discussions on possible dissemination strategies on a regional or national level. The workshop organisers will invite a small audience of key persons from national authorities, NGOs, multilateral and bilateral organisations, as well as national research institutions. These workshops are expected to initiate follow-up programmes aiming at launching SODIS on a large scale. Finally, EAWAG/SANDEC is planning to organise an international SODIS workshop in due time to review and discuss SODIS experiences acquired on a national level.

SODIS Information Material

A 15-minute video on SODIS, produced by EAWAG, presents the water treatment method and laboratory and field tests conducted in Switzerland, Colombia and Costa Rica. English, Spanish, French, and German VHS video cassettes recorded in PAL, SECAM or NTSC are available on request from SANDEC. A second video showing the introduction of SODIS and its practical use in the demonstration projects will be available at the end of 1997. SANDEC also publishes "SODIS News" - an informal newsletter - to enhance information exchange between the project partners. This biannual newsletter can also be ordered from SANDEC.

Acknowledgements

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dan, Yayasan Dian Desa in Indonesia, Khon Kaen University and EC in Thailand, NSAS in China, Swisscontact and AyA in Costa Rica) have tested SODIS and gained valuable field experience. The Swiss Federal Laboratories for Materials Testing and Research (EMPA) have analysed different plastic bags, and the Working Group of Environmental Hygiene at the University of Zurich performed the virus analyses. Finally, EAWAG's Research Departments of Chemistry and Microbiology, including the staff of the workshop, also greatly contributed to developing the SODIS technology which would have not emerged as promising water treatment method without the motivated collaboration from all our partners.

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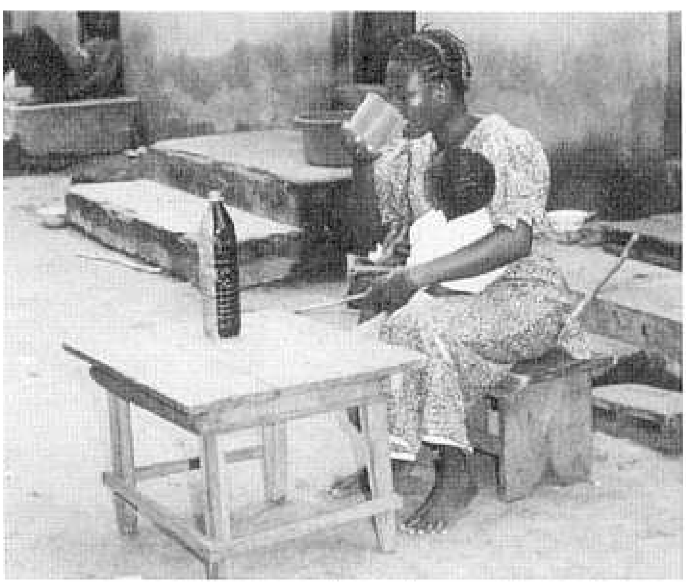


Consumption of SODIS treated water in Togo. The consumers appreciate the pleasant taste of the water.

Desalination at Household Level - Results of a Literature Review

by Bernhard Sommer

The review, covering about 40 books, articles and Internet information, aimed at compiling data on desalination schemes, and at determining the most appropriate methods applicable at household level in rural areas of developing countries. Furthermore, the demand for small-scale distillation schemes was tentatively identified, including potential regions for sustainable introduction of the processes.

Introduction

Since 97 per cent of the water on our planet is saline, use of desalination techniques to make this water potable is a challenging idea. The prospects of finding a solution to the world's water problems, motivated scientists to conduct intensive research in desalination technologies since the Second World War. Desalination can be attained in many different ways, however, the process itself remains the same: freshwater (1 g TDS/l or less) is produced from brackish water (1 - 30 g TDS/l) or sea water (more than 30 g TDS/l) (TDS/l = Total Dissolved Solids per litre).

One of a thousand litres of the world's potable water production is currently desalinated. Half of the desalination plants are located in the Middle East and North Africa. Saudi Arabia ranks first with 27 per cent of the world's total desalination capacity. The installed systems use mainly (86 %) the multi-stage flash distillation and reverse osmosis processes. The multiple effect, electrodialysis, and vapour compression processes make up the remaining 14 per cent. Solar still systems and other small-scale processes amount to less than one per cent of the world's desalination capacity [1].

Desalination ranks among the most expensive water treatment options. The turning of ocean water into drinking water in large plants is four to eight times more expensive (US $ 1 - 2 per cubic metre) than the current average cost of urban water supply [2]. The estimated water price per cubic metre produced by small-scale distillation processes varies between US $ 5 - 25, including construction, which is the most important cost factor, as well as operation and maintenance.

A sustainable introduction of small-scale solar distillation schemes at household level is only realistic in areas fulfilling the following conditions:

- in sparsely populated low-income areas
- in areas where surface water, groundwater and rainwater are already fully depleted
- in areas using saline water because freshwater is already depleted or difficult to exploit
- in areas where ambient air temperatures and solar radiation are high throughout most of the year
- in areas with an annual rainfall below 400 - 600 mm.

Appropriate Desalination Technologies

The common denominators to the most frequently used technologies are their high investment costs and skilled labour requirements for construction, operation and maintenance of the plants with their sophisticated equipment, process technology, expensive spare parts, and enormous and continuous energy requirements. Solar distillation is, therefore, the only appropriate technology which meets our objectives as:

- it involves the target population during construction, operation and maintenance
- locally available material and know-how can be used for construction
- operation and maintenance costs are low and spare parts inexpensive.

Solar Distillation Plants

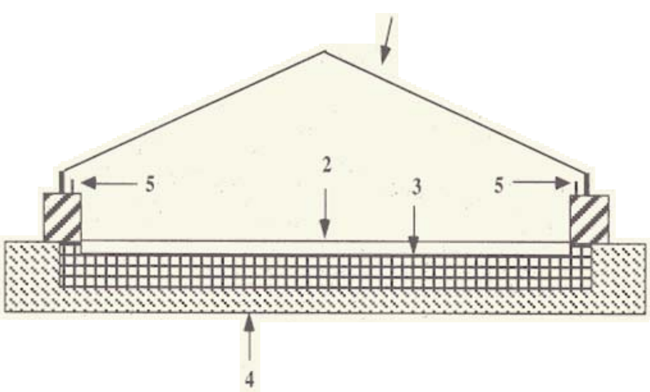
Areas where such plants can successfully be applied are located roughly within latitudes 35 °N and 35 °S; i.e., within the arid zones. Solar still output per unit of solar collection area is determined by solar intensity. Another important parameter is ambient temperature, as high temperatures will result in low heat losses.

About 2300 kJ energy is necessary to transform one litre of water into vapour. Under ideal climatic and geographic conditions, about 20.3 MJ/m^2 solar energy is available per day. Assuming a realistic efficiency of 30 - 50 % for a single-effect solar still, the calculated daily water output ranges between 3 - 4.5 litres per square metre of solar collection area. The energy losses are caused mainly by reflection on the glass cover, heat adsorption in the glass cover itself, reflection at the water surface, convection losses, losses of heat through sidewalls, as well as ground and defective seals. The smaller the distance between water surface and condenser, the lower the convection losses.

Solar distillation can be divided into two groups: the single-effect and multiple-effect processes. The latter reuses the latent energy released in a chamber by the condensing water vapour to heat saline water in the neighbouring chamber. Single-effect processes only use the directly collected sun energy. Energy reuse increases efficiency and, thereby, water production.

Greenhouse Solar Still

The greenhouse type is currently the most widely used distillation process. The floor of a basin filled with saline water is heated by sunlight and water vapour is condensed on the basin's sloping glass roof. Drops of distillate then form small rivulets flowing down on the glass cover to the collector channels on either side.



1 Glass cover

2 Brine basin

3 Insulation

4 Soil

5 Distillate collector channels

Figure 1 Greenhouse Solar Still

The first greenhouse solar still was built in Chile in 1872. It produced about four litres of water a day per square metre of solar collector area. In 1991, the International Desalination Association (IDA) wrote "A general rule of thumb for solar stills is that a solar collection area of about one square metre is needed to produce four litres of water a day. Construction of the stills themselves is expensive. Furthermore, careful operation and maintenance is needed to prevent scale formation caused by drying out basins. Repairs of glass or vapour leaks in the stills are also necessary [3]". This suggests that despite intensive research efforts, efficiency could not be increased significantly over the last century .

The effects of relevant design parameters on process efficiency have thoroughly been investigated and an increase in efficiency is therefore unlikely. A shallow basin (2-5 cm) promotes fast heating of the brine and long evaporation periods. Black butyl rubber proved the best lining material for the basin. Glass is recommended as cover material since plastic foils have adverse wetting characteristics and tend to flap on windy days. This reduces efficiency as distilled water drops back into the brine. In addition, plastic foils have a relatively short service life compared to glass. The distillate should run off quickly through the collector channels to preclude evaporation (losses of up to 17 % were reported). Greenhouses must also be airtight. Numerous publications provide detailed information on greenhouse distillators, including general specifications, details on materials, construction and auxiliaries [e.g. Christian Seufert (1978). Solar Distillation/Desalination, Devices for Small Quantities, GATE / GTZ, P.O. Box 5180, 65726 Eschborn, Germany - T.A. Lawand (1967). Simple Solar Still for the Production of Distilled Water, Brace Research Institute, McGill University, Quebec, Canada].

Other Types of Solar Stills

Since inclined solar stills have smaller air volumes between water surface and condenser (glass cover), convection losses are reduced. On cloudy days (low solar radiation intensity), efficiency was improved by 50 %.

In some experiments, the evaporation surface of inclined solar stills was enlarged with water saturated fabric or single threads. This not only led to a slight increase in efficiency, but also to a more difficult operation and maintenance caused by scale formation on the fabric.

Tests with inclined solar stills, combined with a solar collector as preheater, increased production by 25 %. However, use of a solar collector also increased the overall costs of the stills.

Improved large-scale inclined solar stills produce up to 17.5 litres of water per square metre collector area per day, such as for instance the plant manufactured by a German company which produces 3.5 m^3 of distillate per day. The price of the complete system, excluding assembly and transport, totalled US $ 280,000 in 1994.

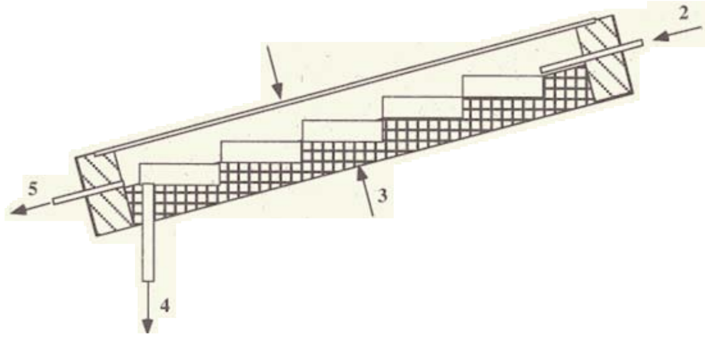
The existing small-scale multiple-effect distillators are laboratory pilot plants producing between 10 - 20 litres of water per day and square metre collector area. The type of material used and the rather complicated design resulted in a reported water price per cubic metre of US $ 15 - 25. Whether these plants can be operated and maintained by the average rural user has not been examined yet.

Market Analysis

A questionnaire was sent out to various institutions to collect information on the demand for solar distillation, and to identify possible regions where this process could be applied successfully. The selected addressees, taken from SANDEC's database, comprised institutions active or interested in improving rural water supplies in developing countries. Another criterion was their geographic location. The 183 questionnaires were sent out to institutions in 47 developing countries with arid or semi-arid regions, and to countries such as the Philippines or Indonesia which are made up of numerous islands. Since only 12 % replied to the questionnaire, representing only 15 out of the selected 47 countries, no conclusive results could be drawn. The analysis could not identify a widespread or significant demand for solar distillation nor potential application sites.

Some districts in Tamil Nadu and Kerala, South India, emerged as potentially appropriate sites for solar distillation. CEPIS in Peru signalled a demand for application of this method in fishing villages with about 250 inhabitants. Some islands in Indonesia also seem interested in solar distillation.

The reported price for transported or desalinated water ranges from US $ 0.01 - 0.93 per litre.



1 Glass cover
2 Salt water inflow
3 Insulation
4 Brine outflow
5 Freshwater outflow

Figure 2 Stepped Inclined Solar Still

Synopsis of the Characteristics of Small-Scale Solar Distillation

The characteristics of small-scale distillation devices are given in Fig. 3. The three characteristics on the right indicate that it is an appropriate technology. On the left, a number of factors reveal

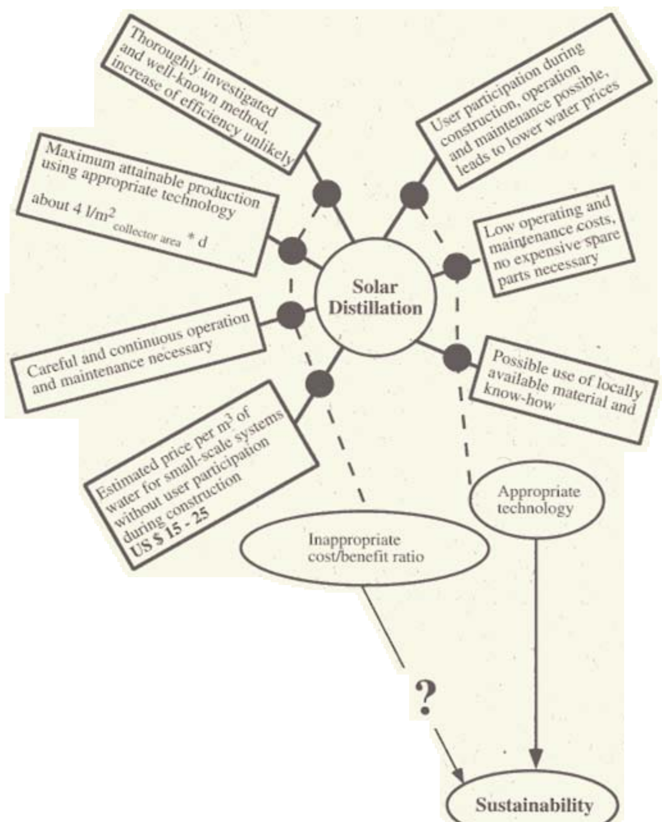


Figure 3 Characteristics of Solar Distillation

inappropriate expenditure/cost-benefit; i.e., requiring a considerable input of time, work and money from the user for the production of a rather limited volume of potable water. Although solar distillation is an appropriate technology for use in developing countries, it may not be sustainable for the aforementioned reason. Acceptance of solar distillation is rather low, and transported water is one of the favoured alternatives.

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SOS - Management of Sludges from On-Site Sanitation

Faecal Sludge (FS) Treatment - Highlights

by Martin Strauss and Udo Heinss
with contributions by:
Chongrak Polprasert & Thammarat Koottatep, AIT[1]; Seth A. Larmie, WRI[2];
Louernie F. de Sales, Jose Marie U. Lim, Ricky Quebral Jr., UP/NEC[3]

Current Field Research Programme and Outlook

Our SOS field research is currently focusing on the following three major treatment options involving three selected partner institutions:

Option/Process	Partner
Solids-liquid separation:	
- Settling-thickening	- WRI
- Sludge drying beds	- WRI
- Planted sludge drying beds (sludge humification; constructed wetlands)	- AIT
Pond treatment:	
- Anaerobic ponds	- WRI
- Attached-growth facultative ponds	- AIT
Soil reclamation:	
- Restoration of soils damaged by volcanic eruptions	- UP/ NEC

The main features and preliminary results of the current field research on planted and unplanted sludge drying beds, as well as on soil reclamation are highlighted in the sections below.

Within the next six month to one year, our FS-related field research will centre primarily on planted sludge drying beds, attached-growth facultative ponds and on anaerobic ponds. The activities might be expanded to comprise anaerobic digestion of fresh, high-strength sludges. These proved to not be inducive to solids-liquid separation or pond treatment.

The soil reclamation studies in the Philippines, which are planned to be continued as scaled-up pilot/field tests, will form part of an urban sanitation project co-financed by the Asian Development Bank. The recultivation experiments shall be complemented by a technical-economic feasibility study on options of FS management.

Results from Selected Field Research Projects

Planted Sludge Drying Beds ("Sludge Humification")

Picture 1

A 2-month old AIT pilot sludge drying bed planted with cattail and loaded with Bangkok septage. Ventilation pipes ensure natural aeration of the root zone and prevent anaerobic conditions and root damange.

1 Asian Institute of Technology, Bangkok
2 Water Research Institute (CSIR), Accra
3 University of the Philippines - National Engineering Center, Manila

The field tests with planted sludge drying beds aim at determining process feasibility for faecal sludge treatment, optimum loading limits to attaining satisfactory/desired sludge dryness and percolating water quality, optimum bed configuration, advantages over conventional, unplanted sludge drying beds, and obtaining sufficient performance data to develop process design guidelines.

Bench-scale drying beds planted with cattail and loaded with septage were used to generate data which subsequently allowed selection of appropriate FS loading rates for the pilot cattail beds. Starting end of April 1997, three pilot-scale sludge drying beds, each 5 x 5 m, were planted with cattail (*Typha*) and loaded with Bangkok septage (avg. TS = 14,000 mg/l) at 3 - 7 day intervals. The three beds are intermittantly loaded at rates equivalent to 80, 125 and 250 kg TS/m^2·year, respectively. Owing to their short operating period, no conclusions can yet be drawn on the long-term feasibility and performance of the planted drying beds. Significant COD (95 - 99 %), NH_4 (80 - 99 %) and phosphorus (75 %) removal was observed in the percolating liquid during the first few weeks of operation. This effect was probably linked to mechanical filtration, mainly. It is assumed that the microbial biomass responsible for degradation was still comparatively small due to the relative shallowness of the overall filter bed at start-up (depths of accumulated sludge = 1 - 5 cm, depending on loading rates). Loading rates appear to have played only a minor role on the quality of the drained liquid. Compared to the unaerated conventional sludge drying beds (see below under "Unplanted sludge drying beds"), natural ventilation appears to significantly enhance nitrification and stripping of ammonia. Average oxygen concentration in the drained liquid amounted to 3.3 mg 0_2/l, and substantial levels of nitrate were observed.

The solids content of the drying sludge ranged between 40 and 60 %TS. The database is not yet large enough to determine the effect of bed loading rate on solids content.

The first tests were performed during the dry season on a still insufficiently deep sludge media to retain enough moisture for plant growth (sludge depths amounted to 1 and 5 cm in the beds loaded with 80 and 250 kg TS/m^2·year, respectively). This led to retarded cattail growth. Measures for restricted ponding of the drained liquid are being developed to prevent water shortage during the early phases of plant growth.

Unplanted ("Conventional") Sludge Drying Beds

Picture 2

Four 4 x 4 m drying beds installed and operated on the premises of WRI in Accra, Ghana. Three beds are equipped with conventional sand and gravel media, and one bed contains a fleece developed especially for sludge dewatering by an Austrian manufacturer.

The tests performed at WRI, Accra, aim at determining feasibility of conventional sludge drying beds for treating various types of FS (see News No. 2 for FS classification), and at fomulating appropriate design criteria and guidelines.

18 sludge drying tests have been conducted to date with public toilet sludge - septage mixtures, unmixed public toilet sludge, and primary pond sludge. The monitoring periods lasted from 5 to 14 days. The sand media was damaged during sludge loading activities in one of the test runs. This indicates the need to protect the filter media and to exert care when hosing the sludge onto the drying beds.

In contrast to the conclusions drawn after the first three test runs, the high-strength and largely undigested public toilet sludges appear to exhibit a rather erratic dewaterability. This can probably be attributed to the fact that such sludges hardly lend themselves to solids-liquid separation and drying on conventional sludge drying beds. Septage, septage/public toilet sludge mixtures and primary pond sludge, however, exhibit a rather reliable dewaterability, with sludge solids contents amounting to 70 - 80 % for public toilet sludge/septage mixtures within 8 days at nominal solids loading rates of 130 kg TS/m^2·yr, and to approx. 30 % TS for primary pond sludges within 8 days at 200 kg TS/m^2·yr.

50 - 80 % of the total FS volume applied to the drying beds drained as percolating water. Contaminant removal in the percolating water (compared to the raw sludge) amounted to ≥ 95 % for susp. solids, 70 - 90 % for COD, 100 % for helminth eggs, and 40 - 60 % for NH_4. COD and NH_4 removal tends to be lower than in planted drying beds (see above). This may be attributed to the fact that since unplanted beds are not equipped with a natural aeration system, anaerobic conditions are likely to develop in the lower sections of the beds. The degree of oxidation and nitrification of carbonaceous compounds is, therefore, most probably lower than in the aerated cattail beds tested in Bangkok.

Considerable levels of helminth eggs at solids (TS) concentrations ≤ 70 % were still observed in drying sludges. This is not surprising as the maximum drying periods lasted only 12 days. Either TS concentrations of >> 90 % or sludge storage periods of several months are required to achieve total or near total egg die-off.

Soil Reclamation

The Lahar reclamation investigations conducted by UP/NEC in Manila aim at determining the cultivation potential and mechanical properties of septage-amended "soil" (see Picture 3 for the definition of Lahar). The investigations will also contribute to gaining experience on the basic use of septage for reclaiming or amending soils which may have been damaged in different ways than through Lahar flooding.

The experiments were conducted on 33 plots of 1 x 1 x 0.6 m each. The bottom of the plots was filled with a layer of 25 cm Lahar onto which 35 cm of varying mixtures of Lahar and soil were added. 25 plots were subsequently loaded with septage. A predetermined number of plots was then planted with Talahib grass (*Saccharum spontaneum L*), a pioneer plant, and Petsai (*Brassicaoleracea*), a locally used leafy vegetable. Allowance was made for varying septage loads (40 and 80 l/m^2, respectively); application methods; i.e., mixing or mulching (surface spreading); and for natural or artificial watering methods. The results obtained to date indicate that the cultivation potential appears to be significantly enhanced by septage amendment in contrast to non-amended Lahar (De Sales et al. 1997). This is true for both the pioneer and the edible crop.

Restoration of Soils Damaged by Volcanic Eruptions

Picture 3
Lahar, the sand-like, infertile volcanic material originating from the Pinatubo volcano eruption in 1991, now covers the flood plains downstream.

Picture 4
Experimental plot planted with Talahib grass, a pioneer plant, on a Lahar/soil mixture amended with septage.

Dissemination of Information

Project Seminars

R+D work is part of our mandate and focuses on existing and foreseeable future problems. The main objectives of SANDEC's applied research comprise the development of technical and managerial solutions with a high degree of sustainability under the varying conditions prevailing in developing countries. Organisation of national or regional seminars with the major problem holders and solvers (government and non-governmental agencies, consulting engineers, external support agencies, applied researchers) are believed to offer an effective way of disseminating the results of applied field research. They allow for critical discussions of recommendations and results of the field research, and also raise awareness of the applied researcher to the most pressing and challenging problems, including the most appropriate future R+D efforts. Furthermore, such events may provide a platform for decision-makers and planners to discuss strategic, economic and institutional issues.

A national/regional seminar, jointly organised by WRI, local consultants and SANDEC, will be held in Accra, Ghana, in late 1997. Its aim is to present results, conclusions and recommendations of the WRI/SANDEC field research on FS settling/thickening, drying and pond treatment. It will also provide a forum for engineers, planners and decision-makers for discussions on FS management problems in Ghana. The seminar coincides with the planning of sanitation upgrading schemes for Ghana's major cities, which will be co-financed by the World Bank.

Similar events shall be organised and implemented jointly with some of our other field research partners.

Publications

SANDEC News No. 2 announced the publication of several reports on selected faecal sludge treatment options. A timely publication of the reports was, however, not possible for several reasons. The document entitled "Anaerobic and Facultative Ponds for Treatment of Septage and Public Toilet Sludges in Tropical Climates" has been externally reviewed by a number of experts. Comments from the reviewers shall be incorporated in the final document. The various reports will be made available in the near future.

Contacts

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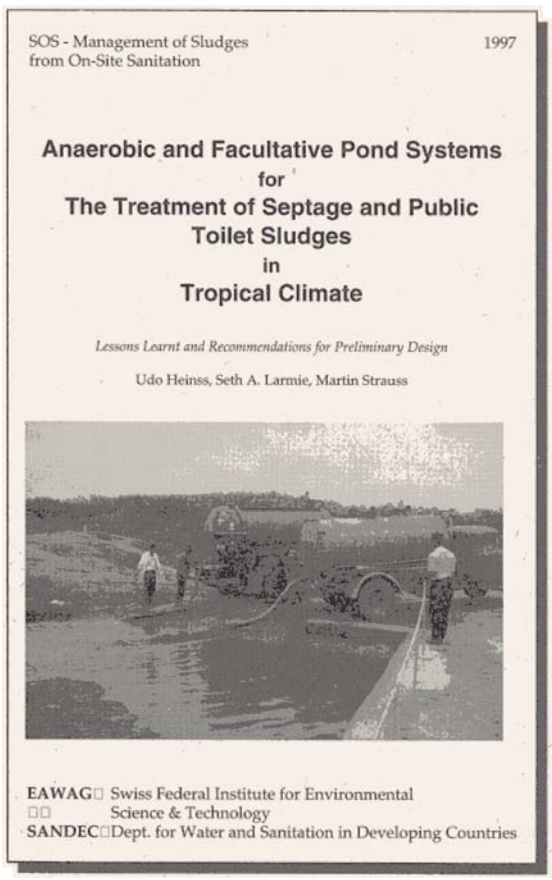
Forthcoming



On the Bookshelf

To our readers we recommend the following publications:

WASTEWATER TREATMENT/REUSE

Analysis of Wastewater for Use in Agriculture. A laboratory manual of parasitological and bacteriological techniques, by Rachel M. Ayres & D.Duncan Mara, WHO 1996. Price: CHF 12.-/USD 10.80; in developing countries: CHF 8.40. Available from WHO, Distributions and Sales, CH-1211 Geneva 27, Switzerland. Fax: +41-22-791 4857, e-mail: publications@who.ch.

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Anaerobic Sewage Treatment. A Practical Guide for Regions with a Hot Climate, 1994, by Adrianus C. van Haandel and Gatze Lettinga. ISBN 0-471-95121-8. Available from Customer Service, John Wiley & Sons Ltd, 1 Oldlands Way, Bognor Regis, West Sussex, PO22 9SA, UK.
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Guidelines for an Appropriate Management of Domestic Sanitary Landfill Sites, by H. Oeltzschner and D. Mutz, 1994. ISBN

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The World Health Report 1995: Bridging the Gaps, WHO 1995. Report of the Director General of WHO. ISBN 92-4-156178-5. Price: CHF 15.-/USD 13.50, in developing countries: CHF 9.-. Available from WHO, Distributions and Sales, CH-1211 Geneva 27, Switzerland. Fax: +41-22-791 4857.
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NEW SANDEC PUBLICATION

In English:
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