TO INVESTIGATE THE EFFICACY OF SOLAR RADIATION DISINFECTION OF SHALLOW WELL WATER CONTAMINATED WITH SUSPENDED SOLIDS.

MUTORO, M.A[1]
THUMBI, GM[2]

[1]Frame Consultants Ltd, Water and sanitation Division, P.O Box 58624, NRB,
[2]Department of Civil and Construction engineering, Technical university of Kenya, P.O Box 52428 NRB

Abstract

The solar disinfection of water (SODIS) is a technique used to inactivate microbes by sunlight. This research was conducted to determine the time and the optimum container sizes required for effectiveness disinfection of water by solar radiation. Turbidity, sample volume, exposure time, and bottle size were varied during the experiments. Experiments were conducted by exposing water collected from unprotected shallow well from Kahawa West area in Nairobiin clear plastic bottles to solar radiation. Turbidity was varied by addition of a random quantity of black cotton soil heated for one hour in dry metallic container. Sample volumes from 0.5, 10, 1.5, 2.0, 3.0 and 5 L, and turbidity values ranging from 2.1 NTU to approximately 90 NTU did not significantly affect inactivation levels when samples were exposed to sunlight for at least 4 hours. Inactivation of E. coli in samples with up to 100 NTU, took longer time. It is evident from this research that, Samples in 500 ML, bottle of low turbidity (of the order of 2.0 NTU), experienced rapid E. coli disinfection rates with exposure times of 2 hours. Samples in 1.0 L, 1.5 L, 2.0L, and 3.0 L bottles experienced similar E. coli disinfection rates with exposure times of 2 hours. Water volumes from 0.5L to 2 L can therefore be treated in approximately the same amount of time. The research has shown that water with turbidity not exceeding 90 NTU and in circular PET bottles of up to 3 liters capacity can be disinfected by solar radiation if exposed to the sun for a period of not less than five hours.

Keywords; Sodis, P.E.TPlastic, Microbes, Water, Disinfection, Sunlight

Introduction

In developing countries, numerous people are without any access to safe drinking water and according to world health organization 10 % of the global burden of disease can be attributed to lack of adequate drinking water, poor hygiene, and inefficient sanitation (WHO 2008).People rely on streams, rivers, ponds, rainwater from roofs, public cisterns, unreliable wells or fountain water (Rijal & Fujioka 2001). According to Wegelin et al. (1994), at least one third of the population in rural areas, poor suburbs and slums of developing countries and crisis areas are regularly exposed to numerous water related diseases due to the consumption of pathogen contaminated water. Children are especially vulnerable to water-borne and diarrhea diseases caused by pathogens(Kehoe et al. 2001). Availability of safe drinking water for everyone throughout the year remains an urgent but unsolved problem(UNICEF 2004). Whereas, long-term operation of sophisticated water supply systems by qualified technical staff, and funds budgeted for long-term maintenance are common in urban centers and industrialised countries, low-cost water purification techniques are required to provide safe and adequate drinking water in developing countries and crisis areas (Dorea C. 2012). Such techniques, preferably applied at household level (e.g. boiling, chlorination, filtration and solar water disinfection), seem to be more feasible and their implementation more likely to be effective and sustainable (T. Clasen, S. cairncross 2007).

Solar Water Disinfection (SODIS) is one of the home-based water treatment methods approved by WHO that takes advantage of solar energy abundant in many developing countries (Kehoe et al. 2001). It requires that water is put in polyethylene terephalate (PET) plastic bottles and then exposed to direct sunlight under clear sky conditions for waterborne pathogens to be inactivated thus making the water safe to drink (Wegelin et al. 1994; Conroy et al. 1996). Pathogenic inactivation is due to the synergistic effect of ultraviolet (UV) light and heat produced by solar radiation (McGuigan et al. 1998; Berney et al. 2006).Previous studies have found that solar disinfection is affected by numerous variables which include the wavelengths of solar radiation, temperature, turbidity, exposure time, and container selection (Acra A. et al., 1989). The SODIS experiment that was undertaken in this research involved treating water contaminated with suspended solids by assessing the inactivation of *E. coli*. The main objective is to obtain the effective time and size of container required to disinfect water using solar radiation. Turbidity was varied using black cotton soil and solar radiation and heating experiments and Solar Heating Only experiments were performed and results recorded. It was observed from the experiment that the samples of 90 NTU turbidity with varying container sizes resulted to 95% deactivation of *E. coli*within 2 hours and the remaining 5% of *E. coli* deactivated completely in another 2 to 4 hours because of cloud cover interferences. Samples with 2.0 NTU amount of turbidity in 500 ml had a rapid E. *coli* disinfection rates in 2 hours' time. Within the exposure time of 2 hours samples in 1.0 L, 1.5 L, 2.0 L, and 3.0 L bottles had a similar disinfection rateof *E. coli*. Water volumes from 0.5L to 2 L can therefore be treated in approximately the same amount of time.

Methodology

The experiments conducted for this study examined variables and their impact on the inactivation of E. coli by solar radiation. The samples for testing were collected from a well in Kahawa west East of Nairobi town. The water was analyzed for Turbidity, and E coli count. The first phase of experiments consisted of placing water with suspended solids solutions in direct sunlight and enumerating viable bacterial counts over time to quantify disinfection by solar radiation and heating. The second phase was testing the effects of solar heating only as it has been hypothesized that disinfection by solar heating is a combination of synergy between heating and UV radiation heating and combination of solar radiation.

Indicator organisms.

The indicator organism to be used in this experiment is Escherichia coli. Generally, Escherichia coli and to a lesser extent thermo tolerant coliform bacteria are considered to best fulfill the criteria to be satisfied by an ideal indicator(APHA-AWWA-WEF 1998). Basically, the criterion is that E. coli must not be detectable in any 100 millilitre (ml) sample.(WHO 2001)

Sampling procedures and analysis

Collection of samples was by bottles of circular shapes with diameter ranging from 50mm for the 500 MLS to 160mm for the 5 liters containers, Sample volume was varied using plastic bottles. Normal clear PET bottles of sizes 500 ml, 1L, 1.5L 2.0 L, 3.0L and 5.0L were used. The test bottles were taken, agitated, the cups removed and the mouth of the bottles framed with a gas lamp for a few seconds (R.H. Reed 1997). The plastic bottles and caps (PET bottles), used in the tests, were sterilized before each experiment. The surfaces both, inside and outside of the bottles was soaked in70% ethanol solution for 1 hour. The interiors of the bottles were then rinsed several times with the test water. This was to ensure that only the organisms in the test water were present in the bottles. Samples not exceeding100ml were taken at two hours intervals. For the small bottles size up to 1.5 liters, approximately 50 ml samples were collected from each of the different sizes of containers every two hours, and immediately stored in a refrigerator at 4^{o}C. The samples were delivered to the government owned Water Resources Management Authority (WARMA) laboratories in Nairobi the following day in a cool box where the coliform count tests were conducted immediately. During each sampling session, the time, weather conditions, water temperatures, air temperature, and sample volumes was recorded. Cloud coverage was estimated and given as a percent of less than 50 percent, or over 50 percent.

Turbidity was varied by using black cotton clay, sterilized by heating for one hour, as an artificial turbidity source, the clay particles settled between sampling sessions. Turbidity was added to specific test solutions in order to test the effects of higher turbidity levels on the inactivation of *E. coli* by solar radiation; however, turbidity level did not exceed 106NTU. The total exposure time of experiments was 8 hours. Sunlight is strongest from 10 am to 3 pm so experiments were conducted to encompass this time bracket by up to 1.0 hours before and up to 3 hours after (from 9:00 am to 5:00 pm).

For heating-only experiments, samples were exposed to solar heating by raising the temperature of the sample from an ambience temperature of 22.0°C to a maximum of 60.0°C., this was the maximum temperature achieved in the day. The heating-only test was conducted in one-liter PET bottles only.

Solar Radiation and Heating Experiments procedure

The impact of the several variables on the inactivation of *E. coli* by solar radiation was tested. Turbidity values ranging from 2.0 ntu to approximately 106 ntu were tested, and the effects of sample volume wastested using 500 mL, 1.0 L, 1.5L, 2.0L, 3.0L and 5.0 L sample bottles.

Two experiments for each variable were done per sample volume. One sample was from the water with lower turbidity, while the second sample was from the water with higher turbidity but from a similar bottle volume.

The experiments were conducted for eight hours, by placing the test bottles on a hard platform (see photo in the appendix). The platform had a clear view of the skies through the day without any obstruction.

For solar radiation without heating enhancement test, on the platform, an Aluminum foil paper was laidon platform before placing the test bottles to aid reflection(S.C. Kehoe, T.M. Joyce, 2001).The exposure experiments started from 9.00hours until17.30hours, each day. The test bottle was half way wrapped in a black polythene sheet, and exposed to the sun when the polythene sheet was under the bottle secured with plastic rubber bands. The progressive temperature gain was recorded every two hours, by the use of a dipping thermometer which was sterilized after ever dip, using 70% alcohol.

Solar Heating Only Experiments Procedure

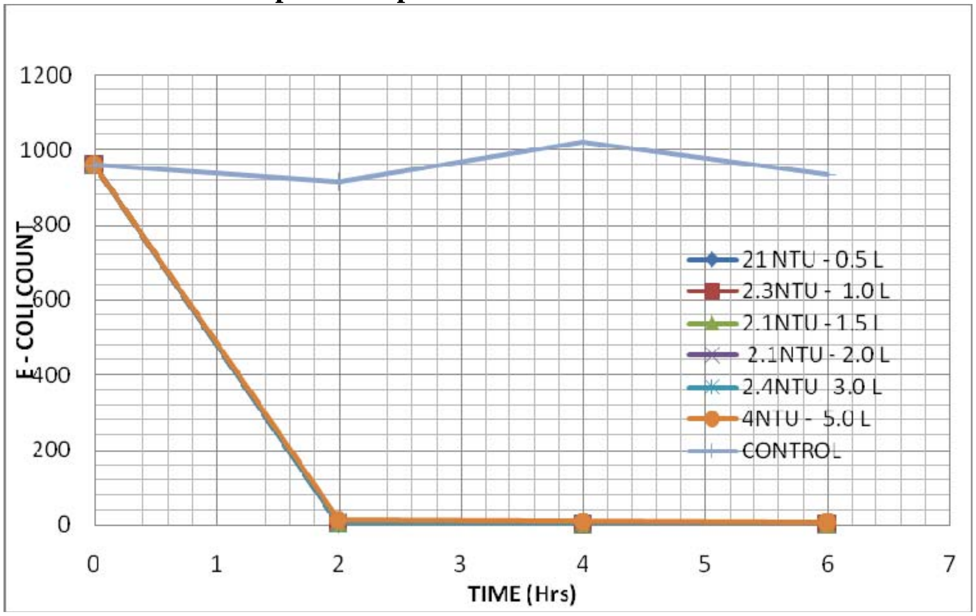
For heating-only experiments, samples were placed in the sun in plastic bottles and covered with a back opaque gauge 1000 and gauge 250 polythene sheet. This was to test the effects of heating only on the inactivation of E. coli. The progressive temperature achieved during the solar heating experiments was recorded every one hour while at the same time samples were collected for laboratory analysis to evaluate the inactivation of E. coli by heating progressively in one hour intervals for seven hours until the water started cooling. Water of low turbidity was tested. The maximum temperature achieve was 56^{o}C for the sample covered with gauge 1000 and 60^{o}C for the one in gauge 250. A control bottle was prepared for each experiment. The control bottle was the same as the test bottles; it contained a pre-measured sample solution without any adjustment. The purpose of the control was to ensure that the bacterial population remained constant over the course of each experiment, with no influences from external factors. The bottle was therefore covered with aluminum foil and placed in a room temperature(B. Sommer, A. Marino 1997). Samples were removed every two hours for the duration of each experiment.

Results and discussion

Exposure Time

Based on counts of colonies with characteristics of *E. coli,* there was over 95% inactivation of *E. coli* bacteria after 2 hours of exposure. Sample in 0.5 liters container, and with the least turbidity of 2.1 ntu, took the shortest time of less than 4hrs to inactivate the E coli completely, while the sample with more turbid water (26.3 ntu) from a similar size of the container took less than 6 hours to completely inactivate the E coli. The 5.0 liters sample with a higher turbidity of the order of 106ntu, showed a marked lag time of approximately 2 hours, to achieve the 95% deactivation. The maximum temperature achieved in the test sample was 38°C, in the smallest container of 0.5litres, while highest temperature achieved in the largest container of 5.0 litres was 35^{0} C. This maximum temperature was reached within 4 hours of exposure time. The inactivation results in the test and control bottles are shown in graph 1.1below.

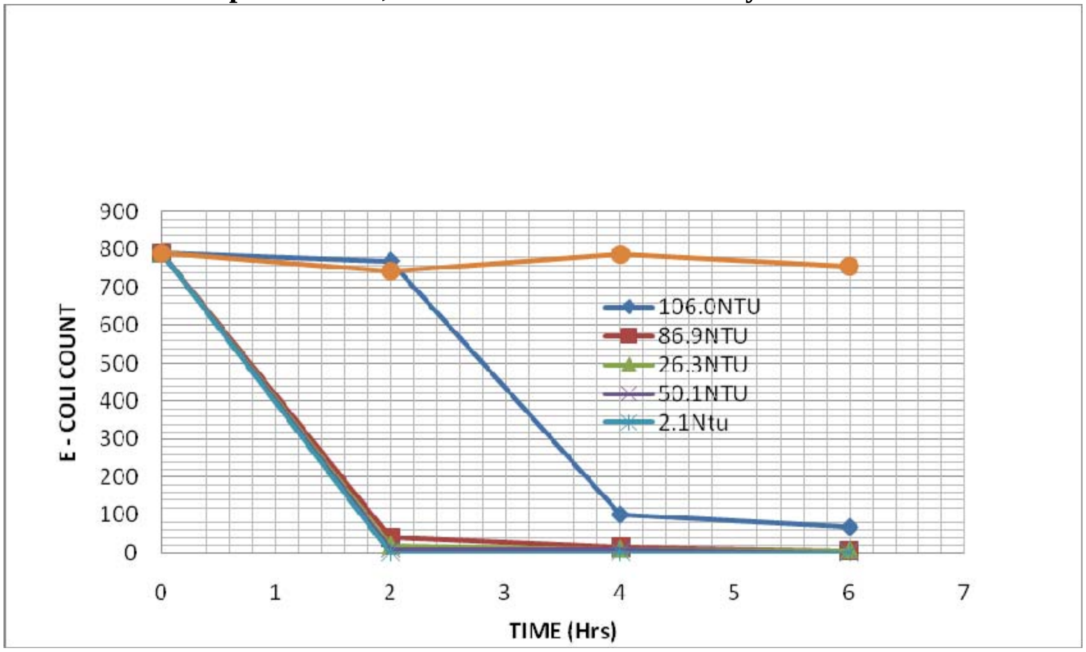
Graph 1.1 Exposure Time and E- Counts



Turbidity Variations

Solar disinfection tests were conducted to compare its effects on turbidity. Figure 1.2 shows the inactivation of *E. coli* for the lowest turbidity sample at 2.1 ntu, to the highest at106 ntu, over a six-hour exposure time. It took longer for the higher turbidity samples to achieve the same inactivation level, as the lower turbidity samples. After 2 hours of exposure time, the 106 ntu sample had only a 26% inactivation of *E. coli*, while the samples with less than 90.0 ntu had almost 95% inactivation. However, most samples had achieved complete inactivation (no detectable counts) of *E. coli* within a 6-hour time span, except the 5.0 liters container bottle, which had significant E coli count even at the end of theexperiment. From the experiment if the samples are exposed to sunlight for at least 6 hours it can be deduced that turbidity is not a significant variable when the value ranges from 0 to 90 ntu. The maximum temperature achieved in the samples with no added turbidity was 36°C; the sample had been exposed to the sun for 4 hours at this time. The water with the highest turbidity of106 ntu reached 35°C in 4 hours. The 2.1 ntu sample reached a maximum temperature of 38°C in 6 hours. The difference in temperature between the different samples was 3°C or less and therefore was not considered significant.

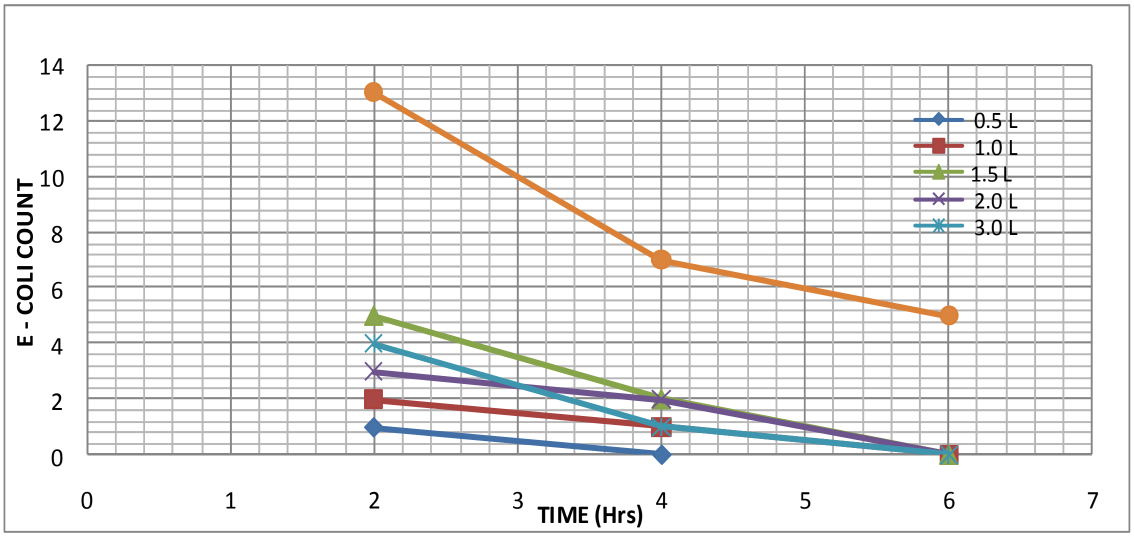
Graph 1.2 Time, E- coli counts and Turbidity variations



Volume Variations

On the relationship between sample volume and E coli inactivation, Samples volumes from 500 mL, 1.0 L 1.5 L, 2.0 L ,3.0 L and 5.0L bottles were tested. The results are shown in Figure 4.3.1 and 4.3.2, all samples had similar log inactivation rates of *E. coli* after two hours of exposure time, except the 5.0litres containers, where even at the end of the experiments there were still some viable e- coli organisms albeit very low numbers (see the chart showing the last four hours of exposure Fig 4.3.2

Fig 1.4 Magnified chart on Volume variations, Time and E- coli counts



The sample volume of 0.5 liters in PET bottle at 18 ^{O}C with turbidity levels of 148.3 NTU had 791 Counts of E coli at the start of the experiment. On subjecting the sample on solar radiation for a period of 4 hours there was a gradual reduction of both turbidity and E-coli counts and an increase in temperature from 18C to 32 ^{O}C. Temperatures above 30 ^{O}C have an important synergistic effect for solar disinfection (Wegelin et al., 1994). At end of 8 hours there were no E coli counts in the solution and a significant reduction in turbidity was witnessed as shown in the table below.

Table 1 .1 0.5 liters PET bottles

TIME (Hrs)	CODE	TURBIDITY (NTU)	GENERAL COLIFORM COUNT	E COLI COUNT	TEMPARATURE. (^{O}C)
	0.5L				
0	0T	148.3	1732	791	18
	0T	27	1986	960	18
2	T	21.5	74	12	32
	C	2.1	6	1	32
4	T	9.1	31	2	38
	C	2.2	6	0	36
6	T	53	9	0	32
	C	2	0	0	31
8	T	21.5	0	0	31
	C	2.1	0	0	29

The results in table 1.3 below shows constant values of turbidity for whole 6 hours solar radiation period. There was raise in temperature from 18 ^{O}C to 32 ^{O}C with the decreasing level of general coliform and E coli which is an indication that the solar energy was increasing the temperature of water by accumulating solar energy in the bottle which was consequently responsible for water disinfection. General Results shows that disinfection efficiency is reducing with increasing sample volume from 0.5L to 5L.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The main aim of conducting this research was to find out the effects of variables on the disinfection properties of solar radiation. The variables tested were turbidity, sample volume, and exposure time.

The following are the conclusions drawn from the research:

1. Exposure time for samples of turbidity of up to 90 ntu, resulted in 95% deactivation of *E. coli* within 2 hours and then another 2 to 4 hours to deactivate completely the remaining 5%, varying with the container size. This long period could be attributed to cloud cover interferences.

   However, since cloud cover is a normal phenomenon, the samples of up to 3.0 liters containers should be exposed to the solar radiation for minimum of 5 hours duration.
2. The *E. coli* bacteria were completely inactivated in samples with turbidity ranging from 2.1 ntu to 90 ntu with 4 hours of sunlight exposure time. If water samples with turbidity values below 90 ntu are exposed to sunlight during the course of an entire day, there is no significant difference in bacterial inactivation levels due to interference of turbidity particles. Samples in 500 ML, bottle of low turbidity (of the order of 2.0 NTU), experienced rapid E. *coli* disinfection rates with exposure times of 2 hours
3. Samples in 1.0 L, 1.5 L, 2.0 L, and 3.0 L bottles experienced similar *E. coli* disinfection rates with exposure times of 2 hours. Water volumes from 0.5 L to 2 L can therefore be treated in approximately the same amount of time.

Recommendations

The following are recommendations for future research.

1. E. coli is a common test organism and inactivation results correlate to the effects of solar disinfection on other organisms such as pathogenic bacteria. Its therefore important that solar disinfection tests and research be conducted on organisms other than bacteria. For example, studies on the effects of solar disinfection on organisms and protozoa.
2. Future research should focus on addressing some of the concerns and gaps in research associated with scaling up of SODIS volumes. These include the potential for leaching of plastic additives into treated water, temperature profiles and climatic conditions under which Water dispenser container perform well and the effectiveness of the method when coupled with pretreatment techniques.
3. At community level, social research is necessary to look at the perceived and acceptance benefits of solar water disinfection and its role in improving the communities economic and social stress in conflict areas.

REFERENCES

1. Acra, A., Jurdi, M., Mu'allem, H., Karahagopian, Y. et Raffoul, Z., (1989), Water disinfection by solar radiation, assessment and application, CRDI, p 86.
2. APHA-AWWA-WEF, American Public Health Association, A.W. Works, W.E.F. Association, Standard Methods for the Examination of Water and Wastewater in, New York, NY, 1998.
3. B. Sommer, A. Marino, Y. Solarte, M.L. Salas, C. Dierolf, C. Valiente, D. Mora, R. Rechsteiner, P. Setter, W. Wirojanagud, H. Ajarmeh, A. AlHassan, M. Wegelin, SODIS – an emerging water treatment process, J. Water SRT – Aqua 46 (1997) 127–137.
4. Dorea CC. Comment on “Emergency water supply: A review of potential technologies and selection criteria.”. Water Res. 2012;46(18):6175–6.
5. Fujioka, R. S., Hashimoto, H. H., Siwak, E. B. & Reginald, H. F. 1981 Effect of sunlight on survival of indicator bacteria in seawater. Appl. & Env. Microbiol. 41(3), 690–696.
6. Kehoe, S. C., Joyce, T.M., Ibrahim, P., Gillespie, J. B., Shahar, R. A. &McGuigan, K. G. 2001 Effect of agitation, turbidity, aluminium foil reflectors and container volume on the inactivation efficiency of batch process solar disinfectors. Wat. Res. 35(4), 1061–1065.
7. Prüss-Üstün ABR, Gore F, Bartram J. Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health. Geneva: World Health Organization; 2008.
8. R.H. Reed, Solar inactivation of faecal bacteria in water: the critical role of oxygen, Lett. Appl. Microbiol. 24 (1997) 276–280.
9. Rijal, G. K. & Fujioka, R. S. 2001 Synergistic effect of solar radiation and solar heating to disinfect drinking water sources. Water Sci. Technol. 43(12), 155–162.
10. S.C. Kehoe, T.M. Joyce, P. Ibrahim, J.B. Gillespie, R.A. Shahar, K.G. McGuigan, Effect of agitation, turbidity, aluminium foil reflectors and container volumeon the inactivation efficiency of batch-process solar disinfectors, Water Res. 35 (2001) 1061–1065.
11. Smith, R. J., Kehoe, S. C., McGuigan, K. G. & Barer, M. R. 2000 Effects of simulated solar disinfection of water on infectivity of Salmonella typhimurium. Letters in Appl. Microb. 31,284–288.
12. Smitt Skydd sinstitutet - WHO, 2001 Assessment of risk and risk management for water-related infectious disease
13. T. Clasen, S. Cairncross, L. Haller, J. Bartram, D. Walker, Cost-effectiveness of water quality interventions for preventing diarrhoeal disease in developing countries, J. Water Health 5 (2007) 599–608.
14. UNICEF (Water, environment and sanitation statistics 2004)
15. Water, environment and sanitation statistics 2004 www.unicef.org/es/index_statistics.html.
16. Wegelin, M., Canonica, S., Alder, A. C., Marazuela, D., Suter, J.-F.,Bucheli, Th. D., Haefliger, O. P., Zenobi, R.,McGuigan, K. G., Kelly, M. T., Ibrahim, P. & Larroque,M. 2001 Does sunlight change the material content of polyethylene terephtalate (PET)bottle? J. Water SRT-Aqua 50(3), 125–133.
17. Wegelin, M., Canonica, S.,Mechsner, K., Pesaro, F. &Metzler, A. 1994 Solar water disinfection: scope of the process and analysis of radiation experiments. J. Water SRT-Aqua 43(3), 154–169.