VARIATION OF THE STERILISATION BOTTLE FOR SOLAR WATER DISINFECTION

Pavel KOUŘÍM[1], Bohumil CHALUPA[1], Josef ZEMAN[1]

[1]*Department of Physics, Faculty of Engineering, Czech University of Life Sciences Prague*

Abstract
The project was inspired by the successful Swiss project Sodis (Solar Disinfection), in the frames of which spreading of the ability to disinfect water by the Sun is under way in the tropical areas of the whole world, namely with the help of used PET bottles, thus almost with no expenses. We tried, with a slight modification of the PET bottles used, to attain the desired effect, i.e. making surface water drinkable also in conditions where there isn't sufficient solar intensity, or the temperatures of ambient air cause too intensive cooling of the water sterilized. All our modifications of the disinfection containers increase the water treatment costs only very slightly. Six variations of sterilisation containers were compared in our test: original simple, a simple one placed into a sheath made of a bigger transparent bottle, a bottle fitted with a half-cylinder aluminium foil reflective element, a bottle with the half-cylinder reflective element placed in a sheath made of a bigger transparent bottle, a blacked bottle, and a lacked bottle placed into a bigger transparent bottle. All bottles for the water were 1.5 litre bottles from the Pepsi drink. 2.25-litre Pepsi bottles then form the outer sheaths. The bottles were filled with water from a pond and exposed to the sun for 10 hours; then the water from each bottle and the water from the pond have undergone microbiological analysis. The number of Escherichia Coli, coliform bacteria, the number of cultivated micro-organisms at 20 and 36 °C for 24 hours were determined in all seven samples. The result is a finding that as long as the water temperature does not reach at least 55 °C, the essential sterilisation factor is the UV component of the incident radiation; from that follows that the best results in immediate E. coli and coliform bacteria concentration has the bottle equipped with a half-cylinder aluminium reflector. Black-painted bottles, on the other hand, had reached by 15 degrees higher temperatures though, however this only caused more successful bacteria reproduction, but their die-off did not arrive due to the impenetrability of the bottles for the UV radiation, and the number of bacteria, especially in the cultivated samples, surpassed the original values by orders of magnitude.

Key words: *water disinfection; Sodis; solar disinfection; PET bottles.*

INTRODUCTION

Unsafe drinking water, along with poor sanitation and hygiene, are the main contributors to an estimated 4 billion cases of diarrhoeal disease annually, causing more than 1.5 million deaths, mostly among children under 5 years of age (*WHO 2005*). As part of its Millennium Development Goals, the United Nations expressed its commitment by 2015 to reduce by one half the people without sustainable access to safe drinking water. Current estimates are that there are still 1.1 billion people without this access (*WHO/UNICEF 2006*). However, results from a recent assessment in six pilot countries, found that 31 % of drinking water samples from boreholes exceeded WHO guideline values (GV) and national drinking water standards in the pilot countries for faecal contamination, the leading source of infection and disease (*-RADWQ 2006*). In one of the pilot countries, only 43.6% of samples from stored water were in compliance with the WHO guideline value and national standards, and more than half of household samples showed post-source contamination.

Boiling or heat treatment of water with fuel is effective against the full range of microbial pathogen s and can be employed regardless of the turbidity or dissolved constituents of water. While the WHO and others recommend bringing water to a rolling boil for 1 minute, this is mainly intended as a visual indication that a high temperature has been achieved; even heating to pasteurization temperatures (60 °C) for a few minutes will kill or deactivate most pathogens (*UNICEF, 2008*). However, the cost and time used in procuring fuel, the potential aggravation of indoor air quality and associated respiratory infections, the increased risk of burn, and questions about the environmental sustainability of boiling have led to other alternatives.

One of the possibilities, besides ceramic filters and water chlorination, is also solar sterilisation according to the SoDis system (*Meierhofer & Wegelin, 2002*). This inexpensive method utilizes cumulative effect of solar heating-up by thermal radiation and the effect of UV radiation in PET bottles with water, exposed to solar radiation for 24 hours.
Solar disinfection has been repeatedly shown to be effective for eliminating microbial pathogens and reduce diarrhoeal morbidity (*Hobbins 2004*) including epidemic cholera (*Conroy 2001*). Among the most practical and economical is the "Sodis" system, developed and promoted by the Swiss Federal Institute for Environmental Science and Technology (http://www.sodis.ch). It consists of placing low turbidity (<30NTU) water in clear plastic bottles (normally 2L PET beverage bottles) after aerating it to increase oxygenation and exposing the bottles to the sun, usually by placing them on roofs. Exposure times vary from 6 to 48 hours depending on the intensity of sunlight. Like filters, thermal and solar disinfection do not provide residual protection against recontamination. Accordingly, householders must have a sufficient number of bottles to allow them to cool and maintain treated water in the bottles until it is actually consumed (*UNICEF, 2008*).
Experiments were also done with various modifications of this method, e.g. glass bottles were used instead of the PET ones (*SODIS, 1998*), with little success though; its reason can be seen in the bad UV transmittance of the glass of the thickness used for common bottles.
The aim of this study was verifying the usability of the SODIS method in higher latitudes (central Europe) using disinfection containers – bottles with several modifications.

MATERIALS AND METHODS

On August 15th 2017 at 8:00 AM seven water samples were taken from an open fire pond at coordinates 50.129788N, 14.374491E in the premises of the Czech University of Life Sciences in Prague, Czech Republic. The samples were placed into six PET bottles according to the SODIS procedure described above; the seventh sample was cooled to 4 °C and left at this temperature in dark place for the whole day. Six variants of sterilisation containers were compared in this test (fig. 1): Original plain one, a plain one placed into a casing of a larger transparent bottle, a bottle equipped with a half-cylinder aluminium foil reflector, a bottle equipped with a half-cylinder aluminium foil reflector placed into a sheath of a larger transparent bottle, a black-painted bottle and a black-painted bottle placed into a sheath of a larger transparent bottle. All bottles for the water were 1.5 litre bottles from the Pepsi drink, the outer sheaths from 2.25 Pepsi then.

Fig. 1 Six variations of sterilisation bottles exposed to the sun.

Besides the temperatures in the bottles, air temperature and solar radiation were measured. Radiation was measured with a CM11 pyranometer from Dutch company Kipp & Zonen B. V. Used thermometers were electronic ones with DS18B20 chip sheathed in stainless steel sheaths, and equipped with a reflexive radiation shield inside the bottles. The air thermometer was equipped with the radiation shield too. After 10 hours elapse, samples were taken from all six bottles into glass containers with ground mouths, see fig. 2, and those stored in dark at 4.5 deg. C till the next morning.

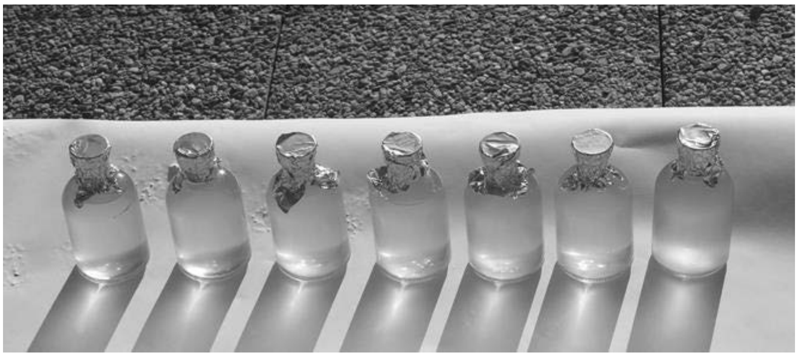

Fig. 2 Samples taken after 10 hours exposition in variously modified containers

Next morning, all seven samples were delivered to an accredited laboratory No. 473-ASLAB T. G. Masaryk Water Research Institute, public research institution, for microbiological analysis, where analysis according to the ČSN EN ISO/IEC 17 025:2005 standard was made.
In the results clarification attempt, GIMP 2.8 program and OceanOptics USB2000+ spectrometer were used for determining relative colours.

RESULTS AND DISCUSSION

On the day of measurement, i.e. August 15th, 2017, it was a nice sunny day; the run of the solar radiation indicates the chart in the following Fig. 3.

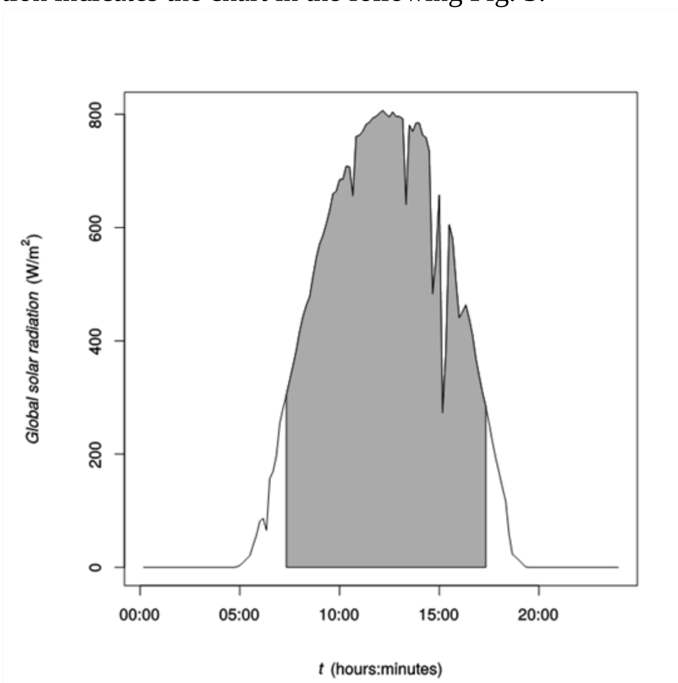

Fig. 3 Solar radiation on the day of measurement. Exposure time of the bottles is highlighted.

Total incident energy per square meter on that day added up to 23.7 MJ, where during the exposure time the energy totalled 22 MJ, i.e. 93 %. Minimum solar radiation during the exposition part of the day was 272.8 W/m^2, maximum 806.8 W/m^2, median 640.7 W/m^2 and mean was 603 ± 172 W/m^2. Incident solar radiation on the PET bottle used totalled about 0.6 MJ.

Following Fig. 4 illustrates that even on a sunny August day, required temperature of above 55 °C necessary for heat pasteurisation of the water *(Luzi et al. 2016)*, cannot be reached with tested bottle combinations. At the same time one can recognize that the influence of the double wall caused usually an 8–9 °C increase, while the black painting a 7 °C one. The bottle with reflector occurred always between the transparent bottle and the black one, in both insulated and non-insulated bottles.

About twice as great mutual thermal differences occurred between bottles with insulation than between bottles w/o insulation. Water temperature maximum over ambient air reached a noon maxima about 10 °C in non-insulated bottles and another 10 °C higher in insulated ones.

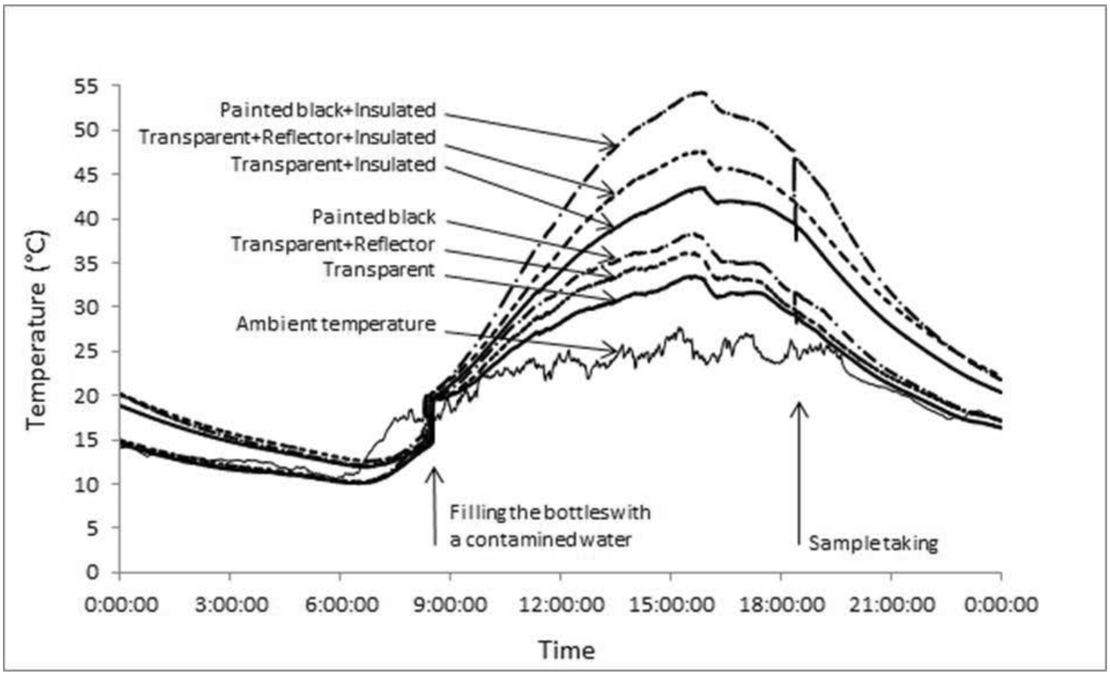

Fig. 4 Temperatures in particular bottles during the measurement day, together with ambient temperature.

Following Table 1 indicates number of organisms in the original water sample REF and in samples treated in six bottle types.

Tab. 1 Results of microbiological analyses of samples. REF – original untreated sample, BL+INS – black painted insulated bottle; BL – black painted bottle; TR+REF+INS – bottle with reflective layer and insulated; TR+REF – transparent bottle with reflective layer; TR+INS – transparent bottle, insulated; TR – transparent bottle; CFU – colony forming units; MO – micro-organisms.

Indicator	Unit	REF	BL+INS	BL	TR+REF+INS	TR+REF	TR+INS	TR
Esch. coli	CFU/100 ml	270±40	<10	180±40	<2	<10	<10	10±40
Colif. bact.	CFU/100 ml	270±40	<10	180±40	<2	<10	<10	10±40
Cultiv. MO at 22 °C	CFU/1 ml	1600±40	56800±40	7000±40	4200±40	5600±40	6400±40	1400±40
Cultiv. MO at 36 °C	CFU/1 ml	1800±40	35000±40	4400±40	6400±40	1800±40	8000±40	2600±40

As a first observation we can state that *Escherichia coli* and coliform bacteria content decreased in all bottle types. After cultivation at 22 °C it appeared though that the number of colonies decreased only in the plain non-insulated transparent bottle. On the other hand, after cultivation at 36 °C, lower number of colonies than in the reference sample was not recorded in any treated sample. Only in the transparent bottle with reflector, the number at least did not increase. Gigantic number of cultivated microorganism colonies at both 22 °C and 36 °C was reached in the black-painted bottle with insulation. Their number increased 20 and 30 times in comparison to the original sample. Generally it can be stated that more colonies were usually found in the insulated bottles than in the single-walled ones after cultivation. This applies absolutely after the cultivation at 36 °C, where double-wallness caused 3 to 8 fold increase. Cultivation at 22 °C recognized an increase in colonies caused by two walls in the transparent bottle and in the black one, while in the bottle with a reflector two walls caused a slight decrease. As can be seen from Tab. 1 from the listed deviations, that at the same time constitute the interval of 86% reliability of the result, all results differ significantly from each other, with the exception of very low concentrations of 10 CFU per reference volume and less. The most dangerous bacteria, E. Coli, were practically killed by the sterilisation process in all bottle types with the exception of simple black-painted bottle. This confirms that temperature cannot disinfect the water by itself when it is not high enough and UV radiation is blocked *(Luzi et al. 2016)*.

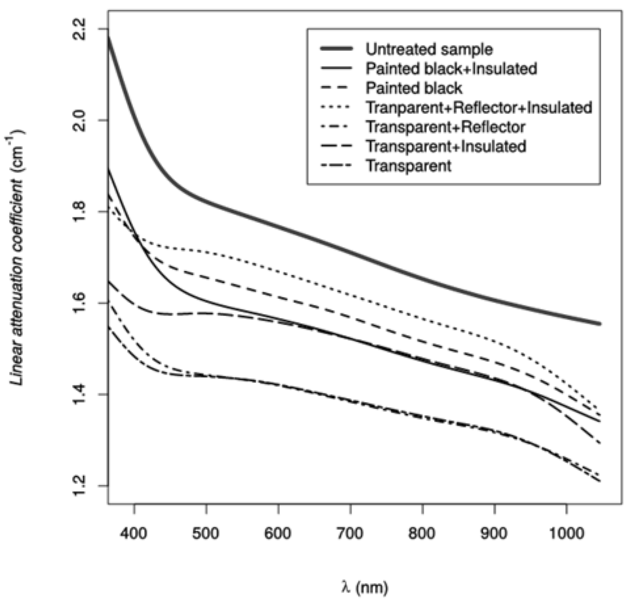

Fig. 5 Coefficient of absorption for non-treated sample and for the six variants of treated samples, for visible and near IR spectra

The absorption coefficient chart indicates that for all samples it applies that they show lowest absorption at the highest wavelengths. The sample that differs most in shape from the other ones by the most increased absorption in the violet spectrum part is the one that was treated in black painted insulated bottle. In this area, the most different from this one is the sample treated in the transparent insulated bottle. Treatment in the plain transparent bottle caused the largest absorption change in the examined wavelength range. The most similar shape to the original absorption curve has the sample treated in black insulated bottle. Mutually most similar shapes have the samples from the transparent bottle and the transparent bottle with reflector.
Following Table 2 shows that relative colour results determined in the GIMP 2.8 program, as mean sample from fig. 1, the spectral curves from Fig. 4 are in accordance with the data in this table.

Tab. 2 Colour composition of bottles with samples from Fig. 1:. REF – original untreated sample, BL+INS – black painted insulated bottle; BL – black painted bottle; TR+REF+INS – bottle with reflective layer and insulated; TR+REF – transparent bottle with reflective layer; TR+INS – transparent bottle, insulated; TR – transparent bottle. Values in the table are 8-bit colour components of the (RGB) colours of respective samples.

colour	REF	BL+INS	BL	TR+REF+INS	TR+REF	TR+INS	TR
Red	157	167	165	160	166	159	165
Green	152	166	163	161	165	159	163
Blue	116	144	121	155	135	136	133

Cardinal result of this work is thus orientation of following studies dealing with water sterilisation by this way in colder conditions, namely in the direction to UV concentration maximisation in the treated sample. At the same time we show that the attempts to cheaply increase the temperature are rather counter-productive. That direction can be successfully omitted from the further optimisation development.

CONCLUSIONS

In the Czech Republic conditions, UV radiation is essential for water sterilisation using bottles. Temperature increase at the cost of UV decrease is highly counter-productive. Intensity of green colouring of the treated water correlates only slightly with the concentration of the dangerous bacteria E. coli and coliform bacteria.

REFERENCES

1. Conroy, R. M., Meegan, M. E., Joyce, T., McGuigan, K., & Barnes, J. (2001). Solar disinfection of drinking water protects against cholera in children under 6 years of age. *Archives of Disease in Childhood.* 85(4), 293–5.
2. Hobbins, M. (2004). *Home-based drinking water purification through sunlight: from effectiveness to health effectiveness*. [PhD thesis]. University of Basel. Retrieved from http://pages.unibas.ch/diss/2006/DabsB_7569.pdf
3. Luzi, S., Tobler, M., Suter, F., & Meierhofer, R. (2016) *SODIS manual* (updated). Eawag, Sandec. Retrieved from http://www.sodis.ch/methode/anwendung/ausbildungsmaterial/dokumente_material/sodis-manual_2016.pdf
4. Meierhofer, R. & Wegelin, M. (2002). *Solar water disinfection — A guide for the application of SODIS* (PDF). Swiss Federal Institute of Environmental Science and Technology (EAWAG).
5. RADWQ (2006). Rapid Assessment of Drinking Water Quality, Summary Report. World Health Organization/UNICEF.
6. SODIS (1998). "SODIS Technical Note # 2 Materials: Plastic versus Glass Bottles". sodis.ch. 20 October 1998.
7. UNICEF (2008). Promotion of Household Water Treatment and Safe Storage in UNICEF Wash Programmes.
8. WHO (2005). Progress towards the Millennium Development Goals. Retrieved from https://unstats.un.org/unsd/mi/goals_2005/goal_2.pdf
9. WHO (2006). Mortality Country Fact Sheet 2006: Ethiopia, Geneva: World Health Organization. Retrieved from http://www.who.int/whosis/mort/profiles/mort_afro_eth_ethiopia.pdf

Corresponding author:
Ing. Pavel Kouřím, Department of Physics, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic, phone: +420 22438 3291, e-mail: kourim@tf.czu.cz