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Using solar disinfected water: On the bacterial regrowth over 1-week of water usage including direct intake after sun exposure and long-term dark storage

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Abstract

Safety and durability of solar disinfected water was studied along 1-week of simulated real water-usage. Water temperature during storage, microbial content and water quality were monitored. Initial raw water containing *Escherichia coli* and total coliforms were exposed to sunlight following SODIS guidelines and then stored prior to use. Simulated actions related to water usage were: direct human intake after disinfection (inoculating water sample in an enriched medium + incubation at 37 °C for 24 h); use of water from partially filled bottles that are back to storage again (water analysis from the same bottle over a week); and use of the entire water volume from fully filled bottles (water analysis from independent bottles over a week). Results show that SODIS treated water that achieved complete disinfection (0 CFU/100 ml) does not pose a health risk if consumed just after disinfection or stored in bottles carefully handled (either using partially or fully filled bottles) to avoid external contamination. For water that presents residual bacteria population after SODIS, regrowth might occur depending on water storage temperature, water nutrients content, storage period, and cells condition after sun exposure.

Keywords: Solar disinfection; Water storage; Regrowth; *E. coli*; Temperature; Health risk

1. Introduction

Solar water treatment is one of the current raising technologies for sustainable clean water production reducing the environmental impact by using renewable energy. There is a wide variety of systems using different mechanisms of solar energy conversion and new advances in material science and engineering reactors technologies: from solar stills (Karimi et al., 2015; Bhardwaj et al., 2015; Malaeb et al., 2016; Gad et al., 2015; Ibrahim and Eshhamarka, 2015), desalination systems (Suárez et al., 2015; Sankar et al., 2015; Salata and Coppi, 2014; Zaragoza et al., 2014) and solar photocatalysis reactors (Lima et al., 2015; Khanna and Shetty, 2014; Wang et al., 2014) intended for industrial applications, to domestic solar cookers (Joshi and Jani, 2015; Farooqui, 2015; Kumar et al., 2010) and low cost solar disinfection (SODIS) using plastic bottles exposed to the sun for safe drinking water generation in developing countries (SODIS, 2002).

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One of the risks of solar disinfection that hampers its widespread is the potential regrowth of the inactivated bacteria when disinfected water is stored prior consumption. As SODIS method does not leave any residual biocide agent in the disinfected water as it occurs after the disinfection by sodium hypochlorite with the residual free chlorine (WHO, 1996), bacteria regrowth might occur posing a health risk to the final user depending on storage water conditions – mainly temperature-, water nutrient content and level of disinfection achieved (CFU/100 ml). Since the first studies on SODIS conducted by Acra et al. in 1984 (Acra et al., 1984), regrowth has been always a major concern. Their initial experiments, using an *Escherichia coli* laboratory strain and storing the disinfected water at room temperature for a period of 5 days, did not present regrowth. Later on, after the first workshop on SODIS held in Montreal (Canada) in 1988, Lawand et al. (1988) summarised the main conclusions and questions about solar disinfection, including several related to potential regrowth. One of the results found was that "non-turbid water stored for long periods of time in dark opaque containers eventually become almost totally free of pathogenic bacteria", but no detail on period length or storage conditions were given. Another interesting future question was "if inactivated pathogenic bacteria that were non-detectable would recover if placed in a proper environment such as the human body".

From that moment onwards, SODIS studies often included a post-irradiation regrowth analysis, with different results. On one side there are studies that have not observed any regrowth, as those from Wegelin et al. in 1994 (Wegelin et al., 1994), which stored the treated water at 20 °C after sun exposure, not detecting any *E. coli* regrowth; or from Sommer et al. (1997) that used instead 30 °C as storage temperature, not observing either any faecal coliforms regrowth within 24 h after exposure and complete inactivation. Oates et al. (2003) in Haiti also stored the water for 1 day with no regrowth but the storage conditions are unkown, and Berney et al. (2006) did not observed any recovery of *E. coli* cells during 5 days after irradiation, showing with different viability indicators that the damage cause by UVA in *E. coli* is irreversible. More recent studies supporting this statement and not showing any bacteria regrowth, including *E. coli* and total coliforms, usually store the water for 2–3 days, all after complete total inactivation (Boyle et al., 2008; Nanvtoft et al., 2008; Sciacca et al., 2010; Ubomba-Jaswa et al., 2010; Alrousan et al., 2012; Rodrigues et al., 2013; Helali et al., 2014; Giannakis et al., 2014; Ndounla et al., 2014; Nalwanga et al., 2014).

But there is also a group of studies that have detected bacteria regrowth in water treated with SODIS. Kehoe et al. (2001) observed *E. coli* regrowth in turbid water (100 NTU) after 24 h and total inactivation, although detection limit was not given and some remaining bacteria might have been present after sun exposure. Fernandez et al. (2005) also detected *E. coli K12* regrowth in water treated only with SODIS and without photocatalyst added after 24 h at room temperature storage, concluding that the reason for regrowth was the presence of viable bacteria that had not achieved complete inactivation after sun exposure. The same conclusions were obtained by Gelover et al. (2006), observing coliform bacteria regrowth after sun exposure with an initial residual concentration of 10 CFU/100 ml during 7 days of storage, but reaching bacteria final death on day 7, in agreement with the findings from Lawand et al. (1988). Additionally, in a work conducted by Mustafa et al. (2013) in Pakistan in 2013, after 1 week of storage at room temperature – not specified – , regrowth was found on 51% of the samples in water that had not been completely disinfected. In a more recent study, Keogh et al., 2015 using 19-L polycarbonate plastic water cooler containers and PET bottles, no regrowth was observed after 24 h at room temperature (25 °C) in the large containers (detection limit of 2 CFU/ml) vs. 2 CFU/ml regrowth found in the PET bottles.

Finally, other authors have studied regrowth but incubating the samples in the dark at 37 °C for 24 h, as Rincon et al. (2004, 2007), which observed *E. coli* K12 regrowth using this method in water that had not been completely inactivated. Following the World Health Organisation (WHO) Drinking-water Guidelines (WHO, 2011), total bacteria inactivation is reached when it is not detected any colony-forming bacteria unit in 100 ml water (0 CFU/100 ml) using standard detection and enumeration methods. In all these studies that present regrowth, this limit had not been reached, so residual bacteria population might have been present and then regrow under suitable conditions. These storage conditions are often not given in the literature, mentioning 'room temperature' in some cases, but without specifying if this corresponds to controlled laboratory room temperature conditions (25 °C). In this regard, Giannakis et al. (2014) have recently shown that water temperature storage might have a role in the regrowth process, inhibiting potential regrowth or increasing it, along with water nutrient content and level of injury in the cells (related to sun exposure period).

The objective of this work is to study the potential regrowth of *E. coli* and Total coliforms when using solar disinfected water over a week after disinfection simulating real water usage and monitoring the storage conditions along with the water quality. This includes direct human intake after disinfection and use of stored water under real storage conditions, both from partially and fully filled plastic bottles.

2. Materials and methodology

Regrowth tests were conducted after solar disinfection of microbial contaminated water in plastic bottles following the SODIS method. The bottles were exposed to the sun at the rooftop facilities of IMDEA Water (Alcalá de Henares, Spain), under sunny climatic conditions over different weather stations of the year, including winter, spring and summer. *E. coli* and total coliforms were used as