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# Disinfection of total coliform bacteria in Falaj water by solar water disinfection (SODIS)

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## ABSTRACT

In this study an attempt has been made to disinfect total coliform bacteria present in Falaj water using solar water disinfection (SODIS) technology. SODIS experiments were conducted in winter (February 2018) and summer (May 2018) using polyethylene terephthalate (PET) bottles (less, thin and thick plastic PETs) and the glass ones of different capacities (0.5, 1 and 1.5 L). The results showed that total coliform disinfection rate in May was two folds greater than that in February. Water depth or volume of sample in the bottle had significant effect on the efficiency of SODIS. Highest disinfection rate was found on the samples collected from water depth of 6 cm (0.5 L), while the lowest was observed on samples of 8 cm in depth (1.5 L). No significant difference was observed in disinfecting total coliform between glass and less plastic PET bottle for shorter exposure periods (1 h). Results of this research have proved SODIS as an appropriate household water treatment and safe storage for disinfecting Falaj water in Oman. This study is a step forward in Oman to employ solar energy in the water and wastewater treatments.

**Key words**: Falaj water, Total coliform bacteria, SODIS, PET bottles.

## INTRODUCTION

The Sultanate of Oman is located in the south-east of the Arabian Peninsula. Conventional water resources, including surface and underground water, constitute 85% of Oman's water resources, while desalinated water and treated wastewater constitute the rest. Mega desalination facilities located at Barka, Muscat, Sur and Sallalah account for 76% of produced water, while small desalination plants and wells contribute 4% and 20% respectively. Wells are considered as strategic long-term reserve, mainly used as an alternative resource during peak consumption or plant shutdowns. Aflaj (singular Falaj) are surface and/or underground channels fed by groundwater, springs, or streams, built to provide water to communities for domestic and/or agricultural use (Al-Marshudi 2001; Zekri & Al-Marshudi 2008). Aflaj system was existed in Oman area date back to 2500 BC. Oman has over 4,000 falaj systems, of those, some 3,000 are still in use, which account for almost 700 $m^3$ water annually (Fairouz Megdiche-Kharrat *et al*. 2017). To date, Falaj channels continue to be the only water supply for many villages. Unfortunately, despite efforts by authorities to educate people about proper use of this resource, it is being polluted by some who use Aflaj for doing laundry, dishwashing, carwashes and bathing. This can release grease and other pollutants into the water. Many studies have been conducted on Aflaj in Oman related to their physical structure, method of construction and governance, irrigation scheduling, water right and market (Abdel Rahmnn & Omezzine 1996; Norman *et al.* 1998; Al-Marshudi 2007; Zoubeida Tayara 2015). However, very little information is available on quality, suitability for domestic purposes and treatment of Falaj water. In Nizwa region, water quality of Falaj Daris is appropriate for drinking. It requires certain methods of disinfection such as chlorination, ozonation or UV sterilization to nullify the effect of BOD values (Yaqoub *et al*. 2015).

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Water quality assessment of the selected Aflaj in Al Jabal Al Akhdar area indicated that quality parameters are within the permissible limits of MD 5/86, 1986 (Regulations for wastewater reuse and discharge in Oman). However, most of the Aflaj are contaminated with *E. coli* bacteria; indicating unacceptable for drinking according to guidelines of Omani and WHO standards (Al-Kalbani *et al.* 2016). From the previous studies, we understood that, Falaj water can be made fit for drinking by simple disinfection. Being simple, reliable and cost effective (Oates *et al.* 2003; Gelover, Gómez *et al.* 2006; Sichel *et al.* 2009; McGuigan *et al*. 2012), SODIS [a standard water treatment method based on the principle of solar (water) disinfection] can be an appropriate household water treatment and safe storage (HWTS) for disinfecting Falaj water, particularly in rural areas. Another advantage of SODIS in Oman is the availability of clear sky, with high temperatures throughout the year. Since disinfection potential of SODIS varies from place to place, needs to be studied under different local environmental conditions, like solar radiation, temperature, precipitation etc. To the best of our knowledge, no studies related SODIS have been conducted in Oman. The main objective of this study is to develop base line data, which may be useful for further research in future.

## MATERIALS AND METHODS

### Falaj water samples

Falaj water required for this study was collected in a clean sterilized plastic container from the Falaj channel located in Birkat al Mouz, in Nizwa Wilayat. Collected samples were transported to environmental engineering lab, University of Nizwa, Nizwa for SODIS treatment and microbial analysis.

### SODIS containers

Batch- process SODIS involves exposing microbially - contaminated drinking water to solar radiation in transparent containers such as plastic bags or plastic or glass bottles. In the present study, transparent conical-shaped polyethylene terephthalate (PET) and glass bottles were used. To examine the effect of bottle wall thickness on SODIS efficiency, less plastic (0.20 mm in wall thickness), thin walled (0.24 mm) and thick-walled (0.30 mm) PET bottles were used. In Oman less plastic and thin-walled PET bottles are used for supplying bottled drinking water and thick walled are used for supplying juices.

### SODIS technique

All the SODIS experiments were performed under natural solar radiation in an open space behind engineering labs at the University of Nizwa, Birkat Al Mouz, Oman (Latitude: 22.8918; Longitude: 57.5554).

As shown in Fig. 1 transparent containers was filled by the Falaj water and exposed to direct sunlight. The efficiency of SODIS in disinfecting Falaj water was tested under different depths/volumes in bottles, type of bottles, atmospheric temperature and UV intensities. The disinfection rate of total coliform (k) of SODIS was calculated from the ratio of the start ($C_0$) and end (C) concentration of total coliform, and the treatment time (t), assuming first order disinfection kinetics.

$$Ln\frac{C}{Co} = -kt$$

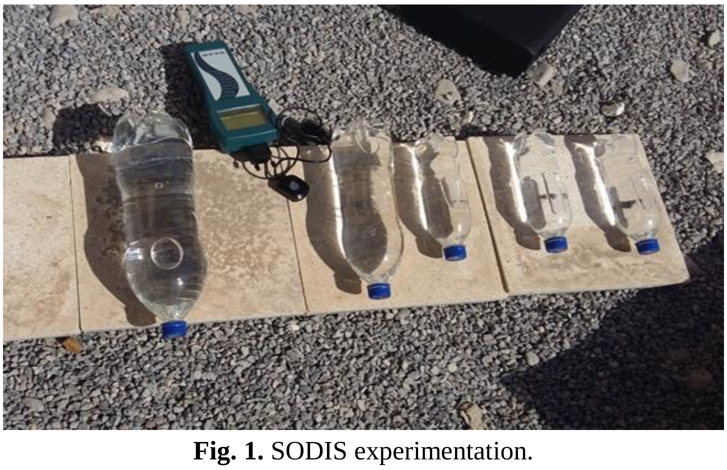

**Fig. 1.** SODIS experimentation.

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### Quantification of total coliform

Efficiency of the SODIS in this study was evaluated in terms of level of disinfection of total coliform bacteria present in the Falaj water. To quantify total coliform before and after SODIS treatment, U.S. Environmental Protection Agency (EPA) approved Colilert-18 Quanti-Tray Enumeration procedure was used.

### Measurement of UV Radiation, ambient temperature and water temperature

During the experiment, UV light intensity for a specific wavelength (254 nm/UV-C, 312 nm $UVB^{-1}$ and 365 nm $UVA^{-1}$) was measured using VLX-3W radio meter. Ambient temperature was monitored using IKON made digital weather station. BENETECH GM1311 food thermometer was used to measure the water temperature during SODIS treatment.

## RESULTS AND DISCUSSION

### Turbidity and total coliform count of Falaj water

To assess the effect of atmospheric temperature on SODIS, this study was carried out in February and May. Turbidity and total coliform count of the Falaj water samples collected in February and May 2018 are presented in Table 1.

**Table 1.** Turbidity and total Coliform count of falaj water.

| Parameter | Month | |
|---|---|---|
| | February 2018 | May 2018 |
| Turbidity (NTU) | 1 | 1 |
| Total coliform (MPN/100 mL) | 201.4 | 29.2 |

Disinfection effectiveness of solar radiation is reduced by suspended particles in the water, which absorb and scatter radiation in the visible and UV range. At a turbidity level of 26 NTU, the intensity of UV radiation decreases by approx. 50% after 10 cm penetration depth, compared to 25% reduction in clear water (Sommer *et al.* 1997). Other studies also showed that the pathogen removal rate of SODIS decreases with the increasing turbidity of water (McGuigan *et al*. 1999; Kehoe 2001; Gómez-Couso *et al*. 2009). A turbidity level of 30 NTU was postulated as a threshold for the upper limit for effective SODIS treatment (Samuel *et al.* 2016). Water with higher turbidity should be pre-treated. Since turbidity of Falaj water was very low, all the SODIS experiments were carried out without any pre-treatment.

WHO (1993) classified the presence of 1-10 faecal coliforms or *E.coli* per 100 mL in water supplies as low risk, 10-100 per 100 mL as intermediate risk, 100-1000 per 100 ml as high risk and above 1000 faecal coliforms or *E-coli* per 100 ml as very high risk. Falaj water in the February and May were classified as high and intermediate risk for water supply respectively. To compliance with WHO guidelines, water supplies should be free from *E-coli* or faecal coliforms.

### UV radiation and ambient temperature

The main mechanism of pathogen disinfection in solar disinfection is direct or mediated damage to proteins and the DNA of the organisms, induced by radiation in the UV-B, UV-A, and possibly the lower visible range (Whitlam & Codd 1986; Woodhead 1987). Ultraviolet (UVA, UVB and UVC) irradiances ($I_{uv}$) measured during the experiment (May and February 2018) are presented in Figs. 2 -3.

In February ultraviolet (UVA+B) light levels ranged from minimum of 4.85 $W/m^2$ in morning conditions to a maximum of 14.128 $W/m^2$ in the afternoons (i.e. 12:00 at noon). In May, ultraviolet (UVA+B) light levels ranged from minimum of 13.66 $W/m^2$ in the morning conditions to a maximum of 33.31 $W/m^2$ in the afternoon. Similar trends were observed in a SODIS study conducted in sub-Saharan weather conditions by Asiimwe *et al.* (2013).

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In February the average ambient temperature ranged from a low of 18 °C to a maximum of 28 °C. In May, average minimum and maximum ambient temperatures were 29 °C and 40 °C respectively.

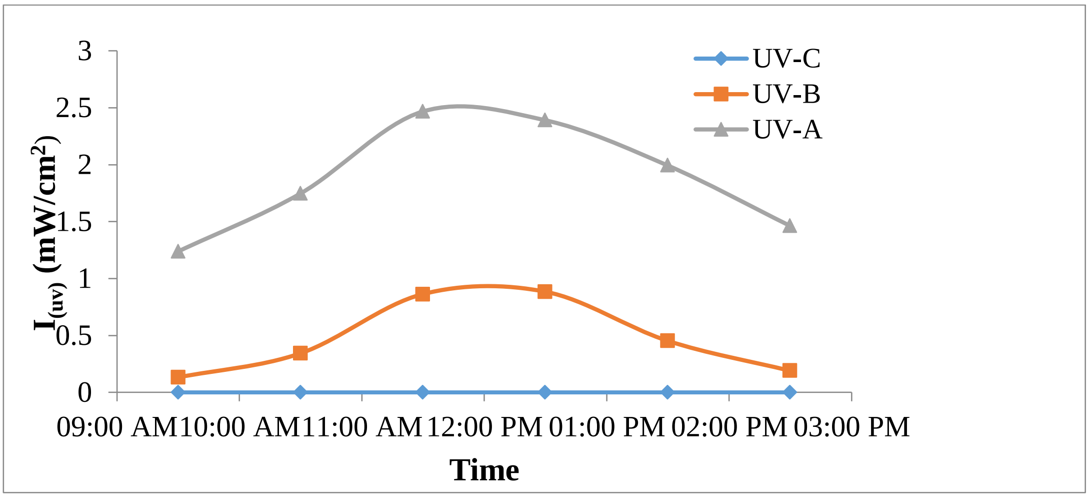


**Fig. 2.** UV irradiance in May 2018 at University of Nizwa, Oman.

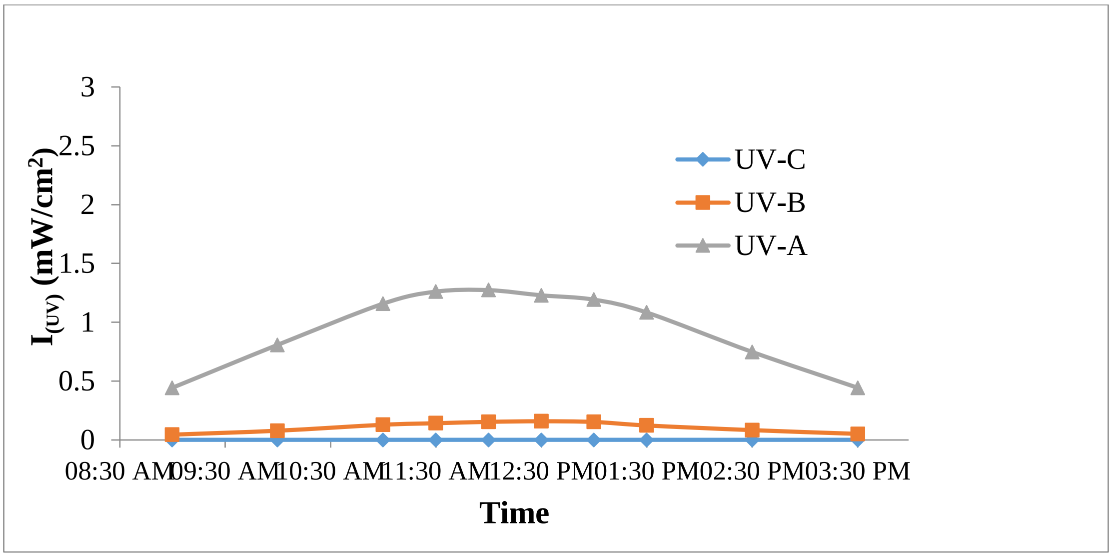


**Fig. 3.** UV irradiance in February 2018 at University of Nizwa, Oman.

**Table 2.** Total coliform counts and disinfection percentages in February 2018.

| Exposure duration (Hours) | Volume/ depth of Falaj water in PET bottle | Water temperature (°C) | Air temperature (°C) | MPN /100 mL | Percentage of reduction of Total Coliform |
|---|---|---|---|---|---|
| 0 | | 21 | 23 | 201.4 | - |
| 3 | 1.5 L/7 cm | 37.5 | 23 | 143.9 | 28.55 |
| 6 | | 36 | 28 | 29.5 | 85.35 |
| 9 | | 36.5 | 25 | 2.0 | 99 |

Results indicate that Falaj water needs more exposure time in February to disinfect the total coliform to undetectable level (Fig. 4). This is mainly due to high count of total coliform, low atmospheric temperature and low UV (A+B) irradiance in the February.

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**Table 3.** Total coliform counts and disinfection percentages in May 2018.

| Exposure duration (Hours) | Volume of Falaj water in PET bottle | Water temperature (°C) | Air temperature (°C) | MPN /100 mL | Percentage reduction of Total Coliform |
|---|---|---|---|---|---|
| 0 | | 30 | 35 | 29.2 | - |
| 1 | 1.5 L/7 cm | 38 | 37 | 25.9 | 11.3 |
| 2 | | 42 | 39 | 14.6 | 50 |
| 3 | | 49 | 40 | <1 | 100 |

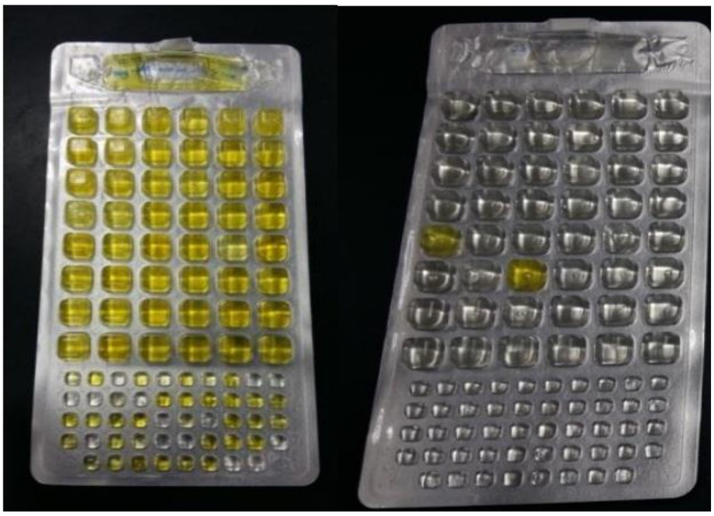

**Fig. 4.** Total coliform count before and after SODIS in Feb. 2018.

Due to high temperatures and low total coliform count in May, complete disinfection happened in three hours. Generally, in sunny conditions the lag phase of bacterial growth before start of disinfection was shorter compared to cloudy conditions (Asiimwe *et al.* 2013). According to Fig. 5, total coliform disinfection rate in May and Feb. 2018 were 0.826/h and 0.428/h respectively. Disinfection rate in May was two folds greater than that in February.

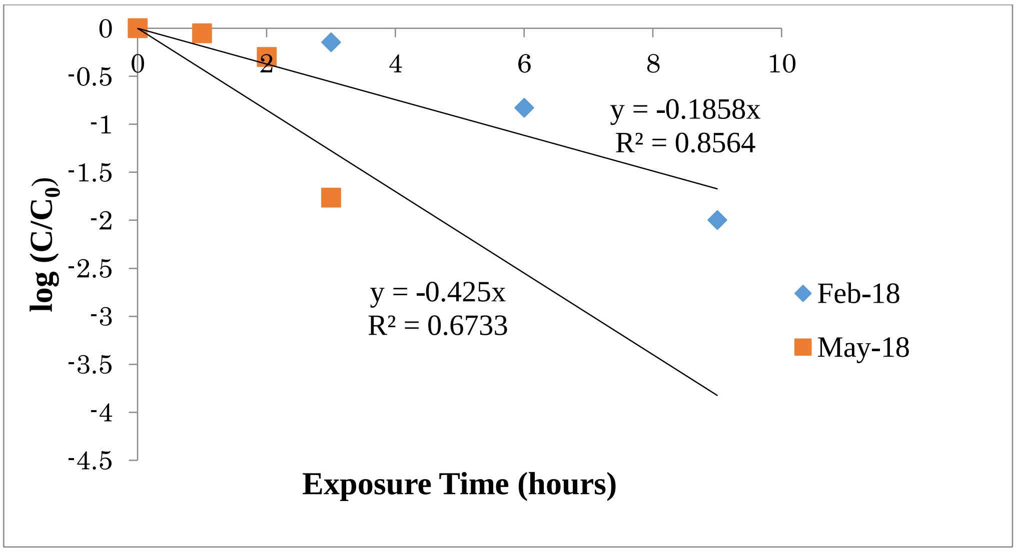


**Fig. 5.** Disinfection kinetics of total coliform in Feb. 2018 and May 2018.

This higher disinfection rate in May is due to high water temperature and high UV-A radiation compared to February. For water temperatures exceeding 45 °C, a synergetic effect of UV-A radiation and water temperature

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increases the bacterial die of rate significantly (Ayoub & Malaeb 2019). In a SODIS study conducted by Awrajaw Dessie *et al*. (2014) in Ethiopia reported that, bacterial disinfection was higher by a factor 1.68 in half surfaced black coloured PET bottles than in raw water samples exposed on cardboard, concrete and CIS surfaces.

**Effect of water volume and depth on SODIS**

Data in Table 4 and 5 show the effect of water volume and depth on disinfection percentages after exposure to natural solar radiation in February and May 2018, respectively.

**Table 4.** Effect of water volume and depth on disinfection of total coliform in February 2018.

| Time | Water Volume (L) | Water temperature (°C) | Water depth in the bottle (cm) | MPN /100 mL | Reduction (%) |
|---|---|---|---|---|---|
| 10:00 am (initial reading) | 1.5 | 21 | 8 | 201.4 | |
| | 1 | | 7 | | |
| | 0.5 | | 6 | | |
| 1:00 pm (after 3 h) | 1.5 | 34 | 8 | 143.9 | 28.55 |
| | 1 | 37 | 7 | 133.4 | 33.76 |
| | 0.5 | 36.5 | 6 | 125.9 | 37.48 |
| 4:00 pm (after 6 h) | 1.5 | 34 | 8 | 29.5 | 85.35 |
| | 1 | 36 | 7 | 7.5 | 96.27 |
| | 0.5 | 35 | 6 | 5.2 | 97.41 |

**Table 5.** Effect of water volume and depth on disinfection of total coliform in May 2018.

| Time | Volume of water (L) | Water depth in the bottle (cm) | Water temperature (°C) | MPN /100 mL | Reduction (%) |
|---|---|---|---|---|---|
| 10:00 am (Initial reading) | 1.5 | 8 | 30 | 29.2 | |
| | 1 | 7 | | | |
| | 0.5 | 6 | | | |
| 11:00 am | 1.5 | 8 | 38 | 25.9 | 11.3 |
| | 1 | 7 | 39 | 24.6 | 15.75 |
| | 0.5 | 6 | 41 | 17.6 | 39.72 |
| 12:00 pm | 1.5 | 8 | 42 | 14.6 | 50 |
| | 1 | 7 | 43 | 1.0 | 96.57 |
| | 0.5 | 6 | 45 | 1.0 | 96.57 |
| 1:00 pm | 1.5 | 8 | 47 | <1 | 100 |
| | 1 | 7 | 47 | <1 | 100 |
| | 0.5 | 6 | 49 | <1 | 100 |

Highest disinfection rate was found on samples having water depth 6 cm, while the lowest one was observed on those from 8 cm both in February and May experimentation (Figs. 6 and 7). This might be due to the reduction of intensity of UV radiation with increasing water depth.

UV irradiation intensity decreases significantly with penetration depth in the water column, even in clear water. SODIS efficacy is, thus, higher in smaller bottles (Dessie *et al.* 2014). This effect is more important if the water contains suspended particles or dissolved organic materials that absorb UV radiation. So that, it is recommended to use bottles that are not larger than 2 L in volume, with a maximum penetration depth of 10 cm (Samuel *et al.* 2016).

**Effect of type of bottle on efficiency of SODIS**

Results of this study (Fig. 8) show that glass and PET bottle with less plastic are more efficient in disinfecting total coli form compared to thick and thin PET bottles at a shorter exposure period (1 hour). Percentage removal is same in all the cases at an exposure period of 4 hours. These results are in agreement with studies conducted by Sommer *et al.* (1997) and Asiimwe *et al.* (2013).

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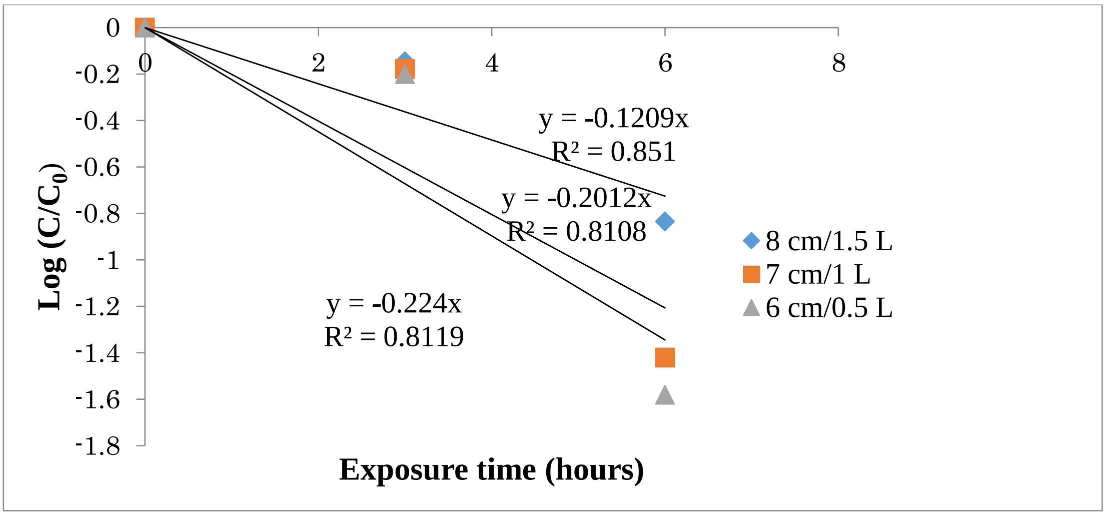


**Fig. 6.** Disinfection kinetics of total coliform on Falaj water samples having different depth/volumes in February 2018.

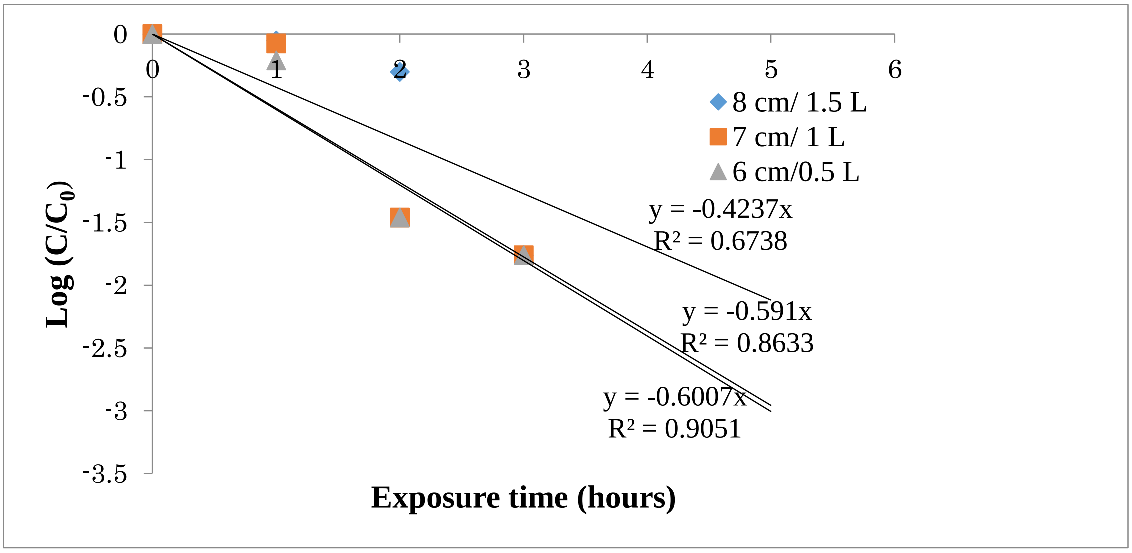


**Fig. 7.** Disinfection kinetics of total coliform on Falaj water samples having different depths/volumes in May 2018.

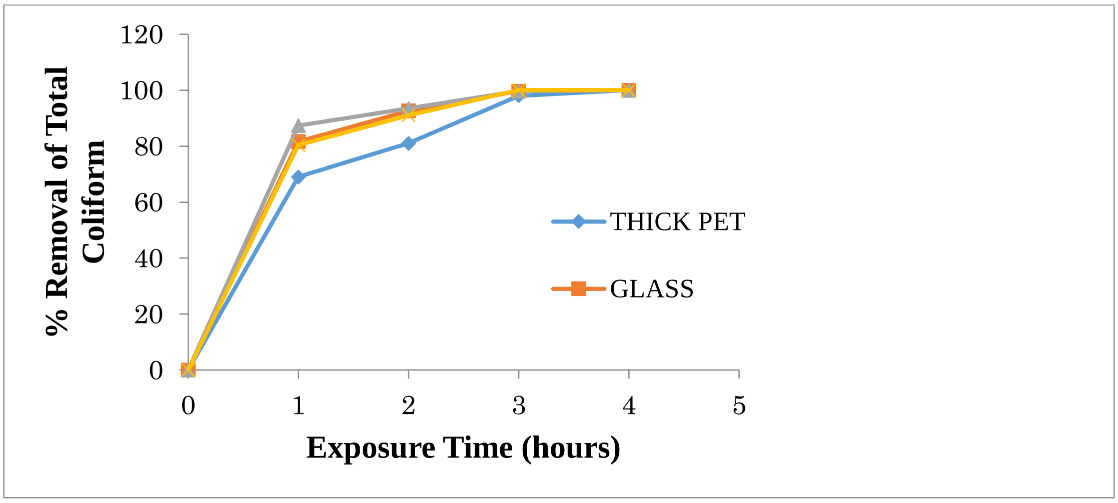


**Fig. 8.** Effect of type of bottle on efficiency of SODIS.

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Sommer *et al.* (1997) reported comparable faecal coliforms and viral disinfection between glass and PET bottles under similar experimental conditions. Asiimwe *et al.* (2013) also reported similar observations in disinfecting *E. coli* in glass and PET bottles under similar weather conditions. Though PET and glass containers have comparable efficiency, it remains the final user's choice depending on availability and cost of either glass or PET bottles, concern of health risks associated with PET bottles and other factors.

Glass bottles also have certain disadvantages compared to PET ones which such as greater weight and risk of breaking, limited availability in suitable sizes, and the lack of reusable caps (Samuel *et al.* 2016).

## CONCLUSION

Results of this study have proved SODIS as an appropriate household water treatment and safe storage (HWTS) for disinfecting Falaj water in Oman. The disinfection of total coliform in Falaj water depends on the length of exposure time, solar radiation and climatic condition under which the sample is exposed to sunlight and type of container/bottle. Due to synergetic effect of UV-A radiation and water temperature, disinfection rate in May 2018 was two folds greater than disinfection rate in Feb. 2018. Samples by water depth of 6 cm had better disinfection rate compared to samples of 8 cm, due to the reducing in intensity of UV radiation with increased water depth. PET bottles with less plastic were more efficient in disinfecting total coliform compared to thick and thin PET ones at a shorter exposure period.

The overall efficiency of the SODIS in this study reduced the concentration of total coliform bacteria in Falaj water from high to low risk concentrations. The base line data that is developed in this study will be useful in developing continuous flow solar disinfection systems.

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### Authors' contribution

Sreedhar Reddy Sajjala proposed the research idea, performed experimental part and wrote the manuscript draft. Munira assisted during experimentation. Salam kadhim and Anwar Ahmed aided in interpreting the results and worked on the manuscript. All authors discussed the results and commented on the manuscript.

### Declarations

It is confirmed that work has not been published, not under consideration for publication elsewhere, approved by all authors and if accepted, it will not be published elsewhere in the same form, in English or in any other language.

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# ضد عفونی باکتری‌های کلی فرم تام در آب فالاج توسط ضدعفونی با نور خورشید

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**چکیده**

در این مطالعه تلاش شده است که باکتری‌های کلی فرم تام را در آب فالاج با استفاده از فناوری ضدعفونی خورشیدی (SODIS) ضدعفونی شود. آزمایش‌های SODIS در فصل زمستان (ماه فوریه ۲۰۱۸) و تابستان (ماه مه ۲۰۱۸) با استفاده از بطری‌های پلی‌اتیلن ترفتالات (PET) انجام شد و سه نوع مختلف (شامل کم غلظت، نازک دیواره و ضخیم دیواره) و همچنین انواع شیشه‌ای با ظرفیت‌های مختلف (۰/۵، ۱ و ۱/۵ لیتری) به کار گرفته شدند. نتایج نشان داد که میزان ضدعفونی کلی فرم‌های تام در ماه مه دو برابر ماه فوریه بود. عمق نمونه‌برداری و حجم نمونه در بطری اثر معنی‌داری بر روی کارایی SODIS داشت. بیشترین میزان ضدعفونی در نمونه‌هایی بود که از عمق ۶ سانتی متر (با حجم ۰/۵ لیتر) برداشته شده بودند در حالی که کمترین میزان مربوط به عمق ۸ سانتی متر (با حجم ۱/۵ لیتر) بود. تفاوت معنی‌داری بین نمونه‌های شیشه‌ای و نمونه‌های مربوط به PET کم غلظت در دوره‌های کوتاه‌تر ( ۱ ساعته) مشاهده نشد. نتایج این مطالعه نشان داد که SODIS روش مناسبی برای تصفیه و ذخیره‌سازی سالم (HWTS) آب فالاج در عمان است. این مطالعه گامی نخست برای به کارگیری انرژی خورشیدی در تصفیه آب و پساب در عمان محسوب می‌شود.

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