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Efficiency evaluation of solar photolysis and solar photocatalysis processes used for the wastewater disinfection

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ABSTRACT

The wastewater reuse, especially for irrigation, requires a safer microbial quality. However, the tertiary treatment is often nonexistent, especially in developing countries where, unfortunately, wastewater treatment needs to be more systematic. Solar water disinfection processes could be appropriate treatments for improving the microbial quality of the wastewater reuse. This study evaluates the effectiveness of both solar photolysis and solar photocatalysis processes in disinfecting secondary-treated wastewater recovered from an activated sludge wastewater treatment plant where the disinfection treatment is not applied. The best parameters of the solar disinfection processes were determined. The experiments were conducted in a bench test composed of 4 flat-bottom flasks with a volume of 2 L each. Then, the disinfection efficiency of both processes was evaluated by a comparative study where 250 Wh/m^2 of UV radiation was cumulated. The disinfection efficiency of studied pathogenic (1) total coliforms, (2) fecal coliforms, (3) streptococci, (4) staphylococci, (5) sulfite-reducing spores, and (6) fungi ranged from 0.86-Log to 3.35-Log reduction. At last, an innovative static plan photoreactor of 50 L allowed reproducing the positive effect of the solar wastewater disinfection. After 8 h of solar exposure duration and a cumulative UV radiation of 360 Wh/m^2, results showed a complete disinfection of all studied pathogenic below the limit detection of the microbial analysis, except of sulfate-reducing spores.

Keywords: Secondary-treated wastewater; Photolysis; SODIS; Photocatalysis; Photoreactors; Solar disinfection efficiency

1. Introduction

The water crisis will become more significant owing that the world population will further increase, and the climate change will amplify water needs for human well-being, agriculture and industrial activities [1]. This trend is confirmed in the Fourth United Nations World Water Development Report. It is projected that in 2050, the world population growth will increase by 3 billion people to reach 9 billion. This will induce an increase by 70% of food demand and by 20% of agricultural water consumption [2].

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As a solution to anticipate water scarcity, many countries have already invested in the seawater desalination. In spite of the mastering technology, it is acknowledged that this fresh water supply is still expensive because of its significant electrical power consumption especially for the agriculture water supply. For example, in 2011, Arabian Gulf countries have consumed 5–12% of electricity generation for desalination [3].

For agriculture water supply, wastewater reuse is a better solution, because it is less expensive and available and that explains its reuse in many countries [4–7]. Wastewater reuse is considered as a valorization because its collection and treatment should be done in first to preserve public health and environment [4,5]. In agriculture, wastewater reuse is envisaged to complete rainwater characterized by an irregular availability. This water management is especially beneficial for arid and semi-arid low-income countries and also for rich water resources countries that suffer from drought periods and water pollution.

In addition, wastewater reuse will encourage the systematic wastewater treatment in developing countries. Indeed, it was estimated that up to 80% of rejected wastewater worldwide still untreated and was at the origin of 3.5 million of death in 2008 [1,8]. In 2011, this situation did not improve; between 150 and 250 million m^3 of untreated wastewater continue to be rejected into natural areas and leached into the subsoil [1].

However, to encourage the systematic wastewater treatment and to benefit from itsadvantages reuse, the electrical power consumption should not lead to the increase in the energy demand more than it is planned. It is provided that, between 2006 and 2030, the wastewater treatment sector will contribute to the increase in energy demand by 44% [9]. Also, energy consumption will lead to financial expenses and greenhouse gas emission that would be the major constraints to the wastewater treatment and reuse. To face this constraint, the use of integrated approaches in a sustainable management of water resources was already recommended in the Johannesburg World Summit on Sustainable Development in 2002 [10].

The aim of this study is to prospect the addition of a solar disinfection treatment in an activated sludge wastewater treatment plant designed to treat 70,000 population equivalents. This to improve the bacterial quality of the secondary treatment wastewater intended for irrigation.

Firstly, four photoreactors containing a volume of 2 L each were used as a bench test to determine the best parameters of solar photolysis and solar photocatalysis processes. Then, these parameters were fixed during a comparative experiment to evaluate the efficiency of the both disinfection processes. The following pathogenic organisms have been considered: (1) total coliforms, (2) fecal coliforms, (3) streptococci, (4) staphylococci, (5) sulfite reducing and (6) fungi

The use of a 50 L photoreactor equipped by a photovoltaic pump allowed reproducing and improving the obtained results.

In the long term, this study is oriented to promote the integration of solar water treatments into the Algerian wastewater treatment sector with the prospect to a sustainable management and the production of a low-cost wastewater reuse for agriculture.

2. Solar water treatments

Several water treatments respond to the sustainable water management as recommended in the Johannesburg world summit [10] among other, solar photolysis and solar photocatalysis processes.

Solar photolysis was applied since the antiquity during the wastewater treatment through the lagooning process. Now, it is also used for fresh water treatment as is the case for solar water disinfection (SODIS). That low-cost water treatment was discovered by Acra, at the end of the seventies, in Lebanon [11,12]. Since 2001, SODIS is recommended by the World Health Organization (WHO) [13,14] for potable water disinfection. This solar water treatment remains used at a family level by around 5 million people in more than 50 countries in Asia, Latin America and Africa [15,16]. Several studies demonstrated that the treatment of a contaminated water using a radiation exposure from sunlight or artificial UV source and a heater up to 50 °C allowed the inactivation of bacteria, fungi, protozoan, cysts and viruses [15–18]. However, water disinfection by SODIS is still limited by the use of low water volumes contained in polyethylene terephthalate bottles. Therefore, studies are conducted to increase the reactors volume and to improve the treatment efficiency using reflective surfaces and compound parabolic collectors (CPC) to treat contaminated water and wastewater [16,18–21].

Solar photocatalysis is also acknowledged as an efficient process that is applied to eliminate both organic pollutants and bacteria contained in polluted water. Recalcitrant organic pollutants are eliminated especially those characterized by a high chemical stability and a low biodegradability such as pesticides, pharmaceuticals, contaminants containing aromatic rings, etc. [22–25]. Regarding bacteria, *Lactobacillus acidophilus, Saccharomyces cerevisiae,* and *Escherichia coli* were the first micro-organisms eliminated by TiO_2 particles using artificial UV light source [26].

Nowadays, several semiconductors exited by natural sunlight allowed the disinfection of contaminated water until and up to 90% of bacteria, phages, protozoan cysts, and viruses [27–30].

3. Materials and methods

3.1. Experiment location

The experiments were conducted in the Development Unit of Solar Equipments (UDES) (latitude 36.633 and longitude 2.700) located at 30 km west of Algiers, during April, May, and June 2011.

The secondary-treated wastewater treated in the experimental setup was recovered from Tipasa wastewater treatment plant located at 40 km west of UDES. The plant is designed to treat 70,000 population equivalents by the activated sludge process at low load with extended aeration followed by sedimentation in settling ponds. The treatment process does not include the disinfection of treated wastewater [31].

3.2. Experiment procedures

The secondary-treated wastewater was recovered, in 20 L cleaned tanks, from the wastewater treatment plant before each experiment. The tests were conducted in an experimental bench composed of four 2 L flat-bottom flasks made of borosilicate glass. Three flasks were used to study three variables of the parameters influencing the solar disinfection of the studied pathogenic. The fourth one was used as a witness sample.

In the first step, during photolysis disinfection, two disinfection parameters were studied. The first experimentation consisted on the determination of the best solar exposure duration. For this, from 9 am, the four flasks were exposed to solar radiation during 5, 6, 7, and 8 h (Fig. 1). Solar exposure durations were chosen to verify the reproducibility of the optimal duration recommended in SODIS use; fixed between 6 and 8 h [32] (i.e. the experimentation was assimilated to SODIS technique because the flasks consisted in a static batch photoreactors simply exposed to solar radiation).

The second experimentation focused on the determination of the best heating temperature. The studied temperatures were fixed at 40, 50, and 60˚C. For this, the three flasks of the experimental bench were placed on a controlled heating plate except the fourth one used as a witness sample. The experimental bench was exposed to solar radiation during 6 h; from 9 am to 3 pm (Fig. 1). The heating temperatures were chosen to verify the optimal temperature recommended in SODIS use; fixed at 50˚C [32].

Fig. 1. Photolysis test bench.

During photocatalysis disinfection, the determination of the best concentrations of titanium dioxide (TiO_2) powder was studied using: 1, 1.5, and 2 g/l. These TiO_2 concentrations were chosen to verify the reproducibility of the optimal concentration reported in the literature [33]. To assure the maintaining of the catalyst suspension, three flasks were placed on a magnetic stirrer operating at 150 rpm except the fourth one used as a witness sample. The experimental bench was exposed to solar radiation during 6 h; from 9 am to 3 pm (Fig. 2).

In a final step, the best studied parameters obtained during the three experimentations, presented above, allowed the setup of a comparative study. This, to evaluate the efficiency of the photolysis and the photocatalysis processes used for the disinfection of the secondary-treated wastewater.

For the microbiologic analyses, before filling the four flasks of the experimental bench, a witness sample of 1.5 L was collected, in sterile conditions, from the secondary-treated wastewater tank. After the experimentations, a sample of 1.5 L was also taken, in sterile conditions, from each 2 L flask.

The second experimental bench consisted on the use of a 50 L plan photoreactor composed of a parallelepiped glass box mounted in a mobile support equipped with a photovoltaic pump [34]. The photoreactor is made of 5 mm thick ordinary glass (i.e. commercially available) with an area of 1 m^2 and a height of 50 mm. The photoreactor was filled with

Fig. 2. Photocatalysis test bench.

Fig. 3. Plan photoreactor [34].

50 L of secondary-treated wastewater and exposed to solar radiation for 8 h (i.e. from 9 am to 5 pm).

During the microbiologic analyses, before the beginning of every experiment, a witness sample of 1.5 L was collected, in sterile conditions, from the photoreactor. From 4 h of solar exposure, five samples of 1.5 L were hourly taken up to duration of 8 h. At the end of the experimentation, a total volume of 9 L was collected and analyzed.

The photoreactor was inclined at 35˚ to optimize the collection of solar radiation (Fig. 3). During solar exposure, incident solar radiation was monitored and measured on hourly basis by a pyranometer brand KIPP and ZONEN, CPM 11. To compare the disinfection efficiency results under different solar radiation, a cumulative solar UV dose was calculated as follows:

$$Dose\ \mathrm{UV} = \int_{t1}^{t2} Iuv \cdot \mathrm{d}t \quad (1)$$

where *Iuv:* incident solar UV radiation (W/m^2) and *t*: time (s).

The UV radiation was estimated at 5% of the received global solar radiation. This value is recorded in south Spain [35,36] where geographical and climatic conditions are nearly similar to those of northern Algeria.

3.3. Microbiologic analyses

Microbiologic analyses were undertaken after the experiments for the counting of the live pathogenic colonies (i.e. the number of colonies inactivated by the disinfection treatments) according to the MPN method (i.e. most probable number), namely total and fecal coliforms, streptococci, staphylococci, sulfite-reducing spores, and fungi (yeasts and molds).

Before every microbiologic analysis, the samples were filtered by 0.45-micrometer membrane. From this first step, coliforms were isolated and seeding in lactose TTC agar with tergitol for an incubation period of 48 h. Incubation temperature was fixed at 37˚C for total coliforms and at 44˚C for fecal coliforms cultures. The coliforms colonies were counted using a selective medium.

Streptococci were isolated and seeding in Slanetz and Bartley medium and cultivated at 37˚C during an incubation period of 48 h. A validation test was effectuated by BEA (i.e. Bile Esculin Agar) to count the black colonies.

Staphylococci were isolated and cultivated in Chapman agar at 37˚C. After an incubation period of 48 h, golden yellow colonies were counted.

Isolation of sulfite-reducing required first the elimination of vegetative cells (80˚C during 10 min). Meat/liver agar was used to the bacterial seeding and culturing conducted at 37˚C during an incubation period of 48 h. The counting was effectuated for colonies surrounded by black halos.

Fungi, especially yeasts and molds, were cultivated in a Sabouraud chloramphenicol agar at ambient temperature (25–30˚C) during 5 days. White and black colonies were counted.

4. Results and discussions

4.1. Characteristics of the secondary-treated wastewater

During the experimentation period (i.e. April-June 2011), treated wastewater produced in Tipasa wastewater plant was characterized as shown in Table 1.

Referring to physical and chemical characteristics, average results indicated a well wastewater treatment according to the Algerian and WHO standards of rejected wastewater. However, the microbiological characteristics were at the limit concentration of fecal coliforms estimated at 970 CF/100 ml (i.e. 2.98 Log). Indeed, according to the Algerian and WHO standards [37,38], this bacteria group should have a concentration inferior to 1,000 CFU/100 ml (i.e. 3 Log) for a safe wastewater reuse in agriculture. This level limitation authorizes only the irrigation of arboriculture, cereal, and industrial crops.

4.2. Solar photolysis wastewater disinfection

The secondary-treated wastewater disinfection studied under different solar exposure duration was carried on 5 June 2011. The 8 h of solar exposure was characterized by a cumulative UV radiation estimated at 204.60 Wh/m^2.

The microbial analysis results, expressed relatively to a detection limit of 0.3 Log (i.e. 2 CFU/ml), indicated the improvement of the microbiologic quality of the secondary-treated wastewater.

After 7 h of solar radiation during which 201.13 Wh/m^2 of UV radiation were cumulated, Fig. 4 shows that a complete reduction in fecal coliforms and streptococci was observed below the limit of the microbial analysis detection. The disinfection efficiency was estimated, respectively, at 2.47-Log reduction and 1.74-Log reduction. This, despite that, after 6 h of solar exposure, fecal coliforms reached only 0.23-Log reduction. Low disinfection efficiency occurred for the rest of the pathogenic. After 8 h of solar exposure, the disinfection efficiency achieved 1.02-Log reduction of total coliforms, 0.87-Log reduction of sulfite-reducing spores and fungi also 0.7-Log reduction of staphylococci.

During the experimentation, the four flasks have been heated by solar radiation until that the wastewater reached 35˚C which is considered as a low temperature for the disinfection [15,32]. The pathogenic inactivation was inducted mostly by photonic rather than thermal effects. With 4.02 kWh/m^2 of cumulative solar radiation, direct photolysis should be the origin of DNA cells damages, which is the responsible of disinfection [24,30].

The evaluation of the solar disinfection efficiency experimented under different heating temperature was carried on 29 May characterized by 3.6 kWh/m^2 of solar radiation cumulated during the 6 h of solar exposure.

Comparatively to the first experimentation (Fig. 4), the disinfection efficiency was improved for all pathogenic. This result was undoubtedly induced by the wastewater heating, applied during the 6 h of solar exposure because the cumulated UV radiations doses were nearly similar. The recorded doses were estimated at 188.35 Wh/m^2 during the first experiment and at 180.68 Wh/m^2 during the second one.

As shown in Fig. 5, the solar exposure of 6 h duration of the secondary-treated wastewater, heated at 40˚C, allowed the complete disinfection of streptococci and fungi below the limit of the microbial

Table 1
Physical, chemical, and microbial characteristics of treated wastewater

Physical and chemical characteristics		Microbiological characteristics	
		Bacteria	Log (CFU/100 ml)
Temperature (˚C)	21.7	Total coliforms	3.488
pH	7.65	Fecal coliforms	2.986
Conductivity (µS/cm)	1,554	Staphylococci	2.227
TSS (mg/l)	9.75	Streptococci	2.553
BOD (mg/l)	4.14	Sulfite-reducing spores	2.786
COD (mg/l)	33.74	Fungi	1.361

TSS: Total suspended solids. BDO_5: Biochemical oxygen demand measured after 5 days. CDO: Chemical oxygen demand.

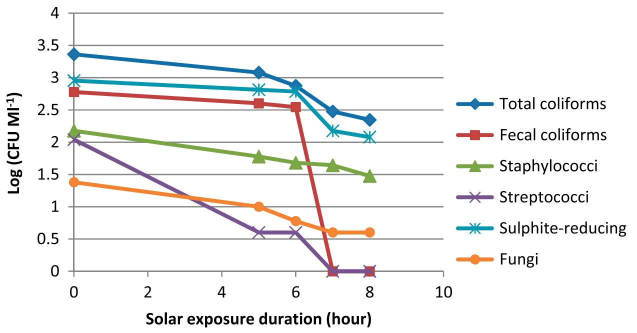

Fig. 4. Temporal evolution of secondary-treated wastewater disinfection using solar photolysis.

analysis. The disinfection efficiency was estimated at 1.87-Log reduction for streptococci and 1-Log reduction for fungi.

The wastewater heating at 50˚C induced the improvement of the disinfection efficiency estimated at 2.6-Log reduction of fecal coliforms. This temperature allowed the complete removing of fecal coliforms below the limit detection. These results indicate that, during solar exposure duration, a heating at 50˚C could be considered as an optimal parameter for the disinfection of the secondary-treated wastewater as specified for drinking water disinfection [32].

The secondary-treated wastewater heated at 60˚C recorded the better experimentation results. In addition of the complete elimination of fecal coliforms, the disinfection achieved 2.7-Log reduction in staphylococci, 1.9-Log reduction in total coliforms and ~0.8-Log reduction in sulfite-reducing spores. Despite this improvement, the disinfection of fecal coliforms, estimated at 2.6-Log reduction, was not as efficient comparatively a value superior to 3-Log reduction in *E. coli* [19]. In this study, the CPC use had undeniably induced the increase in the solar radiation collect and the wastewater heating.

4.3. Solar photocatalysis secondary-treated wastewater disinfection

Solar photocatalysis disinfection studied the effect of the addition of different TiO_2 concentrations during the cloudy day on 26 April. The 6 h of solar exposure were characterized by 630 Wh/m^2 of cumulative solar radiation and 31.50 Wh/m^2 of cumulative UV radiation.

Fig. 6 shows that the best TiO_2 concentration founded during the experimental work was 1.5 g l^{-1}. Comparatively to the witness sample, a complete reduction in sulfite-reducing spores and fungi was observed below the limit of the microbial analysis. Their disinfection efficiency was, respectively, estimated at 1.95-Log reduction and 0.87-Log reduction. However, the disinfection was partial for the rest of pathogenic with 1.67-Log reduction of staphylococci, 1.55-Log reduction of streptococci, 0.73-Log reduction of total coliforms and ~0.36-Log reduction of fecal coliforms.

The use of 1.5 g/l of TiO_2 concentration had not allowed the complete inactivation of coliforms bacteria, and despite the concentration increase until 2 g/l, the results had not been improved.

The TiO_2 concentration of 1.5 g/l was defined as an optimum value by [33] in drinking water photocatalysis tests using a lamp of 125 W of UV at 350 nm. In those conditions, the author obtained between 91 and 99% of coliform bacteria inactivation. Relatively to this literature result, less efficiency was recorded especially for fecal coliforms removal during the experimentation. This was probably due to the low cumulative UV radiation. However, the experimentation conditions were not similar to the mentioned study. Firstly, because the wastewater suspended matter (cf. Table 1) has probably decreased the sunlight absorption. And then, because the organic matter (cf. Table 1) has reduced the microorganism adsorption on the catalyst. Indeed, by analogy to

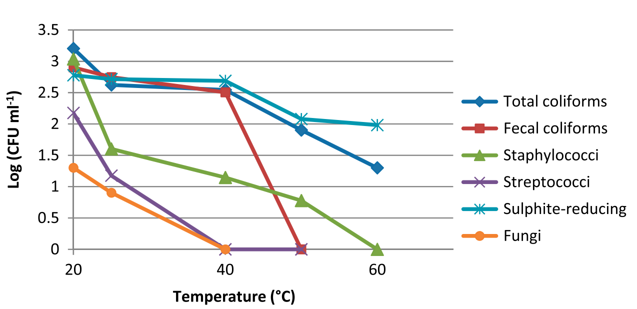

Fig. 5. Evolution of secondary-treated wastewater disinfection using solar photolysis under the heating effect.

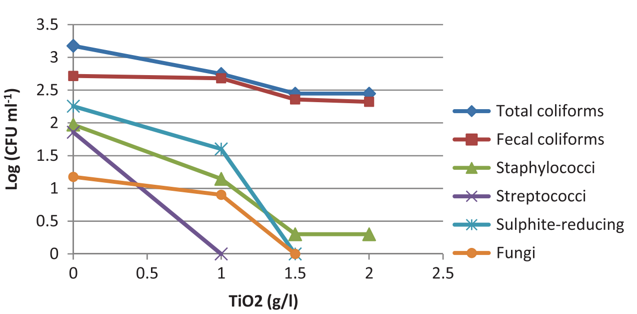

Fig. 6. Evolution of secondary-treated wastewater disinfection using photocatalysis under TiO_2 concentrations.

[33,39], the disinfection efficiency is inversely proportional to coliform bacteria density treated in pure water. Also, the UV inactivation of total coliforms is more difficult to reach in the effluent of municipal wastewater comparatively with a pure culture of *E. coli* [40]. Consequentially, the interaction of wastewater components with the microbial population might be more considerate because it influences the disinfection efficiency of fecal coliforms and also their photoreactivation [41,42].

4.4. Comparative study of photolysis and photocatalysis wastewater disinfection

The best parameters of TiO_2 concentration (i.e. 1.5 g/L), solar exposure duration (i.e. 6 h) and heating temperature (i.e. 50˚C) were used during the comparative study of the use of solar photolysis and solar photocatalysis processes for the disinfection of the secondary-treated wastewater. The experimentation was carried on 14 June and characterized by 5 kWh/m^2 of cumulative solar radiation also by 250.66 Wh/m^2 of cumulative UV radiation.

Fig. 7 illustrates that both solar photolysis and photocatalysis processes were effective especially for the inactivation of coliforms bacteria that were completely removed below the limit of the microbial analysis. Moreover, photocatalysis was more effective comparatively to photolysis regarding the complete remove of staphylococci and fungi. Equally, better disinfection efficiency was recorded for streptococci and sulfite-reducing spores. In photocatalysis, the disinfection efficiency occurred 2.1-Log reduction of streptococci and 1.85-Log reduction of sulfite-reducing spores below the limit detection. This, against 1.98-Log reduction of streptococci and 0.92-Log reduction of sulfite-reducing spores recorded using photolysis process.

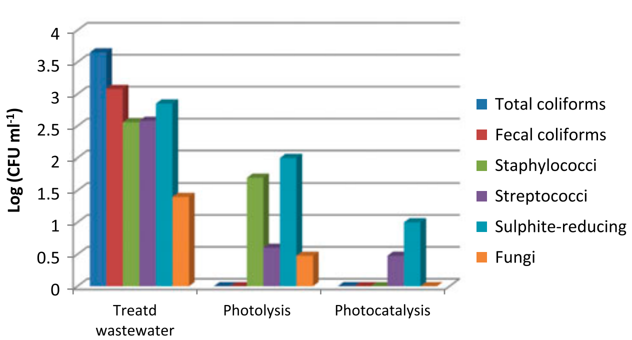

Fig. 7. Comparative study of the photolysis and photocatalysis processes used for secondary-treated wastewater disinfection.

Comparatively to the second experimentation (cf. Fig. 5), photolysis process had recorded better results. The most significant results were recorded for total coliforms. Their disinfection efficiency ranged from 1.3-Log to 3.3-Log reduction. Relatively to total coliforms disinfection, a lesser improvement was recorded for fecal coliforms, streptococci staphylococci, and fungi. However, sulfite-reducing spores were resistant in the both experimentation.

Better disinfection efficiency was also obtained using photocatalysis process. Comparatively to the third essay (cf. Fig. 6), the disinfection efficiency ranged from 0.73-Log to 3.35-Log reduction of total coliforms, from ~0.4-Log to 2.73-Log reduction of fecal coliforms and from 1.67-Log to 2.25-Log reduction of staphylococci.

Certainly, the improvement of the disinfection efficiency was due to the significant increase in the cumulative UV radiation. The UV doses increases were estimated at 27.91% for photolysis and at 87.43% for photocatalysis experiments. But this did not explain the low disinfection efficiency of staphylococci and streptococci obtained during the second photolysis and photocatalysis treatments (Fig. 7). Their high concentration comparatively to the first treatments (Figs. 5 and 6) might be at the origin of these results.

Regarding the wastewater reuse in agriculture, only fecal coliforms restriction is generally taken into account to evaluate their microbial quality. This bacteria restriction must be inferior or equal to 1,000 CFU/ml (i.e. 3 Log) [37,38]. According to these standards, it is not safe to plan the reuse of the secondary-treated wastewater because their fecal coliforms concentration was at the limit of authorized standards. However, this microbial quality could be widely improved as shown in Fig. 7. Both photolysis and photocatalysis processes were efficient to disinfect completely fecal coliforms below the limit detection of the microbial analysis.

Furthermore, on one hand, photolysis was less efficient regarding the remaining pathogenic: staphylococci, streptococci, sulfate-reducing and fungi. On the other hand, the use of solar photolysis process is less-cost and more practical than photocatalysis. Indeed, during the photocatalysis process use, the catalyst must be maintained in suspension using pumps. Equally, at the end of the disinfection treatment, the catalyst must be recovered for its reuse using supplementary treatments.

Lastly, both solar treatments require the imperative use of hybrid systems (solar radiation/UV lamps) to assure the continuity of wastewater disinfection overnight and during cloudy days.

4.5. Solar wastewater disinfection by a 50 L plan photoreactor

The prospect of this experimental investigation is to study the feasibility of the integration of solar wastewater disinfection in the Algerian wastewater plants managed by the National Office of Sanitation (ONA). This is a first step planned toward a sustainable wastewater management approach.

The secondary-treated wastewater disinfection using 50 L static plan photoreactor (cf. Fig. 3) was conducted on 8 May. The 8 h of solar exposure was characterized by 7.2 kWh/m^2 of cumulative solar radiation and 360 Wh/m^2 of cumulative UV radiation.

After 4 h of solar exposure, the treatment recorded a complete inactivation of fecal coliforms below the limit detection of the microbial analysis (Fig. 8). This result was characterized by a disinfection efficiency of 2.87-Log reduction and a cumulative UV dose estimated at 183.50 Wh/m^2. One hour later, the complete inactivation was also reached for total coliforms. Their disinfection efficiency achieved 3.35-Log reduction induced by a cumulative UV dose of 237.41 Wh/m^2. After 6 h which correspond to the optimal solar exposure duration recommended for SODIS use [32], a cumulative UV dose of 286.92 Wh/m^2 was recorded. The disinfection efficiency occurred in ~2.3-Log reduction of streptococci, 0.54-Log reduction of fungi, 0.44-Log reduction of staphylococci, and 0.91-Log reduction of sulfite-reducing spores.

The increase in the solar exposure duration until 8 h increased equally the cumulated UV radiation at 360 Wh/m^2 which continued to improve the disinfection efficiency. This allowed reaching a complete disinfection of all studied pathogenic below the limit detection of the microbial analysis except sulfite-reducing group which were reduced only at 1.6-Log reduction.

Regarding the disinfection efficiency of fecal coliforms (i.e. 2.87-Log reduction), the results are close to those (superior to 3-Log reduction) obtained by the use of a CPC cylindrical reactor [19] even if the 50 L photoreactor was not equipped by a CPC.

Undoubtedly, the geometrical form of the 50 L photoreactor was at the origin of these results. Indeed, against a 20 L cylindrical reactor, the plan one allows to expose a high area (i.e. 1 m^2) and a small height (i.e. 50 mm against 200 mm) to solar radiation. Consequently, this form leads the increase and the homogenization of photons penetration and, at a same time, the quick heating of the wastewater volume to be disinfected (i.e. a heating temperature of 45°C was reached during the second half of the solar exposure duration).

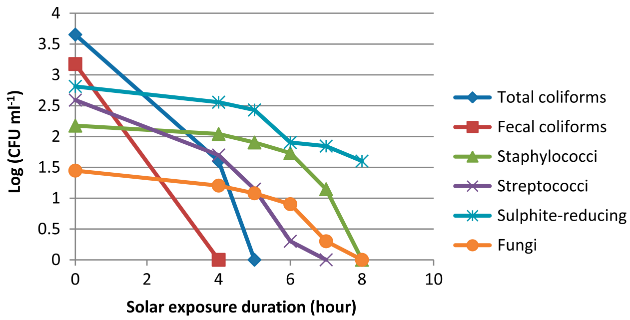

Fig. 8. Performance evaluation of the 50 L plan photoreactor used for a secondary-treated wastewater disinfection by solar photolysis.

At last, it is important to notice that this geometrical form is easily manufactured and that can allow its wide utilization for securing wastewater reuse and drinking water.

In the future, UDES researches project the improvement of the disinfection efficiency by the combined use of solar and artificial radiation. This last will be supplied by electricity from a photovoltaic module. Equally, the maintaining of the optimal temperature of the wastewater heating will use a solar water heater.

5. Conclusion

Solar disinfection processes were used to treat a secondary-treated wastewater intended for irrigation. Initially, it was at the limit of the Algerian and WHO microbiological standards. Results showed that this restriction could be lifted by the use of both solar photolysis and solar photocatalysis processes.

During the photolysis and photocatalysis experiments, the disinfection efficiency was evaluated using an experimental bench test composed of 2 L flat-bottom flasks. The secondary-treated wastewater, infected by more than 3 Log of total and fecal coliforms, was completely disinfected below the limit detection of the microbial analysis. The disinfection efficiency achieved 3.35-Log reduction of total coliforms and 2.78-Log reduction of fecal coliforms. These results were obtained after 6 h of solar exposure which allowed accumulating 250.66 Wh/m^2 of UV radiation.

Moreover, photolysis process was less effective than photocatalysis. Staphylococci and fungi were completely inactivated by photocatalysis which is not the case for photolysis use. Streptococci and sulfate-reducing spores were reduced, respectively at 1.98-Log 0.92-Log using photolysis disinfection. This relatively to photocatalysis witch achieved 2.1-Log and 1.85-Log reduction.

The increase in the secondary-treated wastewater volume from 2 to 50 L, treated in a static plan photoreactor of 1 m^2 area and 50 mm height, allowed reproducing the positive effect of solar photolysis disinfection.

After 5 h of solar exposure and a cumulative UV radiation of 237.41 Wh/m^2, a complete disinfection of total and fecal coliforms was obtained below the limit detection of the microbial analysis. The disinfection efficiency achieved 2.87-Log reduction of fecal coliforms and 3.35-Log reduction of total coliforms. The increase in solar exposure at 8 h, characterized by a cumulative UV radiation of 360 Wh/m^2, improved the disinfection efficiency. A complete disinfection of all studied pathogenic was achieved, below the limit detection of the microbial analysis except of sulfate-reducing spores.

Finally, solar photolysis disinfection should be recommended for a widely used not only in the low-income and developing countries but also in developed countries in a sustainable management of water resources. Given that the peak water demands for irrigation is expressed especially during summer which corresponds to high sunlight intensity and a long solar duration.

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