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Increase by Substitution of Galvanized Steel for Aluminum Mirrors in the UV Solar Radiation in Canal with Fins and Side Panels That Disinfect Wastewater

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Abstract: The need arises to seek new depuration technological responses aimed at the reuse of wastewater, which requires the development and promotion of economically and environmentally sustainable technologies. In this paper, it studies an improvement to a disinfection system sustainable, low-cost, patented in 2019, and based on solar energy. The water passes through a canal of reflective material in the continuous regime, and in the batch regime, the water remains in the canal. The panels are located parallel to the lateral faces of the canal. The fraction of the radiation reflected outside the canal reaches the reflective side panels that return the radiation to the canal. These panels concentrate the radiation in the canal through reflection. The disinfectant canal with fins and side panels uses ultraviolet radiation to eliminate the bacterial load carried by treated wastewater. For this reason, the present work analyzes the incidence in the area of influence of the disinfectant canal. When reflective aluminum mirrors were installed on the sloping walls of the canal, global radiation increased by 4%, when they were used on the side panels, it increased 3%, and when the aluminum mirrors were used on the canal walls and side panels, it increased 8%. The important thing about this work is that it opens windows for improving the system through materiality so the new challenge is the search for the optimal material considering the impact on global radiation and consequently on the bacteriological elimination.

Keywords: solar radiation; disinfection; wastewater

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1. Introduction

Climate change is one of the most complex and important problems and externalities in the environmental paradigm [1]. The speed of climate change will make survival and adaptation more difficult. This being a global dilemma, it will require mitigation measures at all scales, from the local as well as the international community [2].

In the global context, the water resource fulfills three main functions in sustainable development: it plays an important role for human health, it allows economic development, and it allows the different ecosystems worldwide to be viable [3]. The future will present hydrological uncertainty, which is accentuated by the climate change so it is necessary to implement measures to manage water resources [4]. Depending on how greenhouse gas emissions are managed, the temperature in southern Chile could increase by 0.68 °C to 1.51 °C between the years 2050–2065 [5].

A water resource management policy that strives to ensure the water availability for future generations is the reuse of wastewater [6]. This reuse of water is highly desirable since it promotes the conservation of water resources and allows control of water pollution [7]. This management policy allows adaptation to climate change and is also sustainable; thus providing an alternative source of water for use in irrigation, having great potential in rural areas with water scarcity. Since agriculture tends to be one of the most important economic activities [8] it is vital to develop technologies that guarantee optimal treatment and low construction, operation, and maintenance costs [9]. The energy costs and the environmental impact it produces should be determinate to optimize the wastewater treatment [10].

The industry and domestic activities, in their operation, produce wastewater that contains contaminants, so the protection of the water resource is required. To eliminate these pollutants (soluble and insoluble), the treatment methods include physical, chemical, and biological processes [11]. These mainly seeks to regulate water parameters such as turbidity, pH, alkalinity, biological oxygen demand (BOD), chemical oxygen demand (COD), total solids (TS), total organic carbon (TOC), fecal coliforms, and others specified by local regulations [12].

Microbial activity is a contaminant that affects the water quality, both for consumption and for recreation; therefore, it represents a danger to human health [13]. Disinfectants such as ultraviolet radiation (UV), chlorine, and ozone are the most widely used in wastewater treatment and water disinfection [14]. The generation of toxic by-products in chlorination must be considered. Tt has also been identified that these chlorine by-products could be carcinogenic, posing a risk to human health [15,16]. Even regulatory bodies encourage the use of ecologically sustainable technologies [17]. Efforts are also being made to eliminate the use of chlorine in other fields of water treatment [18].

UV radiation is a viable option to chlorination. This technology has been extensively studied as it does not generate harmful by-products and is effective against many of the microbes present in water [16]. Hartman and Eisenstark in 1978 reported the first positive evidence of this process for water disinfection. They demonstrated the bactericidal effect at very low concentration of H_2O_2 ($6 \cdot 10^{-3}$–$6 \cdot 10^{-1}$ M) via a synergistic effect with near UV-radiation (300–400 nm) over Escherichia coli cells in water [19].

This manuscript presents the impact on solar radiation around the disinfectant canal with fins and side panels when galvanized steel is replaced by aluminum mirrors as reflecting material. This new technology, based on the use of solar radiation to disinfect treated wastewater, with a low cost of investment and operation, was patented in 2019 [20].

A comparative analysis of scenarios that progressively shows the differential impact caused by aluminum mirrors using the radiation rate was obtained by measuring the solar radiation in the disinfection canal, the atmospheric solar radiation, and the elimination of total coliforms as the principal quantitative indicators

This system, the disinfectant canal with fins and side panels as well as the Solar disinfection systems (SODIS) strive to inactivate microorganisms through the application of UV radiation, damaging the nucleic acids of the microorganism, making it unable to replicate. There are also photosensitive molecules in the water that manage to absorb visible light, causing oxidizing activities that manage to damage the structure of the cells [21].

Equally the disinfectant canal with fins and side panels and SODIS systems mainly uses ultraviolet radiation from the sun (UVA 320–400 nm and UVB—280–320 nm). In these systems the water circulates through a reactor under the incidence of solar radiation. These reactors are permeable to ultraviolet rays so that the radiation can inactivate the microorganisms present in the water [22], the higher the radiation intensity, the higher the cell damage; however, the inactivation of the microorganisms also depends strongly on the wavelength of the radiation applied [23]. UV radiation (200–400 nm) has three different classifications: UVA (320–400 nm), UVB (280–320 nm), and UVC (200–280 nm); however, UVC radiation and part of UVB are absorbed by the ozone layer while UVA is the main component of UV radiation that, coming from the sun, manages to reach the earth's surface [24].

Different advances made in recent decades have shown that SODIS method of supplying drinking water is effective and economical, being able to reduce prevalence and mortality for waterborne diseases [25]. Usually, SODIS is oriented to developing countries since the system should be able to withstand adverse weather conditions and its maintenance requirements should be minimal [26]. The conventional SODIS use transparent water containers (usually polyethylene terephthalate (PET) plastic bottles) to expose it directly to sunlight for a minimum of 6 h. The pathogens present in the water are inactivated, thus producing safe drinking water for human consumption [27].

The efficiency and time of the SODIS treatment is affected by many factors [28]. In fact, it has been shown that when the turbidity and total suspended solids (TSS) of the water increases, the inactivation of microorganisms is less, preventing UV radiation from achieving disinfection [29].

There are treatments, such as constructed wetlands, that can be designed to remove more than 90% of TSS [30], only requiring good maintenance constructed wetlands [31]. An advantage of artificial wetlands is that they can perform well as a biofilter because they have different physical, chemical, and biological factors that participate in reducing of the number of bacteria of human origin [32,33]. More research efforts must be done in these UV technologies and other sustainable technologies capable of obtaining reclaimed Urban Waste Water for reuse in agriculture with an affordable cost [34]. Constructed wetlands are more cost-effective and low-energy consumption compared to conventional wastewater treatment [35]. Regarding the performance of the wetland in the removal of all pathogens, efficiency of 90% can be achieved when the hydraulic residence time is 1 to 2 days with adequate hydrodynamics [36,37].

In 2019, a new and innovative Solar Disinfection Technology for Treated Wastewater was patented that Integrates Materiality, Geometry, and Reflective Panels. The objective of this technology is the elimination of pathogens by means of UV radiation [38], which is in an optimization process. In this manuscript, the development of one of the improvement ways is exposed, which consists of a change in the materiality using mirrors on the walls and panels that are part of the disinfectant channel. The aim is to increase the UV radiation in the disinfectant canal and consequently increase the elimination of pathogens. We analyzed four different configurations linked to the area where the mirrors are positioned.

2. Methodology

The experimental work shown below searches to define how much the values of the solar radiation rate vary when aluminum mirrors are included as a material in the solar disinfection system since it seeks to increase the amount of UV radiation that manages to reach the canal in order to increase the efficiency of the treatment of fecal coliforms within the wastewater treatment.

Four different configurations were compared and analyzed focusing on the variations of the materiality of the canal inclined walls and that of the panels arranged on the sides. The proposed cases were:

- Condition 1: Canal and side panels of galvanized steel.
- Condition 2: Galvanized steel side panels and installation of aluminum mirrors on sloped canal walls.
- Condition 3: Galvanized steel canal and side panels with aluminum mirror installation.
- Condition 4: Aluminum mirrors on sloping canal walls and on side panels.

For the measurement of solar radiation, different points along and across the canal were considered. The analyzed system is located in the dependencies of the Canteras wastewater treatment plant, Quilleco commune, Bío-Bío region, Chile.

a. *Proposed disinfection system*

The design of the proposed canal and panels, both in geometry and materiality, has the aim of increasing the radiation inside the canal, and finally, in the water [38]. The canal consists of a trapezoidal cross section (see Figure 1) that allows redirecting the sun's rays, in order to increase the radiation in the water. In addition, it has side panels that manage to redirect the outgoing radiation back to the canal which allows for optimizing the disinfection process.

Figure 1. Canal and panels installed. The left figure shows the arrangement of the aluminum mirrors inside the canal, which are installed in the required conditions.

The canal and the installed panels are made of galvanized steel allowing it to maintain the radiation in the residual water and achieve disinfection. Galvanized steel was used as a reflector, due to the ease of obtaining it, its constructability, and the cost reduction in the project.

The supporting structure of the side panels is made up of 4 × 2 radiata pine wood boards. The reflective mirrors are made of aluminum and are 2 mm thick, 1 m long, and 0.5 m wide. This configuration is chosen since there is a decrease in reflectance as the thickness of the aluminum mirror increases, caused by the greater attenuation of the glass, which must be traversed twice [39].

The details and dimensions of the canal can be seen in Figure 2.

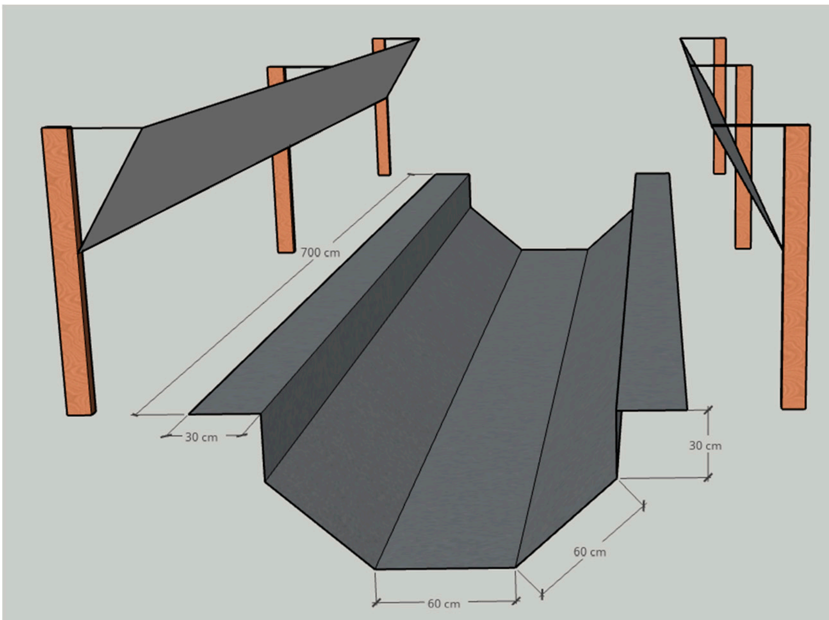

Figure 2. Dimensions of the disinfection canal.

b. *Measurement equipment*

For the measurements, a UV sensor was used, ultraviolet radiation meter (UVA-UVB), model PUV-360, whose technical specifications are detailed below in Table 1.

Table 1. Technical specifications of meter PUV-360.

Monitor/UV Sensor Spectrum	LCD Size: 28 × 19 mm/Bandpass from 290 nm to 390 nm
Measuring/Resolution Ranges	range 1: 2000 uW/cm^2: 1999 uW/cm^2 × 1 uW/cm^2 range 2: 20 mW/cm^2: 19.99 mW/cm^2 × 1 mW/cm^2
Precision	(4% of the read + 2 dig.). Calibration was performed under UVA light and compared with a standard reference field light meter less than 3 V/M and frequency less than 30 MHz
Sensor structure/Sample time	Photo UV sensor with cosine correction filter/1 s approx..
Off/Weight	Auto power off saves battery life/190 g/0.2 LB
Humidity (HR)/Temperature Operation	Less than 85%HR/0 °C to 50 °C
Dimensions/Power Supply	210 × 49 × 40 mm/4 AAA batteries

Likewise, a level was also used, since the meter must be as level as possible to avoid measurement errors.

c. *Measurement distribution*

The measurements made in the similar disinfection canal are distributed in the same way as proposed and worked by Pedro Cisterna et al. [38]. Likewise, to determine the radiation present in the environment, four measurements are considered, one for each side. The distribution of the measurements made can be seen graphically in Figure 3. In addition, four measurements were made at the following times: 9.55; 11:30, 12:15; 13.00. and by the instrument PUV-360.

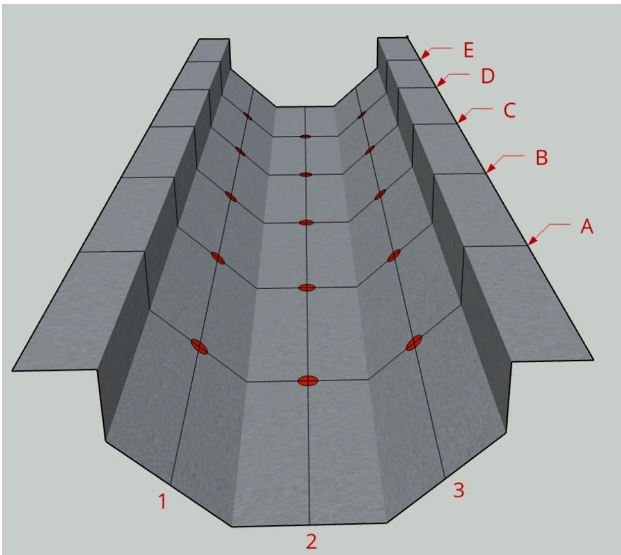

Figure 3. Mesh of measurement points.

d. *Radiation rate as control parameter*

Due to the impossibility of comparing the measurements between them, due to the environmental radiation conditions where the radiation is obtained in the measurement matrix, a dimensionless indicator is proposed that allows this comparison of the measurements of different days in a consistent way. Since there are daily different values of solar radiation that are random and cannot be controlled or reproduced due to the natural variable, a parameter is defined as: Radiation Ratio. This allows comparing the radiation measurements Rij corresponding to each point of the radiation matrix, linking the radiation measured in the matrix in a position, with respect to the Environmental Radiation (Ra) [38].

If Rij = Ra, Rij/Ra, RR = 1, for Rij > Ra, RR > 1 and for Rij < Ra, RR will be less to 1.

Hence: $RR = Rij/Ra$, $i = A,,,D,E$; $j = 1,2,3$.

For this case, the environmental solar radiation (Ra) is considered the average of the four measurements made around the canal.

e. *Determination of the Total Coliform*

Measurements of total coliform elimination were also carried out in a disinfectant canal with similar characteristics at different radiation ratios, which are used as references in order to correlate them with those obtained in this investigation.

The treated sewage was deposited in the canal and subjected to disinfection using the technology based on exposure to solar radiation. A sample was collected to measure the total coliforms. This activity was performed in a time range of 225 min, with samples taken each 45 min.

The wastewater treated without disinfection corresponded to time 0. After 225 min of exposure to UV radiation, the canal was emptied and washed. A sample of the residual treated water was taken at the beginning of the experiment using a 250 mL closed glass with a top. This closed glass was submerged between 5 and 10 cm. Once submerged, the glass was opened, allowing the entrance of water. Then, the glass was pulled out of the water and introduced to a cooler. This process was repeated for the following samples and according to the predefined residence times. Finally, the samples were sent to the laboratory for analysis. The samples collected for microbiological analysis were kept at a low temperature in a cooler and analyzed on the same day they were collected. The multiple tube technique was used for the total coliform counts and most probable number (MPN) determination [40].

The treated wastewater was disinfected under two situations. (A) In the disinfection canal and (B) in the disinfection canal with reflective side panels. Two experiments of coliform abatement were conducted considering a residence time range from 0 to 225 min. In both cases, two measurements were made.

The initial coliform condition, TCo, in the wastewater that was subjected to disinfection was measured at different hydraulic residence times, and, with this data, we estimated the efficiency of the coliform removal.

$$\text{Elimination} = (\text{TCt} - \text{TCo})/\text{TCo}$$

Such that,

$$\text{TCt} = \text{MPN to time t}$$

$$\text{TCo} = \text{MPN to time 0.}$$

3. Results and Analysis

The radiation measurements were made according to Figure 2. The positions of the respective UV radiation measurements are indicated, with the letters A, B, C, D, E corresponding to the abscissas and the ordinates with the numbers 1, 2, 3.

These results were obtained in real atmospheric conditions, and due to its variability, the data shown are normalized and compared by using the Radiation Ratio. This was done for each of the proposed configurations since it seeks to establish the inference in solar radiation when aluminum mirrors are used.

Stainless steel shows a low spectral reflectance of around 50–60% in the visible wavelength range, like galvanized steel, less than other material, such as aluminum and copper. Therefore, the results can improve using others materials [41].

a. *Results*

Next, the results obtained with the normalization are shown, applying the radiation ratio, already carried out.

The values obtained in condition 1 (Table 2), that is, with canal and galvanized steel side panels, showed that 28 data out of 60, which represent 47% of the total sample, presented values greater than or equal to 1; that is, values of radiation equal to or greater than the environmental radiation (Ra).

Table 2. Radiation ratios obtained in canal and galvanized steel side panels.

	Data	A	B	C	D	E	Time
Measurement 1	1	1.7	1.02	1.07	1.06	1.10	11:30
	2	0.98	1.00	0.93	1.01	1.01	
	3	1.01	1.03	1.00	1.03	1.05	
Measurement 2	1	0.99	0.99	0.97	0.99	0.97	12:30
	2	0.99	0.98	1.00	1.00	0.98	
	3	1.05	1.04	1.00	0.96	1.01	
Measurement 3	1	0.95	0.94	0.95	0.94	0.92	13:30
	2	0.97	0.93	0.95	0.95	0.93	
	3	1.02	1.02	1.00	1.01	1.02	
Measurement 4	1	0.92	0.93	0.96	0.93	0.95	14:30
	2	0.92	0.93	0.93	0.95	0.97	
	3	1.05	1.01	1.02	1.05	1.05	

For condition 2 (Table 3), it was obtained that 48 of 60 data are greater than or equal to the environmental radiation (Ra). This increase from 47% to 80% of radiation rate values greater than or equal to 1 can be attributed to the presence of aluminum mirrors on the slopes of the canal, despite the fact that the side panels are made of galvanized steel.

Table 3. Radiation ratios with galvanized steel side panels and installation of aluminum mirrors on inclined canal walls.

	Data	A	B	C	D	E	Time
Measurement 1	1	0.98	1.00	0.94	1.00	0.98	11:30
	2	1.02	1.01	0.97	1.01	1.01	
	3	1.05	1.03	1.00	1.00	0.98	
Measurement 2	1	1.05	1.05	1.05	1.05	1.05	12:30
	2	1.10	1.08	1.03	1.08	1.08	
	3	1.12	1.07	1.02	1.13	1.06	
Measurement 3	1	1.01	1.02	1.01	1.01	1.01	13:30
	2	1.02	1.01	1.01	1.04	1.00	
	3	1.04	1.05	0.97	1.00	0.98	
Measurement 4	1	0.98	0.98	0.98	0.97	0.97	14:30
	2	1.00	1.03	1.03	1.02	1.03	
	3	1.04	1.08	1.01	1.07	1.15	

Regarding the radiation measured in the canal, when aluminum mirrors are available on the side panels and the canal retains its materiality of galvanized steel corresponding condition 3, (Table 4), 29 of 60 radiation rate values greater than or equal to the environmental radiation are obtained; in other words, 48% of the total sample. This amount is similar to condition 1 and much lower than the values obtained in condition 2.

Finally, the condition 4, regarding the condition in which aluminum mirrors are present on the inclined walls canal and on the side panels (Table 5), the highest percentage of radiation rate is observed, which exceeds the value measured in the environment. Measurements above environment radiation represent 82% of the sample, obtaining 49 of 60 values that fulfill this condition.

Table 4. Radiation ratios with galvanized steel canal and side panels with aluminum mirror installation.

	Data	A	B	C	D	E	Time
Measurement 1	1	0.97	0.97	0.97	0.97	0.97	11:30
	2	1.00	1.00	1.01	1.01	1.00	
	3	1.00	0.99	0.99	1.05	1.02	
Measurement 2	1	0.99	0.99	0.99	0.99	0.99	12:30
	2	0.99	0.99	0.99	0.99	0.98	
	3	1.12	1.13	1.02	1.12	1.15	
Measurement 3	1	0.98	0.98	0.98	0.98	0.98	13:30
	2	1.00	1.00	1.00	1.00	1.00	
	3	1.09	1.11	1.15	1.20	1.19	
Measurement 4	1	0.98	0.96	0.98	0.96	0.97	14:30
	2	1.02	0.99	0.99	0.99	0.98	
	3	1.15	1.10	1.11	1.13	1.16	

Table 5. Radiation ratios with galvanized steel canal and side panels with aluminum mirror installation.

	Data	A	B	C	D	E	Time
Measurement 1	1	0.99	1.02	1	1.05	1.09	11:30
	2	1.01	1.04	1.02	1.04	1.03	
	3	1.26	1.26	1.22	1.24	1.25	
Measurement 2	1	0.97	0.98	0.96	1	1.02	12:30
	2	1	1.02	1.01	1.03	1.03	
	3	1.1	1.11	1.08	1.17	1.25	
Measurement 3	1	0.97	0.99	0.96	1.01	1.04	13:30
	2	1.01	1.03	1.01	1.04	1.05	
	3	1.1	1.11	1.08	1.17	1.24	
Measurement 4	1	0.94	0.97	0.96	0.99	1	14:30
	2	1.02	1.03	1	1.02	1.01	
	3	1.2	1.23	1.22	1.18	1.12	

From the above and Figure 4, a hierarchical correlation can be established, in terms of the raw values of the radiation rates. In comparison the value that the environmental radiation presented during the measurements, from the lowest value to the highest, would be: condition 1, condition 3, condition 2 and finally, condition 4. Respect to the data variability, it can be seen that some cases are more variable than others; however, this is analyzed later.

b. *Analysis and results comparison*

According to the measurements made, the results were processed and analyzed statistically, this is shown in Figure 5 (average of each point of the canal, for this calculation the four measurements made for each point were considered).

From the analysis of the results for condition 1, it is revealed that this is the sample with the lowest average values of radiation ratio, obtaining a maximum value of 1.10 and a minimum of 0.92. Likewise with all 60 data obtained, a global average of 0.99 is calculated for this condition. Although this value may be reliable, a confidence interval was also estimated for the global average (95% confidence). It has a lower limit of 0.98 and greater than 1.00, thus having an error of ± 0.01. Figure 6 shows that this global average is the lowest of all conditions. From this it could be inferred that, by adding aluminum mirrors to the side walls of the canal and/or to the side panels, the system's ability to concentrate solar radiation is improved.

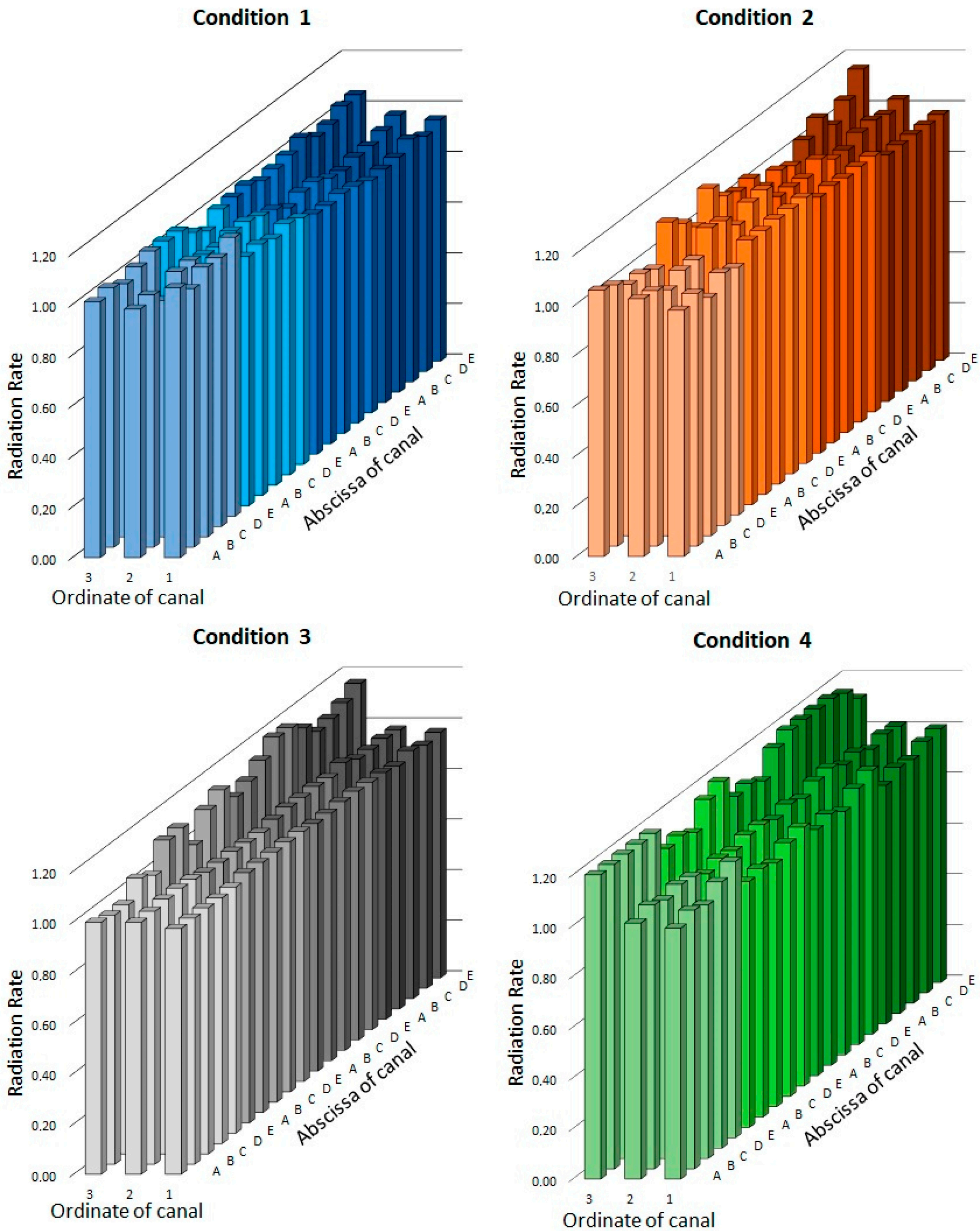

Figure 4. Graphic representation of estimated radiation ratios.

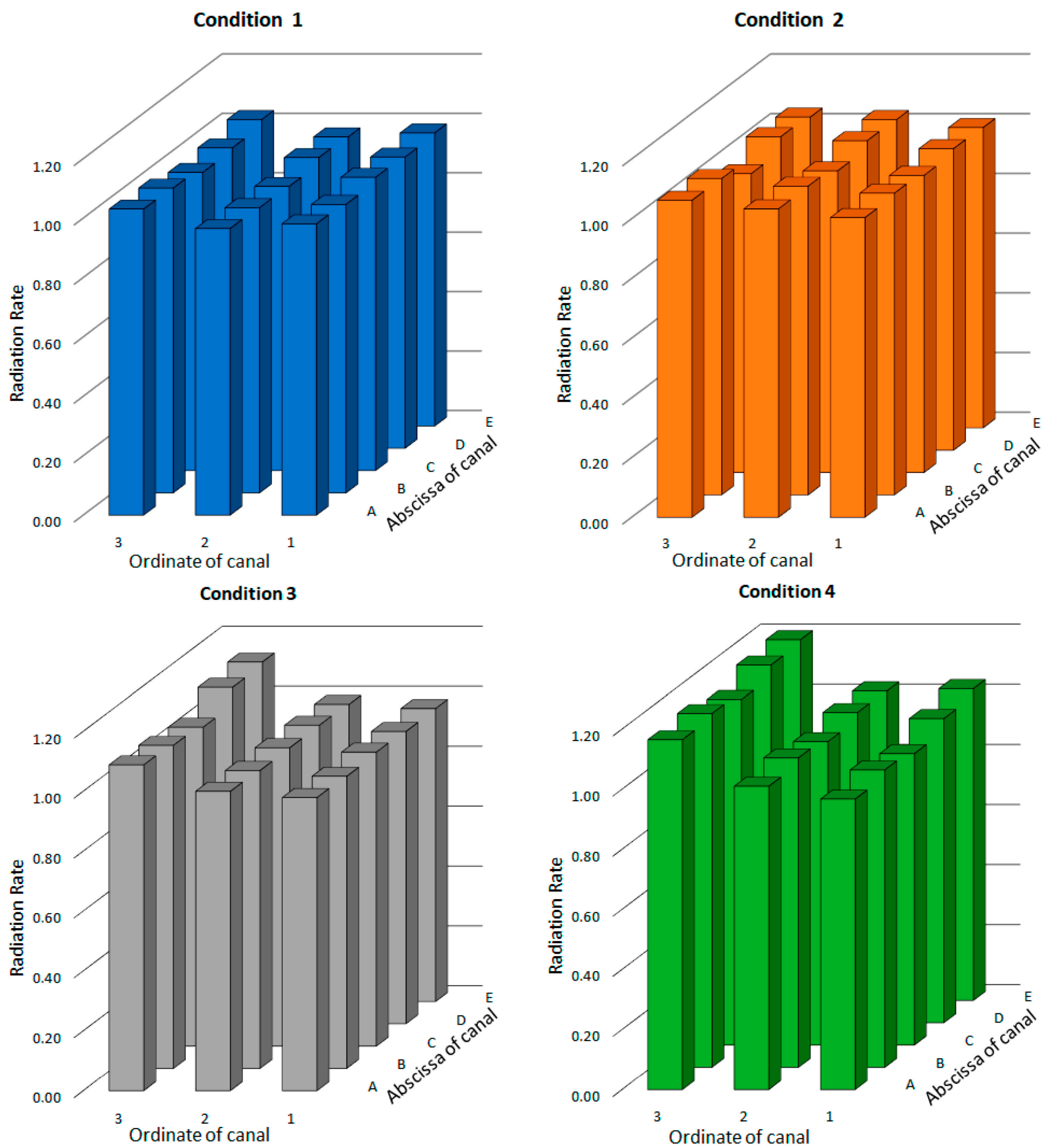

Figure 5. Graphic representation of the means of the Radiation Ratios indices obtained, for each condition.

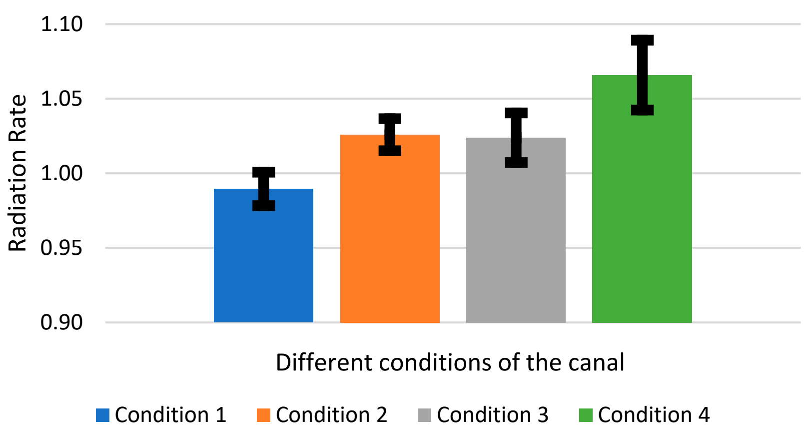

Figure 6. Overall average for each condition at 95% confidence interval.

Regarding conditions 2 and 3, related to the global average of the radiation ratio, these are similar, showing values of 1.03 and 1.02, respectively. Likewise, it can be seen in Figure 4, that the global average of radiation ratio presents greater variability for condition 3, with an error of ±0.02, while for condition 2, it is ±0.01 at a confidence of 95%. In addition, for condition 2, the data obtained show a maximum average radiation index of 1.15 and a minimum of 0.94. On the other hand, the radiation index values for condition 3 reach a maximum of 1.20 and a minimum of 0.96. These data are extracted directly from the canal-averaged data and are plotted in Figure 3.

This similarity in the results obtained for conditions 2 and 3 could be due to the presence of aluminum mirrors, but only in one of the components of the system.

According to condition 4, which presents aluminum mirrors both on the lateral walls of the canal and on the side panels, the highest radiation index results are obtained with a global average radiation index of 1.07 and a variability of ± 0.02. Relative to the mean values observed in Figure 3, a maximum of 1.26 and a minimum of 0.94 were determined.

Regarding the overall averages, it clearly shows in Figure 6 that the results obtained in condition 1 are the most unfavorable, being the one with the lowest general average radiation ratio. Subsequently, conditions 2 and 3 are the most similar, with only a difference of 1%, condition 2 being superior; however, the presence of aluminum mirrors in one part of the system, the canal or the side panels, allows obtaining better results than when the material is only galvanized steel. Finally, when conditions 2 and 3 overlap, condition 4 is obtained, which consists of the presence of aluminum mirrors on the side walls and on the side panels of the canal. It is the condition that has been the one of the best results, as to the general performance of the radiation ratio, being 0.08 higher than the base condition, that is, condition 1.

The variability of the data presented for each condition is different. According to Figures 4 and 6, it can be established that the data with the greatest variability are those presented in condition 4, and this decreases until reaching condition 1, which is the most uniform. This is shown by having the smallest confidence interval and thus the smallest standard deviation and variance.

For this reason, an analysis was also carried out regarding how the radiations are distributed throughout the complete canal, thus obtaining Figure 7.

Concerning the cross section, the zone that presents the highest values of radiation ratio is zone 3, and from there it decreases to zone 1. This is the case for all conditions except for 1, which has its lowest value in zone 2. Figure 7 shows that the radiation, with respect to the cross section, is highly variable, presenting grid differences between zone 3 and 1; however, condition 2 is the one that achieves greater uniformity in the results of the radiation ratio, which may be mainly due to the presence of aluminum mirrors, but only on the canal walls. This large difference in the values of the radiation ratio may be due to the plan orientation of the system, which causes the radiation to be concentrated in a single zone of the canal.

This can be a problem in terms of coliform removal as the process is not guaranteed to be homogeneous.

For the longitudinal section, it can be mentioned that the distribution of the radiation ratios is uniform, different to conditions 2 and 4, which present a great variability; however, this does not mean that it affects the performance of the system, since the water crosses the complete canal, thus achieving the disinfection of the fluid.

In general, the distribution of radiation follows the same behavior regarding the general average, since the values observed are greater for condition 4, except in the cross section, and being so variable there are values that are less than condition 2. Therefore the latter is more uniform. Conditions 2 and 3 are an intermediate condition between conditions 1 and 4; however, they differ more in terms of cross section since condition 2 is more uniform than condition 3. Finally, condition 1 is the one with the lowest values, so it serves as a standard situation for the other cases for which a comparison of the partial averages was made and can be seen in Figure 8.

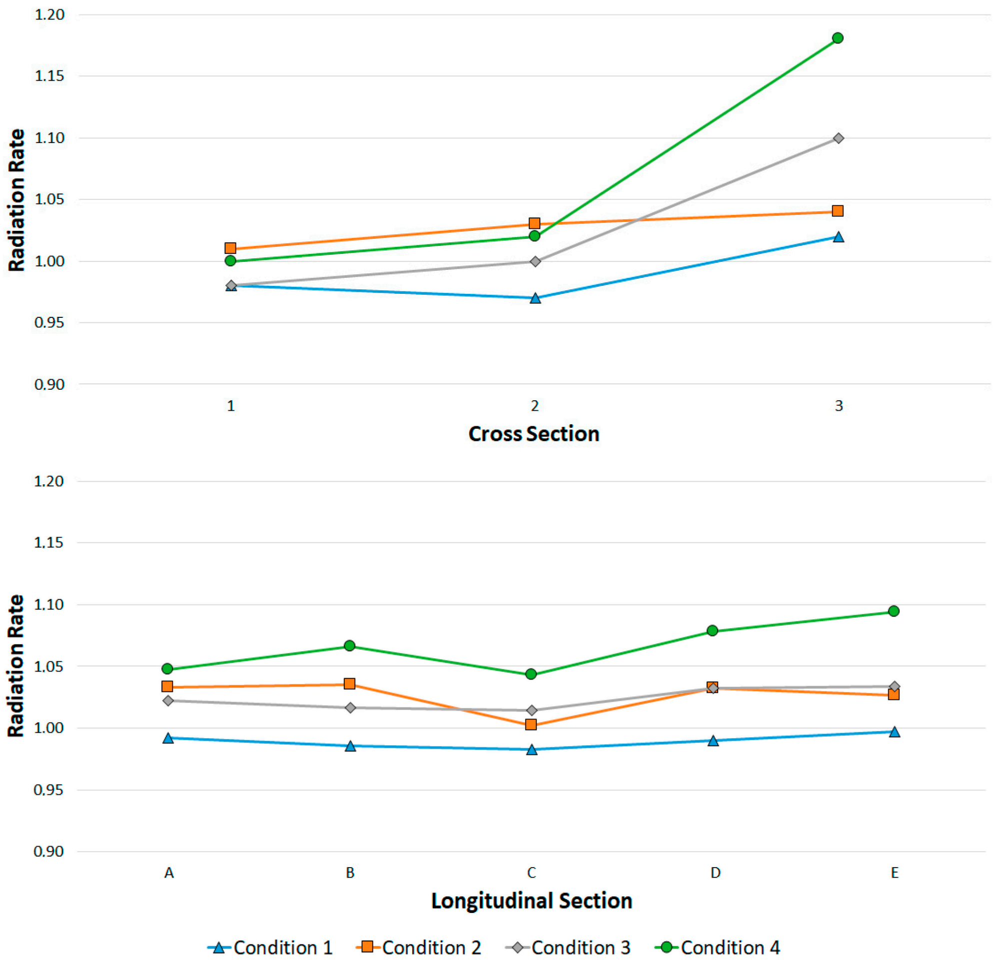

Figure 7. Plot of average radiation ratio distributions.

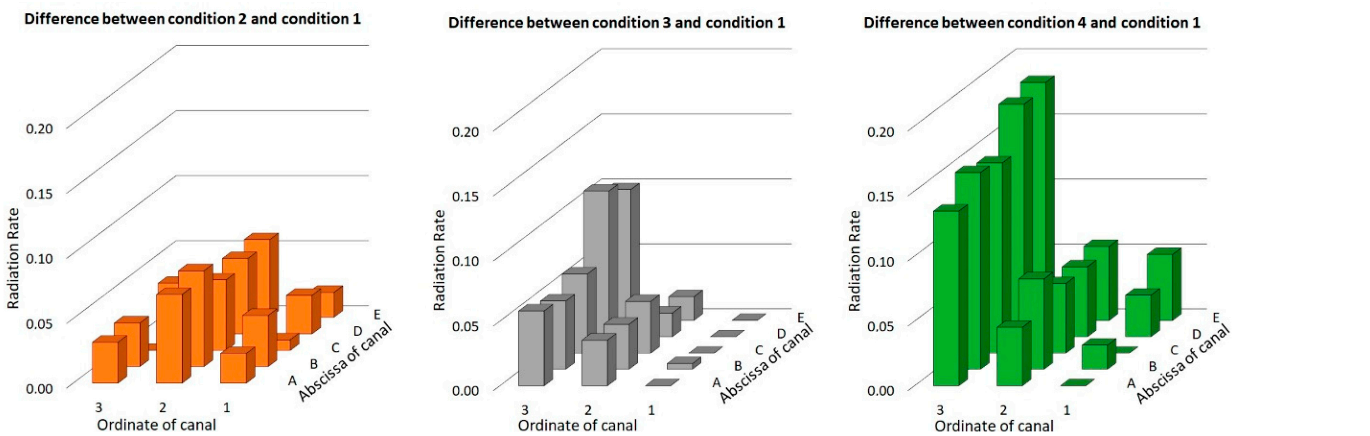

Figure 8. Difference of the partial means between conditions 2, 3 and 4, with respect to the standard condition 1.

Figure 8 reaffirms, in accord to the magnitude, distribution, and variability, that condition 4 is the highest value, although they are also the most variable and their distribution concentrates the highest radiation in zone 1. Concerning to conditions 2 and 3, these present similar differences with respect to the magnitudes of radiation, being lower than condition 4 but greater than condition 1; however, the difference between these last two cases is the distribution of radiation, being that condition 2 is the one that presents more uniform radiations with respect to the number, which could be a difference at the moment of the elimination of coliforms.

c. *Incidence of the radiation ratio on the elimination of coliforms.*

According to the prototype proposed in the study "First Results: Innovative Solar Disinfection Technology for Treated Wastewater that Integrates Materiality, Geometry, and Reflective Panels" [38], a direct relationship can be established between the total elimination of coliforms and the radiation ratio. To find this relationship, the radiation and coliform elimination data presented in the aforementioned study were used and a graph was made in which the cases of the present study were extrapolated as related to the efficiency of the prototype to remove coliforms. This relationship of total elimination of coliforms against radiation ratio was worked with three hydraulic residence times: 135, 180 and 225 min. The graph made is represented in Figure 8. It is worth mentioning that the extrapolated points are the ones with white filling; instead, the real data are A and B. Also, since point B and condition 1 have the same radiation ratio, these have the same efficiency and therefore overlap.

When comparing the results shown in Figure 9 with similar research, their consistency is verified. The maximum removal of total coliform was found to be 92.95% at 10 cm depth for sunny conditions, at 110 NTU, white container, 240 min [42].

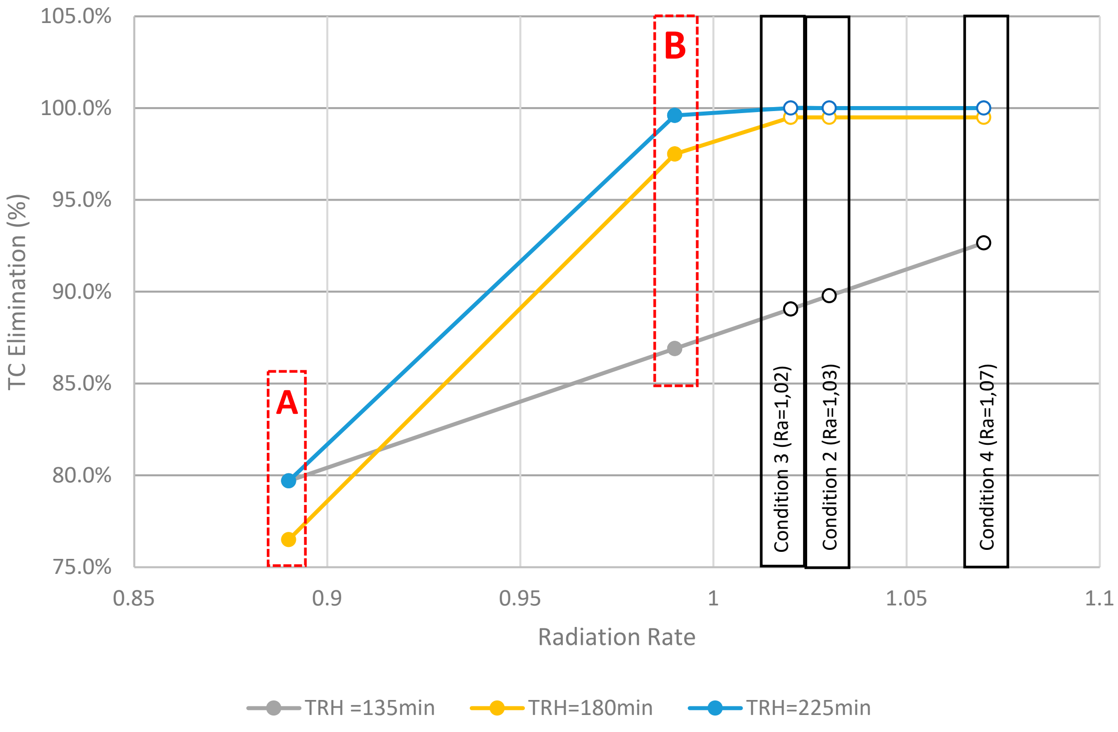

Figure 9. Theoretical relationship between the radiation ratio and the total removal of coliforms.

Figure 9 shows that total removal of coliform increases as the average radiation ratio increases for each hydraulic residence time. This considering that the same climatic and radiation conditions are developed for all cases. This could mean that, to the extent that aluminum mirrors are included in the materiality of the prototype, it could increase its total removal of coliforms. In other research, the high reflection coatings significantly improve the surface reflectivity in a specific wavelength range. A coating can be designed as a long or short pass filter, or an aluminum mirror with a specific reflectivity [43]. The increase in efficiency is reflected for different hydraulic residence times so this increase is applied to the different cases that may be found.

In sewage treatment experiences with a treatment system consisting of a constructed wetland and a disinfectant canal with flaps-panels, an excellent result of MPN/100 mL = 23 was reached [38]. Previous work of the constructed wetland is substantive for this achievement. The higher removal of fecal and pathogenic bacteria in constructed wetlands depends on certain factors, such as: the hydraulic regime, wastewater characteristics, and even the local climate [44]. The constructed wetlands with hydraulic improvement can also be proposed as a sustainable solution for pathogen removal [45].

Noteworthy, photochemical processes for the treatment of water and wastewater have been receiving increased attention for being sustainable treatments. Even different oxidative agents such as peroxymonosulfate, persulfate, and peracetic acid, have been recently investigated to enhance the action of the solar photons for water disinfection, aiming for their future implementation at full scale [34]; thus validating this alternative technology developed in Chile, since it is very easy to implement at different scales due to the continuous flow condition that characterizes it.

4. Conclusions

When only the aluminum mirrors are applied on the sloping walls of canal (condition 2) or on the side panels (condition 3), a similar increase in radiation (3 and 4% increase, respectively) is evident in the treatment zone. However, the best performance of the system, with the 8% increase in radiation compared to the base case, is achieved when using aluminum mirrors simultaneously on the sloped canal walls and on the side panels (condition 4).

It is concluded that the use of aluminum mirrors increases UV solar radiation in the area of influence of the canal, thus obtaining better results with respect to galvanized steel, and consequently increasing the elimination of pathogens.

The results obtained with the use of aluminum mirrors in the disinfectant channel, confirm the validity of this new technological solution to replace chlorine treatment as a disinfectant for treated wastewater.

This technology can be improved and, with further research directed towards the geometry, materiality, and fins-panels, it will be possible to reduce residence times, equipment size, and associated investment costs.

It should be noted that this equipment is technologically very simple, with a low investment and operating cost. In addition, as a goal, it is intended to obtain a competitive disinfectant equipment that is attractive to communities of people who need to reuse treated wastewater in the context of water and economic crisis through research and technological optimization.

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