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Self-Power UVC-LED Bacteria Reduction Base on Piezoelectric Nano Generator (PENG)

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Abstract

Environmental pollution as an early common reason for natural resources' unsafety, directly menaces human life hygienic indexes. Microbial pollution in water resources, food materials, and common surfaces has produced new problems with infected contacts in daily life activities. Purgation costs and traditional cleaning methods are inadequate and the pollution rate is ascending. Therefore interdisciplinary methods are required to rectify environmental pollution problems smartly while costs and side effects are defined in a sustainability context. The study was conducted to evaluate pulsed mood irradiation operation with UVC LED and a self-power system based on a Piezoelectric Nano Generator (PENG). The study tries to demonstrate the new approach compatibility in an interdisciplinary experiment designed for cleaning environmental pollution. Self-power system in the study is based on produced and tested PENG system that was designed with a proper circuit for a UVC LED power supply. Also, pulsed simulation with a pneumatic cylinder is used to create the required kinetic. Four UVC LEDs were used to make irradiation on diluted samples in the pour plate method. The ritual is an experiment designed in the Design of experiments (DOE) process for an optimized number of tests. The statistical analysis exerted to show impressive elements correlation with disinfection rate. Furthermore, continued irradiation mood was designed for results validation. The exposed samples were analyzed with image processing in python within the OpenCV library to avoid vision errors with edge detection technique. The results showed pulsed base UVC LED with a self-power system reaches high efficiency of disinfection while energy consumption and costs decreased. Most of the experiment cases successfully achieved full disinfection (LOG=6) and in some cases meaningful (LOG<6) disinfection was achieved. The study verified the linear and direct relation of irradiation distance, time, and frequency which cause high-efficiency operation of self-power pulsed irradiation system.

Keywords: Self Power Irradiation, UVC LED, PENG

1 Introduction

According to new technologies, developed UVC LEDs with destroyer emission wavelength were proven to have bactericidal disinfection efficacy. Reducing and non-activating microbial quantity as a common ritual works for wastewater treatment and surface disinfection process [1]. Regarding costs and economic benefits in wastewater treatment or surface, cleaning is a key problem for related fields in investment. Clean and safe water resource restriction for agriculture and daily activity regards as a high-priority problem that needs assessment by environmental researchers [2]. Reusing waste also considers a solution for water demands, hereupon new methods with high efficiency and low costs could be necessary [3], [4]. Bacterial pollution on surfaces in the identical form of pollution cause unsafe condition for patients, clients, and medical staff and need the same ritual for waste treatment ritual for disinfection. Therefore this study introduced a new interdisciplinary method base on UVC LED irradiation in pulse mood and self-power to rectify all defeats and drawbacks of the disinfection process, using ultraviolet germicidal irradiation (UVGI) with short-wave ultraviolet energy to inactivate viral, bacterial, and fungal organisms is a known way, so infection factors affected and unable to reproduction.

2 Literature Review

UVC irradiation disrupts the deoxyribonucleic acid (DNA) of a wide range of microorganisms, rendering them harmless [5]. Research proved that the most impressive UV wavelength range for disinfection and inactivation of microorganisms is between 220 and 280 nm, and peak effectiveness is near 265 nm [6]. In the other part of the study, the self-power system base on PIEZO electric nanogenerator (PENG) is used to gain the required energy source. This system's utility rate was ascending for self-power systems lately [7]. The unique property of materials like PIEZO material incentives reproduction of free energy sources nevertheless it needs more study to enhance these generators' power as a reliable source but using several PENG plates is adequate for any ritual in the environment. Previous studies are considered to conduct this case for instance using UVC for COVID-19 assessment [5] with the high-efficiency operation of disinfection, in other study UVC with 222 wavelength effect on bacterial analysis and results were endorsing high efficiency [6], even low wavelength UVC irradiation were evaluated to check out disinfection power on foods surfaces E. Coli problem and it achieved good action [8]. Another problem in the environment refers to water infection and pollution therefore in research UVC LED base approach is exerted to disinfect water and wastewater in an optimized planet and reach a high quality for

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this aim [9], [10]. UVC LED systems are useful and cheap for sorts of problems moreover flexibility in use for a variety of rituals is a good advantage [11]. In hygienic spaces and surfaces UVC irradiation is common and efficiencies for this aim were proved [11] and the growth of using refer to mercury ultraviolet systems drawbacks include large size or high costs [8] also flexibility is important and determining, discussed by researchers [9], UVC LED's do not need pre-installation and do not effect by environment temperature [11]. Totally base on a study [12] UVC LED's capability in microbial disinfection was proven by researchers, spot-lightly E.coli O157:H7, salmonella enteric serovar Typhimurium, and Listeria monocytogenes have high efficiencies reaction to irradiation while COVID-19 had similar reaction [5]. Self-power system based on PIEZO electric materials produced with the electro-spinning method and tested in UMA central Labrador which the ingredients include ZnO and PVDF. Totally 15 nano-films, each one with a high voltage of 25 V and max current of 4mA also 0.1 w output power, all nano-films in parallel contact to feed UVC LED's energy for E. Coli disinfection. The system used in this study depicted in figure 1 includes kinetic, energy PDC, and UVC-led parts.

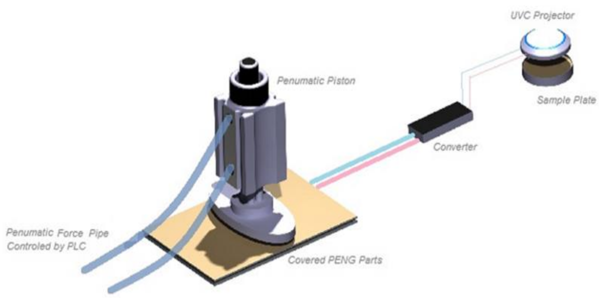

Figure 1: Used system parts

3 Methods

3.1. Experiment Design

The main method of this study focuses on an experimental approach. Three major steps of the experiment include designing an experiment, completing all rituals, and evaluating results. The experiment optimization process is applied to reduce the number of samples and avoid costs and probably experimental errors all in the design of the experiment (DOE) process. Design expert software's central composite method (CCD) was used to reduce the number of states and conduct optimum experiments in 20 cases. One categorical factor considered is emission frequency with two states of 1 Hz and 2 Hz, subsequently a quarter of a second and two-quarters of a second. Two numerical factors are distance in 0 (~0.5 cm), 1 cm, and 2 cm also the time of emission in each experiment was in the range of 20 s to 540 s.

3.2 The UVC LED System and Modeling

The routine source of UVC in commercial systems is low-pressure mercury vapor lamps, which emit mainly near-optimal 253.7 nm UVC [13]. But UVC LED is cheap and powerful to conquest UVC lamps [14], [15]. UVC LED system contains 4 main LEDs of 0.7 W and 260-280 wavelength made by *Shenzhen CZINE light technology Co* and attached in a circle plate for emission on the samples plate. Irradiation (I) spouted on sample plates in three different conditions, one categorical factor is emission frequency [16] with two states of 1 Hz and 2 Hz subsequently one at 0.25 per second and two times 0.25 per second. Two numerical factors are distance in 0 (~0.5 cm), 1 cm, and 2 cm also the time of emission in each experiment is in a range of 20s to 540s. The emission plate was designed with 4 LEDs at equal distances between to produce homogenized irradiation [17] as well shown in Figure 2 the plate is in 7cm diameter. For dosage (D) calculation first irradiation is recorded and the result is used in equation 1 to calculate every experiment's dosage according to total time (T) and total pulse period.

$$D\left(\frac{J}{m^2}\right) = I\left(\frac{W}{m^2}\right) T\text{Pulse Period (s)} \times (T\text{ Total (s)} \times f(\text{Hz})) \qquad \text{(Eq. 1)}$$

Figure 2: UVC LEDs and radiation reactor

According to irradiation facts at the first second of emission, irradiation is equal to dosage then irradiation confronts a constant value and dosage has a cumulative increase in each second of emission, so frequency, distance, and time of emission give adequate tools for emission modeling in this study. The input of the model works as irradiance and the output is considered as UVC dosage. Based on theories dosage increase cumulatively and each second of emission add a constant value of irradiation to the current dosage value which is achievable with equation 1 and the input formalized as equation 2 and 3 subsequently for 1Hz and 2Hz in a sinusoid wave shape shown in figure3.

Input= (sinax+|sinax|) 0.5 (Eq. 2)

Input= (sinax/2+|sinax/2|)0.5 (Eq. 3)

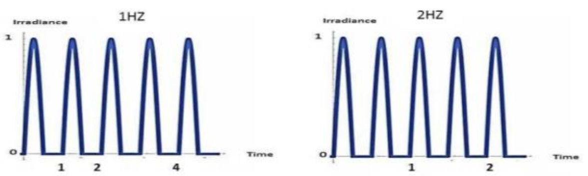

Figure 3: Irradiance wave model per frequency

The irradiation values recorded in the experiment and as mentioned dosage obtained by calculation, results of 1-second irradiation, and dosage base on table1 used for dosage.

3.3 Self-Power System Design and Specifications

Materials like ZnO and PVDF with Piezoelectric specifications produce electric energy that is transformed from kinetic energy in piezoelectric nanofilms, these materials are high efficiency and good conductive [18]. The self-power system with a PDC energy source is based on PENG exerted for UVC LED irradiation[18]. Kinetic simulation derived by Pneumatic cylinder with pulsed pressure on nanofilms and output of nanofilms produced PDC [18]. In the real cases of environment or industrial states the kinetic considers water current pressure, wind current pressure, road or railways load pressure, and any natural free kinetic sources. Nanofilms in 15 numbers with 4ma current and 25v voltage and a maximum power of 0.1 w were tested in the laboratory then contacted in parallel and AC to DC ritual was done to produce PDC as the final energy source for UVC LEDs. Modeling equations and figures obtained and depicted subsequently in equations 4, 5, and figure 4. The self-power systems structure and PENG used in the study are shown in Figures 5 and 6.

$$F(x)=C_0(x+\sin^2 a/2x)-b \quad \text{(Eq. 4)}$$

$$F(x)= C_0\,(x+\sin^2 ax)-b/2 \quad \text{(Eq. 5)}$$

Table 1: Irradiation values per second

Dose	Irradiance	d	f
mj/cm^2	mw/cm^2	cm	Hz
0.95	3.821	0.5	1
0.23	0.95	1	
0.057	0.23	2	
1.91	3.821	0.5	2
0.475	0.95	1	
0.115	0.23	2	

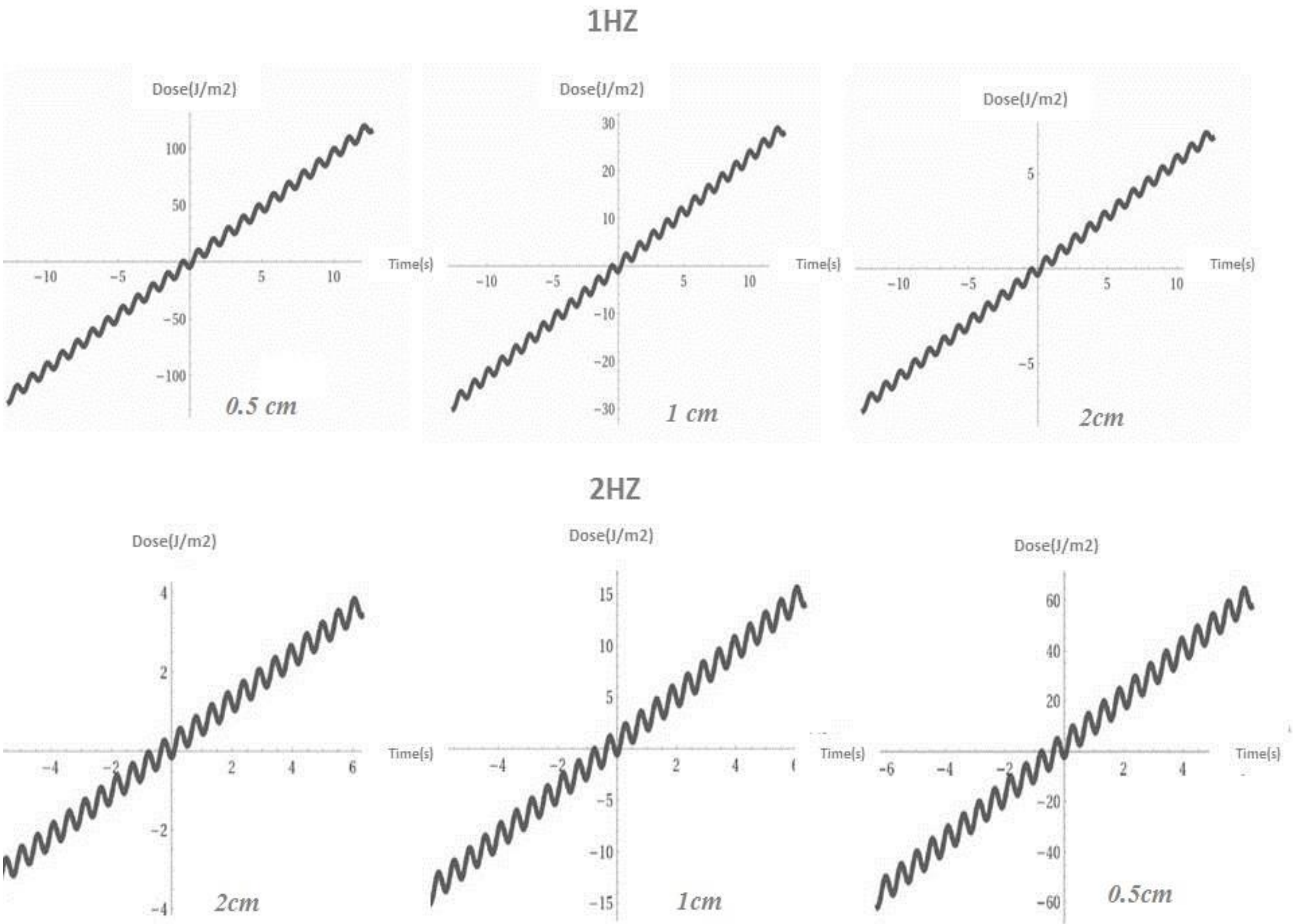

Figure 4: Dosage modeling

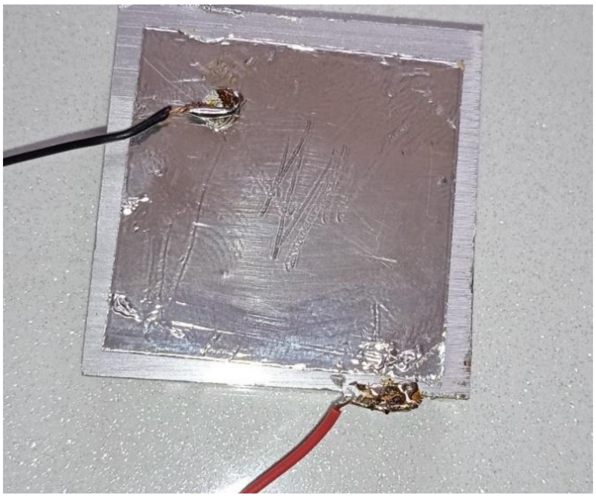

Figure 5: PENG plate

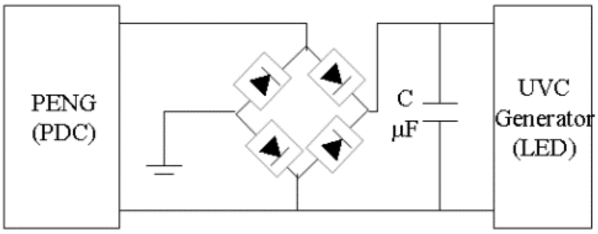

Figure 6: PDC self-power system

The structure of the self-power PENG simulation showed a pulsed output with AC in three steps as shown in figure 7. Area of "I" and "III" are considered as producing areas, and the second area of "II" indicates that output turns to the opposite peak while crossing the zero production range. While the "II" areas range is large the output has low efficiency and the PDC source is weak.

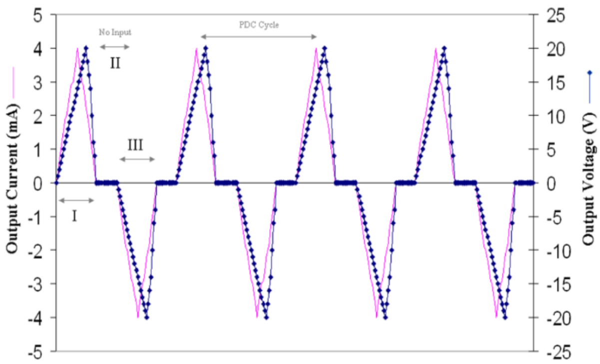

Fig.7 PENG output voltage

3.4 Sampling

Health science indexes E. coli bacteria considered as hygienic standards both in drinkable water and wastewater quality for reuses. This study maneuvered on E. coli samples inactivation and disinfection in a designed self-power reactor while exposed to UVC irradiation [19]. The samples were provided from the *Karaj River* downstream. The possible cultivation step is done by the MLP method in 15 pipes in autoclaved *Lauryl Sulfate Broth* medium. Through a routine time of 48hr samples in 37C were assessed the positive samples with turbidity due to bacteria fermentation were marked. The next verification step was conducted in *EC- Broth* ، *BGB* and *EC-MUG* cultivation mediums subsequently for thermophilic bacteria, in this case, E. coli with 44.5C durability. The samples in Bain-*Maries* checked and produced gas in test tubes verifying the bacteria availability. The samples provided in the *Pour Plate* method in *Nutrient Agar* medium, each plat contain 10ml solution and the bacteria number estimated around 10^6 in this state. The dilution process was conducted firstly with *0.5 McFarland* standard for bacteria samples which were obtained for cultivation with spectrophotometry analysis. The prepared sample in 1 ml mixed with 9ml physiological serum to provide 1 to 1 ratio sample, this ritual was repeated with 1ml of new sample mixed with 0.9ml physiological serum to provide a 1 to 10 ratio sample, subsequently rest of the diluted samples provided in plates and prepared for UVC irradiation in two frequency state and three distance state also different exposing time from the 20 s to 540s considered. The exposed samples then were placed in Incubator at 37ºC for 24 hr to assess possible disinfection. All samples prepared within designed experiments number in pulsed irradiation mood and continuous irradiation.

3.5 Evaluation methods

The experimental results are comparable and parameters are changeable. Samples results were clear enough to evaluate directly without the microscope, meanwhile artificial intelligent image processing tools include the python edge detection method with OPENCV library used to clean scatter unpleasant spots and avoid little colonies neglection. The final results were compared in two moods of pulsed and continued irradiation. Also, statistical evaluation is exerted for parameter impressiveness. The modeling results were used in the notional description. The samples disinfection was reported with *LOG* (N_{0}/N_{Active}) of the disinfection portion. To calculate the bacteria numbers each colony in plates must be subtracted to $10^{(\text{dilution rate})}$, this estimation of bacterial numbers is a mathematical method.

4 Results

4.1 Pulsed Irradiation Results

The irradiation categorical factor in two moods of 1Hz and 2Hz was basically for results distinction in pulsed irradiation mood and continued mood. The CCD state was used for optimizing the experiment design and it concluded 20 tests, hereupon parameters were determined and all experiments were conducted to analyze the pulsed irradiation effect on the bacteria samples made with the pour plate method. After all operations in pulsed mood irradiation and after spending 24hr in Incubator the results of the sample were recorded as shown in table 2. The results showed a pretty linear, direct, and inverse relation of factors with dosage (mj/cm^2) in the range of LOG 1 (least disinfection, where there is one colony in the plate with a 1:5 rate of dilution) to LOG 6 (top disinfection where there is 1 colony in the plate with 1:1 rate of dilution). The meaningful results (LOG<6) plates are shown in figure 8 and chart 1. The image processing results verified the obvious results in plates, especially in meaningful (LOG<6) plates the number of colonies exactly obtained. At the continued irradiation mood bacteria inactivation operated as well which is depicted in figure 9 and described in the next part with ingredients.

Table 2: Pulsed irradiation results

Test number	Distance (cm)	Time (s)	Frequency (Hz)	Dose (mj/cm^2)	Log	Disinfection in %
1	0	100	f1	95	6	99.9999
2	2	280	f1	168	5	99.9999
3	2	500	f2	57	6	99.9999
4	1	80	f2	48	6	99.9999
5	2	20	f1	1.15	1	90
6	0	20	f2	92	6	99.9999
7	1	520	f1	23.8	6	99.9999
8	2	540	f1	31.05	6	99.9999
9	1	300	f1	63	6	99.9999
10	1	60	f1	14.27	5	99.999
11	0	540	f2	10.26	6	99.9999
12	1	260	f1	60	6	99.9999
13	1	20	f1	4.72	4	99.99
14	2	280	f2	30.3	6	99.9999
15	1	280	f1	69	6	99.9999
16	2	40	f1	3.5	3	99.9
17	1	220	f1	52.4	6	99.9999
18	0	20	f1	21	6	99.9999
19	0	540	f1	423	6	99.9999
20	2	20	f2	2.3	2	99

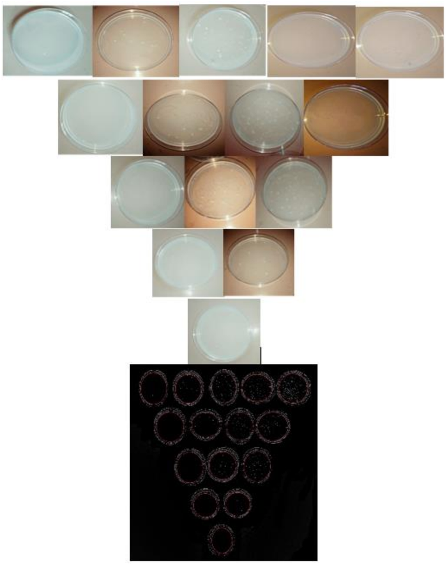

Figure 8: Pulsed irradiation results in plates

Figure 9: Continued irradiation noncomplete disinfection case

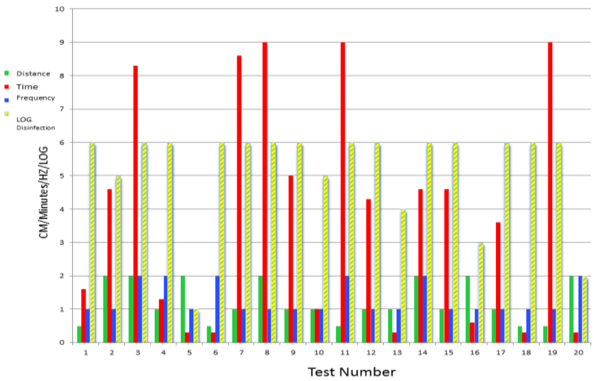

Chart 1: Pulsed irradiation results

4.2 Continued Irradiation Results

This part of the study was conducted for validation aims to evaluate and compare the pulsed results with common UVC disinfection results. Hereupon irradiation was used in the continued mood on plates and two numerical parameters of distances (0.5 cm, 1 cm, 2 cm) and time (20-540s) were considered. The experiments were done instatestate of the pulsed based base on DOE. The results shown in table 3 and meaningful (LOG<6) results in the plate shown in figure 9 and chart 2 also python OPENCV library base edge detection image processing results verify the number of plate colonies as well.

Table 3: Continued irradiation results

Distance (cm)						Time
0.5		1		2		
log	dose(mj/cm2)	log	dose(mj/cm2)	log	dose(mj/cm2)	s
6	45	6	20	5	7	20
6	140	6	32	5	10	40
6	200	6	53	5	12	60
6	290	6	73	6	19.5	80
6	370	6	90	6	22	100
6	400	6	99	6	27	120

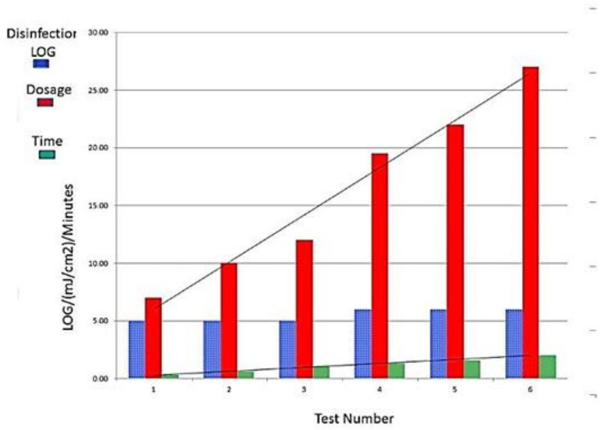

Chart 2: Continued results

4.3 Statistical Results

The experiments' statistical result relies on correlation and regression between parameters and disinfection level (LOG). According to figure 10 and both moods of irradiation, it is directly related to emission distance and time of irradiance. This is more verifiable with pulsed mood dosage modeling in figure 4 where dosage amount is directly increasing with time incrassation and shows a positive correlation. In other states distance made a negative correlation but in direct relation, far irradiation distance defeats the dosage effect, unlike near emission. Frequency as a unique categorical parameter operated in pulsed mood and the correlation reach a positive powerful level as shown in figure 10 where 2Hz rather than 1Hz made a meaningful effect on plates while other parameters were constant. also, linear regression analysis between parameters indicated that a single effect of parameters probably disqualifies as a seriously impressive element while the number of tests is confined in DOE, and results verified this point. The results of regression in overall also showed high relation and meaningful effect ($p<0.05$). Both overall and secluded regression results are available in Figures 11, 12, and Table 4.

The PENG releasing energy in optimum voltage(Vmax=25v), directly feeds irradiation which is assumed for ON mood(irradiance=1). Frequency power supply feeding makes a change where 2Hz and 1Hz irradiation cause different disinfection effects at the end of the experiment, the differences are shown in Figure 13 where respectively first disinfection is achieved in around 41st second of 2Hz irradiance in comparison to 1Hz irradiance first disinfection achieved in around 77th second. This shows a clear relation between self-power PDC power supply feeding system and pulsed irradiation with a vivid indication of frequency element as the most impressive index.

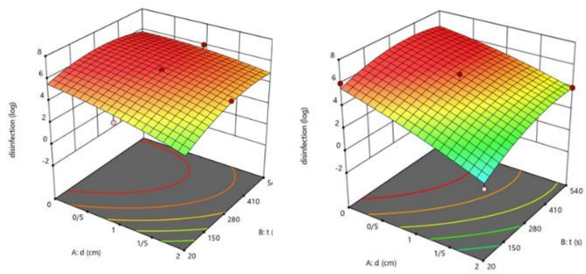

Figure 10: Pulsed irradiation element relation

Table 4: Parameters of overall regression with Log disinfection

Source	df	F	p-value	r-square	r(adj)-square
Regression	6	10.9	0.0002	0.834	0.757

5 Discussion

The study was conducted to evaluate pulsed mood irradiation operation with UVC LED and a self-power system based on PENG. The study tries to demonstrate the new approach compatibility in an interdisciplinary experiment designed for cleaning environmental pollution. Self-power system in the study is based on produced and tested PIEZO electric nanogenerator system that was designed with the proper circuit for a UVC LED power supply. Also, pulsed simulation with a pneumatic cylinder was used to create the required kinetic. The PENG specification and its modeling showed a pulsing base DC or PDC with a constant feeding state for the system and this point on large scale indicates the economical role of self-power systems to modify disinfection rituals drawbacks as a major barrier of UV base sanitization. Also, there is a direct relation between PDC output and UVC LED maximum irradiation as depicted in figure 13. Image processing results that were conducted in a machine learning algorithm (python-OPENCVl) verified the samples' true colonies in acceptable size to avoid vision error this process with high efficiency of 99.99% verified. The results recorded for pulsed irradiation as mentioned were meaningful (LOG<6) in some samples. According to table 2 most dosage amount recorded in the most irradiation time (540 s), least irradiation distance (0.5cm~0), and 2 Hz of irradiation frequency were achieved to 10.26 mj/cm^2 of dosage.

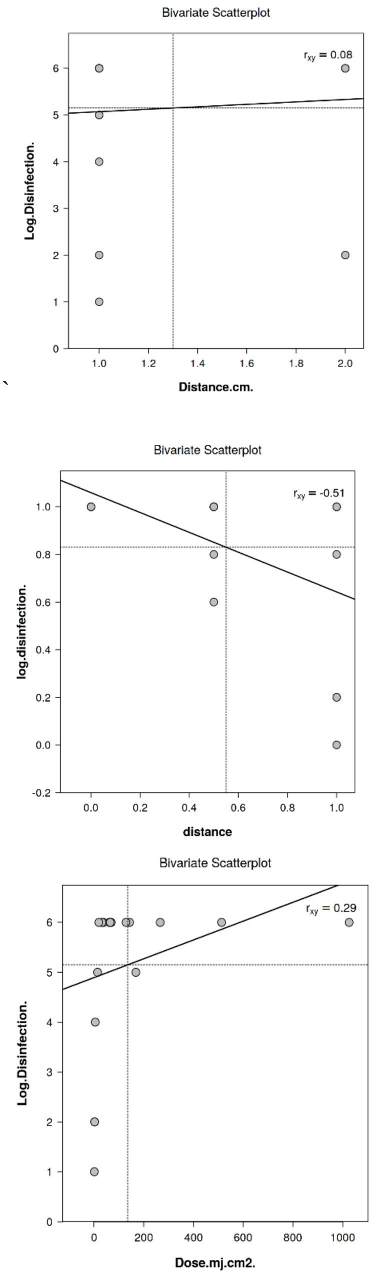

Figure 11: Each parameter regression with Log disinfection

Also, these parameters released good effects of irradiation under pulsed mood on samples cultivation after 24hr in *Incubator* where inactivation reached to high level (LOG=6) or 99.9999% disinfection in contrast to primary bacteria number. In other words, it is probably possible to find 1 colony in the sample with a 1:1 dilution rate. The last dosage amount was recorded in the least irradiation time (20 s), most irradiation distance (2 cm), and 1Hz of frequency, and this situation caused irradiation results to achieve 1.15 mj/cm^2 of dosage. Also, these parameters released weak effects on sample cultivation after 24 hr in Incubator which concluded in low disinfection level (LOG=1) or 90% disinfection in contrast to the primary bacteria number. In other words, it is probably possible to find 1 colony in the sample with a 1:5 dilution rate. The continued irradiation mood showed the least dosage of 7 mj/cm^2 in 2cm and 20s which is more than pulsed values in similar cases, while one colony in a plate with a 1:10 dilution rate was found (LOG=5). Also, continued irradiation results showed a dosage of 973mj/cm2 in 540s as a high period of irradiation with the least distance (0.5~0) as the best condition in which disinfection achieved full inactivation (LOG=6). Close analysis of pulsed irradiation shows self-power system efficiency, where the operation is done without defeat in the power supply feeding process that leads to UVC LEDs irradiance or consequently disinfection condition.

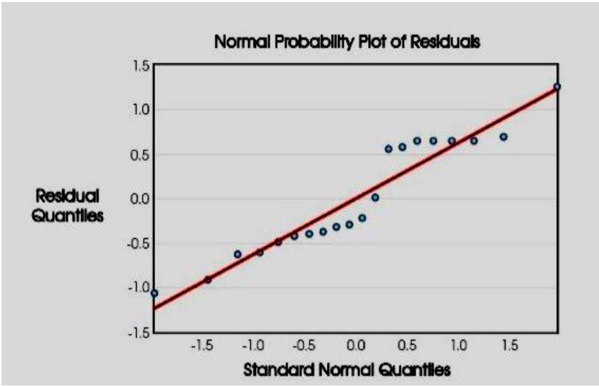

Figure 12: Overal regression results

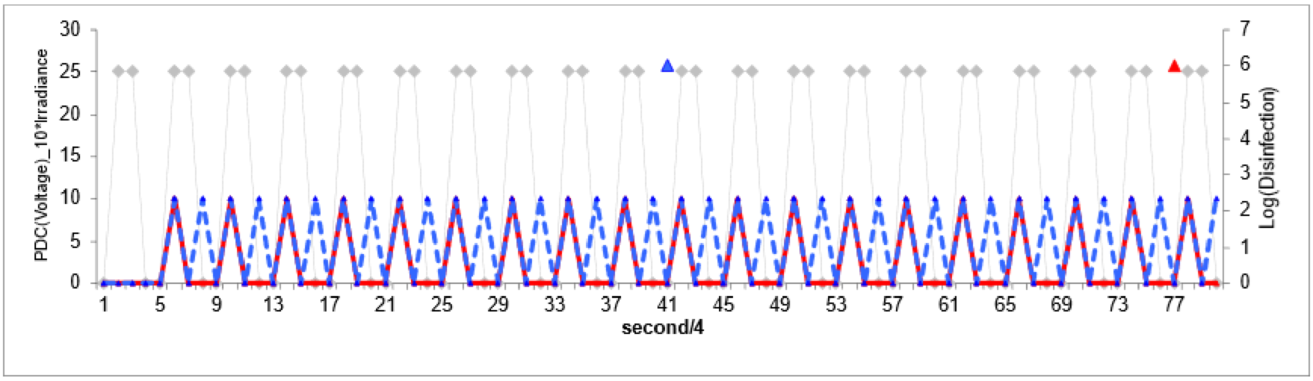

Figure 13: PDC relation to irradiance and disinfection

The results are showing a direct and linear relationship between parameters and disinfection (LOG) or dosage. Where the frequency and time of emission increase and simultaneously distance decrease incentives the disinfection rate enhancement. Also in reverse situations, changes cause a meaningful (LOG<6) decrease in disinfection or dosage rate. This fact is vividly derivable from Figure 12 of modeling and statistical results as well as shown in Table 4 where the overall regression ($r2=0.834$) confirms the relations. Continued mood irradiation results showed a powerful disinfection operation on plates and only a 2 cm distance confronts meaningful(LOG<6) operation. Irradiation times of 60 s or lower in 2 cm distance causes the dosage amount to reach 12 mj/cm^2 or lower and disinfection achieved 99/999% successfulness (LOG=5), in other words, there was 1 colony in the plate with a dilution rate of 1:10 as shown in Figure 8. In comparison, pulsed irradiation in 20 tests with an optimized design showed a relatively successful operation. In meaningful (LOG<6) disinfection cases which are 6 cases the results achieved worst (LOG=1) and relatively bad (LOG=2 to LOG=5) disinfection. In the least disinfection operation UVC LED pulsed irradiation affected 90% of primary bacteria numbers and qualify as LOG=1 this case was tested in a 2 cm distance and 1Hz in 20 s, then irradiation in 2cm, 2Hz, and 120s emission showed 99% of successfulness and reach to LOG=2 at next case irradiation in 2 cm, 1Hz and 40s emission showed 99.9% of successfulness and reach to LOG=3 at next case. Again in another case of pulsed irradiation with self-power system irradiation in 1cm, 1Hz and 20s emission showed 99.99% of successfulness and reach LOG=4 in the final two cases with meaningful (LOG<6) disinfection two cases achieved 99.999% successfulness or LOG=5 of disinfection but with different elements that reveal parameters linear and direct relation. First irradiation in 2cm, 1Hz and 280 s, and the second case in 1 cm, 1 Hz, and 60 s and this verifies the compensational role of irradiation distance, frequency, and time as one of them creates a negative effect other one rectified the operation weak points to reach equal disinfection with two different case elements. These results are in compatibility with previous studies that are considered to research using UVC for disinfection [5] with the high-efficiency operation of disinfection and this fact proved in the study where flexibility can rectify fast operation. In another study UVC irradiation with 222 wavelength effects on bacteria, and the results analyzed endorsed high efficiency [6], even low wavelength UVC irradiation was evaluated to check out disinfection power on food surfaces E. Coli problem and it achieved good action [8]. Another problem in environmental issues refers to water infection and pollution therefore in research UVC LED base approach was exerted to disinfect water and wastewater in the optimized planet and reach a high quality for this aim [9], [10]. UVC LED systems are useful and cheap for sorts of problems. Moreover, flexibility in use for a variety of rituals is a good advantage [11]. In hygienic spaces and surfaces with cleaning requirements, UVC irradiation is common and high efficiency for this aim was proved [8] also flexibility is important and determining, as discussed by researchers [9], UVC LEDs do not need pre-installation and do not affect by environment temperature [10] so a self-power system with UVC LED develops this advantage more and more [11]. Side elements in UVC operation were researched in other studies [12] and proved that distance, frequency, and time are the most important factors for E. Coli disinfection. Other studies in this field verified the environmental parameters' effect on UVC sanitation application [13].

6 Conclusion

From a logical viewpoint, it seems to be clear that using the self-power system PENG for UVC LEDs due to flexibility and low costs also reducing energy costs is the main purpose of the system and study conduction. The results in each part recorded and totally in sanitization results the whole idea of self-power UVC LED irradiation system base on PENG verified, where disinfection with pulsed self-power system achieved high efficiency of disinfection and with a neglectable different in compare to continued irradiation, pulsed irradiation with the self-power system qualify as a creative method for disinfection and cleaning. The disadvantage of the method is defined as a relatively slower operation that is very slight and neglect able while an increasing number of LEDs, frequency, reducing irradiation, and irradiation time incrassation could rectify this slight problem but this method creates resounding differences in economical aspects and costs with self-power supply also flexible portable parts make facilitation for the cleaning process.

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Ethical issue

Authors are aware of and comply with, best practices in publication ethics specifically about authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that no conflict of interest would prejudice the impartiality of this scientific work.

Authors contribution

All authors of this study have a complete contribution to data collection, data analyses, and manuscript writing.

References

1. Tabatabaei S-H, Nourmahnad N, Kermani SG, Tabatabaei S-A, Najafi P, Heidarpour M. Urban wastewater reuse in agriculture for irrigation in arid and semi-arid regions-A review. International Journal of Recycling of Organic Waste in Agriculture. 2020;9(2):193-220.
2. Voulvoulis N. Water reuse from a circular economy perspective and potential risks from an unregulated approach. Current Opinion in Environmental Science & Health. 2018;2:32-45.
3. Ataei A, Panjeshahi M, GHARAEI M. New method for industrial water reuse and energy minimization. 2009.
4. Viraraghavan T, Subramanian K, Aruldoss J. Arsenic in drinking water—problems and solutions. Water Science and Technology. 1999;40(2):69-76.
5. Rezaie A, Leite GG, Melmed GY, Mathur R, Villanueva-Millan MJ, Parodi G, et al. Ultraviolet A light effectively reduces bacteria and viruses including coronavirus. PloS one. 2020;15(7):e0236199.
6. Narita K, Asano K, Naito K, Ohashi H, Sasaki M, Morimoto Y, et al. Ultraviolet C light with wavelength of 222 nm inactivates a wide spectrum of microbial pathogens. Journal of Hospital Infection. 2020;105(3):459-67.
7. Priya S, Song H-C, Zhou Y, Varghese R, Chopra A, Kim S-G, et al. A review on piezoelectric energy harvesting: materials, methods, and circuits. Energy Harvesting and Systems. 2017;4(1):3-39.

8. Kim D-k, Kang D-H. Effect of surface characteristics on the bactericidal efficacy of UVC LEDs. Food Control. 2020;108:106869.
9. Jarvis P, Autin O, Goslan EH, Hassard F. Application of ultraviolet light-emitting diodes (UV-LED) to full-scale drinking-water disinfection. Water. 2019;11(9):1894.
10. Song K, Mohseni M, Taghipour F. Application of ultraviolet light-emitting diodes (UV-LEDs) for water disinfection: A review. Water research. 2016;94:341-9.Shin J-Y, Kim S-J, Kim D-K, Kang D-H. Fundamental characteristics of deep-UV light-emitting diodes and their application to control foodborne pathogens. Applied and environmental microbiology. 2016;82(1):2-10.
11. Kim S-J, Kim D-K, Kang D-H. Using UVC light-emitting diodes at wavelengths of 266 to 279 nanometers to inactivate foodborne pathogens and pasteurize sliced cheese. Applied and environmental microbiology. 2016;82(1):11-7.
12. Donnaz S. Water reuse practices, solutions and trends at international. Advances in Chemical Pollution, Environmental Management and Protection. 6: Elsevier; 2020. p. 65-102.
13. Gerchman Y, Mamane H, Friedman N, Mandelboim M. UV-LED disinfection of Coronavirus: Wavelength effect. Journal of Photochemistry and Photobiology B: Biology. 2020;212:112044.
14. Kim D-K, Kang D-H. UVC LED irradiation effectively inactivates aerosolized viruses, bacteria, and fungi in a chamber-type air disinfection system. Applied and environmental microbiology. 2018;84(17):e00944-18.
15. Yaun BR, Sumner SS, Eifert JD, Marcy JE. Response of Salmonella and Escherichia coli O157: H7 to UV energy. Journal of Food Protection. 2003;66(6):1071-3.
16. Gross A, Stangl F, Hoenes K, Sift M, Hessling M. Improved drinking water disinfection with UVC-LEDs for Escherichia coli and Bacillus subtilis utilizing quartz tubes as light guide. Water. 2015;7(9):4605-21.
17. Ahsanulhaq Q, Umar A, Hahn Y. Growth of aligned ZnO nanorods and nanopencils on ZnO/Si in aqueous solution: growth mechanism and structural and optical properties. Nanotechnology. 2007;18(11):115603.
18. Eisenlöffel L, Reutter T, Horn M, Schlegel S, Truyen U, Speck S. Impact of UVC-sustained recirculating air filtration on airborne bacteria and dust in a pig facility. PloS one. 2019;14(11):e0225047.