Desalination and Water Treatment 11 (2009) 132–143
www.deswater.com
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Performance evaluation of the household ultraviolet water purifier

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Received 12 February 2009; Accepted 31 August 2009

ABSTRACT

In this study water disinfection capability of three household ultraviolet water purifiers was studied. The first two purifiers were composed of three housings, namely, for polypropylene yarn cartridge, for granular activated carbon cartridge and for 4-pin ultraviolet lamp. The third purifier was a horizontal water flow system containing a bi-pin ultraviolet lamp labeled as UV water Sterilizer. This study focused on the performance of the cylindrical UV disinfection reactor. Eleven ultraviolet lamps were labeled and placed in the UV sets turn wise. 100 ml of water samples collected from various sites were studied for coliform colonies growth before UV irradiation and after the process. To study the affect of the biodose on the efficiency of UV lamps, one/two ml of sewage was injected in 25 liters of tube well water. The performance of various lamps was studied after 24 hours incubation. The lamps were efficient for low bio-dose but none of the lamps was found efficient against high-bio-dose. The public health services require that UV lamp should have a minimum UV dose of 16,000-µw sec./cm^2. Spectroscopic studies revealed that all the UV lamps irradiate a beam of 253.7 nm,. These lamps differed in the emitted UV dose and the arc length only. Quartz sleeves surround UV lamps in the disinfection reactor. Four quartz sleeves were spectroscopically studied for UV transmittance. It was found that the green sleeve was pure silicate glass having zero percent transmittance for UVC, while the other three were good quality quartz sleeves. The hydraulic contact time of water film with UV lamp, and its optimum length was calculated from the analysis. As UV lamp of the optimum length and UV dose was not available, in order to achieve the required results the stainless steel jacket surrounding the sleeved lamp was replaced by a highly UV reflecting metallic jacket, or UV photo reflector. The improved design produced encouraging results.

Keywords: Ultraviolet water purifier; Quartz sleeves; Leachate; Germicidal lamps; Ultraviolet photo-reflector

1. Introduction

Drinking water is purified through a number of unit operations and processes, like, screening, coagulation, flocculation, sedimentation, floatation, granular bed filtration, and adsorption etc, which result in the removal of color and turbidity, improvement of taste and odor etc [1].

These processes can successfully remove micro particles and dissolved organics from water but cannot kill or inactivate microorganisms. A number of techniques are commonly used for water disinfection, like Chlorine (aqueous) either in the form of $HOCl^+$ or OCl^- disinfects microorganisms but generates byproducts from organics present in water [2]. Ozone being an allotrope of oxygen is an important oxidizer, improving taste and odor of drinking water [3]. Ozone has residual effects; it is an unstable gas and has a very short life. It oxidizes and deteriorates all the downstream pipes. Distillation is an effective means of disinfection where vaporization leaves all contaminates behind. Distillation adds nothing to water and removes contaminants by physical means, but it is costly, time and space consuming.

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Presented at CESE-2009, Challenges in Environmental Science & Engineering, 14–17 July, 2009, Townsville, Queensland, Australia.

doi: 10.5004/dwt.2009.8kl

Silver ions have been used for disinfection of water for centuries [4]. This method is not very costly, but it needs special expertise. Ultraviolet rays in the range of 200 to 280 nm (UVC) are germicidal rays [5]. These rays disrupt the DNA structure of the microbe. In DNA a sequence of four nitrogenous bases (Adenine, Cytosine, Guanine, and Thymine) link the double-stranded helical structure by hydrogen bonds. The fact that the power/intensity of UV radiation in air drops as the square of the distance from the source (the inverse square law) [6] is elaborated in Figs. 5 and 6.

Important factors which may affect the UV lamp performance are; the intensity of the lamp, which should not be less than 16,000-µw sec./cm^2, the transmittance of UV rays through the glass of the lamp as well as of the sleeve surrounding it, the symmetry of the sleeve, the depth of the water film, which should not exceed 1 cm, the flow rate of water, the clearance of the sleeve from scaling, the hydraulic contact time of water with UV lamp, the level of water turbidity, which should not exceed 10 NTU, color should not exceed 15 TCU, Iron content inside it should not cross 0.2 ppm and the temperature of water should remain at 104°F.

Ultraviolet disinfection is at the top of all other methods, because ultraviolet rays if properly irradiated, destroy all microbes and have no residual effects.

2. Materials and methods

The following sequence was followed during the experimental work:

2.1. Labeling of UV lamps and quartz sleeves

A number of Ultraviolet lamps and Quartz sleeves were collected. All the lamps were labeled alphabetically from "A" to "O" and the sleeves from "a" to "d" simplifying the analysis work as shown in Table 1.

2.2. Measurement of the input power of the lamps

The input power of UV lamps was recorded in the presence of ballast set in the circuit. The current through the circuit was measured and multiplied by the input voltage (220 volts) to find input power in watts.

2.3. Spectroscopic analysis of ultraviolet lamps and sleeves

Spectroscopic analysis (UV-Vis-IR) of four sleeves and eleven lamps was done for percent UV transmission. Results were obtained graphically.

2.4. Quantitative study

In the quantitative phase, the emittance power of 253.7 nm of 10 UV lamps was recorded at various distances from a given UV lamp in air. The intensity was calculated by dividing the recorded values with the area of the sensor (03 films 016, only sensitive to 253.7 nm) connected with the probe of the wattmeter. (Due to non availability of radiometer, UV wattmeter recorded linear emittance.)

Specifications of the UV sensor are;
Percent transmittance of 253.7 nm

= 11.54

Area of the UV sensor

$= \pi r^2$
$= 1.1309$ cm^2

Intensity (m Watts/Unit Area)

= mW/area
= mW/1.1309 cm^2
= 0.884 mW/cm^2
= 884 µw/cm^2

Considering 0.884 mW/cm^2 as a unit; Intensity of the lamp "L" when the sensor was placed just above it

$= 2.314 \times 0.884$ mw/cm^2
= 2045.576 µw/cm^2

Dose of UV rays is equal to the product of the intensity and hydraulic contact time [6].

$$\text{Dose} = \text{Intensity} \times \text{Time} \quad (1)$$

Ultraviolet dose per unit time emitting from the surface of the lamp "L";

= 2045.58 µw s/cm^2

In order to find the power, intensity and dose of 253.7 nm of a lamp in water, Beer's law was used

$$I = I_o e^{-kx} \quad (2)$$

where; I_o is the maximum intensity recorded at a distance of "0" cm, just above the sensor, I is the intensity of the UV rays at a distance x from the lamp, k is the coefficient of absorption in water, (the value of k was heuristically selected as 0.18 from the literature [7].

The accepted dose of UV radiation for successful disinfection of water is 16000-µw.s/cm^2.

From reciprocity law, in equation (1);

$$T_c = \text{dose/intensity} \quad (3)$$

Dividing the value of standard dose (16000 µw s/cm^2) by the intensity of a lamp at a given distance from the sensor of the wattmeter as calculated from equation (2), the required hydraulic contact time of water with radiation for disinfection can be calculated. For example the intensity of lamp "J" at one cm from the sensor in water is 1433.64 µw/cm^2. The hydraulic contact time T_c of one cm

Table 1
Specifications of UV lamps and sleeves collected for studies.

S. No	Labels on the lamps	Length cm	Diameter mm	Make up	Input watts (printed)	Arc length cm
1	A	32.6	25.3	Philips lamp used in Mabzi filter	10	30.6
2	B	28.1	14.6	No label (collected from Lahore)	Unknown	22.0
3	C	25.1	16.7	Damaged lamp of So~Safe (donated by Mr. Javed Iqbal)	Unknown	16.0
4	D	24.7	16.0	Sankyo Denki (Fused)	Unknown	15.5
5	E	20.9	15.7	Two-pinned lamp collected from Lahore	Unknown	16.0
6	F	24.7	15.4	No label	Unknown	16.0
7	G	28.3	15.2	USA labeled (collected from Lahore)	10	22.0
8	H	24.7	14.8	Bin.Qutab lamp, (Sankyo Denki) (installed in the E&ME College)	Unknown	15.5
9	I	28.7	14.9	Fused lamp of So~Safe (collected from Mr. Kifayat Pasha, an employee of So~Safe companies)	Unknown	17.5
10	J	28.7	14.9	Aqua safe (donated by Bin-Qutab)	Unknown	22.0
11	K	43.5	26.1	Phillips lamp (Bin-Qutab donation in sterilizer set)	10	41.5
12	L	28.1	15.1	So~Safe gold (donation by So~Safe)	18	20.2
13	M	25.1	16.1	Sankyo Denki (donated by Bin. Qutab)	Unknown	15.5
14	N	24.9	15.1	Sankyo Denki, (donated by So~Safe)	Unknown	15.5
15	O			So~Safe gold (installed at IESE)	Unknown	20.2
Sleeves		Note = Some of these lamps fused during the analysis work				
a		26.2 cm	23.1 mm	Green Sleeve (donated by AMPHA water filters agency)		
b		22.2 cm	23.1 mm	Donation by Bin-Qutab industries		
c		26.7 cm	22.3 mm	Donation by So~Safe industries		
d		28.1 cm	23.1 mm	Purchased from Abkari Bazar Lahore		

water film flowing in between the sleeve and the metallic jacket of the purifier will be;

$T_c = 16000\ \mu$ watts s/1434.64 μ watts or
$T_c = 11.15$ s

2.5. Calculation of the optimum length L of the lamp

The flow rate Q of a liquid through a jacket of given length L and cross sectional area A is equal to the product of the area of the jacket and velocity V of the liquid.

Mathematically,

$$Q = A\,V$$
$$Q = A\,L/T_c \quad \text{or}$$
$$\mathrm{L} = \mathrm{Q}\,\mathrm{T}_c/\mathrm{A} \tag{4}$$

where Q is in liters per minute, A is the effective area of water film in between the inner diameter of metallic jacket and the outer diameter of quartz sleeve containing germicidal lamp. The inner diameter of the jacket is 3.235 cm. The outer diameter of the quartz sleeve is 2.235 cm. The gap between the two surfaces accommodates 1 cm deep-water film. If R1 is the inner radius of the jacket, R_2 is the outer radius of the sleeve;

The cross sectional area of the jacket

$$= \pi R_1^2 = 8.219 \text{ cm}^2$$

The cross sectional area of the sleeve

$$= \pi R_2^2 = 3.923 \text{ cm}^2$$

Area of the water film in between the jacket and the sleeve

$$A = \pi (R_1^2 - R_2^2) \tag{5}$$

$$A = 4.296 \text{ cm}^2.$$

From equation (3), we get the optimum length "L" of the lamp.

$$L = Q\,T_c/A \qquad \text{or}$$

$$L = (Q/A)T_c \tag{6}$$

For a given flow rate Q and area A the ratio Q/A becomes a constant quantity.

Equation (5) may be written as

$$L = \text{Constant } T_c$$

$$L \,\alpha\, T_c \tag{7}$$

Let us select lamp J:
Depth of the water film $x = 1$ cm
Let the flow rate is $Q = 1$ L/minute
The calculated value of hydraulic contact time
$T_c = 11.16$ seconds
Putting the values in equation (6); we get,

$$L = 1 \times 10^{-3} \text{ m}^3/60 \text{ s} \times 11.16/4.296 \times 10^{-4} \text{ cm}^2$$

$$L = 111.1/256.14 \text{ m}$$

$$L = 0.435 \text{ m}$$

$$L = 43.57 \text{ cm} \tag{8}$$

2.6. Statistical analysis of the data

Simple statistical techniques like arithmetic mean, variance and standard deviations were applied to the results obtained at one-cm depth of water film.

2.7. Performance evaluation of the designs

Performance of UV sterilizer as well as the triplet set was analyzed. In order to study parameters like; the importance of the effective depth of water film exposed to UV radiation; the effect of the UV reflecting metallic jacket containing water sample and sleeved lamp on the performance of the purifier; effect of water turbidity on the performance of the lamp; effect of flow rate of water on the performance of the lamp the following steps were followed:

- 50 liters of water sample was collected from rapid sand filtration plant Islamabad prior to chlorination. 100 ml of sample was analyzed before and after UV irradiation using the sterilizer set which was a horizontal water flow system with bi-pin lamp "K" fabricated by Philips Company, installed in the PVC system without sleeve.
- 50 liters of microbe free water sample was collected from a tube well. One ml of sewage was injected in 25 liters of the sample. 100 ml of the *coliform* injected sample was irradiated with different UV lamps in the triplet set, and the results were recorded.

In the light of the test results the performance of the triplet set was tried for improvement. The diameter of the jacket was found to be 12 mm, which exceeded 2 mm from 1 cm. In order to study the effect of the reflection of UV from the inner surface of the jacket on disinfection process a number of materials were studied.

- A poly vinyl chloride jacket equal in length to the metallic jacket of the triplet set was fabricated, so that it could accommodate water film of 1 cm depth, in between its inner surface and the outer surface of the sleeve. The calculated volume of the water inside the jacket was 83 ml. Sewerage water was injected in water sample collected from tube well at the ratio of 1 ml in 25 liters. The water sample was analyzed for various hydraulic contact times.
- Another jacket was fabricated from the same plastic, which was provided hydro cyclone socket of flowing water design at the bottom to provide long hydraulic contact time and to hold the sleeve exactly in the center of the water volume. The inner surface of the jacket was made reflecting with aluminum foil to act as a photo reflector for UV rays. In order to study the effect of the enhanced reflections from the aluminized Jacket on UV intensity, sewage water (1 ml/25 L) was injected in the fresh tube well sample and performance of the lamps was analyzed.
- Aluminum jacket (UV photo reflector) of the size of PVC jacket discussed above, was fabricated and tested for microbial disinfection. Both the aluminized PVC jacket, as well as the original Al jacket had very close results.
- In order to compare the performance of the photo-reflector with that of a stainless steel jacket, 100 ml of *coliform* injected samples were irradiated and analyzed.

2.8. Aluminum leachate determination

The layer of aluminum oxide leaches in water with the rise in temperature. It was necessary to check the leachate of aluminum in the irradiated water. Four samples were analyzed with the help of atomic absorption spectroscope.

Samples tested were;

(i) Sample from Al jacket without Al foil.
(ii) Sample from jacket with Al foil pasted inside.
(iii) Sample from foiled jacket after six-hour continuous use.
(iv) Sample from water warmed in an Al container for 4 minutes.

3. Results and discussion

The UV reactor practically contains linear UV lamp/lamps. There is an Air/Quartz/Water interface. One should know about the percent refraction and reflection through these surfaces. For this purpose Multiple Point Source Summation Approximation Model (MPSS) [8] gives proper results using the refractive indices of air, quartz and water. At this stage we have "swiched off" the refractive indices of air, quartz and water for simplicity.

3.1. Input power of the lamps

Theoretically, lamps with high input power give high emission. It was practically seen during the quantitative analysis that lamps with high input power emitted intense beam of UV rays while those taking low input power emitted weak beam of UV rays. The analysis shows that most of the lamps require an input of 52.8 watts while some of them take 35.2 watts (Table 2).

Table 2
Measured values of the input power of ultraviolet lamps (with ballast set in circuit).

Lamp	Current (Amps)	Voltage (Volts)	Apparent power (Watts)	Power (Watts) with 0.8 power factor
A	0.3	220	66	52.8
B	0.2	220	44	35.2
C	0.3	220	66	52.8
D	0.3	220	66	52.8
E	0.3	220	66	52.8
F	0.3	220	44	52.8
G	0.2	220	44	35.2
H	0.2	220	44	35.2
J	0.3	220	66	52.8
K	0.3	220	66	52.8
L	0.3	220	66	52.8
M	0.2	220	44	35.2
N	0.2	220	44	35.2
O	0.3	220	66	52.8

3.2. Qualitative analysis of the emitting rays

Spectra of all the lamps show peaks at 253.7 nm (UVC), 311.8 nm (UVB) and 364.2 nm (UVA). Figure 1 represents the overall trend of all the lamps. This qualitative study indicates that all the lamps are medium pressure mercury lamps [9], in which the plasma with high temperature is produced, where mercury atoms are excited to multiple high orbital levels, which, upon collapse, produce the characteristic broad spectral emission. All of the lamps were germicidal in nature which could be employed for UV water disinfection.

3.3. Transmittance through the glass of sleeves and lamps

The transmittance of 253.7 nm through the sleeves was ranging from 60% to 67.8% and through the glass of the lamps from 43.6% to 68%. The percent transmittance spectra through the glass of 4 sleeves, 8 UV lamps and a silicate glass (water drinking bowl) were taken. They have been discussed below.

3.3.1. Sleeve a

This sleeve is generally known as "green quartz" in market. Figure 2 which is representative spectrum for the greens sleeve as well as the silicate glass, depict that the sleeve has zero percent transmittance of UVC.

This sleeve is made from Silicate glass and cannot be used in UV water purifier [10]. The fact was further elaborated from the spectrum of ordinary Silicate glass bowl, which almost has the same trend.

3.3.2. Sleeve b, c and d

All the three sleeves were comparatively good quality UV transmitting materials, these sleeves allow

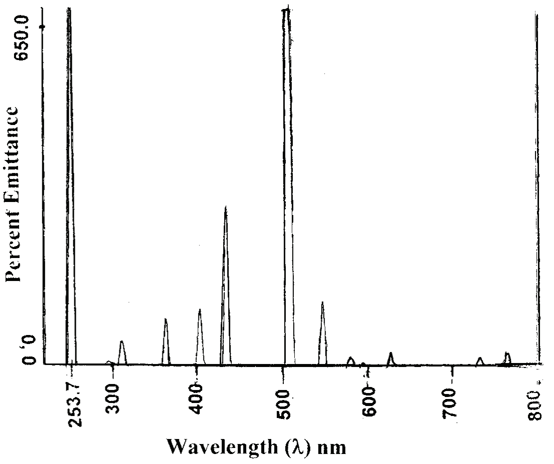

Fig. 1. Percent relative emittance from lamp "G".

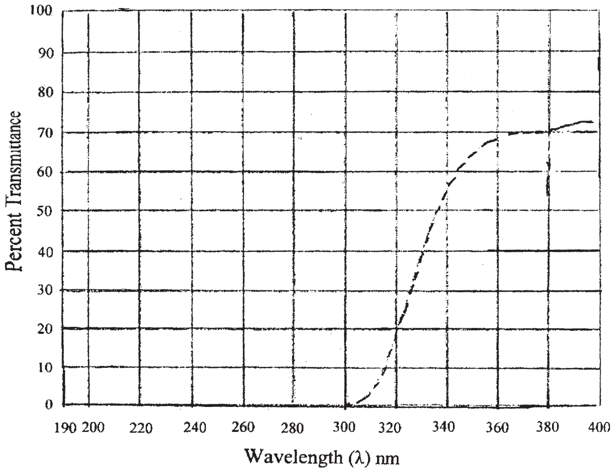

Fig. 2. Percent relative transmittance of 253.7 nm through the green sleeve "a".

Table 3
Percent transmittance of 253.7 nm through the glass of sleeves and lamps.

Lamp/Sleeve	Range of wavelength transmitted (nm)	% Transmittance of 253.7 (nm)
Sleeve a	300–400	0.0
Sleeve b	190–400	60
Sleeve c	190–400	63.4
Sleeve d	190–400	67.9
Lamp O	217–400	53.2
Lamp L	217–400	68.2
Lamp K	200–400	48
Lamp F	200–400	50
Lamp N	200–400	47.4
Lamp J	193–400	68
Lamp A	190–400	52

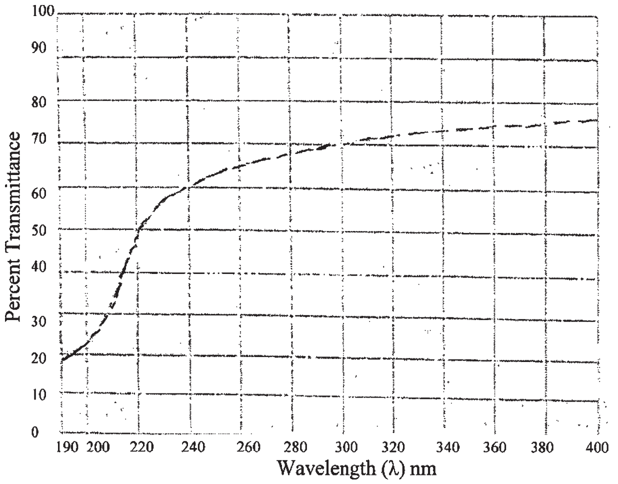

Fig. 3. Percent UV transmittance through the glass of sleeve "c".

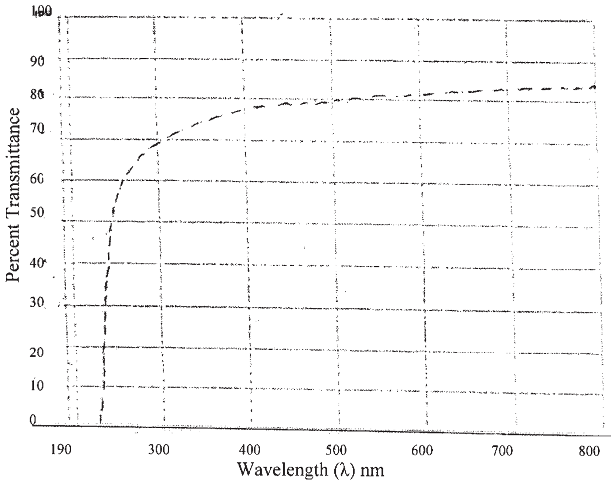

Fig. 4. Percent relative transmittance of 253.7 nm through the glass of lamp "L".

60, 63.5 to 68% transmittance that is clear from figure 3, which has a representative trend for sleeve b, c and d. It revealed that all the three sleeves, b, c and d were made of fused quartz [10].

3.4. Glass of UV lamps

Eight lamps labeled as L, F, J, K, M, N, O were studied. Out of these lamps, glass of the lamp "A" was 52 percent, lamps "L" and "J" was 68 percent, lamp "M" was 43.6 percent and lamp "O" showed 53.2 percent transmittance. Percent transmittance has been shown in Table 3.

Figure 4 for lamp "L" has a representative sketch for all the lamps. In this case UV rays transmit through four surfaces of the sleeve and lamps, and further these tubes/glass sleeves contain an air gap/gas inside, which play considerable role in percentage loss of transmittance. Hence these results are less than the expected value as quartz is 98 percent transparent to ultraviolet rays [10]. In addition to this the transmission of rays may further decrease when salt scaling settles on the glass of the lamps and sleeves. The glass of all the lamps is quartz material but of different qualities.

3.5. The emittance power of UV rays in air and water

The fact that the intensity of UV radiation in air decreases as the square of the distance from the source [6], revealed from Figs. 1 and 2, here the trend of the graph is in good agreement with the law.

The intensity and dose of UV rays in water was calculated. The trend of the graph indicates that intensity of radiation decrease with the increase in the distance from the lamp exponentially.

The trend line equation derived is

$$y = 2327.6\ e^{-0.18x} \tag{9}$$

Equation (9) is beer's law with maximum intensity of radiation of 2327.6 µw/cm² at a distance of zero cm from the source.

3.6. The hydraulic contact time T_c

The hydraulic contact time of water with UV radiation calculated for ten lamps showed that more intense the lamp, less hydraulic contact time of UV rays will be required (Table 4). Figure 7 shows inverse proportionality between the required hydraulic contact time and the emittance power of the UV lamps.

The trend line equation of the proportionality is

$$y = -0.1972\ x + 3.528 \tag{10}$$

Equation (10) provides an easy way of finding the hydraulic contact time required for complete disinfection at one cm depth of water film surrounding an UV lamp of given emittance power.

3.7. The optimum length of the lamps

Lengths of the UV lamps were calculated as given in Table 4 for 1-cm water film and 1 liter per minute flow rate. It is shown that, for constant flow rate of water and constant area of the cylinder, the calculated length of the lamp is proportional to the time of contact, as shown in Figure 8. It means that longer the lamp greater will be the time of contact for disinfection of water.

3.8. Performance evaluation of the lamps

Performance of all the lamps placed inside the triplet set was evaluated at different flow rate of the sample

Table 4
Optimum length "*L*" and hydraulic contact time "T_c" of UV lamps at one cm depth in water with flow rate "*Q*".

Lamp	Flow rate *Q* lit/min	Hydraulic contact time T_c (seconds)	Optimum length of the lamp (cm)	Optimum length of the lamp (inch)
J	1.0	11.40	44.0	17.32
	1.5	12.48	48	18.89
	2.0	13.65	53	20.87
N	1.0	12.07	46.8	18.42
	1.5	13.17	51.1	20.12
	2.0	14.42	56	22.04
L	1.0	9.43	36.5	14.37
	1.5	10.31	40	15.74
	2.0	11.28	43.7	17.204
M	1.0	12.07	46.8	18.42
	1.5	13.17	51	20.09
	2.0	14.41	55.6	21.89
G	1.0	12.2	46.7	18.38
	1.5	13.17	51	20.08
	2.0	14.0	56	22.04
B	1.0	12.07	47.7	18.78
	1.5	13.17	51	20.09
	2.0	14.40	56	22.04
O	1.0	8.23	32	12.59
	1.5	9.12	35	13.78
	2.0	9.98	38.7	15.24
F	1.0	10.34	40	13.15
	1.5	11.29	44	17.32
	2.0	12.35	48	18.89
K	1.0	7.54	29.2	11.49
	1.5	8.17	31.7	12.4
	2.0	8.94	34.6	13.6
A	1.0	7.54	29	11.42
	1.5	8.17	31.7	12.48
	2.0	8.95	34.7	13.66

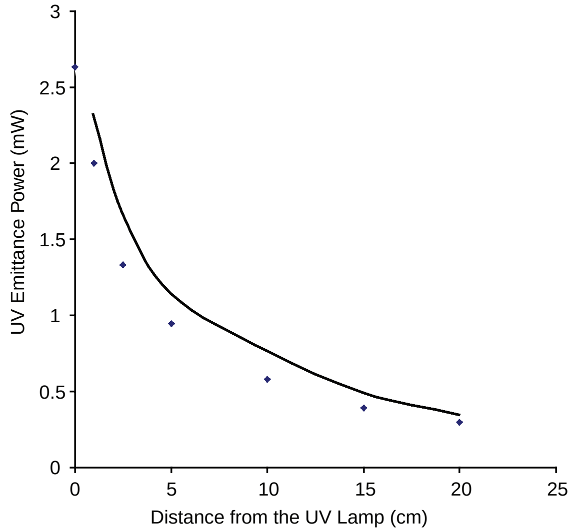

Fig. 5. Emittance power of UV lamp VS distance in air.

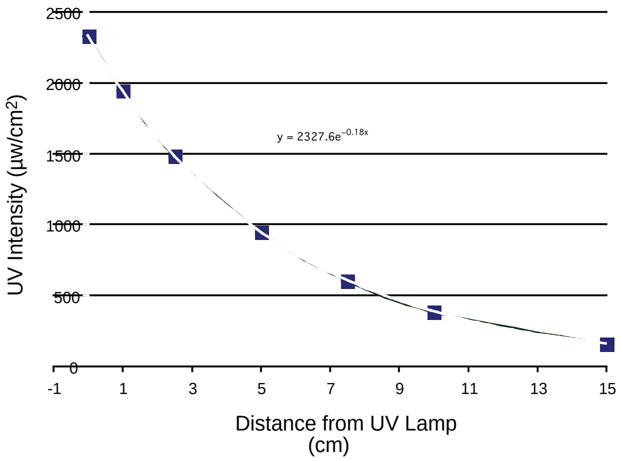

Fig. 6. Intensity of UV rays VS distance in water.

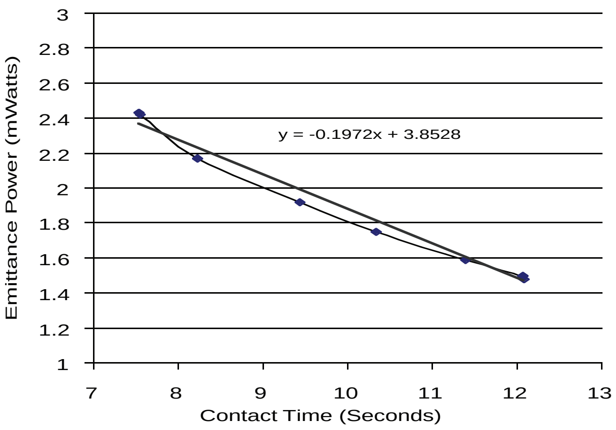

Fig. 7. Trend of hydraulic contact time and emittance power of UV lamp.

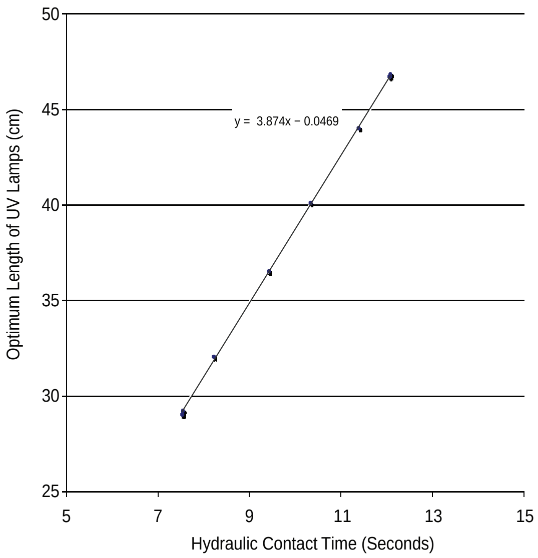

Fig. 8. The hydraulic contact time and optimum length of lamp.

Table 5
Performance of UV lamps at different flow rates (water sample collected from rapid sand filtration plant Islamabad).

UV lamp	Flow rate lit/minute	Number of coliform colonies/100 ml
B	3	Nil
	0.35	Nil
F	2.4	Nil
	0.68	Nil
G	3.16	One
	0.49	Nil
H	2.67	Two
	0.53	Nil
J	3.45	Nil
	0.57	Nil
L	4	Two

collected from rapid sand filtration plant Islamabad, which receives water from Rawal-Lake. Lamps L, J, G, and B inactivated the sample completely; while lamp F inactivated 7 out of 8 and lamp H inactivated 6 out of 8 colonies (Table 5). The lapse in the results was due to low intensity of UV lamps.

Second, the lengths of the lamps were not to the desired measure to provide long hydraulic contact time and desired UV dose to water film. Lamps F and H were hardly 6 inches while the calculated length of these lamps should be 13 inches. The proportionality of length of lamps and hydraulic contact time are shown in figure 8.

Lamp L disinfected all the samples at moderate flow rates, but its performance was badly affected at increased flow rate of 4.0 lit/minute in the second test.

3.9. Performance of the lamps at high bio-dose

In order to check the performance of the lamps at high bio-dose, water sample of 50 liters was collected from a tube well. One ml of sewage was injected in 25 liters of the sample. A sample was checked initially, without UV irradiation, which contained infinite number of *coliform* colonies per 100 ml (Figure 9).

Water tests were performed one after the other, using different UV lamps. Although in case of low concentration of *coliform* colonies, the poorest lamps could reduce 8 colonies to 2, but in high microbial contamination the better lamps like lamp L (So~Safe gold) could reduce the number of colonies from infinite to 8 showing 94.6 percent efficiency while the poorest lamp again was proved to be lamp H having 77.33 percent efficiency (Table 6).

Analysis of the sterilizer set having lamp “K” showed that 8 *coliform* colonies were totally cleaned. The UV sterilizer gave 100% efficiency. This test again supports the impact of *coliform* density as well as the intensity and length of the lamp. The lamp inside the set was 16.4 inches (41.5 cm). Water film around the lamp was 2.39 cm deep, which exceeded by 1.39 cm from the standard 1 cm length. Further UV reflectance of plastic is very poor, but again 8 colonies were successfully inactivated. It means that in case of lower number of *coliform* colonies, if a long and intense lamp is placed in the sample, better results are expected.

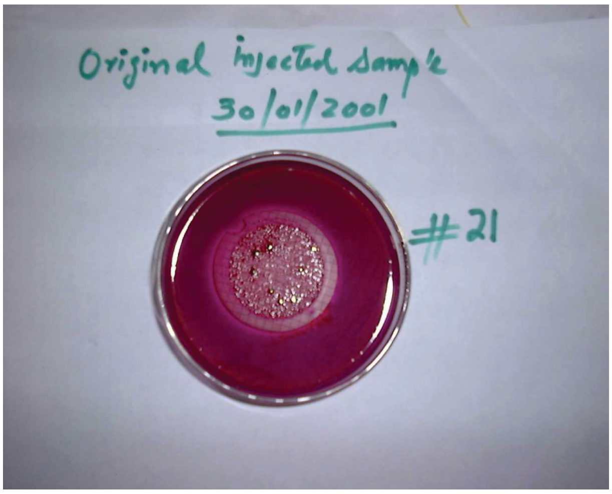

Fig. 9. Water sample before UV irradiation contained chunks of microbes.

Table 6
Comparative performance of UV lamps in sewage injected water at flow rate of one l/minute.

Lamp	No. of coliform colonies before UV irradiation	No. of coliform colonies after UV irradiation
B	Infinite	17
F	Infinite	16
G	Infinite	11
H	Infinite	34
J	Infinite	10
L	Infinite	8

4. The optimal results

The following results are inferred from the data.

(i) The optimal value of the intensity of radiation at 1 cm depth of water is 2121.6 μw/cm^2 as shown in Figure 10. This is the intensity of UV lamp A and K. These lamps are bi-polar lamps of the Phillips Company, usually placed in water purifiers without quartz sleeve.

(ii) In order to have proper disinfection, the water film may absorb sufficient amount of UV energy. In this way either the lamp should be intense enough or should have sufficient length to provide contact time to water film with UV rays. Figure 11 clearly justifies this argument. The least intense lamps have maximum calculated length, i.e. G, M, N, and B which is 47.7 cm, and most intense lamp A and K have minimum length required of 32 cm.

(iii) The least intense lamp needs to be having sufficient length to provide proper hydraulic contact to water film for disinfection. Figure 12 shows the maximum calculated value of the hydraulic contact time of lamps G, B, M and N is 12.7 seconds, while the minimum value of the intense lamps A and K is 7.54 seconds.

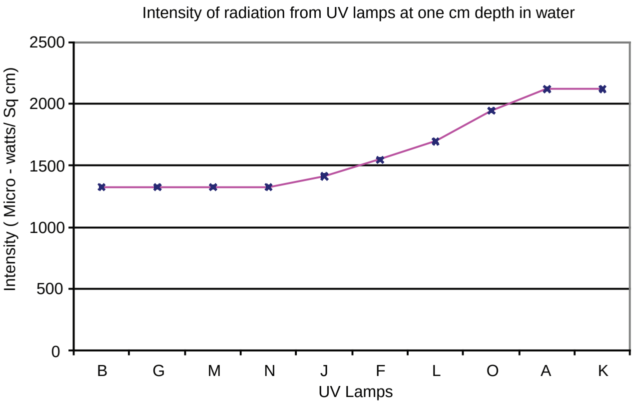

Fig. 10. Intensity of UV lamps at one cm depth in water.

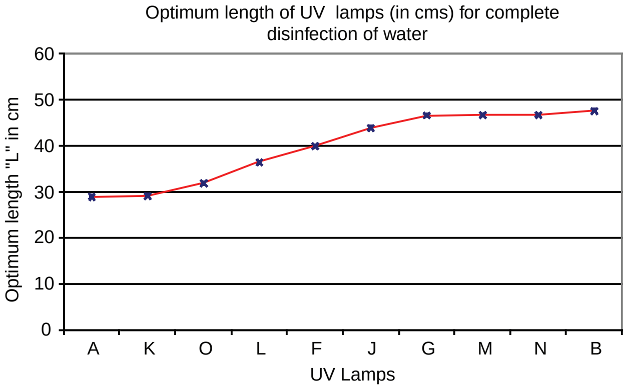

Fig. 11. Optimum length for proper contact time of UV rays with water.

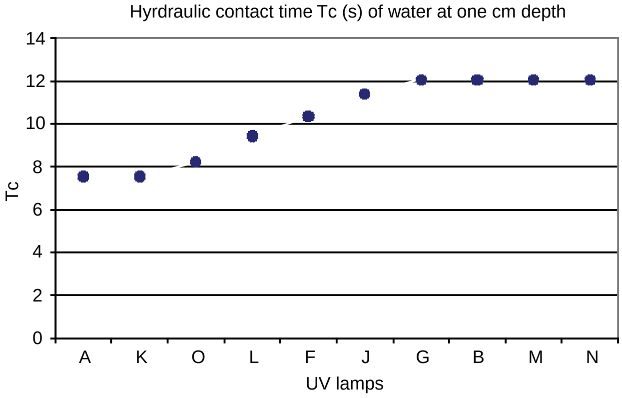

Fig. 12. The optimum hydraulic contact time at one cm depth on water for disinfection.

5. UV reflecting materials

It was found from literature that aluminized mirrors are better UV reflectors [11].

This idea was further strengthened from the study of So~Safe compiled literature in their education section from US literature of the department of health services showing that stainless steel gives 20 to 30% reflectance to UV rays, while Al is 88 to 90% UV reflecting [12].

In case of simple PVC cylinder the numbers of colonies reduced from infinity to countable, but due to poor UV reflectance 100 percent results were not found. Having the same lamp used in simple PVC cylinder, provided hundred percent results in aluminum foil reflection, as well as in the aluminum cylinder of the optimum diameter. *Coliform* injected sample was irradiated with UV light in stainless steel cylinder and then in Aluminum cylinder. The results clearly indicate that with little increase in the flow rate of water the inactivation in the stainless steel cylinder decreases, while Aluminum gives better results comparatively (Table 8).

Table 7
Percent reflectance of UV rays from various metal surfaces.

S. No	Material	% Reflectance
1	Aluminum, Etched	88
2	Aluminum polished commercial	73
3	Aluminum, Foil	73
4	Chromium	45
5	Nickel	38
6	Stainless steel	20–30
7	Silver	22
8	Tin-plated steel	28
9	White wall plaster	40–60
10	White paper	25
11	White cotton	30
12	White oil paints	5–10
13	White porcelain enamel	5
14	Glass	4
15	Water paints	10–30

Values obtained at normal incidence [12].

6. Aluminum leachate determination

Aluminum oxide leaches in water at high temperature. Boiling water in aluminum containers, especially water containing acidic substance causes aluminum to leach into water and food. High dose in food and water may lead to serious physiological and neurological health effects [13]. In order to understand this effect, four samples were studied. The results of aluminum leachate are shown in Fig.13. The first two samples were collected from UV photo-reflector after two minute flow time, where the first photo-reflector was pure aluminum jacket and the second was PVC pipe with aluminum foil lining inside. The leachate in both the samples resulted as 0.32 and 0.44 mg/l. The temperature of flowing water in this time interval cannot reach the boiling point, hence the aluminum leachate was recorded in very small amount. In the third sample where photo- was used continuously for 6 h, the leachate recorded was 0.67 mg/l, which clearly indicate that if a UV lamps glows inside flowing water for quite a long time its temperature does not reach boiling point, and the leachate does not reach non-tolerable level. In the fourth case an aluminum kitchenware containing one liter of water was heated for four minutes. In this case 0.55 mg/l was the leachate recorded. It indicates that standing water of considerable volume does not rise in temperature to reach boiling point and produce non tolerable levels of aluminum

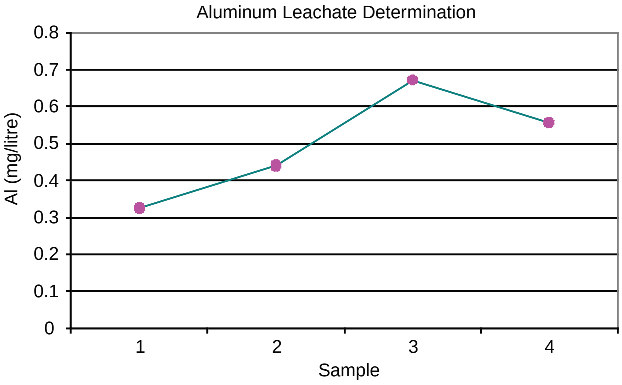

Fig. 13. Al leachate/sample.

Table 8
Performance of UV lamp in aluminum photo-reflector.

S. No	Volume of sample (ml)	Flow rate *l*/min	Number of colonies left
1	100	1.6	Nil
2	100	0.6	Nil
3	100	0.4	Nil

leachate in water if heated for limited time, but it may start boiling after long time and may leach out aluminum in greater amounts.

In all these cases the leachate recorded is less than 1 ppm, and it is expected that this amount could easily be flushed out by human kidneys without accumulation in the body. It is recommended that standing water inside the photoreflector must be flushed out before use. In case of water standing inside a UV photoreactor, in addition to aluminum leachate sufficient amount of other chemicals may produce as a result of rise in temperature. As a further precaution, aluminum leachate can also be adsorbed by activated carbon if an extra miniature cartridge is adjusted after UV lamp section.

7. Conclusion

After detailed study of existing design of Ultraviolet Water Purifier it was concluded that; the existing design of the UV purifier was better because water rose vertically in the metallic cylinder around UV lamp, due to which its velocity was controlled and dense matter present in water settles down to the bottom of the housing, so the scaling process on the sleeves was less and slow comparatively. The most stringent parameters responsible for the low performance of the purifier were the intensity of the UV lamp and the transmittance through the Quartz sleeve. The low intensity lamps were named as "Sankyo Denki" in the market. The most UVC opaque sleeve was the Green sleeve, which was simply a silicate glass material. Hundred percent results are expected out of the existing design; if an UV lamp of the required intensity/optimum length is surrounded by a pure quartz sleeve. UV intensity should be enhanced if an UV photo reflector is placed around the UV lamp surrounded by a pure quartz sleeve in water. Further work is recommended to be done for avoiding aluminum oxide layer production on the UV reflecting surface of the jacket inside water.

Acknowledgements

The authors gratefully acknowledge the unforgettable cooperation, advice and assistance received from, Dr. James Bolton, Dr. Javed Iqbal, Dr. Shoukat Hameed, Mr. Gohar khan of PEPA, So~Safe and Bin-Qutab water purifiers.

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