Study of Ultraviolet Disinfection of Water and Factors in Treatment Efficiency

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Potable water must be provided for drinking and culinary purposes on vessels operated in interstate traffic. In ports of the United States and its possessions, potable water may be obtained only from water supplies and at watering points approved by the Surgeon General of the Public Health Service. If the water is treated aboard, the methods used must be approved by the Surgeon General. Many vessels sailing to foreign ports, particularly those carrying a large number of passengers, do not have sufficient potable-water tank capacity or distilling units to meet the demands, and water from foreign ports is taken on board. These supplies are usually of a satisfactory bacteriological quality, but they may require a second disinfection.

The American President Lines has been interested in the use of the ultraviolet process for disinfecting water on its ships which cruise around the world. In February 1961, experimental testing of an ultraviolet process was started on the SS *President Polk* and continued during six around-the-world cruises. In December 1961, Dr. Rodney Yoell (deceased), chief surgeon of the American President Lines, requested the Surgeon General to evaluate the process under actual operating conditions. One of the authors of the following paper, C. B. Huff, performed engineering and bacteriological tests aboard the *President Polk* when she sailed from San Francisco via Asian and European ports to New York, April 28 to July 23, 1963. However, the results of these tests were not conclusive because water loaded from most ports was of fairly good quality.

Further evaluation was therefore undertaken under controlled conditions, and the following is a report of this controlled study to evaluate the efficiency of the ultraviolet process for shipboard use.

Consideration of use of the utraviolet process for disinfecting water on board a vessel must take into account these factors: (*a*) length of the piping system, which is usually relatively short; (*b*) exposure of pipes for inspection; (*c*) provision of safeguards to assure that inadequately treated water is diverted from the distribution system; and (*d*) location of the equipment, so that it can be under constant and competent supervision.—RICHARD S. MARK, *chief, Interstate Carrier Branch, Division of Environmental Engineering and Food Protection, Public Health Service.*

THE GERMICIDAL effect of ultraviolet energy is thought to be associated with its absorption by various organic molecular components essential to the cell's functioning. Energy dissipation by excitation causing disruption of unsaturated bonds, particularly of the purine and pyrimidine components of nucleoproteins, appears to produce a progressive, lethal biochemical change. Loofbourow (*1*), using "action spectrum techniques," has related the percentage absorption of ultraviolet energy by ribose nucleic acid to minimum-maximum inhibitory effects on *Escherichia coli* through the range of germicidal wavelengths.

Numerous quantitative investigations have been performed to establish the relationship of wavelength, energy, type of organism, and other factors to the lethal effect of ultraviolet irradiation on micro-organisms. The earlier basic findings have been reviewed by Reddish (*2*), and by Loofbourow (*1*) in his studies of wavelength function.

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For most species, the bactericidal effect as a function of wavelength is greatest at about 2,500 to 2,600 A., with an abrupt decrease at 2,900 to 3,000 A. and a continual decrease to visible light. Some investigators have reported a secondary minimum effectiveness at 2,300 to 2,400 A., followed by an increase toward shorter wavelengths.

At any particular wavelength there seems to be a threshold energy dose below which the inhibition is nil and above which the percent kill or inhibition rises rapidly at first and then more slowly. Plotting the log of percent of surviving cells as a function of energy dose, or percent kill as a function of the log of energy dose, approximates a straight line over a wide range of values.

The sensitivity of different micro-organisms to ultraviolet energy has been determined by many investigators. Nagy (*3*) reported that *E. coli* has a greater resistance than other waterborne enteric pathogens to ultraviolet energy. Cortelyou and co-workers (*4*) found no *Salmonella typhosa* survivors after densities of 7,000 to 20,900 per 100 ml. had been irradiated in an ultraviolet unit being tested; slightly higher densities of *E. coli* receiving similar doses showed 99.97 to 99.99 percent kill. Kawabata and Harada (*5*) listed the following times required to inactivate 99.9 percent of these species at a fixed ultraviolet intensity—gram-negative organisms: *E. coli*, 60 seconds; a *Shigella* species, 47 seconds; *S. typhosa*, 49 seconds; gram-positive organisms: *Streptococcus faecalis*, 165 seconds; *Bacillus subtilis*, 240 seconds; *B. subtilis* spores, 369 seconds.

The results presented by these investigators and others indicate that *E. coli*, as a representative of the coliform group, and because it has greater comparative resistance than other enteric pathogens, should be an adequate bacteriological test organism for evaluating the effectiveness of treatment of drinking water by ultraviolet irradiation.

Application to Water Treatment

Until the introduction of more efficient sources of germicidal ultraviolet energy at 2,537 A., the possibilities of its practical application to disinfection of water were not realized. With the advent of low-pressure mercury arc "cold" lamps, emitting 85 percent or more of their energy in this region of the spectrum, investigations of radiation requirements and design and testing of equipment for this purpose were carried out by many workers.

There appears to be little question of the germicidal efficiency of ultraviolet energy if sufficient dosages reach the organism, and, theoretically, water can be disinfected to any degree required. Luckiesh and Holliday (*6*), using several hundred cultures, have presented basic data on the survival ratio relationship of waterborne *E. coli* and the total dosage of ultraviolet irradiation. The exponential equation thereby determined is expressed as

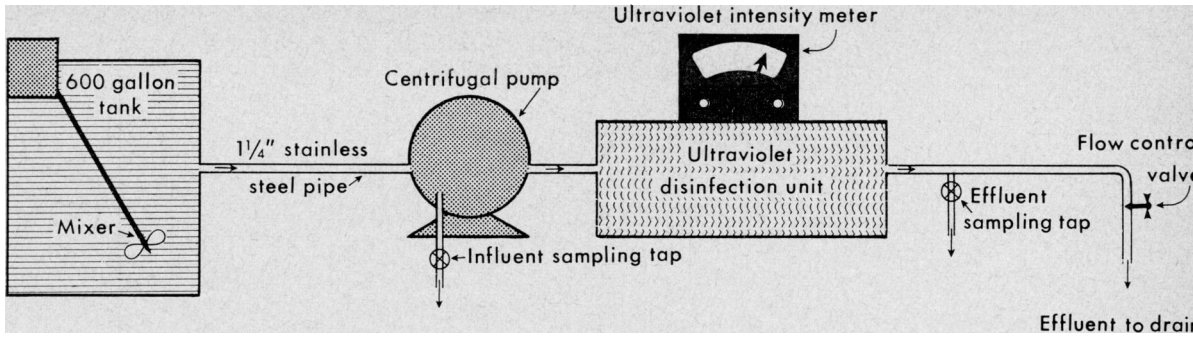
$$P/P_o = e^{-Et/Q} \qquad [1]$$

where

P is the average number surviving,
P_o is the original number before irradiation,
E is the intensity of germicidal energy,
t is the time of exposure in minutes, and
Q is the exposure (Et), termed a unit lethal exposure, found to be approximately 40 microwatt-minutes per cm.^{2}

For practical purposes this equation appears to represent the relationship adequately, and it has been the basis for the design of a number of sterilizing units with safety factors of two or more as recommended by these investigators. Cortelyou and associates (*4*) reported the equation to be approximately correct, but found variations with high flow rates in a unit they tested. With structural modifications to obtain adequate agitation, the efficiency was increased at the faster rates.

Factors that affect the penetration of ultraviolet energy through water and, hence, the effective destruction of organisms are discussed by Luckiesh and associates (*7*). Absorption coefficients at 2,537 A. were affected mainly by turbidity, iron salts, and organic compounds. Compounds of Ca, Mg, Na, and Al had little effect on transmission, unless two or more of the compounds formed a precipitate. Filtering water samples through coarse- to fine-fritted glass filters increased the transmission percentage in many cases. Gilcreas and DeLalla (*8*), in testing an ultraviolet unit, studied the effects of added turbidity (by using diatomaceous



Schematic diagram of experimental ultraviolet disinfection unit

earth), color (tea), and iron compounds. Effective treatment at designed capacity was obtained for coliform densities from 2,400 to 240,000 per 100 ml. with the following combinations of these factors (in ppm): (*a*) turbidity 85, iron 3, color 90; and (*b*) turbidity 15, iron 5, color 150.

Cortelyou and co-workers (*9*) found two major factors that may reduce lamp intensity: line voltage fluctuations and ambient temperatures. A drop in voltage from 110 to 100 v. lowered the intensity 22 percent. Temperatures of 0° to 10° C. reduced intensity to 26 percent of that at 20° C. with quartz enclosures for the lamps and to 42 to 78 percent of that at 20° C. without quartz enclosures. In a study of age of lamps, intensities were still adequate after 4,000 to 5,000 hours of use, and it was suggested that after 6 months of continuous use the lamps be changed.

Many ultraviolet unit designs have been tested and found satisfactory for disinfection of water of various qualities and for various uses. Luckiesh and Holliday (*6*) and Cortelyou and co-workers (*4*), however, considered it desirable to determine the reliability of any design under specific conditions that may affect the safe minimum dose established and its actual performance and efficiency by bacteriological studies.

The evaluation study reported here was undertaken to determine: (*a*) the percent kill obtained with relatively high densities of *E. coli* and other organisms at rated capacity of operation; (*b*) the point or area at which there is treatment breakdown at capacities over that of design; (*c*) the effect of color, turbidity, iron, and other factors on treatment efficiency of the unit; (*d*) the reliability of a meter for monitoring energy intensities; and (*e*) whether the minimum intensity level, as limited by the design of the unit, provides adequate treatment.

Materials and Methods

The experimental, commercially manufactured, ultraviolet disinfecting system for treatment of drinking water was designed primarily for use on shipboard (see diagram). It has an influent line at one end and an effluent line at the opposite end of a stainless steel, cylindrical treatment chamber 30 inches long and 8 inches in diameter. Two 115-volt Westinghouse G36T6L ultraviolet tubes, with an ultraviolet output of 13.8 watts in quartz enclosures, extend the length of the unit. The tubes are positioned midway in the chamber to provide radiation to water at a maximum depth of about 3 inches. Electrical components are housed in a rectangular base on which the chamber is mounted. The unit has no baffles.

A quartz window on the side of the unit provides for metering the energy intensity applied at the periphery of the flow within the chamber, after the radiation has passed through the treated water. A meter, equipped with a metal sleeve to fit the window and attachments to hold it in place, allows recording of intensities at the germicidal wavelength in all experimental runs. The rated capacity is 500 gallons per hour (gph) at a minimum intensity reading on the meter scale of 15 units. Approximate ultraviolet (UV) dosages at 8.5 gallons per minute (gpm) for intensities of 8 and 15 on the meter are 6,500 and 11,000 microwatt-seconds per cm.^{2}. At 14.5 gpm, intensities of 8 and 15 on the meter are equivalent to about 4,000 and 7,000 microwatt-seconds per cm.^{2}.

Water under pressure was delivered to the unit by a 1-horsepower electric pump installed between a 600-gallon steel storage tank and the influent line of the sterilizer. A rotary mixer was used to mix additives in the test waters. A flow control valve was installed on the effluent line of the unit. Flow rates obtained with these valves under pressure delivery were 8.5 or 14.5 gpm (510 and 870 gph).

Demineralized water of not less than 500,000 ohms per cm. specific resistance was used as the base test vehicle. For each test of water of different added characteristics, only the design flow rate was tested at ultraviolet intensities of approximately 15 and 7 units on the meter scale. If factors introduced to the water did not cause a decrease to 15 units, the intensity was brought down to this level by regulating the voltage to the lamps.

Physical factors introduced to test waters included turbidity, color, and iron. Fuller's earth or kaolinite (a type of clay product) were used to obtain varying turbidities. Tea, Orzan S (organic coloring material), an extract of boiled leaves, or methylene blue were used as color additives. Ferrous sulfate or ferric chloride were used as iron additives.

Before each experimental run, the lamps and meter were turned on for a warmup period of 2 minutes or more, the meter adjusted for a zero reading with the lamps off, and the lines and unit flushed with the lamps on for 3 to 5 minutes at low flow rates (4 to 5 gpm).

Bacteriological Tests

During a test run it was usually possible to obtain three effluent samples for each controlled variation in flow rate and ultraviolet intensity. These samples were collected at 1- to 2-minute intervals with the unit in continuous operation. The composite counts of the three individual samples were used in the calculations for final analysis.

E. coli and *Aerobacter aerogenes* cultures were the test organisms used as representative of the coliform group. Studies were also made with *S. faecalis* cultures and *Bacillus cereus* spores and vegetative cells.

The membrane filter procedure was used for detection and quantification of all organisms. M-Endo broth MF was used as a differential medium for the two coliform organisms, as described in "Standard Methods" (*10*), and confirmation was made on a representative number of colonies (on all colonies when 10 or less were present). "Sheen" colonies were verified as *E. coli* by planting in phenol red lactose broth at 35° C. for 48 hours and transferring acid-gas positive cultures to EC medium at 44.5° C. ±0.5° for gas production in 24 hours. Sheen colonies were verified as *A. aerogenes* by a similar procedure with brilliant green lactose bile broth as the confirming medium at 35° C. ±0.5°. *S. faecalis* was enumerated by the MF fecal streptococci test described by Kenner and associates (*11*). *B. cereus* counts were determined by a total count medium (M-enrichment broth), and microscopic examination was carried out on all colonies for confirmation as gram-positive rods. The demineralized test water was examined quantitatively before it was loaded with *B. cereus* to make certain no gram-positive bacilli were present.

Cultures of the test organisms were grown in nutrient broth or brain-heart infusion broth at 35° C. for 24 hours. A sufficient volume of the broth culture was then added to 300 to 400 gallons of the test water to obtain a density of about 1 million per 100 ml. Control samples of the test water were collected at the following points: (*a*) the influent line before seeding with the test organism (background counts); (*b*) the influent line after seeding, mixing, and allowing for flow time to the influent tap (to obtain counts of the test organism before irradiation); and (*c*) the effluent sampling tap, by using exposures considerably above those of the experimental run (for a sterility check of the effluent tap before an actual test run was made).

Results

Coliform and fecal streptococcal organisms were rarely detected in the demineralized water before it was loaded with these test organisms; other bacterial forms were detected occasionally. After seeding, influent counts at the beginning and end of test runs showed no significant difference. Samples taken to check sterility of the effluent tap before experimental runs were always free of contaminating orga-

nisms. Comparisons of recovery of *E. coli* and *A. aerogenes* on the coliform medium and on a total count enrichment broth were within acceptable limits.

The relationship of the effluent counts to ultraviolet intensity, as determined by meter readings for all tests run, is shown in table 1 for the three pollution indicators. The intensity readings were grouped as: (*a*) 13 units or higher, (*b*) 8–13 units, and (*c*) below 8 units. The variability of meter readings, when meters were reset at zero periodically during a run, was in the range of ±2 units; therefore, the minimum intensity as a control for operation was lowered from 15 to 13 for this evaluation. Meter readings from 8 to 13 represent intensities below the minimum as set by design, but not less than about two-thirds of the minimum. Readings below 8 represent intensities less than two-thirds of the minimum. Separation of groups *b* and *c* is somewhat arbitrary, but it points out the beginning of a breakdown in treatment effectiveness in group *c* at 8.5 gpm.

Within the minimum intensity and maximum flow rate as specified by design (group *a* at 8.5 gpm), the percent kill results are all above 99.9999 for the three pollution indicator organisms, and in no experimental run was the effluent density as high as 1 per 100 ml. At meter readings of 8–13 at 8.5 gpm, only one of nine *E. coli* effluent counts was greater than 1 per 100 ml. (3.1 per 100 ml. being the highest). Below 8 units of intensity, more than 50 percent of the *E. coli* effluent counts were greater than 3 per 100 ml. and as high as 330 per 100 ml. *A. aerogenes* and *S. faecalis* showed similar progressive increases in surviving organisms at these lower intensities.

At a flow rate of 14.5 gpm (1.8 times the designed maximum) and an intensity of 13 units and above, effluent counts were all less than 1 per 100 ml. for *E. coli*; below 13 and above 8 units of intensity, five of seven effluent counts were 1 per 100 ml. or higher with a high of 375 per 100 ml. Below 8 units of intensity, seven of eight runs gave effluent counts for *E. coli* over 1 per 100 ml. with two greater than 1,000 per 100 ml. *A. aerogenes* and *S. faecalis* survival counts in the intensity range below 13 at a 14.5 gpm flow rate were greater than 100 per 100 ml. in several runs.

Color as a factor in limiting transmission of ultraviolet energy and the resulting efficiency in destruction of organisms are shown in table 2. Methylene blue in concentrations giving 30–33 units of color did not decrease intensities below

Table 1. Relationship of effluent counts to ultraviolet intensity for three pollution-indicator organisms at two flow rates

Organism and flow rate (gpm)	Range of UV meter readings	Number of runs	Range of influent counts ($\times 10^6$/100 ml.)	Range of effluent counts (per 100 ml.)
E. coli:				
8.5	13–28	13	0.27– 4.6	<0.067– 0.2
	8–13	9	.57– 3.9	<.067– 3.1
	5– 8	7	.57– 4.4	<.067– 330.0
14.5	13–30	10	.27– 4.6	<.067– .13
	8–13	7	.57– 3.9	<.13 – 375.0
	5– 8	8	.57– 4.4	.2 –>1,500.0
A. aerogenes:				
8.5	13–32	11	.21– 5.9	<.067– .96
	8–13	3	3.5 – 6.0	<.067– .33
	4– 8	9	.63– 10.0	.067– 6.1
14.5	13–33	11	.21– 6.7	<.067– 3.5
	8–13	4	2.8 – 4.8	<.067– 160.0
	4– 8	8	.63– 10.0	.13 – 280.0
S. faecalis:				
8.5	13–28	11	3.5 –100.0	<.067– .67
	8–13	8	2.5 – 20.0	.067– 2.5
	7– 8	3	4.6 – 18.0	.13 – 120.0
14.5	13–30	8	3.5 –100.0	.13 – 3.1
	8–13	5	9.6 – 20.0	<.17 – 9.0
	6– 8	4	2.5 – 18.0	.67 –>1,000.0

15 on the meter, whereas Orzan S, tea, and extract of leaves reduced intensities to 7–13 when introduced in amounts to give only 7 units of color or less. At capacity flow rate, effluent densities with 30 units of methylene blue color were all less than 1 per 100 ml. Effluent densities with 15 units of color produced by Orzan S and 12 units by tea were greater than 100 per 100 ml. for *E. coli*. This was also reflected by effluent coliform counts of less than 1 per 100 ml. in five of six runs at capacity flow rates (one density was 1 per 100 ml.).

Results of studies of turbidity are presented in table 3. Turbidity introduced to test waters by addition of kaolinite and fuller's earth in intensity readings of only 2 and 5 units on the meter. Units of color of 5 to 7 using these two materials and the extract of leaves resulted in color densities with 15 units of methylene blue color ml. in five of six runs at capacity flow rates (one density was 1 per 100 ml.).

Table 2. Effect of color on ultraviolet intensity and treatment efficiency [1]

Coloring agent and organism	Units of color	UV meter reading	Influent count (per 100 ml.)	Effluent count (per 100 ml.)
Methylene blue:				
E. coli	33	16	2, 100, 000	<0. 067
A. aerogenes	30	15	210, 000	<. 067
	15	[2] 20	3, 400, 000	<. 067
S. faecalis	33	16	4, 600, 000	<. 067
Orzan S:				
E. coli	15	2	40, 000	150. 0
	7	7	3, 400, 000	<. 067
	5	11	1, 900, 000	<. 067
A. aerogenes	7	7–8	630, 000	<. 17
S. faecalis	7	7	18, 000, 000	. 13
	5	11	9, 600, 000	. 067
Tea:				
E. coli	12	5	4, 000, 000	330. 0
	7	9	1, 400, 000	1. 0
A. aerogenes	10	5–6	10, 000, 000	3. 3
	7	13	3, 400, 000	<. 13
Extract of leaves:				
A. aerogenes	10	4	8, 300, 000	. 2
	5	9–10	3, 500, 000	<. 067

[1] Flow rate 8.5 gpm.
[2] Decreased to 15 by voltage.

Table 3. Effect of turbidity on ultraviolet intensity and treatment efficiency [1]

Turbidity agent and organism	Units of turbidity	UV meter reading	Influent count (per 100 ml.)	Effluent count (per 100 ml.)
Kaolinite:				
E. coli	190	11	3, 900, 000	<0. 17
	55	[2] 28	4, 600, 000	. 11
A. aerogenes	90	9–10	4, 800, 000	<. 13
S. faecalis	190	11	3, 900, 000	<. 17
	55	[2] 28	100, 000, 000	<. 067
Fuller's earth:				
E. coli	20	12–13	570, 000	. 13
	5	[2] 18	310, 000	<. 08
A. aerogenes	20	12–13	6, 000, 000	. 33
	5	[2] 20	5, 900, 000	. 067
S. faecalis	20	9	2, 500, 000	1. 6
Sewage diluted 1:20:	5	15	10, 000, 000	. 67
Total coliform	20	5–6	14, 000	2. 5

[1] Flow rate 8.5 gpm.
[2] Decreased by voltage to 15.

Table 4. Effect of iron on ultraviolet intensity and treatment efficiency [1]

Organism and iron compound	Fe (ppm)	UV meter reading	Influent count (per 100 ml.)	Effluent count (per 100 ml.)
E. coli:				
$FeCl_3$	4.8	9–10	2,300,000	<0.11
	3.7	[2] 18	2,300,000	<.077
$FeSO_4$	3.7	15	280,000	<.077
	.3	[2] 35	270,000	<.067
A. aerogenes:				
$FeCl_3$	2.5	13	2,000,000	.96
	.7	[2] 20	2,400,000	.15
$FeSO_4$	1.0	[2] 35	2,200,000	.067

[1] Flow rate 8.5 gpm.
[2] Decreased by voltage to 15.

caused significantly different decreases in intensity when units of turbidity added by each substance were compared. Kaolinite turbidities (as determined by a Jackson candle turbidimeter) ranging from 55 to 190 units caused intensity to fall from 28 to 10 on the meter, while turbidity from fuller's earth at only 5 to 20 units (obtained by dilution of a stock solution of known turbidity) caused decreases in intensity from 20 to 9. Kaolinite turbidities ranging from 55 to 190 units and fuller's earth turbidities up to 20 units resulted in effluent counts of less than 1 per 100 ml. for coliform organisms at rated capacity. Diluted sewage having a turbidity of 20 units, however, had an effluent count of 2.5 per 100 ml.

The effects of iron are shown in table 4. Iron did not affect intensity at 0.3 ppm; only when a concentration of 4.8 ppm was reached did intensity fall below the 15-unit limit to 9 on the meter. At design capacity flow rate, waters with this range of iron concentrations had effluent counts of less than 1 per 100 ml. for the two coliform test organisms.

By using a combination of 0.3 ppm iron, 5–7 units of turbidity (fuller's earth), and 5–7 units of color (tea), the intensity was decreased to 13. At maximum design flow rate, effluent count per 100 ml. was 0.16 for *E. coli* and 0.33 for *A. aerogenes*.

A mixture of protein digest products (proteoses, peptones, yeast extract) was introduced to a demineralized test water in amounts up to 40 ppm. Decreases in intensity of 6–8 units on the meter were noted with each 10 ppm added. At 40 ppm and a resulting intensity drop to 13, the *E. coli* effluent count was less than 0.067 per 100 ml. at rated capacity. Lactose added to test water in a concentration of 20 ppm did not lower ultraviolet intensity. Potassium chloride at 500 ppm did not cause a significant decrease in intensity, and effluent counts were less than 1 per 100 ml. at rated capacity.

Tap water from the municipal supply of Cincinnati, Ohio, used as a test vehicle did not give intensity readings as low as 15, and effluent counts were all less than 1 per 100 ml. Test waters from the Little Miami River and domestic sewage decreased intensity readings to 5 and less than 2, considerably below design limits. Sewage diluted 1:20 with tap water gave an intensity reading of 5–6 and an effluent coliform count of 2.5 per 100 ml. at capacity rate, at a turbidity of 20 units (table 3).

Temperatures of the demineralized test waters were fairly constant at about 10°C.±3°. Meter readings of intensity showed little variation of demineralized water at these temperatures before the experimental factors were added.

An experiment was conducted to determine

Table 5. Percent survival of Escherichia coli as a function of initial density [1]

Initial density (per 100 ml.)	Effluent count (per 100 ml.)	Percent survival (P/P_o)
8,000	2.96	0.037
60,000	16.3	.027
500,000	98.3	.020
5,000,000	1,100.0	.022

[1] Ultraviolet intensity=6; flow rate 14.5 gpm.

whether, at variable densities, a constant percentage of organisms survives under conditions just exceeding breakdown in treatment efficiency. Table 5 shows the results for *E. coli* densities varied over an approximate 1,000-fold range. The percent survival, which ranged from 0.020 to 0.037 for the four initial densities of from 8,000 to 5 million per 100 ml., is not considered significantly different.

A culture of *B. cereus* was irradiated under controlled conditions with two different total energy doses to determine the comparative resistance of spores and vegetative cells. The percent survival of spore forms was 0.20 for one dose and 1.0 for the other. For vegetative cells the percent survival was 0.0026 for one dose and 0.014 for the other. The ratio of percent survival of spores to vegetative cells was 77 and 71, respectively. The greater resistance of the spores is demonstrated in the survival percentage ratios.

Virological Tests

The details concerning the equipment and its use are essentially the same as described previously. Virus inactivation studies were conducted at the designed capacity of the treatment unit as well as under conditions to determine its limitations.

Five viruses were used as test organisms: the three types of poliovirus, a strain of ECHO 7, and Coxsackie A9 virus. Viruses were added at a calculated dosage of approximately 1,000 plaque-forming units per ml. to 200 gallons of demineralized water (pH 7.1 –7.3) contained in the 600-gallon-capacity steel storage tank. After the test virus was added, the water was mixed for 5 minutes in the tank before samples were taken. As a control, a sample of water was examined for virus before it was seeded with the particular virus used in a given experiment; no virus was recovered. For testing, 500-ml. water samples were collected and between 50 and 100 ml. of each sample was frozen at −18° C., after 1 percent calf serum was added to it. Frozen samples were checked for virus as soon as tissue cultures became available.

All virus assays were performed with monkey kidney cells and the agar overlay plaque technique. Cell monolayers in 6-ounce prescription bottles were inoculated with 0.2 ml. per bottle of the test sample (table 6), incubated for 1 hour at 37° C., and then overlaid with an agar base medium essentially similar to that described by Hsiung and Melnick (*12*). The volumes shown in table 6 are the total volume inoculate with each test material.

In most instances more than one experiment was made with each virus at the inoculum level indicated above. In addition, experiments were

Table 6. Inactivation of viruses by ultraviolet light

Virus and UV meter readings	Flow rate (gpm)	Plaque-forming units recovered
Poliovirus I:		
0 [1]	8.5	2.6×10^3/ml.
15	8.5	0/0.2 ml.
15	14.5	0/0.2 ml.
7.5	8.5	0/0.2 ml.
4	8.5	0/0.2 ml.
Poliovirus II:		
0 [1]	8.5	1.5×10^3/ml.
15	8.5	0/6 ml.
Poliovirus III:		
0 [1]	8.5	1.1×10^3/ml.
15	8.5	0/0.4 ml.
15	14.5	0/0.4 ml.
7.5	8.5	0/0.4 ml.
4	8.5	0/0.4 ml.
ECHO 7:		
0 [1]	8.5	1.2×10^2/ml.
15	8.5	0/0.4 ml.
7.5	8.5	0/0.4 ml.
7.5	14.5	0/0.4 ml.
3	8.5	0/0.4 ml.
Coxsackie A9:		
0 [2]	8.5	1.4×10^2/ml.
15	8.5	1/0.8 ml.
7.5	8.5	3/0.8 ml.
Poliovirus I (increased virus inoculum):		
0 [1]	8.5	1.7×10^4/ml.
15	8.5	1/0.4 ml.
15	14.5	0/0.4 ml.
7.5	8.5	1/0.4 ml.
7.5	14.5	12/0.4 ml.
Poliovirus II+4.5 ppm $FeCl_3$:		
0 [1]	8.5	1.1×10^3/ml.
4	8.5	0/0.4 ml.
2	8.5	0/0.2 ml.
2	14.5	0/0.4 ml.
Poliovirus II+9 standard units of color (instant tea):		
0 [1]	8.5	1.3×10^3/ml.
2	8.5	17/0.8 ml.
2	14.5	6/0.8 ml.

[1] Control samples obtained at the effluent sampling tap (see diagram).
[2] Control sample obtained at the influent sampling tap (see diagram).

also conducted to determine the effect of higher levels of virus inoculum, particulate matter, and color on inactivation of certain of these viruses.

Results

The results of the virus experiments are summarized in table 6. It is apparent from these data that the three types of poliovirus tested were inactivated at the maximum flow rates and minimum ultraviolet intensities specified by the manufacturer of the treatment unit. Even when the UV intensity was decreased to approximately one-half the recommended meter reading or the flow rate was increased to about 1.8 times the designed capacity, no virus was detected in the effluent. ECHO 7 virus was also inactivated under all test conditions, even when the unit was operated at 1.8 times the recommended flow rate and at about one-half the recommended ultraviolet meter intensity reading.

The apparent breakthrough in the experiments with Coxsackie virus is not significant, since none of these "plaques" could be passed to new cell cultures, which indicates that they were of nonviral origin. Addition of 4.5 ppm $FeCl_3$ to test water containing poliovirus II did not affect virus inactivation.

Virus was not completely inactivated under two test conditions. When the initial poliovirus I titer was increased about 7-fold (from 2,600 to 17,000 per ml.) live virus appeared in the treated water. Addition of nine standard color units of tea to water containing poliovirus II also resulted in appearance of live virus in the treated water.

Discussion

Effluent counts for the two coliform test organisms, *E. coli* and *A. aerogenes*, within the minimum intensity reading and maximum flow rate as specified by design, are equivalent to those expected in potable water. The percent kill of 99.9999 or more and the fact that all effluent densities were less than 1 per 100 ml. indicate a comparatively high degree of treatment effectiveness under operational controls of flow rate and minimum intensity as measured by the meter. The effluent counts at intensity range 8 to 13 at 8.5 gpm averaged less than 0.6 per 100 ml.; only one had a density greater than 1 per 100 ml. (3.1 per 100 ml.). In view of the total energy dose applied at this flow rate, a safety factor of 1.7 is indicated at the minimum intensity for operation. Below 8 units of intensity at 8.5 gpm, the effluent counts show this to be the area of breakdown in treatment efficiency.

At a flow rate of 14.5 gpm and intensities at or above the minimum specified, effluent counts are equivalent to those expected in potable water. In the intensity range of 8 to 13 at this flow rate, breakdown in treatment efficiency is indicated. In view of the total energy dose applied at an intensity reading of 15 and a flow rate of 14.5 gpm, a safety factor of 1.6 is indicated at designed maximum flow rate and minimum intensity.

Units of color from 5 to 7 did not reduce treatment efficiency below minimum standards, though energy intensity was decreased slightly below minimum levels. There seems to be no consistent quantitative relationship between units of color, as determined by analytical methods for water standards, and decreased transmission. This is demonstrated by the significantly different decreases of intensity caused by methylene blue and the three more complex organic materials used. The greater effect of organic materials on absorption coefficient at 2,537 A. compared with that of inorganic materials was suggested by Luckiesh (7) and is demonstrated in these studies. Protein digest products caused a decrease of 6–8 units in intensity per 10 ppm, and potassium chloride at 500 ppm had no appreciable effect on transmission. It seems likely, therefore, that the organic molecular structure rather than the color is related to decreased intensities.

Turbidities of 5 units did not reduce intensity below the minimum, and effluent counts were within acceptable limits. Turbidities of 20 units sometimes reduced intensity to the minimum and, in two instances, below the minimum (5–9 on the meter). All effluent coliform counts, however, except those from diluted sewage, were within acceptable limits for potable water at capacity flow rates. Different quantitative relationships were noted in comparing units of turbidity with the effect on

transmission of ultraviolet for kaolinite and fuller's earth. Kaolinite turbidities of more than four times those of fuller's earth were needed to bring about a similar reduction in intensity. Therefore, units of turbidity cannot be used as an accurate indication of the effect that all materials which cause turbidity will have on transmission of ultraviolet energy through water.

Iron concentrations up to 3.7 ppm did not decrease intensity to below minimum levels, and effluent coliform counts at rated capacity were within acceptable limits.

Varying initial densities of *E. coli* irradiated at a fixed dosage considerably below minimum resulted in a fairly constant percent survival over a range of initial counts from 8,000 to 5 million per 100 ml. This demonstrates the consistency of the P/P_0 ratio in Luckiesh's exponential equation at the dosage resulting in a 99.96 to 99.98 percent kill.

B. cereus spores were shown to have a greater resistance to ultraviolet irradiation than vegetative cells. At two dosages, the effluent counts resulted in P/P_0 ratios for spores 71 to 77 times those for vegetative cells. From the limited number of virus studies conducted, viruses also seem to be more resistant to ultraviolet irradiation than vegetative bacterial cells.

Summary

An evaluation of a commercially manufactured ultraviolet disinfecting system for water, designed primarily for shipboard use, indicated that the system will give satisfactory results if factors affecting transmission do not lower the intensity of ultraviolet energy below 15 on the meter, and if the designed flow rate is not exceeded. The safety factor for the designed minimum total dosage is 1.6 to 1.7 for *Escherichia coli* at initial densities of 1 million per 100 ml., as determined by breakdown in treatment efficiency at two flow rates.

Color, at a maximum level of 5 units, or iron, up to 3.7 ppm, as interfering factors in ultraviolet transmission did not decrease efficiency of treatment. Turbidity levels of 15 to 20 units may cause a decrease in intensity below the designed minimum. Turbidity levels up to 5 units did not decrease treatment efficiency below acceptable limits. Generally, units of color and units of turbidity are not adequate measures of the decrease that may occur in ultraviolet energy transmission. The organic nature of materials present in waters can give rise to significant transmission difficulties.

Waters relatively low in turbidity, color, iron content, and organic composition were adequately treated by the unit; however, most river waters, sewage, and other sources of high turbidity and organic and iron content usually did not result in a potable product at designed capacity.

The apparatus also effectively inactivated certain enteric viruses when operated at the recommended intensity and flow rate, when virus levels were kept at approximately 1,000 plaque-forming units per milliliter. When the virus titer was raised above this level or when color material (instant tea) was added, live virus was detected in the treated water.

The use of an accurate meter to record minimum intensity at 2,537 A. was a reliable means, along with flow-control valves, of monitoring the minimum dosage applied. These two controls incorporated in the continuous operation of a unit should provide an adequate checking system for treatment efficiency.

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Program Notes

Seminar on Exercise for Health

Participants in an exercise seminar held at Boston University's Sargent College in February 1965 worked out with a cycle exerciser, a rowing machine, isometric rope, and medicine ball. They examined and discussed a calorie meter designed to indicate to a bicycle rider the amount of calories consumed by the body at the rate the bicycle is ridden. The National Committee for Safe Bicycling, headed by Dr. Paul Dudley White, authority on heart disease, sponsored the seminar. Representatives of medicine, law, education, communications, and industry attended.

"Johnny Gets the Word"

The New York City Department of Health is distributing comic books to get the word about venereal disease to the city's youth.

On the cover of "Johnny Gets the Word" ("Diego Recibe el Mensaje," in the Spanish version), an angry-looking girl seems to be telling off a sober-faced youth—Johnny. His girl friend is coming up from behind, so shocked she is dropping a soda bottle. The cover text says: "Johnny took a foolish gamble and he lost plenty—But at least he learned something. Here's how Johnny got the word about a 'game' in which the odds are stacked against EVERYBODY."

On the back cover are addresses and phone numbers of the New York City Health Department's social hygiene clinics.

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Salmonellosis Control in Utah

A salmonellosis epidemic in Utah in 1964 brought an unprecedented number of requests for examination of food products for microbiological organisms capable of causing human disease. As a result, the Utah State Department of Health has developed a food sanitation unit in its microbiological laboratory to handle such requests. Because of the increased number of reported cases of gastroenteritis, the department has also established a salmonellosis control unit. This unit traced the 1964 epidemic to contaminated frozen egg slurries used commercially in the area.

Florida Health Board's History

The Florida Board of Health recently published a 175-page book of its activities over the past 75 years. A yellow fever epidemic in 1888 led to establishment of the board the following year. Only 15 years before, the State legislature had turned down an appropriation of $200 for a State board of health as "exorbitant."

Psychology Course for Police

Many northern Ohio police officers took time off during March and April 1965 to attend a course in "Psychology for the Law Enforcement Officer." The course included special application of psychological techniques, basic psychological principles of normal and abnormal behavior, and "the intricate psychopathology of the criminal." The class was one of several suburban police school classes held at the Law-Medicine Center on the campus of Western Reserve University.

Seminars on Alcohol for Teachers

One-day seminars for teachers on alcohol education were held in three separate areas of Pennsylvania in April 1965. In a pilot program of experimental workshops, seminar participants sought to find more effective ways to reach school teenagers with the pertinent facts about use of alcohol. Local Councils on Alcoholism in each area sponsored the meetings in cooperation with the State departments of health and public instruction.

Items for this page: Health departments, health agencies, and others are invited to share their program successes with others by contributing items for brief mention on this page. Flag them for "Program Notes" and address as indicated in masthead.
