TREATMENT OF BUTTER WASH WATER WITH ULTRA-VIOLET LIGHT

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SUMMARY

Tests of the effectiveness of sterilization of butter wash water by the use of ultra-violet light showed that, provided the water was clean, a 99 per cent. bacterial destruction was obtained; with cloudy water the destruction was less than 90 per cent. The quartz tube and reflector need cleaning at intervals of 1-2 months, depending on the cleanliness of the water. No off-flavours in butter could be attributed to the treatment. Corrosion of factory equipment was less than with chlorine-treated water. Modifications in the installation of the non-automatic model are suggested and costs of operation are given.

I. INTRODUCTION

Since the bactericidal action of sunlight was shown by Downs and Blunt in 1878 to be associated with the short-waved ultra-violet rays, the effects of wavelength and energy of radiation on bacteria have been studied by many workers.

The effectiveness of sterilization of water by ultra-violet energy depends primarily on the wavelength and intensity and exposure time of the radiant energy; it is at a maximum at a wavelength of 2600Å and falls almost to zero at 3200Å (Luckiesh 1946).

Ultra-violet rays lack penetrative power and are obstructed by dirt and water; hence water to be treated should be as free as possible from suspended material. It was also shown by Luckiesh and Holladay (1944) that the rate of disinfection of a water depends upon the turbidity and absorption coefficient of the water. They used lamps emitting 25–30 per cent. of their energy at a wavelength of 2537Å to investigate the penetration of ultra-violet light into various waters, and used parabolic reflectors to effect economy and cause the rays to strike the water at different angles.

Various other factors influencing transmission and absorption coefficients were studied by Luckiesh, Taylor, and Kerr (1944). Compounds of calcium, magnesium, sodium and aluminium in solution did not appreciably reduce the transmission, but 1 p.p.m. of iron (as ferric chloride) reduced it from 93 to 7 per cent. in a 5 in. depth of water. Reducing the temperature of the water from 25 to 4°C did not affect the transmission.

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Nelis and Lafontaine (1951), using a 200 A lamp emitting wavelengths of 2537Å, completely destroyed heavy inocula of *Escherichia coli* (13 million per ml) with rates of water flow up to 300 l. per hr. They also found that ultra-violet rays were not so effective against sporulating organisms such as *Bacillus subtilis,* or against the poliomyelitis virus. This was confirmed by Koller (1952), who found *B. subtilis* to be 5–10 times as resistant as *E. coli.*

Calculations of optical densities of various waters were made by Hoather (1955). Using a lamp with radiation at a wavelength almost entirely of 254 $m\mu$, he performed experiments designed to correlate the rate of bactericidal action with the intensity of ultra-violet radiation, calculated from the depth and optical density of the water.

Ricks *et al.* (1955), using a so-called A.R.F. ultra-violet water purifier, showed that intensities greater than 650 mw/ft^2. are effective against large populations of *E. coli.* They found that the available intensity of the lamp after burning 14 hr per day for 12 months was still greater than the limit of 650 mw/ft^2.

Most of these studies were concerned with the use of "low-pressure" mercury vapour discharge lamps, which emit ultra-violet radiation at a predominant wavelength of 2537Å (254 $m\mu$). Hoather (1955) stated that for medium and higher pressure mercury vapour lamps in quartz, the same wavelength is near the central, and probably the most important part of, the range emitted. He considered that the broad conclusions of his work with low-pressure lamps could be applied to the medium and higher pressure sources as well.

Results of tests of an ultra-violet light water sterilizer were given in test report 54C/2 (1954) issued by the National Institute for Research in Dairying (Great Britain). A high percentage kill of both *E. coli* and *B. subtilis* was recorded.

Roberts and Aldous (1949) claimed that certain types of *E. coli* may be reactivated after ultra-violet light treatment and the increase in survival level may be as much as one hundredfold. Kaudewitz (1959) suggested a lag in growth of organisms following ultra-violet light treatment.

In Queensland butter factories, water is usually treated with sodium hypochlorite to render it suitable for use in washing butter grains. Several factories are not using chlorine treatment because of the risk of chlorine or chlorphenol taints being imparted to butter, or of corrosion of the cold-water tank. This investigation was carried out to determine whether ultra-violet light could have a practical application in butter factories for the treatment of hard butter wash waters, which are prevalent in Queensland.

II. METHODS

The sterilizer used for this work was a model designed for manual rather than automatic operation; it was similar to the one tested by the National Institute for Research in Dairying (1954). A general view of the unit is shown in Figure 1. The unit consists of a horizontal cylinder $19\frac{1}{2}$ in. long, 4 in. in internal diameter, and chromium-plated internally both for protection and for internal reflection. This surrounds a quartz cylinder, $1\frac{7}{8}$ in. in external diameter and closed at one end, which contains the arc tube. The $1\frac{1}{16}$ in. annular chamber thus formed admits water in a tangential swirl from a $1\frac{1}{2}$ in. inlet pipe below to a similar outlet pipe above at the other end. A $1\frac{1}{4}$ in. diameter window is provided to allow observation of the lamp.

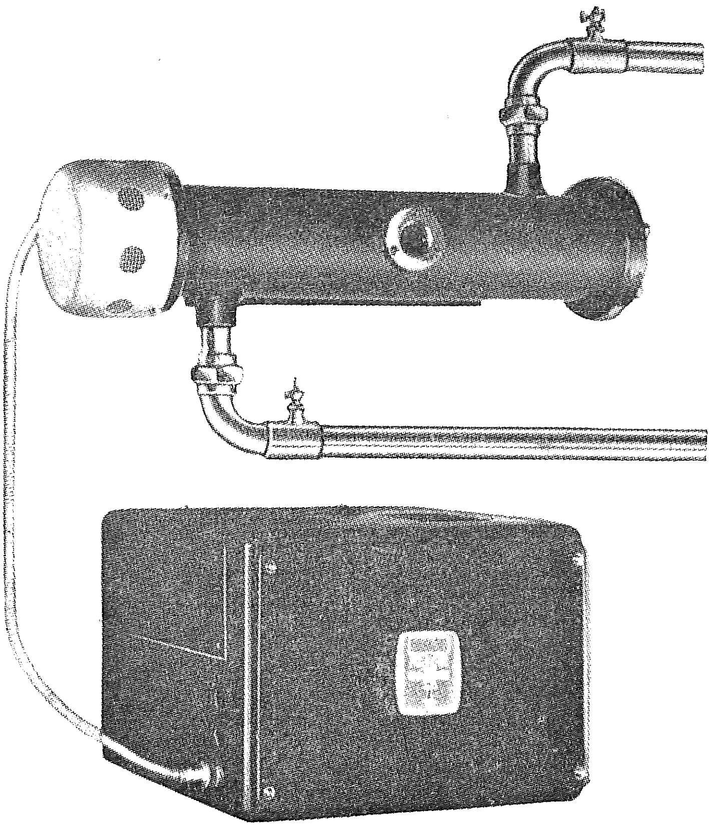

Fig. 1.—Ultra-violet light water sterilizer.

The mercury-vapour lamp in the quartz tube is of the high-pressure type and has an effective length of 9 in. and a rated consumption of 1100 W. An activating transformer supplies electric current to the arc tube, the primary current being supplied from a 230-250 V source. Starting voltage for the lamp is 450 V; this falls to 300 V for the running period. The lamp is not efficient until 2-3 min after starting, and during this time water must be run through the unit to keep it from overheating. This water is run to waste. Rated capacity of the unit is 50-2500 gal per hr.

The unit was installed on the wall of a Queensland butter factory, on the inlet side of the cold-water tank. A more desirable position for the unit would be between the cold-water tank and the churns, in order to avoid the possibility of recontamination of the water, but as the flow rate of 4000 gal per hr through the 3 in. lines from the cold-water storage tank to the churns was greater than the rated capacity of the unit, it was placed on the intake side of the tank for purposes of the test.

The flow of water through the unit into the cold-water tank was controlled by float valves in the tank, which also shut off the flow when the tank was filled. To ensure that water would always be flowing through the unit while the current was switched on, a ½ in. by-pass line was run off from the pipeline on the outlet side of the unit, and a control valve fitted to this line. This valve was opened slightly prior to starting the unit so that the flow rate was at least 50 gal per hr. Samples of water were taken from this line for testing the efficiency of the unit.

The treated water was also sampled at three places—from the pipeline entering the top of the cold-water tank, from the cold-water line at the churn, and from a tap in the cold-water line. This was done to check on any after-contamination from the cold-water tank and pipeline between this tank and the butter churns. A cloth strainer was sometimes placed on the outlet of the cold-water line at the churn, in which case a sample was drawn from the tap in the line to check if the cloth strainer was causing after-contamination.

All samples were taken in sterilized pyrex 8 oz bottles, which were kept in iced boxes until delivered to the laboratory. Except where elsewhere stated, plating was performed in triplicate 1-3 hr after sampling. Tryptone glucose extract agar was used as the medium for total bacterial counts, the plates being incubated at 20-22°C for two days. Desoxycholate agar medium was used for counts of coliform bacteria, the plates being incubated for 24 hr at 30°C; 10 ml of treated water and 1 ml of untreated water were plated in triplicate. Presumptive coliform tests were made using single- and double-strength MacConkey broth, the tubes being incubated for two days at 30°C; 0·1 ml untreated water and 1 ml treated water were inoculated into 4 ml of single-strength broth, and 10 ml and 100 ml of treated water were inoculated into 10 ml and 100 ml respectively of double-strength broth.

The factory water supply was a mixture from a spring and a deep well. Normally it was clear but sometimes it became turbid after rain.

In order to check the possibility of quick regrowth of bacteria in the butter wash water, samples of treated and untreated water were examined 1½, 3, 5, 7 and 24 hr after sampling.

TABLE 1

TOTAL BACTERIAL COUNTS OF RAW AND TREATED WATER (PER ML)

Sampling Date	Untreated Water	Treated Water ex Sterilizer	Treated Water ex Cold Water Tank	Remarks
9.ix.58	480	26	8	
15.ix.58	8,110	11	128	
16.ix.58	190	11	247	
22.ix.58	337	1	46	
23.ix.58	140	2	29	
7.x.58	5,070	15	43	
23.xii.58	1,970	12	Not taken	New tube installed 23.xii.50
6.i.59	1,000	3	122	
13.i.59	290	260	636	Water turbid after rain
27.i.59	5,000	45* 88†	335*	Water slightly turbid after rain. Quartz tube cleaned after sampling
4.ii.59	1,210	3	86	
10.ii.59	2,370	9	78	
17.ii.59	830	16	108	
24.ii.59	1,310	9	217	
3.iii.59	2,130	29	224	
10.iii.59	1,560	15	240	
24.iii.59	1,230	19	79	
7.iv.59	980	29	65	
14.iv.59	780	2	38	Quartz tube cleaned 9.iv.59
21.iv.59	850	6	47	
28.iv.59	2,580	1	31	
5.v.59	376	1	73	
12.v.59	650	3	67	
20.v.59	780	1	22	
27.v.59	730	3	16	
2.vi.59	350	4	Not taken	
17.vi.59	530	3	42	
23.vi.59	410	4	42	
30.vi.59	710	2	58	
7.vii.59	190	3	22	
23.ix.59	700	2		Average of 12 untreated, 18 untreated
29.ix.59	2,730	22		
20.x.59	7,170	142		
22.xii.59	4,730	130		New tube installed 22.xii.59
28.xii.59	520	11		
5.i.60	1,390	1		
12.i.60	1,580	3		
19.i.60	420	2		
26.i.60	330	3		
16.ii.60	470	2		New tube installed 12.ii.60
23.ii.60	190	7		
1.iii.60	460	10		
8.iii.60	280	8		
15.iii.60	210	3		

* Before cleaning.
† After Cleaning.

III. RESULTS

(a) Total Counts

The total counts for the 18 months during which the unit was under test are listed in Table 1, which indicates that they varied from 140 to 8110 colonies per ml on the untreated water. The counts for the treated water, samples after passage through the unit, varied from 1 to 260 colonies per ml. The total counts exceeded 100 per ml on only three occasions, when the water was either turbid after rain or the tube and reflector needed cleaning. Ignoring these three results, the average plate count for the turbid waters was 16 colonies per ml, compared with an average of 1460 per ml for the raw water, i.e., nearly a 99 per cent. destruction. It was also found that the counts on the water sampled from the cold-water tank were almost invariably higher than those on the water sampled immediately after passage through the unit. This was to be expected and indicates either contamination from the cold-water tank or growth of the surviving organisms in the cold-water tank. Hence it can be seen that the best place for the ultra-violet light unit is between the cold-water tank and the churn.

(b) Coliforms

The results of the desoxycholate agar medium counts and McConkey broth presumptive coliform tests are given in Table 2. Coliform counts in the untreated waters varied from 10 to 390 per ml, while in the treated waters the counts varied from 3 to 160 per 100 ml. The most probable number of coliform organisms per 100 ml, calculated on the results of four water samples, was much lower than the count obtained on desoxycholate agar with the same water. In all but the first sample (20.x.59), the presumptive coliform tests were negative in 10 ml water.

TABLE 2

Coliform Tests on Raw and Treated Water

Date	Untreated Water (coliforms per ml on desoxycholate agar)	Treated Water (coliforms per 100 ml)	Presumptive Coliform Tests				
			Untreated Water (0·1 ml)	Treated Water			
				1 ml	10 ml	100 ml	M.P.N. 100 ml
20.x.59	378	160	+++	−−−	+++	+	
22.xii.59	28	120	+++	−−−	−−−	+	
28.xii.59	33	3	−−−	−−−	−−−	−	
5.i.60	40	3	+−−	−−−	−−−	+	
12.i.60	390	27	++−	−−−	−−−	−	
19.i.60	12	7	+−−	−−−	−−−	+	
26.i.60	19	3	+++	−−−	−−−	−	
16.ii.60	49	3	++−	−−−	−−−	+	
23.ii.60	24	17	++−	−−−	−−−	++−	0·9
1.iii.60	10	10	++−	−−−	−−−	−−−	0
8.iii.60	11	7	+−−	−−−	−−−	−−−	0
15.iii.60	15	13	+−−	−−−	−−−	−−−	0

TABLE 3

PLATE COUNTS OF TREATED AND UNTREATED WATERS AFTER HOLDING FOR VARIOUS PERIODS AFTER SAMPLING

Time after Sampling (hr)	Plate Counts per ml			
	Before U.V. Treatment		After U.V. Treatment	
	(a)	*(b)*	*(a)*	*(b)*
1½	485	2,840	3	11
3	560	2,595	2	12
5	690	2,955	3	28
7	1,020	2,895	2	24
24	712	2,545	2	27
Average	700	2,730	2	22

(c) Regrowth after Treatment

Table 3 gives the plate counts of two samples of treated and untreated water held for periods of 1½, 3, 5, 7 and 24 hr after sampling to see if any reactivation of the organisms occurred during these period after ultra-violet light treatment. Although these tests were of limited numbers, the results reveal that no reactivation of growth occurs up to 24 hr after treatment.

It was observed that there was less corrosion of the cold-water tank with ultra-violet light treatment than with chlorinated water. No off-flavours in the butter could be attributed to the treatment.

The quartz tube and reflector require periodic cleaning to maintain efficiency, the frequency depending on the cleanliness of the water. Cleaning at intervals of one to two months appears to be satisfactory, as reflected by the total counts.

IV. DISCUSSION

Best use of the ultra-violet light unit can be made by installing it between the cold-water tank and the churns. If the rate of flow of the cold water is greater than 2500 gal per hr, two units placed in parallel would be satisfactory. An alternative but possibly more costly method of installation with the higher rate of water flow would be to use one unit to sterilize the water leaving the cold-water tank, and to have a balance tank installed between the ultra-violet light unit and the churns. This tank should hold enough water to wash one churning of butter. Provided the tank is sterilized each day before use, no contamination of the wash water should occur.

In the non-automatic model, the following precautions are necessary:—

(1) The water should not become too hot, as this may cause the tube to blow. This can be prevented by the installation of the small "bleeder" line mentioned previously to ensure continuous flow of water through the unit, and by the incorporation of a thermostat.

(2) The unit should be switched on 3-5 min before water is required. A solenoid valve fitted to the small "bleeder" line ensures that no water is run to waste while the unit is not in operation.

(3) Sterilized water should not run to waste unnecessarily. The solenoid valve can also be used to keep water flowing through the unit while the arc tube is reaching full bactericidal efficiency.

The routine operation of the unit is as follows:—

(1) Five minutes before wash water is needed, switch on the unit, thereby opening the solenoid valve on the "bleeder" line. This ensures that only a little water is lost during the warm-up period.

(2) When the wash water is required, open the valve at the churn and run the cold, treated water into the churn.

(3) Turn off this valve when sufficient water is in the churn and switch off the unit to avoid waste of electricity and cold water.

If too much refrigeration is being lost by the flow of water through the "bleeder" line, a small line and a pump can be used to pump this water back to the cold-water tank.

A valve in the line between the unit and the "bleeder" line can be turned off overnight to prevent contamination of the treated water between the unit and the churns.

These precautions apply only to the manually operated unit. They are unnecessary with the fully automatic model which is designed to cut off the flow of water or electric current or both if operating conditions for either become disrupted.

The operational costs for water treatment depend largely on the life given by each tube, the replacement cost of which is £45. A warranty of 1000 hours' use is given, but reports from other users suggest that longer periods than this can be expected. In these trials the usual life of each tube was only 600-700 hr. If 1000 hr is taken as the expected life of the tube, the replacement cost is 10·8d. per hr. Assuming a warm-up period of 4 min and a churn-filling time of 6 min per churn at a rate of flow of 4000 gal of water per hr through two units in parallel as outlined above, the replacement cost is then 3·6d. per churning. Electricity charges vary from place to place, but assuming a charge of 3d. per unit, operating costs for two units for 10 min would be 1·2d., giving a total cost (replacement tube and running costs) of approximately 4·8d. per churning of butter. Obviously, the longer the life of the tube the lower the cost, and the lower the rate of water flow to the churn, the higher the operating costs.

V. ACKNOWLEDGEMENTS

It is desired to acknowledge the helpful co-operation given by Watson Victor Ltd. in supplying the unit under test, and the Caboolture Co-operative Dairy Association Ltd. for allowing the unit to be tested in its Caboolture factory.

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(Received for publication March 30, 1961)