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A bacteriological investigation of two leisure centre swimming pools disinfected with ozone

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SUMMARY

A bacteriological study was carried out on the first Leisure Centre swimming pools in the United Kingdom to be disinfected with ozone/chlorine. Results suggested that a free chlorine concentration of approximately 0·8 mg/l was necessary to maintain the pools in a bacteriologically satisfactory condition. This amount of free chlorine was similar to that required when the pool was disinfected with chlorine alone. However, the associated amount of combined chlorine was much lower when disinfection was by ozone/chlorine and this gave more acceptable bathing conditions. Implications for the management of pools disinfected by this method are discussed.

INTRODUCTION

In the United Kingdom there are some 1055 public indoor swimming pools, the majority of which rely on chlorine for disinfection of the pool water (Technical Unit for Sport, 1977). When chlorine dissolves in water it forms hydrochloric acid, hypochlorous acid and hypochlorite ions. The latter two compounds oxidize organic and inorganic matter in the water to form chloramines and nitrochloride compounds. Although this 'combined chlorine' has some antimicrobial activity it is much less than that of free chlorine. With the current practice of 'breakpoint' chlorination, more chlorine is added until all the organic and inorganic matter is oxidized and a free chlorine residual of between 1 and 2 mg/l is obtained. For more detailed accounts of the chemistry of chlorine in water see Department of the Environment (1975), Black *et al.* (1970). As the bathing load increases so does the amount of organic and inorganic matter added to the water and thus the amount of combined chlorine. It is the high concentration of combined chlorine which has been found (Eichelsdorfer *et al.* 1976) to be the cause of the irritation of eyes and mucous membranes frequently experienced by bathers in chlorinated swimming pool water. As some of the compounds comprising combined chlorine are volatile, they are also found in the atmosphere of the pool hall and are the main contributors to the 'swimming bath odour'. As well as the transient irritation to pool users and spectators, there are also a number of pool users, especially children, who suffer more serious effects such as sinusitis and rhinitis. Most of these undesirable side

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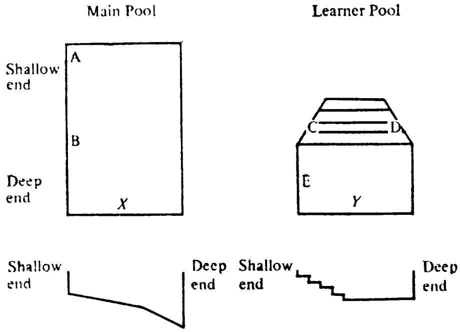

	Main Pool	Learner Pool
Length	25 m	12·5 m
Width	12·5 m	12·5 m
Depth: Deep end	2 m	450 mm
Depth: Shallow end	900 mm	450 mm
Type	Both are centre inlet level deck	
Capacity	449·757 l	122·661 l
Turnover time	3 h	1·5 h

Fig. 1. Specification of the swimming pools at the Valley Leisure Centre. Diagrams are not to scale.

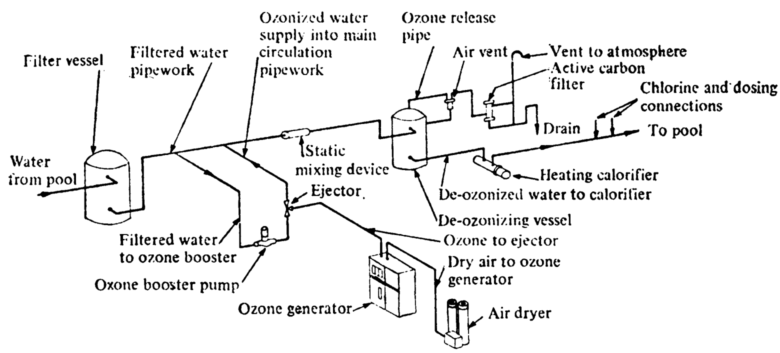

Fig. 2. The ozonization process at the Valley Leisure Centre.

effects of disinfection by chlorine would be eliminated if the amount of combined chlorine in the water were much reduced.

In Great Britain, ozone has been used to disinfect water for domestic supply and has been little used for the disinfection of swimming pool water (Holden, 1970), but it is much more widely used in Europe for the latter purpose. Evidence from Germany indicates that, in comparison with chlorine, ozone has both a higher antimicrobial activity (German Association of Gas and Water Companies, 1975) and a greater ability to assist in the removal of organic and inorganic compounds from swimming pool water (Heintz, 1975). German practice is that ozone must not be present either in the pool water or in the atmosphere of the pool hall for toxicological reasons (German Association of Gas and Water Companies, 1975; Herschman, 1976) and thus must be removed after treating the water. Chlorine is then added to provide continuing antimicrobial activity during the circulation time through the pool. However, because of the highly effective removal of organic and inorganic compounds by ozonization, the combined chlorine is much reduced and only a relatively small amount of chlorine is needed to achieve 'breakpoint' (Heintz, 1975).

Recently, the first Leisure Centre swimming pools (Fig. 1) in the United Kingdom disinfected with ozone were opened at the Valley Leisure Centre, Newtownabbey, near Belfast, Northern Ireland. The system of disinfection follows that used in Germany and an outline of the process is shown in Fig. 2. Ozone is generated from oxygen in the air by electrical discharge and the mixture of air and ozone is passed into the stream of water coming from the main filters. Because of the limited solubility of ozone, the gas is vigorously mixed with the water to form an unstable suspension. After a contact time of 2 min, the treated water passes to a deozonizer where the gaseous ozone bubbles off and the small amount that has dissolved is catalytically converted to oxygen by means of a special filter medium. The ozone present in the gas mixture removed from the deozonizer is similarly converted to oxygen and then vented to the atmosphere. After the ozonization stage of the process the water is then dosed with chlorine in the normal way before being returned to the pool.

This paper reports the findings of two bacteriological surveys of the water quality in the pools of the Valley Leisure Centre. The second survey was found to be necessary to overcome certain problems which had become apparent in the earlier study.

MATERIALS AND METHODS

Sampling

Sites. In the first survey, measurement of water temperature and samples for the estimation of chlorine levels and pH were taken at the pool surface above the inlets to the pools at points X and Y (Fig. 1). Samples for bacteriological analysis were removed at points A, B, C, D and E. At points A, B and E the sample was taken underwater at the base of the wall whilst at points C and D, the sample was taken from the highest step completely covered with water.

Differences in the second survey included: measuring chlorine at points A, B, C and E as well as at points X and Y and the inclusion of an additional sampling point (BS) at the surface of the pool above point B. Point D was not used.

Times. In the first survey chlorine, pH and temperature were measured hourly, whilst samples for bacteriological examination were taken at four times during the day (Table 1).

In the second survey, temperature was measured twice daily, pH was measured at the time of bacteriological sampling (Table 2) and chlorine was measured hourly at the pool inlets and also at the times of bacteriological sampling (Table 3).

Procedure. Temperature was measured directly in the pool using a standard pool thermometer (Brannan, England).

In the first survey, samples of water for the measurement of pH and chlorine were removed from the pool surface in a wide necked polythene bottle.

Table 1. *Bacteriological results obtained from samples during the survey period of disinfection by chlorine alone*

Day ...	1			2			3			4			5			6			7		
Bacterial count†	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Site§										**Time 1‡**											
Inlet (L)‖	—	ND	—	0·8 (F)	—	1·2 (C)	0·6 (F)	—	0·7 (C)	<0·1 (F)	—	1·8 (C)	1·5 (F)	—	1·0 (C)	1·3 (F)	—	1·8 (C)	0·8 (F)	—	1·7 (C)
Inlet (M)	—	ND	—	1·0 (F)	—	1·3 (C)	0·4 (F)	—	0·9 (C)	0·8 (F)	—	1·0 (C)	2·3 (F)	—	1·3 (C)	1·3 (F)	—	1·3 (C)	1·8 (F)	—	1·3 (C)
A	0	0	5	0	0	38	0	0	16	0	0	12	0	0	1	0	0	6	0	0	1
B	0	0	1	0	0	47	0	0	9	0	0	5	0	0	1	0	0	9	0	0	2
C	0	0	12	0	0	140	0	0	>1000	1*	0	>1000	0	0	33	0	0	32	0	0	36
D	0	0	4	0	0	448	0	0	>1000	1*	0	>1000	0	0	13	1*	0	38	2*	0	112
E	0	0	2	0	0	74	0	0	>1000	0	0	>1000	0	0	3	1*	0	11	0	0	6
										Time 2											
Inlet (L)	1·8 (F)	—	1·3 (C)	0·4 (F)	—	1·4 (C)	0·9 (F)	—	0·9 (C)	0·6 (F)	—	1·2 (C)	0·8 (F)	—	1·7 (C)	0·6 (F)	—	1·9 (C)	0·2 (F)	—	1·6 (C)
Inlet (M)	1·5 (F)	—	0·8 (C)	0·8 (F)	—	1·2 (C)	2·3 (F)	—	0·2 (C)	1·8 (F)	—	1·3 (C)	1·5 (F)	—	1·0 (C)	1·0 (F)	—	1·0 (C)	2·5 (F)	—	1·5 (C)
A	0	0	<1	0	0	45	0	0	4	0	0	2	0	0	11	0	0	35	0	0	1
B	0	0	<1	0	0	36	0	0	2	0	0	1	0	0	2	0	0	31	0	0	<1
C	0	0	5	0	0	976	0	0	96	0	0	24	0	0	24	0	0	16	0	0	80
D	0	0	2	0	0	>1000	0	0	113	0	0	72	0	0	32	0	0	92	0	0	87
E		ND		0	0	872	0	0	138	0	0	8	0	0	4	0	0	27	0	0	23
										Time 3											
Inlet (L)	0·8 (F)	—	1·7 (C)	0·1 (F)	—	0·4 (C)	0·8 (F)	—	1·2 (C)	0·8 (F)	—	1·4 (C)	0·2 (F)	—	2·0 (C)	2·0 (F)	—	2·0 (C)	0·2 (F)	—	1·8 (C)
Inlet (M)	1·3 (F)	—	1·5 (C)	0·3 (F)	—	1·5 (C)	1·8 (F)	—	1·0 (C)	2·8 (F)	—	0·8 (C)	1·5 (F)	—	1·3 (C)	2·0 (F)	—	2·0 (C)	2·5 (F)	—	1·5 (C)
A	0	0	2	0	0	40	0	0	3	0	0	26	0	0	12	0	0	4	0	0	2
B	0	0	2	0	0	29	0	0	5	0	0	8	0	0	1	0	0	1	0	0	1
C	0	0	9	1*	0	>1000	0	0	>1000	0	0	41	0	0	139	0	0	16	1*	0	136
D	1*	0	33	3*	3	>1000	0	0	264	0	0	112	0	0	93	0	0	3	3*	1	99
E	—	ND	—	0	0	>1000	0	0	286	0	0	5	0	0	10	0	0	21	0	0	75
										Time 4											
Inlet (L)	—	ND	—	0·4 (F)	—	1·1 (C)	—	ND	—	1·3 (F)	—	1·0 (C)	0·2 (F)	—	1·8 (C)	2·5 (F)	—	1·5 (C)	—	ND	—
Inlet (M)	—	ND	—	0·4 (F)	—	1·1 (C)	—	ND	—	2·3 (F)	—	1·8 (C)	1·0 (F)	—	1·5 (C)	2·3 (F)	—	1 8 (C)	—	ND	—
A	0	0	14	1*	0	116	0	0	8	0	0	1	0	0	24	0	0	17	1*	0	31
B	0	0	4	0	0	27	0	0	1	0	0	5	0	0	7	0	0	2	0	0	<1
C	1*	0	32	0	0	>1000	3*	0	>1000	0	0	5	0	0	17	0	0	5	1*	1	116
D	0	0	41	0	0	>1000	0	0	228	0	0	45	0	0	60	0	0	8	1*	0	65
E	0	0	31	0	0	>1000	2*	0	>1000	0	0	3	0	0	14	0	0	5	1*	0	54

* Indicates an 'Unsatisfactory' sample.

† Bacterial counts are represented by: (1) Most probable number of coliform organisms per 100 ml. (2) Most probable number of *E. coli* type 1 per 100 ml. (3) Plate count (organisms per ml.)

‡ The times of sampling for days 1–6 were: (1) 09.30 h, (2) 16.00 h, (3) 20.00 h, (4) 21.15 h. On day 7 the times were 09.30 h, 14.15 h, 16.15 h and 18.15 h respectively. All times were ± 45 min.

§ Positions in the pool from where samples were taken (Fig. 1).

‖ (L) and (M) indicates the learner and main pools and (F) and (C) the free and combined levels of chlorine (mg/l).

Table 2. *The variation in pH and amount of chlorine in the pool water during the second survey*

Approximate amount of free chlorine (mg/l)		Recorded amount of free chlorine (mg/l)		pH	
		Free	Combined	Learner	Main
0·2	Max.	0·3	0·3	7·8	7·8
	Min.	0·1	<0·1	7·8	7·6
0·5	Max.	0·7	0·3	8·2	7·6
	Min.	0·3	<0·1	7·6	7·4
0·8	Max.	0·9	0·2	7·6	7·8
	Min.	0·6	<0·1	7·5	7·6
1·3	Max.	1·6	0·2	7·6	7·6
	Min.	0·8	<0·1	7·5	7·5

In the second survey the bottle was attached to a three foot length of rigid wire which enabled it to be plunged rapidly to the sampling site when necessary. It should be noted, however, that at point B, the bottle did not reach to the base of the wall and the sample was thus taken approximately 30 cm from the pool bottom. In all cases the bottle was rinsed twice with water from the site before removing the sample which was then analysed within 10 min.

Samples for bacteriological examination were collected in 250 ml glass stoppered bottles containing the amount of sodium thiosulphate and sterilized as recommended in Water Report No. 71 (Department of Health and Social Security, 1969). In the first survey samples were obtained by opening the sampling bottle underwater whilst in the second survey the polythene bottle attached to the length of wire as described earlier was used. In the latter case the water in the polythene bottle was transferred to the 250 ml bottle immediately on removing it from the pool. All bottles were then placed at 4 °C before being transported to the laboratory for examination. The maximum length of time samples were kept at 4 °C was 24 h.

Analyses

All colorimetric measurements were made with a Lovibond 1000 Comparator by the same operator throughout each survey. Different operators, however, took part in surveys 1 and 2.

pH. One phenol red tablet (The Tintometer Ltd., Salisbury, England) was crushed into 10 ml of pool water and the colour intensity read immediately against Lovibond Disk 2/1J (pH range 6·8–8·4).

Free and combined chlorine. In the first survey, a standard DPD tablet method was used (Department of the Environment, 1975) for measuring both free and combined chlorine. A more precise method of measuring free chlorine was used in the second survey (Watts D., personal communication) in which 0·5 g of Palin DPD chlorine test powder (Wilkinson and Simpson Ltd., Low Friar Street, Newcastle-upon-Tyne, England) was mixed with 50 ml of pool water in a measur-

Table 3. Bacteriological results obtained during the second survey

Day ...		1			2			3			4		
Approximate amount of free chlorine (mg/l) ...		0·2			0·5			0·8			1·3		
Bacterial count† ...		1	2	3	1	2	3	1	2	3	1	2	3
Time (h)	Site§												
10·30	A	0	0	9	0	0	116	0	0	5	1*	0	3
	B	0	0	2	0	0	15	0	0	11	0	0	4
	BS	0	0	8	0	0	17	0	0	1	0	0	1
	C	2*	0	2	0	0	5	0	0	2	0	0	3
	E	0	0	1	0	0	140	0	0	2	0	0	4
11·30	A	0	0	55	0	0	3	0	0	< 1	0	0	2
	B	0	0	124	0	0	5	0	0	5	0	0	< 1
	BS	0	0	49	0	0	11	0	0	6	0	0	19
	C	0	0	116	1*	1	23	0	0	12	0	0	< 1
	E	0	0	212	0	0	172	0	0	2	0	0	1
12·30	A	0	0	144	0	0	11	0	0	5	1*	0	12
	B	0	0	59	0	0	3	0	0	32	0	0	< 1
	BS	0	0	94	0	0	1	0	0	1	0	0	5
	C	0	0	672	0	0	50	0	0	3	0	0	3
	E	0	0	89	0	0	37	0	0	3	0	0	< 1
15·30	A	0	0	14	0	0	< 1	0	0	< 1	0	0	< 1
	B	0	0	22	0	0	8	0	0	< 1	0	0	< 1
	BS	0	0	27	0	0	6	0	0	< 1	0	0	2
	C	0	0	19	0	0	17	0	0	< 1	0	0	1
	E	0	0	5	0	0	3	0	0	< 1	0	0	3
18·30	A	0	0	8	0	0	6	0	0	7	0	0	2
	B	0	0	6	0	0	94	0	0	4	0	0	< 1
	BS	0	0	6	0	0	4	0	0	2	0	0	< 1
	C	0	0	21	0	0	1	0	0	4	0	0	< 1
	E	1*	0	13	0	0	10	0	0	6	0	0	1
21·30	A	0	0	26	0	0	< 1	0	0	2	0	0	3
	B	0	0	17	0	0	< 1	0	0	1	0	0	< 1
	BS	0	0	7	0	0	< 1	0	0	1	0	0	< 1
	C	0	0	21	0	0	2	0	0	13	0	0	< 1
	E	0	0	7	0	0	< 1	0	0	< 1	0	0	< 1

†, § See Table 1.

ing cylinder. An aliquot was immediately transferred to a cuvette and the colour intensity determined in the Comparator.

The amount of total chlorine present in the sample was then determined with tabletted reagents by the standard method in both surveys and the amount of combined chlorine found by subtraction.

Bacteriology. The following tests as described by Water Report No. 71 (Department of Health and Social Security, 1969) were performed on each water sample: a presumptive count of coliform organisms determined by the multiple tube method with McConkey Broth, a faecal coliform count determined by the indole and Eijkman tests and a plate count.

The categorization of bacteriological findings was as follows: (A) 'Satisfactory' – no coliform organisms in 100 ml of water and a plate count of < 10 organisms per ml. (B) 'Unsatisfactory' – the presence of coliform organisms in 100 ml. (C) Samples showing no coliform organisms but plate counts of > 10 organisms per ml were not classified as 'Satisfactory' or 'Unsatisfactory' but were commented on individually.

RESULTS

The pools at the Valley Leisure Centre were opened on 1 April 1977 and disinfected with chlorine alone until the 29 May 1977. Subsequently, ozone in conjunction with chlorine was used as the disinfecting agent.

Survey 1

This survey compared the quality of the water in the two pools during the final week of disinfection with chlorine alone (23–29 May 1977) with that obtained during the first week when ozone/chlorine was used (30 May–5 June 1977).

Pool temperature

The temperature of the water in the main and learner pools during the two sampling periods was measured hourly and no large fluctuations were seen. The temperature in the learner pool during both sampling periods varied between 28·5 and 30 °C, whilst that in the main pool during the periods of disinfection with ozone/chlorine varied between 27·5 and 29 °C and during the period when only chlorine was used varied between 27 and 28·5 °C.

pH

This was also measured hourly in both pools. In the learner pool the pH varied between 7·8 and 8·4 during the period when chlorine alone was used for disinfection and between 7·1 and 8·3 when ozone/chlorine was used. In the main pool the variations were between 7·4 and 8·3 and between 7·2 and 7·9 respectively (Table 4).

Bathing loads

These were determined by counting the number of people in the two pools at hourly intervals (Figs. 3, 4). During the two surveys the loads were broadly

Table 4. *The variation in pH of the pool water during the first survey periods*

pH	Day no. ...	1	2	3	4	5	6	7
		Chlorine alone						
Learner pool	Maximum	8·1	8·2	8·2	8·1	8·1	8·3	8·4
	Minimum	7·9	7·9	8·1	7·8	7·9	7·9	8·1
Main pool	Maximum	7·7	8·3	8·3	7·7	8·1	7·9	7·9
	Minimum	7·4	7·5	8·1	7·5	7·7	7·7	7·5
		Ozone/chlorine						
Learner pool	Maximum	8·3	7·9	8·3	8·1	8·0	8·1	8·1
	Minimum	7·8	7·1	7·7	7·8	7·8	7·8	7·9
Main pool	Maximum	7·7	7·6	7·9	7·5	7·9	7·5	7·5
	Minimum	7·5	7·4	7·6	7·2	7·5	7·3	7·2

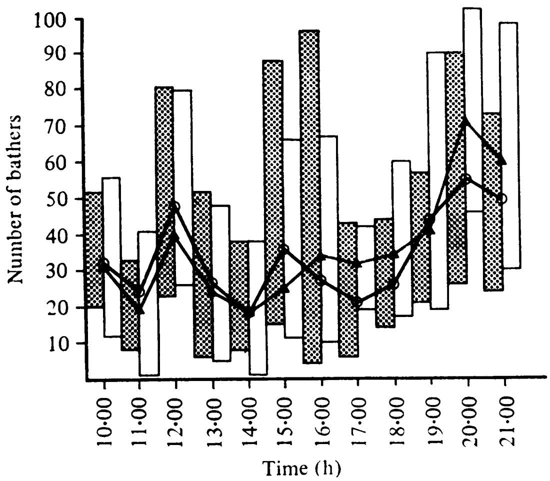

Fig. 3

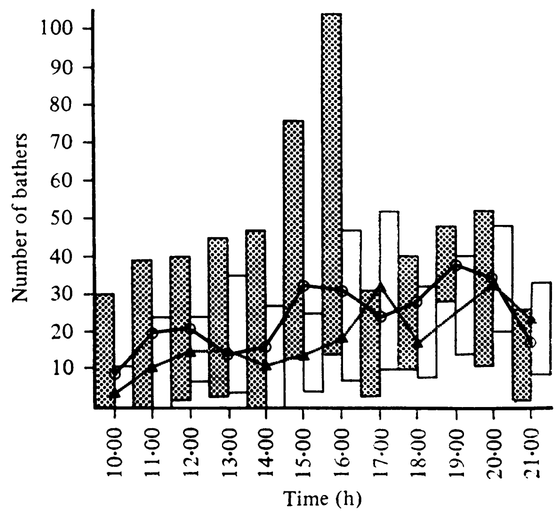

Fig. 4

Fig. 3. Bathing loads in the main pool during the first survey periods. ○—○ represents the mean and ▩ the range of the hourly counts taken over the 7-day period of disinfection by chlorine alone. ▲—▲ and □ represent the same figures for disinfection by ozone/chlorine.

Fig. 4. Bathing loads in the learner pool during the first survey periods. See Fig. 3 for explanation of symbols.

comparable, consisting of mainly school groups during the day and the general public in the evening.

Chlorine concentrations

Free and combined chlorine were measured hourly at the inlets to the pools, but only those measures made at the bacteriological sampling times have been recorded (Tables 1 and 5). During the period when chlorine alone was used for disinfection, free chlorine varied during the week between 0 mg/l (learner pool, 09.30 h day 4) and 2·8 mg/l (main pool, 20.00 h day 4; Table 1). The maximum variation in amount of free chlorine in one day occurred in the main pool on day 4 when it varied between 0·8 and 2·8 mg/l. Smaller variations in the amount of free chlorine were obtained during the period when ozone/chlorine was used for disinfection (Table 5). The maximum variation was between 0 mg/l (learner pool, 09.30 h day 4) and 1·3 mg/l which was obtained in the learner pool on three occasions during day 7. The maximum daily fluctuation of between 0·1 and 0·7 mg/l occurred in the learner pool on day 3.

Bacteriological results

These are also shown in Tables 1 and 5 and those found to be 'Unsatisfactory' (i.e. containing coliform organisms) have been asterisked. In the main pool during the period of disinfection with chlorine alone, two out of 56 results (3·6 %) were 'Unsatisfactory' (Table 1). In both cases a large number of bathers (90 and 96 respectively) had been in the water before the sample was taken and in the former case a low value for free chlorine (0·4 mg/l) was present in the inlet water. Unfortunately, chlorine values were not available for the latter 'Unsatisfactory' sample. By contrast, in the learner pool, 16 out of 82 results (19·5 %) were 'Unsatisfactory' (Table 1). These generally correlated with the higher bathing loads present in the evening on days 1, 2, 3 and 7 and where results were available, with low levels of free chlorine. Very high plate counts (> 1000 organisms/ml) in the absence of coliform organisms were obtained on a further ten occasions in the learner pool during this period and again were usually associated with the above factors.

Compared with a total of 18 'Unsatisfactory' results obtained when chlorine alone was used for disinfection, 47 out of 140 results (28·6 %) were 'Unsatisfactory' and a further four samples had very high plate counts when ozone/chlorine was used (Table 5). Again, these usually correlated with high bathing loads and low levels of free chlorine although high bathing loads could not account for the 14 'Unsatisfactory' results obtained at 09.30 h.

Survey 2

In view of the many 'Unsatisfactory' results obtained during both sampling periods, a second survey was carried out in which the main deficiencies of the first survey were overcome. These deficiencies were, firstly, that the amount of free chlorine in the inlet water fluctuated widely, and secondly that the operator taking the samples had several readings to take at similar times and thus found it difficult to maintain precision and accuracy. As the pool for administrative reasons could not be returned to disinfection using chlorine alone, the second survey was confined to disinfection with ozone/chlorine.

Table 5. *Bacteriological results obtained from samples during the survey period of disinfection by ozone/chlorine*

Day ...	1			2			3			4			5			6			7		
Bacterial count†	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Time 1‡																					
Inlet (L)‖	0·2 (F)	—	1·3 (C)	<0·1 (F)	—	0·3 (C)	<0·1 (F)	—	0·6 (C)	<0·1 (F)	—	0·1 (C)	0·1 (F)	—	0·3 (C)	0·5 (F)	—	0·1 (C)	0·9 (F)	—	0·6 (C)
Inlet (M)	0·3 (F)	—	1·5 (C)	0·3 (F)	—	1·2 (C)	<0·1 (F)	—	0·6 (C)	0·1 (F)	—	0·6 (C)	0·1 (F)	—	0·2 (C)	0·2 (F)	—	0·3 (C)	0·3 (F)	—	0·4 (C)
A	0	0	41	5*	0	36	1*	0	69	0	0	264	5*	0	>1000	1*	0	88	0	0	62
B	0	0	7	0	0	11	0	0	93	0	0	310	0	0	>1000	1*	0	25	0	0	5
C	0	0	136	1*	0	268	0	0	123	0	0	>1000	7*	5	212	0	0	37	0	0	310
D	0	0	149	7*	0	236	3*	0	162	0	0	>1000	8*	8	240	0	0	41	0	0	124
E	13*	0	204	3*	0	93	1*	1	90	0	0	>1000	11*	11	112	0	0	31	0	0	204
Time 2																					
Inlet (L)	0·1 (F)	—	1·4 (C)	0·3 (F)	—	0·7 (C)	0·1 (F)	—	0·6 (C)	0·5 (F)	—	0·2 (C)	0·1 (F)	—	0·2 (C)	0·7 (F)	—	0·9 (C)	1·3 (F)	—	0·4 (C)
Inlet (M)	0·7 (F)	—	1·0 (C)	1·0 (F)	—	1·0 (C)	0·6 (F)	—	0·4 (C)	0·3 (F)	—	0·5 (C)	0·3 (F)	—	0·2 (C)	0·3 (F)	—	0·2 (C)	0·3 (F)	—	0·3 (C)
A	0	0	25	0	0	1	0	0	8	0	0	90	0	0	69	0	0	16	0	0	188
B	0	0	1	0	0	5	0	0	54	0	0	35	0	0	154	0	0	4	0	0	4
C	0	0	84	0	0	26	13*	13	138	1*	0	164	0	0	76	0	0	14	0	0	132
D	0	0	99	0	0	5	5*	5	161	0	0	148	0	0	79	0	0	92	0	0	116
E	0	0	71	0	0	27	14*	14	146	0	0	118	35*	35	71	1*	1	22	0	0	86
Time 3																					
Inlet (L)	—	ND	—	—	ND	—	0·4 (F)	—	0·2 (C)	0·3 (F)	—	<0·1 (C)	0·1 (F)	—	0·4 (C)	1·0 (F)	—	0·1 (C)	1·3 (F)	—	0·4 (C)
Inlet (M)	—	ND	—	0·7 (F)	—	1·0 (C)	0·4 (F)	—	0·4 (C)	0·2 (F)	—	0·2 (C)	0·1 (F)	—	0·3 (C)	0·3 (F)	—	0·2 (C)	0·3 (F)	—	0·5 (C)
A	3*	0	43	0	0	21	0	0	11	7*	1	>1000	0	0	85	0	0	63	0	0	25
B	0	0	8	0	0	19	0	0	18	10*	4	>1000	0	0	92	0	0	22	0	0	6
C	7*	0	101	0	0	12	35*	35	108	1*	1	74	1*	0	49	0	0	98	1*	0	94
D	1*	0	576	0	0	57	35*	35	144	5*	2	260	0	0	178	1*	1	152	3*	1	49
E	1*	0	93	0	0	6	17*	17	136	1*	0	126	1*	0	81	0	0	176	3*	1	63
Time 4																					
Inlet (L)	—	ND	—	0·2 (F)	—	0·6 (C)	0·7 (F)	—	0·2 (C)	0·2 (F)	—	0·1 (C)	—	ND	—	1·0 (F)	—	0·3 (C)	1·3 (F)	—	0·4 (C)
Inlet (M)	—	ND	—	0·5 (F)	—	1·0 (C)	0·3 (F)	—	1·0 (C)	0·1 (F)	—	0·3 (C)	—	ND	—	0·3 (F)	—	0·2 (C)	0·3 (F)	—	0·5 (C)
A	0	0	5	0	0	158	0	0	6	35*	35	>1000	0	0	93	0	0	116	0	0	1
B	0	0	13	0	0	1	0	0	25	17*	17	>1000	0	0	66	0	0	20	0	0	15
C	0	0	62	0	0	49	0	0	63	3*	3	308	1*	1	63	0	0	152	0	0	12
D	0	0	58	0	0	172	1*	0	62	1*	1	224	5*	5	158	0	0	184	0	0	9
E	0	0	23	0	0	39	0	0	31	8*	1	196	11*	1	148	0	0	178	0	0	18

Footnote references as in Table 1.

Chlorine concentrations

Different amounts of free chlorine (0·2, 0·5, 0·8 and 1·3 mg/l) were used on four separate days and the required concentration was set on the previous evening to allow the pool to equilibrate overnight. During the day of sampling, chlorine was measured hourly at the inlets to both pools and slight adjustments were made to the chlorinators to maintain a constant amount in the pool in the light of changing bathing loads. Free chlorine was also measured both at the sites and times used for bacteriological sampling (Table 3). The same sites as described in the first survey were used but included an additional point BS, at the surface of the main pool at point B. The variation in free chlorine both in the inlet water and at the sampling sites was ± 0·2 mg/l except during the day when the approximate value was 1·3 mg/l. A larger variation was seen on this day (+0·3 to −0·5 mg/l) primarily because the free chlorine in the morning was lower (at 0·8 mg/l) than that required. A variation of ± 0·2 mg/l was thought to be acceptable in view of the precision of the measuring technique.

Pool temperature

Temperatures were measured twice during each day of sampling and were found to be higher than those observed in the first survey. The temperature of the main pool did not fluctuate greatly from 31·5 °C, while that in the learner pool usually ranged between 32·5 and 34·5 °C.

pH

Measurements of pH (Table 2) were made at the pool inlets at the times of bacteriological sampling. In the main pool the pH variation over the survey period was between 7·4 and 7·8 and in the learner pool the variation was between 7·5 and 8·2. The largest daily fluctuation in pH was 0·6 and occurred in the learner pool on the day when the free chlorine was approximately 0·5 mg/l. Apart from this the maximum variation was 0·2 (Table 2).

Bacteriological results

These are shown in Table 3. At a concentration of free chlorine of 0·2 mg/l, coliform organisms were obtained on two occasions (asterisked) and five out of 30 plate counts (16·7 %) showed > 100 organisms/ml. All of these were obtained in the morning. Smaller increases in the plate count were seen during the evening when the bathing load was comparable (Fig. 5). With a free chlorine value of 0·5 mg/l, 17 out of 30 samples (56·7 %) were 'Satisfactory', one was 'Unsatisfactory' (one coliform organism/100 ml) and three out of 30 samples (10 %) had total counts of > 100 organisms/ml. When the free chlorine was raised to 0·8 mg/l 'Satisfactory' results were obtained almost throughout the day. No coliform organisms were found in any sample but four out of the 30 samples (13·3 %) had total counts of > 10 organisms/ml. However, three of these were counts of 11, 12 and 13 organisms/ml. With free chlorine at 1·3 mg/l two samples containing coliform organisms were obtained but the plate count in both these cases was low

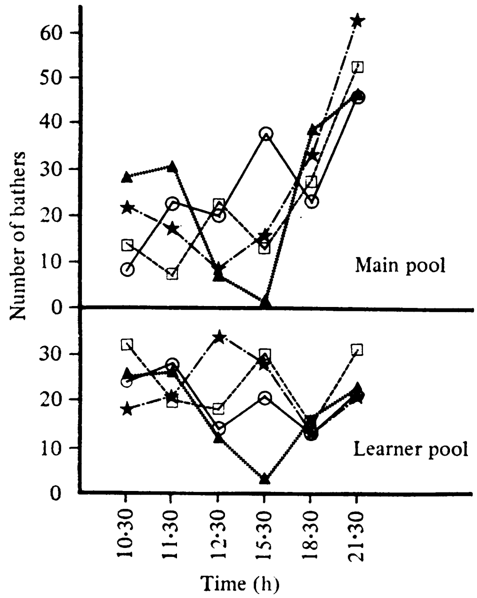

Fig. 5. Bathing loads during the second survey. The approximate concentrations of free chlorine were: 0·2 mg/l (▲---▲), 0·5 mg/l (□---□), 0·8 mg/l (○—○), 1·3 mg/l (★-·· -·★).

(3 and 12 organisms/ml respectively). Low plate counts were also obtained in the rest of the samples including 12 out of 30 (40 %) which contained < 1 organism/ml.

DISCUSSION

Ozone has not been widely used for swimming pool disinfection in the United Kingdom, but in Europe many pools are disinfected by this method. In Germany the suggested value for residual free chlorine in swimming pool water disinfected by ozone is between 0·2 and 0·5 mg/l (Anon., 1976). At the Valley Leisure Centre in the first survey, during the period of disinfection by ozone/chlorine, the majority of free chlorine concentrations were less than 0·5 mg/l. This resulted in 47 out of 140 samples (33·6 %) showing the presence of coliform organisms (Table 5). Even overnight exposure to these amounts of chlorine did not result in bacteriologically 'Satisfactory' water in the morning.

The difference between our findings and the German recommendations could have been due to: (*a*) inaccuracies in the methods used, and (*b*) variations in the pool conditions.

(*a*) *Inaccuracies in the methods.* Measurement of free chlorine by the DPD method suffers from variations in the tabletted reagents (Watts, D., personal communication) and for this reason DPD chlorine test powder was used in the second survey. Heintz (1975) cites evidence that the measurement of chlorine content alone does not enable the disinfectant activity of pool water to be adequately assessed and that redox potential is a more accurate criterion. However, in practice at this pool as with many others, chlorine is measured by the DPD method and we felt that it would be more meaningful to follow the same procedure.

In both surveys the maximum time that samples for bacteriological analysis were stored at 4 °C was 24 h, a time similar to that used by Black *et al.* (1970). Storage for not more than 6 h at this temperature has been recommended by the Department of Health and Social Security (1969) but we found it impracticable to comply with this time. Recently, Standridge & Lesar (1977) have studied the effects of storage times and temperatures on the recovery of faecal coliform organisms from non-potable waters. They found that in many cases the counts of organisms obtained after storage for 24 h at 4 °C did not differ significantly from the counts obtained after storage for 4 h. Furthermore, as samples in our study obtained at particular times on differing days were stored for the same lengths of time, any change in counts should have been comparable.

(*b*) *Variations in the pool conditions.* It is unlikely that the difference in circulation time (3 h main pool and 1·5 h learner pool; Fig. 1) compared with similar pools in Germany (2·5 h and 1 h respectively; H. Reid, personal communication) or the absence of dilution (30 l/day/bather in German pools; Anon., 1976) would account for the higher chlorine value required at the Valley Leisure Centre.

Changes in the pH of swimming pool water markedly affect the amount of free chlorine available as hypochlorous acid, the main bactericidal component, especially if the pH moves outside the desirable range of 7·2–8·0 (U.K. limits: Department of Environment, 1975) or 7·2–8·2 (American Public Health Association; Black *et al.* 1970). Even within these ranges, the amount of hypochlorous acid decreases considerably as the pH increases (Black *et al.* 1970). The generally high pH values experienced, especially in the learner pool (Table 4) during this survey could partly explain the poor bacteriological results.

The bacteriological findings in the first survey during the period of disinfection with ozone/chlorine did not indicate a value for free chlorine which would give 'Satisfactory' pool water samples (Fig. 6). This was because the values chosen were generally too low, as we had expected that ozonization would reduce the amount of free chlorine required. Also, the free chlorine was not kept constant, as hourly measurements showed random fluctuations (e.g. between 0–1·3 mg/l) during individual days. These fluctuations caused an uneven distribution of chlorine and probably accounted for 'Unsatisfactory' results which were obtained with theoretically adequate concentrations of free chlorine and 'Satisfactory' results obtained with very low values. Measurements in the main pool with an average bathing load, showed that it took approximately 2 h for the free chlorine at the surface to be reflected at the base of the wall at the deep end and approximately 1·5 h for the change to occur at the shallow end. In the learner pool equilibrium was much more rapid and occurred in about 30 min.

The second survey was undertaken to establish a free chlorine value that would give bacteriologically 'Satisfactory' water samples and to reduce the errors caused by fluctuations in pH and free chlorine occurring in the first survey.

The range of pH encountered during this second survey (Table 2) was sufficiently small not to have grossly affected the recorded concentrations of free chlorine.

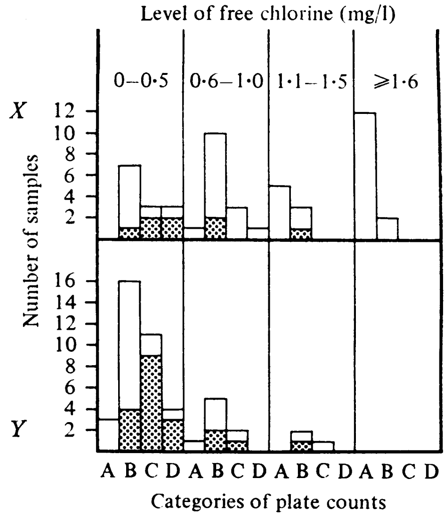

Fig. 6. The relation between the plate counts of bacteria and the concentration of free chlorine during the first survey. *X* = week of disinfection by chlorine alone. *Y* = week of disinfection by ozone/chlorine. The categories of plate counts are represented by: A, 0–10; B, 11–100; C, 101–1000; D, > 1000 organisms/ml. □ represents the number of samples within a particular category of plate count. ▦ represents the number of samples within a category which contained coliform organisms.

However, the pH of 8·2 found in the learner pool for 3 h during one morning (free chlorine approximately 0·5 mg/l) possibly accounted for the poor bacteriological results obtained at 11.15 and 12.30 hours. The reason for this high pH is not known.

Fluctuations in the free chlorine were largely prevented by equilibrating the pool overnight and carefully maintaining the selected concentration throughout the day. No major difference in free chlorine between point B and BS were then seen.

As in the first survey, the small temperature fluctuations seen do not seem to be sufficient to affect a comparison of the differing chlorine concentrations, nor would the variations observed in the number and composition of the bathing load (Fig. 5).

The bacteriological results of the second survey (Table 3) showed that generally 'Satisfactory' samples were only obtained when a value of 0·8 mg/l was maintained in the pool. Concentrations of free chlorine of 0·2 and 0·5 mg/l resulted in high plate counts (> 10 organisms/ml) in a considerable proportion of the samples although on only three occasions were coliform organisms found. At both 0·8 and 1·3 mg/l, low plate counts and no coliform organisms were generally found (Fig. 6) and therefore the concentration of 0·8 mg/l would seem to be suitable for general use.

When chlorine alone was used to disinfect the pools in the first survey, 'Satisfactory' samples were not obtained when the free chlorine was less than 1·0 mg/l (Fig. 6). This finding is in agreement with the U.K. recommendations that 1·0 mg/l is suitable for disinfection (Department of Environment, 1975), but contrasts

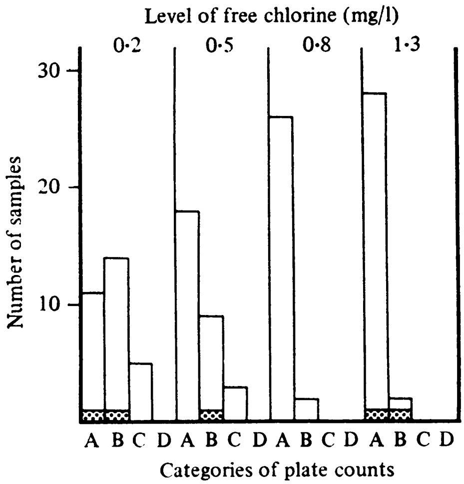

Fig. 7. The relation between the plate counts of bacteria and the concentration of free chlorine during the second survey. See Fig. 6 for explanation of symbols.

with the recommended German level of 0·3–0·6 mg/l (Anon., 1976). Our finding that a free chlorine value of 0·8 mg/l was necessary during disinfection with ozone/chlorine is also different from the German recommendation of between 0·3 and 0·5 mg/l (Anon., 1976). The discrepancy in both these cases may be explained by the differing standards adopted in the two countries. In Germany the requirements are that swimming pool water should contain no coliforms/100 ml and a plate count of ⩽ 100 organisms/ml, compared with the U.K. requirement of no coliforms/100 ml and a plate count of ⩽ 10 organisms/ml in 75 % of samples. If the German standards are applied to our findings in the second survey (Fig. 7) generally 'Satisfactory' pool conditions would be obtained at a free chlorine value of about 0·5 mg/l, in agreement with their recommendations. A similar correlation could not be obtained with either method of disinfection in the first survey (Fig. 6) presumably because of the difficulties that occurred.

Another factor that may be influencing the apparent discrepancy between the amounts of free chlorine necessary at the Valley Leisure Centre and those specified for German pools may lie in the German provision of more effective pre-cleanse facilities. During the second survey, although the number of bathers at any one time in the morning and the evening were similar (Fig. 5), in the mornings the pools had a very high turnover of bathers because of use by schools. The majority of samples showing raised plate counts were obtained at free chlorine values of 0·2 and 0·5 mg/l during this morning period (Table 3).

Although the amount of free chlorine needed to maintain the pools at the Valley Leisure Centre in a bacteriologically 'Satisfactory' condition was similar with both methods of disinfection, we do not feel that this negates the use of ozone. In their experiments with rabbits, Eichelsdorfer *et al.* (1976) showed that it was the amount of combined chlorine rather than that of free chlorine that was responsible for eye irritation. During the first survey when the pools were disinfected with chlorine alone, combined chlorine in the inlet water varied (Table 1) between a minimum of 0·2 mg/l and a maximum of 2·0 mg/l, with 41 out of 48 readings (85 %) showing ≥ 1·0 mg/l. With ozone/chlorine in the first survey (Table 5), combined chlorine showed a minimum value of 0 mg/l and a maximum of 1·5 mg/l. Only nine out of 49 readings (18%) showed ≥ 1·0 mg/l and as eight of these were obtained within two days of the changeover from chlorine alone, they may have represented a 'hangover' effect and thus not be representative. Further confirmation of the very low concentrations of combined chlorine experienced with disinfection by ozone/chlorine was obtained in the second survey (Table 2) where the maximum found in 158 readings was 0·3 mg/l. These values were independent of the amount of free chlorine. Subjectively, at a concentration of free chlorine of 0·8 mg/l the authors and other colleagues could not detect a smell of chlorine in the atmosphere of the pool hall nor taste it in the water.

If ozone is to be used for the disinfection of swimming pools, we feel that pool managers should be made aware of the need to maintain a constant amount of free chlorine in the water. In the second survey this was achieved by hourly measurement and fine adjustment of the chlorinators in the light of bathing loads. As this would prove tedious in routine practice, there may be a strong argument for the use of automatic monitoring and dosing equipment as has been suggested by Heintz (1975). This could with advantage be combined with automatic pH control. Certainly, the rather coarse methods of adjustment which are employed in many pools disinfected with chlorine alone would appear to be inappropriate.

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