

5 Materials and Methods

5.1 *Experimental rationale*

In order to write a mass balance for N, Cl, and C within the pool it was necessary to identify all inputs, rates of accumulation and outputs within the pool system. Inputs to the pool that were measured and/ or calculated on a daily basis and included measurements of C, N and Cl within the BFA, the humic acid, the hypochlorite and hydrochloric acid stock and the dilution water. Accumulation of products within the pool water was measured daily by taking samples directly from the pool. The only major output route from the pool system in these experiments was via the pool headspace which was constantly being refreshed. It was therefore necessary to attempt to sample this air, in order to quantify the losses of C, Cl and N to this pathway. The method employed to attempt this sampling, and the results of these experiments (along with the validation technique used to quantify the accuracy of this technique) are presented in Sections 5.3.4 and 5.4.1.

To be able to establish a protocol to evaluate various pool technologies, it was necessary to experiment with bather dosing techniques, with variations in bather load and with various pollutants (Section 5.4.3). After an optimum dosing technique had been identified (i.e. that which best mimicked all conditions within a municipal swimming pool), this dosing technique was then used in all further experimentation (Section 5.4.4).

The original test pool was commissioned and constructed in 1994 and details of other research related to the pool can be found in Black (1997) and Black and Judd (2000). This original pool was used in all 'rig' based experiments, after modifications such as the installation of a new ozonation device ('ozonator') and a UV device, improved dosing capabilities, and regeneration of GAC, had taken place. Details of these modifications are included in the following section (Section 5.2.1).

5.2 Materials

5.2.1 Test pool specifications

The pool had a volumetric capacity of approximately 2.2m^3 and was a one-seventh linear scale model of the 25m installation at Cheltenham College, Cheltenham, UK. The treatment system included in-line free chlorine measurement and hypochlorite addition, in-line pH adjustment, sand filtration, temperature control and air circulation. Full design and operating parameters are included in Table 5.1.

The test pool was constructed of uPVC sheet and Perspex by Thermalek Engineering, (Glossop), and the chlorine, acid and ozonation dosing was provided by ProMinent Fluid Controls, (Ashby de la Zouch). Its internal dimensions were 3895mm x 2095mm wide at the shallow end and 170 mm deep and 357mm at the base pump (in centre of pool), and 343 mm deep at the balance tank end. The sampling and injection tubes in the pool were nylon, whilst the pipework was uPVC. Figure 5.1 shows the pool from the balance tank end and the sand filter can be seen to the left of the picture.

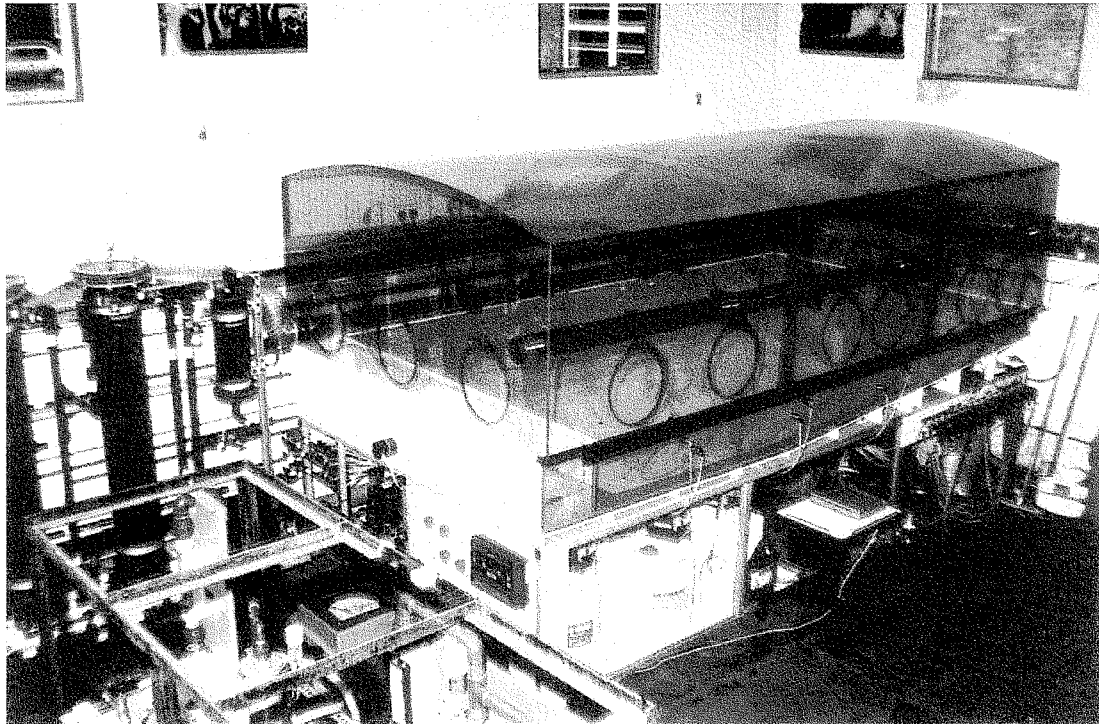


Figure 5.1 The test pool, taken from deep end

Circulation of the pool water was achieved through a level deck design, which allows the overflow of water around the edge of the pool into a trough before flowing into

the balance tank. Water was also drawn through the base drains at the bottom of the pool, and mixed with the balance tank water before reaching the pump. The circulating pump was a single stage CR2-20 *Grundfos* pump, rated for 1m³/hr at 6m head. A full bore in line flow meter was used between the pump and sand filter for flow measurement.

Table 5.1 Test pool design values

Parameter	Value
Volume of pool, m ³	2.2
Circulation, m ³ /hr	0.85
Turnover time, hrs	2.5
Head space above pool, m ³	12
Air flow, m ³ /hr	75
Turnover time, hrs	0.17
Temperature of water, °C	29
Temperature of air, °C	30

The sand filter was a 200 Nominal Bore sand filter, with a nozzle collection system covered with 6mm pebbles to a depth of 200mm. The filter sand was of 16/30 grade and was approximately 1m deep. The GAC filter material was virgin and of RTS grade (derived from coconut) manufactured by Carbonlin (Wigan) and supplied by Thermelek Engineering. Figure 5.2 shows the layout of both filtration systems, with the GAC filter on the left.

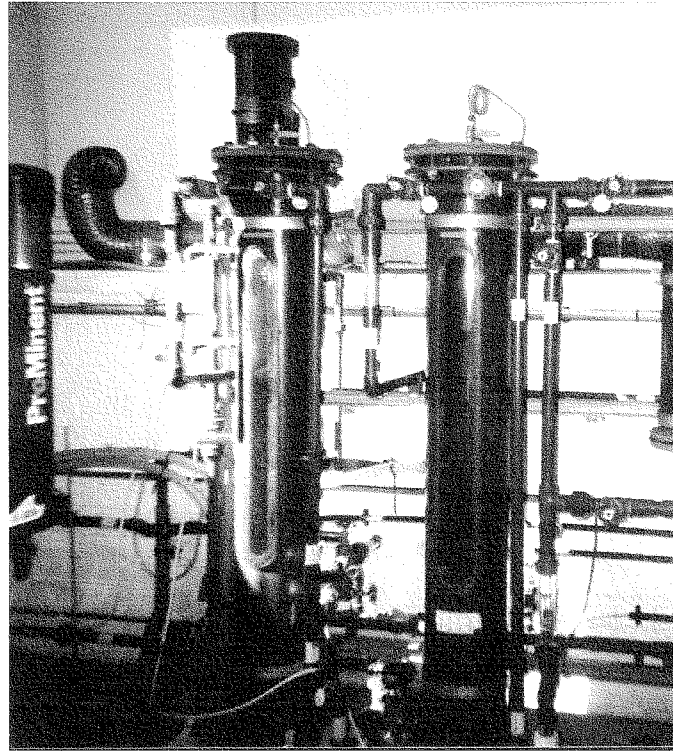


Figure 5.2 GAC and sand filtration system

The GAC filter was of the same dimensions as the sand filter, with a cross sectional area of 0.04m^2 and a bed depth of around 1m. Both GAC and sand filters were fitted with a sight glass at the front and an air release valve at the top. Each system also had a valve arrangement for the backwash operation and bypass of the system.

Air was supplied to the top of one (long) side of the pool and extracted from the opposite side of the pool from just above the pool surface. The air system was rated at $75\text{m}^3/\text{h}$ and was also heated, (Table 5.1) and both fan and heater were supplied by Nu Aire Limited (Caerphilly). The pool water was heated using an inline 3KW heater supplied by Thermalec (Devon). Air speed was maintained by a *Solomat* processor in conjunction with a 129 MS/GN hotwire anemometer probe to measure the speed at the inlet and outlet to the pool (Thermalec)

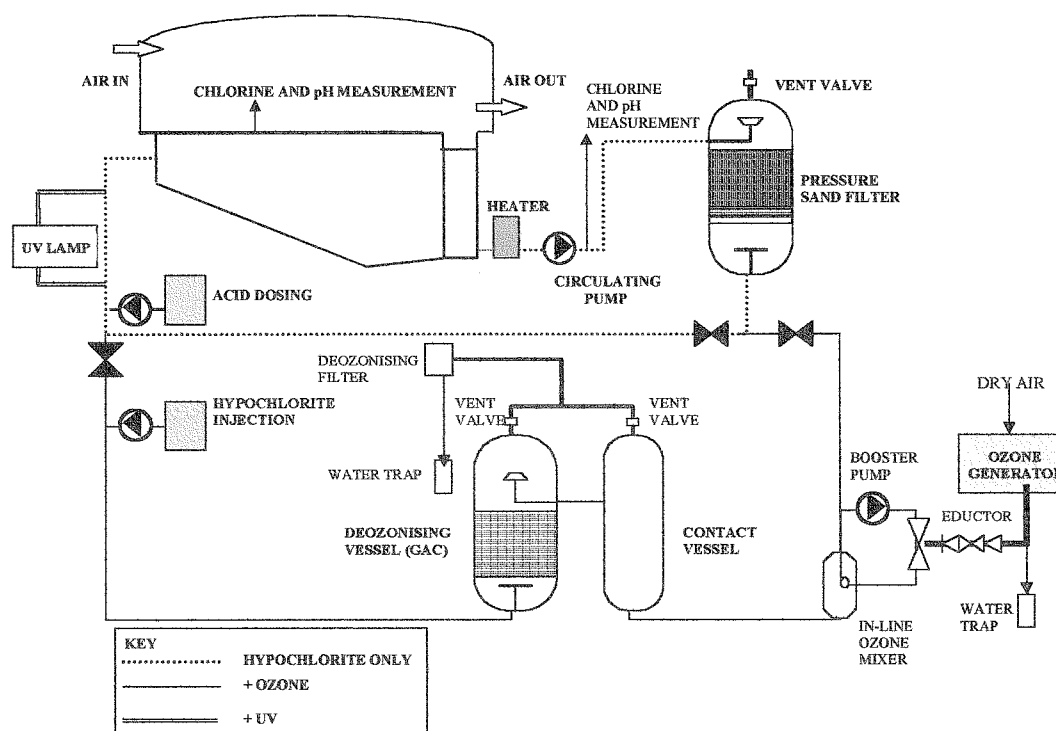


Figure 5.3 Schematic diagram of pool treatment system

The flow of water through the treatment system was altered by employing by-pass routes that were controlled by opening and closing a series of valves. A schematic diagram of the whole treatment system with the three varying treatment options is shown in Figure 5.3

5.3 Advanced Treatment Processes

5.3.1 Ozone

The 'Ozonofilt® OzVa' ozone generator was supplied by Prominent, and was rated at 0.8mg/l as O_3 at a minimum of 2 minutes contact time. Ozone was generated from dry air by electrical discharge at a voltage of around 10,000V. The ozone was then mixed with pool water by bubbling it through a mixing chamber. Figure 5.4 shows the ozone generator control unit and the ozone/water mixing chamber to the right.

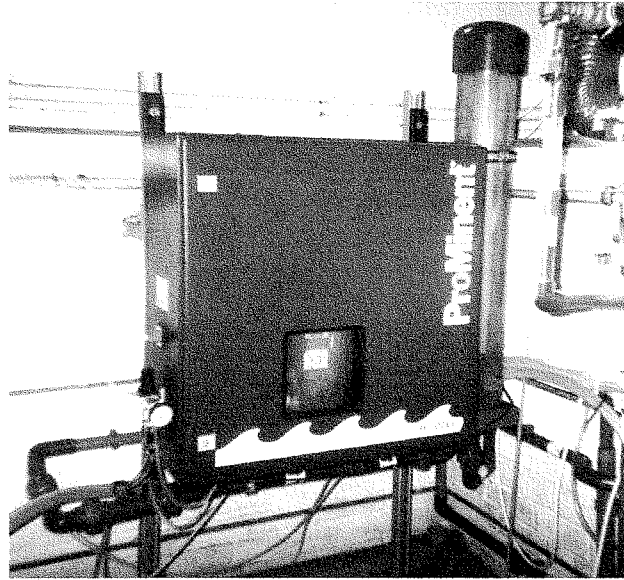


Figure 5.4 Ozone generator and mixing column

5.3.2 UV

The UV machine was designed and supplied by Aqua System (Denmark) and had a maximum flow of 500l/hr with a low-pressure UV lamp 'UV-C 8.8W' type, giving a maximum dose of 8.8 W m^3 . The UV system was scaled down for the test pool by obscuring part of the UV lamp with opaque black tubing. A slit of 10mm width was left to reduce the wattage to around $3\text{-}5 \text{ W m}^3$. Figure 5.5 shows the UV control unit (top) and UV lamp holder/chamber (below). The sensors at the front of the lamp chamber measured the wattage being produced by the UV lamp and displayed the result on the control unit above.

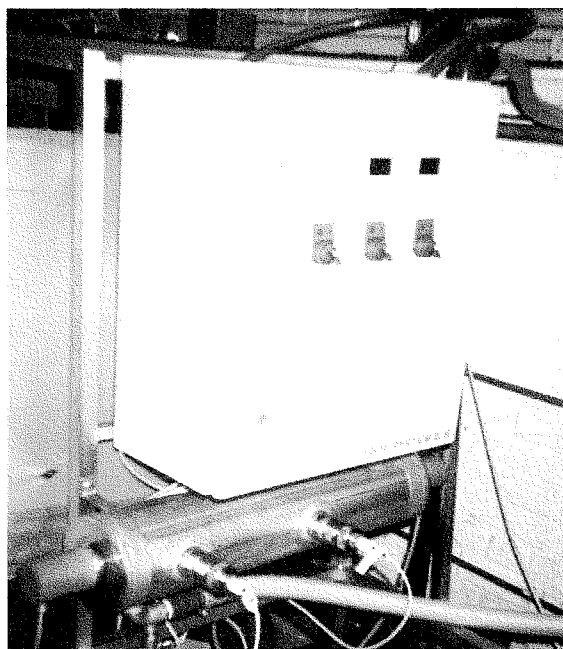


Figure 5.5 UV control unit and lamp chamber

5.3.3 Online Monitoring

pH was measured online using a *Dulcotest* (Prominent Fluid Controls) type PHE 112 SE pH probe with temperature compensation. Chlorine was also measured in line using a Dulcotest type CLE 2.2 probe supplied by Prominent. Both of these probes were regulated using a *Dulcomarin* chemical dosing/regulating control panel (ProMinent) in to which the parameters required (e.g. the free chlorine level required) were programmed.

5.3.4 Air sampling materials

To sample the pool air in the original and validation experiments, an air pump was employed, to draw air from the pool headspace and through a collection bottle. The air pump was rated at ~ 2 l/min. A flow meter was connected between the air pump to measure and regulate the air flow. The connection tubing was made of uPVC. The collection bottles used in both experiments were Dreschel Bottles (Merck) with sintered glass aerators of porosity 3. 200 ml of deionised water (Table 5.6) was used in the collection bottle.

Tests were conducted to evaluate the efficiency of the sampling device using ‘spiked’ water samples containing known concentrations of THMs and chloramines (an actual sample of pool water). Air was drawn sequentially through 200ml volumes of sample and collection water at a rate of 1.3 litres min⁻¹, the lowest rate achievable. Both the sample and the absorbant were analysed following sparging. The influence of the following modifications on the efficiency of the analysis were assessed:

- chilling the collecting water to 5°C
- using a 50% methanol / 50% deionised (DI) water mix

5.3.5 Bather load

A urine analogue was used to simulate bather load containing key nitrogenous organic compounds as used in previous studies (Judd and Black 2000). Sodium phosphate was added to maintain pH without contributing to the inorganic carbon.

Table 5.2 shows the high and low estimates of concentrations of the chosen constituents in urine, along with calculations showing the contribution (in mg) per bather of N and C into a pool. Whilst the BFA formula (Table 5.5) does not contain *all* of the chemicals present in urine and sweat, the total absolute and relative concentrations of carbon and nitrogen are similar to those found in a 4:1 mixture of sweat and urine (Putnam, 1971). 200ml sweat and 50ml urine were assumed to be emitted from an average bather every hour (Judd and Black, 2000), and the bather loading rates were calculated based on an average pool volume of 500m³ (PWTAG 1999), assuming pool operation for 12 hours a day and 7 days a week. Organic soiling (dirt) from natural organic matter (NOM) was represented by humic acid (HA) which, along with fulvic acids, may constitute as much as 95% of the total dissolved NOM in aquatic systems (Stevenson, 1994). Of these two fractions, humic materials have the highest THM formation propensity (Trussel and Umphres, 1978; Krasner *et al*, 1996).

Table 5.2 Concentration of constituents in real urine and calculated dose required for test pool

Constituents of urine	Conc in urine ^a mg/l		¹ addition per person per visit mg		mg N added per person per visit		mg/C added, per person per visit	
	low	high	low	high	low	high	low	high
Urea	9300	23,300	465	1165	218	547	93	233
Hippuric acid	50	1670	2.5	83.5	0.2	6.68	3.11	50.9
Histidine	40	330	2	16.5	0.54	4.46	0.92	7.59
Ammonia	200	730	10	365	-	-	6.3	229
Citric acid	90	930	4.5	46.5	-	-	1.67	17.2
Uric acid	40	670	2	33.5	0.66	11.06	0.72	12.06
Dose to 500m ³ capacity pool per person:					219.4	569.2	105.72	549.75
² Dose to 2.2 m ³ capacity pool per person:					0.96	2.51	0.46	2.42

^aFrom NASA report

¹ based on 50 ml addition of urine per person

² scaled down from a pool with average size of 500,000l to test pool with 2,200 litres (divided by 227)

Table 5.3 Total addition of C and N that should be added to pool per hour to simulate real pools

No. of bathers per hour	Total addition of Nitrogen to test pool (mg/hr)		Total addition of carbon to test pool (mg/hr)	
	low	high	low	high
50	48	126	23	121
100	96	251	46	242
150	144	377	69	363
200	192	502	92	484

Table 5.4 Details of BFA constituents

BFA constituent	Formulae	Fraction N	Fraction C
Ammonium Chloride	NH_4Cl	0.26	0
Urea	NH_2CONH_2	0.47	0.20
L-Histidine	$\text{C}_6\text{H}_9\text{N}_3\text{O}_2$	0.27	0.46
Hippuric acid	$\text{C}_6\text{H}_5\text{CONCH}_2\text{CO}_2\text{H}$	0.08	0.61
Uric acid	$\text{C}_5\text{H}_4\text{N}_4\text{O}_3$	0.33	0.36
Citric acid	$\text{C}_6\text{H}_8\text{O}_7\text{H}_2$	0	0.37
Creatinine	$\text{CH}_3\text{NCHCONHCNH}$	0.38	0.43

Table 5.2 shows the calculated flows of BFA that are required to simulate different bather loads as given by the number of bathers * (TON and TOC)/ pool volume. The actual limits of the TON and TOC mass loading rates are shown in Table 5.3.

Table 5.5 BFA formulation, adapted from Judd and Black (2000)

Constituent	Concentration mg/l	Carbon mg/l ³	Nitrogen mg/l	Grade and supplier
Ammonium Chloride	2000	-	520	BDH 'AnalaR' 35% w/w
Urea	14,800	2,960	6,900	BDH 'AnalaR'
L-Histidine	1,210	560	320	Aldrich 98%
Hippuric acid	1,710	1,040	134	Aldrich 98%
Uric acid	490	180	160	Aldrich 99+ %
Citric acid	640	240	-	Fisher 'SLR'
Buffer	4,300	-	-	BDH 'AnalaR'
Creatinine ¹	1800	770	67	Aldrich 99%
TOTAL ²	4,980	4,980	7,890	-

¹Runs 6 - 9 only, ² not including creatinine, ³ 96-98% organic

5.3.6 Chemical dosing

Chlorine was dosed into the pool as sodium hypochlorite diluted to 24g/l as Cl_2 . pH was regulated using 35% w/w hydrochloric acid (Table 5.6). The dosing of both the

hypochlorite and hydrochloric acid were controlled using the *Dulcomarin* chemical dosing/regulating control panel and pumped on a demand-only basis. ProMinent Fluid Controls also supplied the four Gamma G4 self-metering chemical dosing pumps used for hypochlorite, acid, BFA and humic dosing. The humic acid (HA) was diluted to 0.39g/l and centrifuged at 7500 rpm for 5 minutes before being filtered using *Schleicher & Schuell* Grade 52 filter paper to remove suspended solids before dosing. All water used in dilutions and to fill the pool was provided by a standard twin bed deionisation plant.

Table 5.6 Reagents used

Chemical	Grade	Concentration	Supplier
Sodium hypochlorite	GPR grade	12% w/v as Cl ₂	Merck Ltd. (Lutterworth, Leics.).
Hydrochloric acid	GPR Rectapur™	35%v/v	Merck Ltd.
Humic acid (HA), disodium salt	99+%	around 39% C ¹	Sigma Aldrich Ltd (Poole, Dorset)
Methanol	AnalaR grade	99.8+% v/v	Merck Ltd.
Sodium thiosulphate, anhydrous	GPR	97% w/w	Merck Ltd.
Deionised water	Chiltern 'Hydrofine 200',		USF, Derbyshire

¹approximately 96-98 % organic carbon

5.3.7 Laboratory based experiments

In these experiments, humic acid and BFA constituents were chlorinated and then sampled over time. Samples were diluted to 1 litre with DI water before being chlorinated. Samples were stored in 250 ml amber glass vials with PTFE lined tops.

5.4 Methods

5.4.1 Air sampling

Estimates of THM and chloramines levels in the pool atmosphere were obtained by sampling of the pool air from the exit vent of the pool ventilation system at a rate of 1.4 l/min. This air was drawn through a collection water using a sintered Deschel Bottle.

The sampling efficiency of the absorption system used was assessed in a control environment whereby a water sample containing a known quantity of THMs was sparged and the gas was passed through two sequential Dreschel Bottles filled with water or 50% methanol in water, at ambient temperatures or at 5°C (Figure 5.6). The pool atmosphere was sampled at the same air flow rate as the control experiment. The absorbent was then assayed for THMs and/or chloramines.

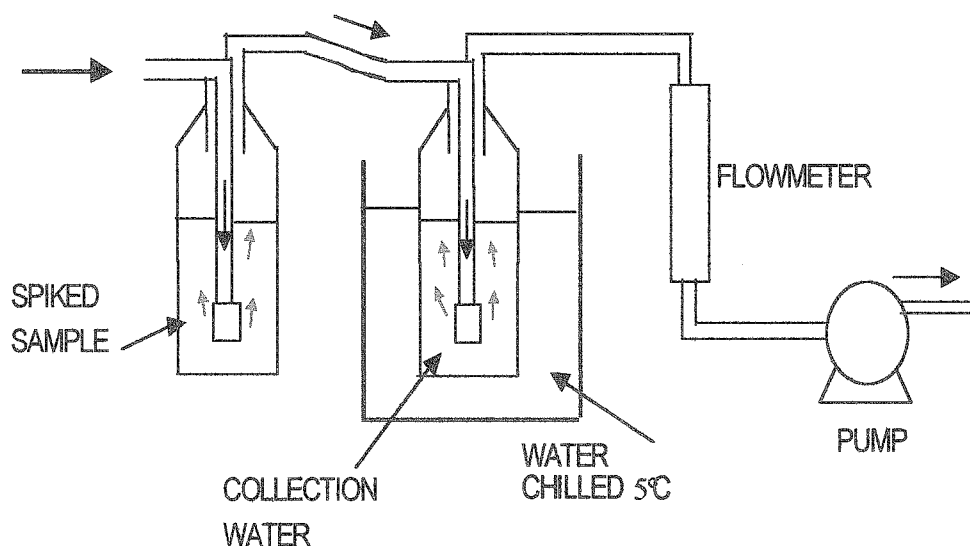


Figure 5.6 Experiment to test efficiency of Dreschel bottles for gas washing

A further Dreschel Bottle was subsequently placed after the first absorption bottle, to assess whether any chloramines/THMs were either not adsorbed by the first bottle, or else desorbed from it by the high air flow. The collection water was assayed for THM content by GC and titrimetrically for free and combined chlorine using the standard DPD method.

Table 5.7 Experimental parameters for air sampling

Experimental parameter	Rate
Air Sampling rate, l/min.	1.3-2
Air sampling time, mins.	30-105
Validation experiment flow rate, l/min	0.13
Validation experiment time, mins.	3-45

5.4.1.1 Zero ventilation run

All air sampling experiments were carried out on the pool during a controlled experiment (as in Table 5.1.3, Runs 1-10) In these cases, the pool air flow was controlled at 75 m³/hr. As scoping experiments under these conditions resulted in low concentrations being measured from the pool air, a further validation experiment was carried out to evaluate the effect of the air flow. It was postulated that as the air flow system on the pool employed fresh air only, (with no recycled air as in a normal municipal pool), then the concentrations of pollutants actually occurring in the pool air were not at all representative of those actually being produced. This validation experiment therefore involved a 'zero ventilation' experiment where the air flow was reduced to zero.

5.4.1.2 Water sampling

Original scoping experiments involved the collection of one sample from a set sample tap at the front of the pool. Analysis of these samples showed huge variation in THM levels which were not consistent with the dosing regime. Various experiments were thus carried to out to establish the most accurate way of sampling the pool water for THMs. These involved investigating the effect of sampling/sample storage techniques, the effect of temporal variation and to see whether there was any spatial variation within the pool.

5.4.1.3 Multiple sampling using pipette

It was postulated that the pouring of water from the sample tap into a container for storage or analysis caused agitation of the water and lead to the loss of THMs. In this experiment a sample was taken directly from the pool surface using a pipette, and analysed immediately after being quenched. This method should minimise agitation of the sample and thus eliminate the potential loss/decay of THMs that may have occurred during storage.

5.4.1.4 Temporal variation

To assess temporal variation, which was possibly due to intermittent dosing of hypochlorite, multiple samples were taken from one point in the pool over a period of 6 hours using the above method.

5.4.1.5 Spatial variation

Multiple samples were taken from the shallow end, the middle and the deep end of the pool at the same time. Samples were taken at varying depths also: at the bottom, in the middle and 1cm below the surface to assess THM variations in depth.

5.4.1.6 Composite sample analysis

Two experiments were conducted using a composite sample, the second of which also employed the use of a stirrer to mix the sample.

- 1) Using a wide necked 1 litre container, and with as minimal agitation as possible, a sample was taken directly from the pool at the shallow end before being apportioned into vials and stored until analysis.
- 2) After the sample had been taken, the water was then homogenised by stirring with a magnetic flea before being apportioned into vials and stored until analysis.

All samples were quenched using sodium sulphite and stored in airtight vials. Chlorine residual measurements showed there to be no residual chlorine following the quenching.

For full details of sampling methodology and results of various methods see Annex B.

5.4.1.7 Sampling methods used during experimentation

Samples of water were extracted 1cm below the pool surface for chloramine, nitrate, total nitrogen and TOC analysis. All were stored at 5°C for no more than 3 hours prior to analysis. Samples for THM analysis were obtained using a method adapted from that specified in standard methods 1060B(b) (APHA, 1998) for composite sampling (also described in detail Section 5.1.4.6). A 1l sample was taken directly from the pool, quenched with sodium thiosulphate, and then stirred for 5 minutes in a sealed container before being apportioned into 3x15ml amber glass vials with PTFE-lined stoppers for storage.

5.4.2 Analyses

Free and combined chlorine levels were assayed using the conventional DPD ferrous titrimetric method 4500-Cl F (APHA *et al* 1998). THM concentration was measured using a purge-and-trap gas chromatograph fitted with a 0.53 mm diameter, 15m long column, and an electron capture detector (Table 5.8). The method use was a variation of the 'purge and trap chromatographic method' 6232D (APHA *et al*, 1998). All samples were quenched before analysis using sodium thiosulphate, and stored in a refrigerator. GC calibration was achieved by using a '5 THM' mix solution from Thames Chromatography. Alkalinity was measured using method 2320B (titration method) (APHA *et al* 1998) regulation of the pH at the start of each run was achieved by adding measured amounts of Na₂HPO₄ to the pool water.

Nitrate and Total Nitrogen and chloride were all measured using test kits obtained from Camlab (Cambs) (Table 5.8).

The GC Method and sampling methods associated with the GC analysis were subject to scrutiny due to large initial variations in results. The standard deviation of both the GC and the sampling/calibration methods were calculated. Results from 4 experiments gave a percentage standard deviation ranging between 6 and 20% (Annex A).

Table 5.8 Water quality determinant measurement: instrumentation

Determinant	Instrument	Range/LoD	Supplier
Nitrate	Nitrate Chromotropic Acid test kit	0-30 mg/l	<i>Camlab, Over, Cambs.</i>
Total Nitrogen	TNT test kit	0-150 mg/l	<i>Camlab, Over, Cambs.</i>
Chloride	Mercuric chloride test kit	0-20 mg/l	<i>Camlab, Over, Cambs.</i>
(reading of above tests)	Hach 2010 portable datalogging spectrophotometer	-	<i>Camlab, Over, Cambs.</i>
THMs	purge-and-trap GC	0.5-100µg/l	<i>Interscience, Dublin</i>
TOC & TIC	TOC 5000A Shimadzu	0-500mg/l	<i>Shimadzu, Milton Keynes</i>

5.4.3 Chemical dosing

Scoping experiments based on those of Black (1997) repeated the dosing techniques being employed for hypochlorite and BFA/Humic acid to result in a dosing regime that was both inaccurate and inconsistent. The original BFA dosing technique resulted in the settling of flocs/ crystals from the BFA in both the dosing container and the pipe work leading to the pool, yielding inconsistent dosing of C and N. This problem was remedied in a number of ways:

- installation of a new, larger dosing pump and container,
- dilution of BFA by a factor of eight and increasing of the dose rate to reduce the residence time of in the pipe work.
- stirring of BFA stock solution using a magnetic stirrer.
- the humic acid, originally a component of the BFA formulation was dosed from a separate solution allowing its dose to be controlled independently of that of the BFA.

These improvements resulted in negligible settling of BFA materials and humic acid in either the dosing containers or pipe work.

Dosing of hypochlorite was also modified by decreasing the concentration of stock hypochlorite in the dosing container, with a subsequent increase in the dose rate, to reduce gross fluctuations in the chlorine concentration in the pool. These fluctuations arose due to the limitations of the control instrumentation based on an oxidation-reduction potential measured at the pool outlet. This meant that large amounts of hypochlorite solution could be dosed into the pool during dosing periods, yielding significant temporal variations in DBP levels and chloramines in particular. The increased dilution of hypochlorite resulted in much reduced fluctuations in chlorine levels.

5.4.4 Test pool operation

Three stages of experiments were carried out, the first of which employed chlorine alone. This first stage was designed to establish the effect of variation of pH and chlorine concentration on DBP formation and also to establish a 'baseline' with which to compare the effects of alternative technology. Stages two and three respectively concerned the use of a combination of ozone (and GAC) with chlorine and UV with chlorine. All experiments were duplicated at two set pH and free chlorine values.

Table 5.9 pH and chlorine parameters for all experiments

Parameter	Set level
pH	a) 7.8 (limits of 7.7-7.9)
	b) 7.2 (limits of 7.1-7.3)
Free chlorine, mg/l	a) 1.8 (limits of 1.7-1.9)
	b) 0.5 (limits 0.45-0.55)

5.4.4.1 Stage one: BFA variation and chlorine disinfection

This first part of this stage was carried out using chlorine with varying BFA formulation to attempt to identify the formulation producing DBPs most representative of those found in real pools.

Operating parameter values for the test pool are summarised in Table 5.9 and specific conditions appropriate to each run stipulated in Table 5.10. Carbon and nitrogen dose

rates calculated from the analogue composition were compared with those from TOC and total N measurements of both the BFA and the HA solutions. The contribution to the N balance from the humic acid was assumed to be insignificant at the doses applied.

Table 5.10 Test pool operating conditions with chlorine.

Run no.	pH	Free Cl ₂ level mg/l	Bather dose (bathers/m ³ /hr)	Carbon dose, g/hr C (from BFA)	Nitrogen dose, g/hr N (from BFA)	Carbon dose, from humic acid, g/hr C
1	7.8	1.8	0.06	0.082	0.1305	-
2	7.8	1.8	0.12	0.164	0.261	-
3	7.8	1.8	0.12	0.164	0.261	0.009
4	7.8	1.8	0.12	0.164	0.261	0.019
5	7.8	1.8	0.15	0.210	0.333	-
6 ¹	7.8	1.8	0.1	0.137	0.217	-
7 ¹	7.8	1.8	0.3	0.411	0.651	-
8 ¹	7.8	1.8	0.1	0.137	0.217	-
9 ¹	7.8	1.8	0.1	0.137	0.217	-
10	7.2	0.5	0.12	0.164	0.261	0.019

¹with creatinine,

On completing initial scoping experiments, the most representative dosing conditions were identified. Conditions employed for these runs were used in the Stage two and stage three experiments.

5.4.4.2 Stage Two: Ozone trial

Both experiments were conducted using the same BFA and humic acid doses as those used in Runs 4 and 10 (Table 5.10)

The pool system was allowed to equilibrate prior to ozonation; the TOC level was allowed to reach a stable concentration. The water was then circulated through the sand filter, as in all other experiments, and then directed through the ozone mixing chamber followed by the GAC filter which removed any unreacted/free ozone. The

water was then dosed with chlorine and acid and re-circulated back to the pool. Dosing and pH conditions are given in Table 5.11

Table 5.11 Details of ozone experiments

Run No.	pH	Free chlorine residual, mg/l as Cl ₂	Ozone dose, g/hr
11	7.8	1.8	1
12	7.2	0.5	1

5.4.4.3 Stage Three: UV trial

One extended experiment was conducted, incorporating a step change in pH and free chlorine level (following equilibrium) using the BFA and humic acid dose as outlined in Runs 4 and 10. The UV lamp was operated at the same power in both experiments, although fouling of the lamp/mixing chamber after run 13 resulted in a decreased UV dose for run 14, as detailed in Table 5.12. For these experiments, 35 % of the flow through the treatment system (300 l/hr) was directed through the UV mixing chamber, representing the maximum flow capacity of the UV mixing chamber and equating to a pool turnover of around 7 hours. UV treatment followed both sand filtration and chlorine/acid addition. Chlorination would normally precede UV irradiation, but this was not possible due to constraints on space within the pipework of the rest of the treatment system.

Table 5.12 Details of UV experiments

Run no	pH	free chlorine residual, mg/l as Cl ₂	UV dose, Wm ³
13	7.2	0.5	5.3
14	7.8	1.8	3

5.4.5 Bench Scale Chlorination

The stock sodium hypochlorite solution (see Table 5.6) was diluted to between 1.25 and 67 mg/l as Cl₂ in a 1 litre sample, before being mixed with a 1 litre solution of either BFA or HA. Table 5.13 details all experiments conducted with different pollutants and varying concentrations. After mixing, the chlorinated solution was

immediately sampled and was then delivered into 250 ml amber glass vials, and sealed. All samples were stored in the dark in at 20°C (in an incubator) until analysis.

Table 5.13 Lab based BFA experiments

Exp. no.	Pollutant	Conc mg/l	Conc N mg/l	Conc. of N (mM)	Conc of Cl ₂ mg/l	Conc Cl ₂ (mM)	Molar ratio of Cl ₂ / N
1	NH ₄ Cl	19.4	5	0.36	9.9	0.13	0.38
2	NH ₄ Cl	16.4	4.2	0.3	67	0.81	2.66
3	Urea	205	9.6	6.85	9	0.13	0.01
4	Uric acid	10	3.3	0.23	9	0.021	0.09
5	Uric acid	10	3.3	0.23	18	0.101	0.43
6	Hippuric acid	3034	243	16.9	67	0.9	0.053
7	Histidine	73	19.7	1.4	67	0.408	0.289
8	BFA (a)	-	0.79	0.06	2	0.017	2286
9	BFA (b)	-	18.9	1.35	1.25	0.017	95
10	BFA & humic acid ¹	-	18.9	1.35	1.25	0.017	95

¹= 0.15 mg/l carbon from HA

(a) = 0.1 ml BFA and (b)= 2.4 ml BFA, where BFA is 7.9 g/l as N

In the case of experiments employing humic acid and citric acid, trihalomethane formation potential (THMFP) alone was determined (Table 5.14). A centrifuged and filtered humic acid sample was diluted and then chlorinated using the same method as that used for the BFA experiments. The samples were then assayed at regular intervals for both THM and free chlorine concentration.

Table 5.14 Humic acid and citric acid THMFP tests

Experiment no.	Conc, mg/l	Carbon mg/l	Conc. of HOCl, mg/l as Cl ₂	ratio of Cl ₂ to C
H1	0.5	0.195	1.25	6.4:1
H2	0.5	0.195	50	256:1
H3	5	1.95	5	2.5:1
H4 Citric Acid	170	63	5	0.08:1