Chapter 4

BIOFOULING CONTROL BY BIOCIDE AND BIODISPERSANT TREATMENT IN POWER STATION OPEN RECIRCULATING COOLING WATER SYSTEMS

ABSTRACT

Cooling water treatment programmes were monitored in the open recirculating cooling water systems at four fossil fired power stations. Combinations of three biodispersants and four biocides were evaluated. The bulk water and a Robbins Device biofouling monitor were analysed microbiologically for total aerobic and anaerobic bacteria as well as sulphate reducing bacteria. Visual system inspections were carried out where possible. All of the biodispersants resulted in increases in the numbers of planktonic bacteria, ranging from 22592% to 654%. Biocides resulted in percentage kills of planktonic bacteria of between 83.2% and 100%, with only one exception, where no change in the numbers of anaerobic bacteria occurred. The biodispersants resulted in decreases in sessile aerobic bacteria numbers in 80% of the cases and the biocides resulted in decreases in all of the systems evaluated. Inspections at Grootvlei Power Station revealed that the biodispersant/biocide combination removed sessile microbiological deposits and aided in the penetration of the biocides into inorganic deposits by softening the overlying nodules. The use of combinations of biodispersants and biocides effectively controlled microbiological growth in all the cooling water systems. However, the treatment products did not produce the same effects in different systems. Thus, biodispersants and biocides have varied effects and treatment products have to therefore be evaluated for each individual system.

INTRODUCTION

To conserve water, modern power stations are operated on the policy of zero liquid discharge. This policy ensures that no water is discharged back into public water sources, but is treated and reutilised in the power station (Nell and Aspden, 1990). In an attempt to further conserve water, open recirculating cooling water systems are operated at increased cycles of concentration (8 - 20 cycles). Due to this cycling of water, nutrients and microorganisms are concentrated in the water and consequently, problems associated with unchecked microbiological growth occur (McCoy, 1980). These problems include biofouling and microbiologically influenced corrosion (MIC), particularly that caused by the influence of the sulphate reducing bacteria (SRB) (Pope, 1987). These types of problems are commonly experienced in power utility cooling water systems (Fellers, 1990; Puckorius, 1991).

One of the methods of controlling microbiological growth is the use of biocides (Matson and Characklis, 1982). Oxidising and non-oxidising biocides have been tested in cooling water systems and it has been found that planktonic microbiological populations quickly recover from the effect of these biocides (Cloete *et al.*, 1989). In addition, it has been widely reported that planktonic bacteria are more susceptible to the action of biocides than are their sessile counterparts (Le Chevallier *et al.*, 1988; Blenkinsopp and Costerton, 1991). It is, however, still common practice to add biocides to cooling water systems to control sessile bacteria and thus alternative treatments need to be evaluated.

One of the alternate treatments for the control of microbiological growth in open recirculating cooling water systems, is the use of biodispersants (Poulton and Nixon, 1990). An effective biodispersant should disperse sessile microbial populations into the bulk water, rendering them more susceptible to the action of biocides (Strauss and Puckorius, 1984). Furthermore, biodispersants should aid in the penetration of biocides into inorganic deposits, thus assisting in the destruction of SRB growing in anaerobic areas. These deposits are at the same time softened, allowing their removal by the turbulence of the circulating water (Hart *et al.*, 1990; Lutey and Allison, 1991). Laboratory and field studies carried out by Lutey *et al.* (1989), showed that a biodispersant was effective in removing established biofilms and resulted in an increase in the number of planktonic bacteria. In addition, the biodispersant was shown to restrict the formation of biofilms on clean surfaces, was able to mitigate MIC and had no effect on biocide efficacy.

Thus, if bacteria could be dispersed into the bulk water prior to the addition of a biocide, the biocide would be used more cost effectively. Biodispersants are generally less costly than biocides and can be used at lower concentrations. It is unlikely that biodispersants will have any mutagenic effects on bacteria, or that microorganisms would be able to become resistant to the action of biodispersants, as can be the case with biocides (Russell, 1990; Brözel and Cloete, 1991).

No correlation has been established between the numbers of sessile and planktonic bacteria in cooling water systems (Cloete *et al.*, 1989). It is therefore essential, to monitor both the planktonic and sessile microbiological phases, in order to establish the efficacy of a microbiological treatment programme (Wolfaardt *et al.*, 1991). One of the techniques commonly used to monitor sessile bacteria is the Robbins Device biofouling monitor (Blenkinsopp and Costerton, 1991). This device has been in use in South Africa for a number of years and is reported to be an effective method of monitoring sessile bacteria (Costerton *et al.*, 1986).

The objectives of this study were to evaluate the effect of combinations of biocides and biodispersants on both planktonic and sessile microorganisms, in the open recirculating cooling water systems at four fossil fired power stations.

MATERIALS AND METHODS

Biocide and biodispersant treatment programmes were monitored in the open recirculating cooling water systems at four different fossil fired power stations.

System parameters

The system parameters of the four power stations where treatment programmes were monitored are detailed in Table 4.1. As Tutuka Power Station has two separate cooling water systems, two different biodispersant/biocide treatment programmes were monitored simultaneously.

Table 4.1 : System parameters of four open recirculating cooling water systems where treatment programmes were monitored to determine their efficacy in controlling microbiological growth.

POWER STATION	SYSTEM VOLUME (MEGALITRES)	CYCLES OF CONCENTRATION
1. Grootvlei	36	10
2. Lethabo (west)	64	15
3. Matimba	0.7	5
4. Tutuka (west)	64	20
5. Tutuka (east)	64	20

Treatment chemicals

Three biodispersants and four biocides were tested at concentrations recommended by the suppliers (Table 4.2).

Table 4.2 : Biodispersants and biocides utilised for the treatment of the open recirculating cooling water systems at four power stations.

PRODUCT	DESCRIPTION
BIODISPERSANT	
A	Liquid non-ionic penetrant/surfactant
B	Liquid non-ionic biodispersant
C	Liquid anionic biodispersant
BIOCIDE	
A	Dithiocarbamate
B	Organosulphur
C	Bromine containing oxidising biocide
D	Isothiazolin

The biodispersant/biocide combinations used at the various power stations, the dosing method, time of addition and concentrations used are detailed in Table 4.3.

Table 4.3 : Biodispersants and biocides programmes used to treat the open recirculating cooling water systems at four power stations.

POWER STATION	BIODISPERSANT				BIOCIDE			
	PRODUCT	DOSING METHOD	TIME[a] (h)	CONC (ppm)	PRODUCT	DOSING METHOD	TIME[a] (h)	CONC (ppm)
1.[b]	A[c]	continuous	2.0	12.0	A[c]	slug	46.5	12.0
					B	slug	46.5	12.0
2.	A	continuous	2.0	7.0	C	slug	95.0	8.0
3.	A	slug	2.0	21.0	A	slug	42.0	49.0
		slug	5.0	14.0	B	slug	42.0	84.0
		slug	17.0	14.0				
		slug	53.5	14.0				
4.	B	slug	2.0	9.0	D	slug	24.0	21.0
5.	A	continuous	2.0	8.0	A	slug	68.0	11.0

[a] time in hours after the start of each evaluation
[b] For key to figures see Table 4.1
[c] For key to letters see Table 4.2

Robbins Device biofouling monitors

Robbins Device biofouling monitors were installed on by-pass lines, on the "hot" side of the cooling water systems where the temperature (37°C), was considered to be favorable for microbial growth. Robbins Devices were installed two to four weeks before the start of the evaluation, to allow a biofilm to develop on the sample stud surfaces. Robbins Devices were constructed of mild steel, with nylon studs in brass holders. A water velocity of between 1 and 1.2 $m.s^{-1}$ was maintained through the devices.

Sampling times for microbiological analysis

The sampling times varied for each evaluation, depending on the individual system parameters and conditions. The sampling times, in hours after the start of each evaluation, are detailed in Table 4.4.

Table 4.4 : Sampling times for microbiological analysis at four power stations where *biodispersant/biocide* treatment programmes were monitored.

	POWER STATION									
	1[a]		2		3		4		5	
	BW[b]	RD[c]	BW	RD	BW	RD	BW	RD	BW	RD
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2.5	23.0	2.0	30.0	5.0	3.0	3.0	21.0	3.0	21.0
	4.5	53.0	5.0	50.0	17.0	41.0	9.0	45.0	21.0	31.5
S	7.0	72.0	7.0	122.0	21.0	49.0	21.0	67.5	25.5	45.0
A	11.0		10.0	223.0	25.0	65.5	27.5	76.0	29.5	67.5
M	15.0		13.0		41.0	113.0	31.5	92.0	31.5	92.0
P	19.0		16.0		45.0		39.0		39.0	
L	23.0		19.0		49.0		45.0		45.0	
I	26.5		23.0		59.0		57.0		67.5	
N	32.0		27.0		65.5		53.0		92.0	
G	36.0		31.0		89.5		67.5		116.0	
	45.0		35.0		113.5		69.0		140.0	
T	46.5		40.0				70.0		164.0	
I	47.5		45.0				72.0			
M	49.5		50.0				74.0			
E	53.0		59.0				75.0			
S	58.0		69.0				76.0			
	63.0		75.0				80.0			
	68.0		98.0				84.0			
(h)	72.0		117.0				88.0			
			122.0				92.0			
			146.0				116.0			
			223.0				140.0			
							164.0			

[a] For key to numbers see Table 4.1
[b] BW = bulk water
[c] RD = Robbins Device

Sampling procedure

One 500 ml sample was taken from the recirculating cooling water of all systems for each analysis, in a sterile Whirl Pak bag (Nasco, USA). Recirculating cooling water samples were taken from sample points on the "hot" side of the system.

Two studs were removed from the Robbins Device, for each sampling time using sterile forceps. Studs were placed into 10ml sterile, quarter strength Ringer's solution, immediately after removal from the Robbins Device. Prior to analysis, the studs were agitated on a vortex mixer for 2 min, to disperse the sessile bacteria on the stud surfaces. The resultant suspension was then analysed as described in Table 4.5. All samples were analysed within 12 h of sampling and retained at 4°C until they were analysed.

Microbiological analysis

Samples were diluted in sterile, quarter strength Ringer's solution and subjected to duplicate plate counts. All incubation approximated the temperature of the systems from which the samples were taken, i.e. 37°C. Anaerobic incubation was carried out in an anaerobic jar, filled with nitrogen. The techniques used for microbiological analyses are detailed in Table 4.5. Plates containing between 30 and 300 colonies were counted.

Table 4.5 : *Techniques used to quantify planktonic and sessile bacteria in four open recirculating cooling water systems where biodispersant/biocide treatment programmes were monitored.*

MICROBIAL TYPE	TECHNIQUE	INCUBATION TIME (d)	ATMOSPHERE	GROWTH MEDIUM
Total aerobic bacteria	Pour plate	2	aerobic	Nutrient Agar (Biolab)
Total anaerobic bacteria	Pour plate	3	anaerobic	Nutrient Agar (Biolab)
SRB	Agar tubes	14	anaerobic	SABS method 1497-1989

Calculations to determine changes in numbers of planktonic and sessile bacteria

Percentage increases in planktonic bacteria were calculated as follows :

$$\% \text{ increase} = \frac{\text{Increase in number of bacteria after treatment}}{\text{original number before treatment}} \times 100$$

Percentage kills or decreases in planktonic and sessile bacteria were calculated as follows :

$$\% \text{ kill or decrease} = 100 - \left(\frac{\text{Number of survivors}}{\text{original number}} \times 100 \right)$$

Visual inspections

Visual inspections were carried out at Grootvlei Power Station before the initiation of treatment, and then after three weeks and after nine months of treatment. It was possible to inspect this system as the cooling water strainer boxes, located at the condenser inlets, could be isolated and inspected while the system was in operation. Deposits observed in the strainer boxes were removed using sterile forceps and tested for the presence of SRB (Table 4.5). The cooling towers were also visually inspected for signs of algal growth.

RESULTS AND DISCUSSION

Microbiological analyses

For practical reasons, at some of the power stations, it was not possible to analyse the anaerobic bacteria for the duration of the evaluation. In addition, all the systems could not be monitored for the same length of time.

Numbers of both planktonic and sessile bacteria quantified in the bulk water and by means of the Robbins Device, are shown in Figures 4.1 - 4.5.

Changes in the numbers of planktonic and sessile bacteria, after biodispersant and biocide treatment, are detailed in Table 4.6.

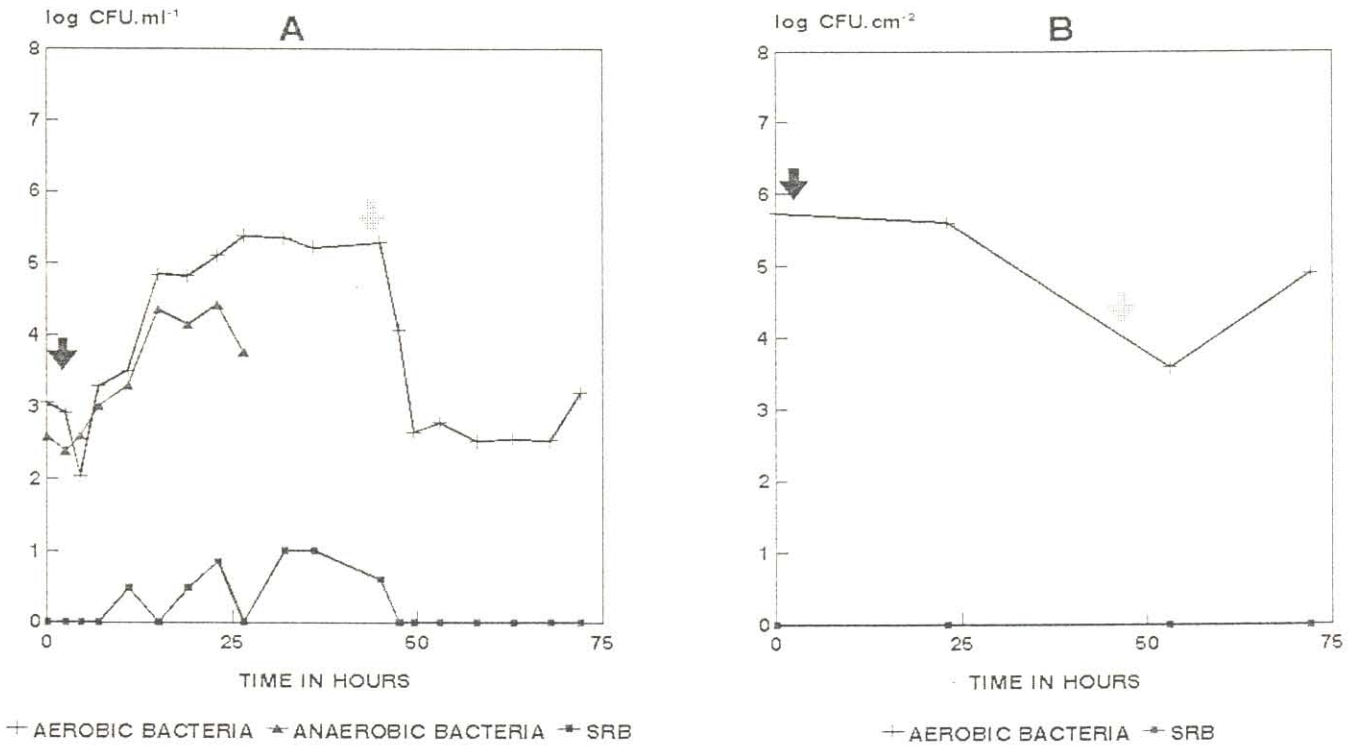


Figure 4.1 : Microbiological analysis of bulk water (A) and Robbins Device studs (B) at Grootvlei Power Station. ↓ indicates biodispersant addition and ✛ biocide addition.

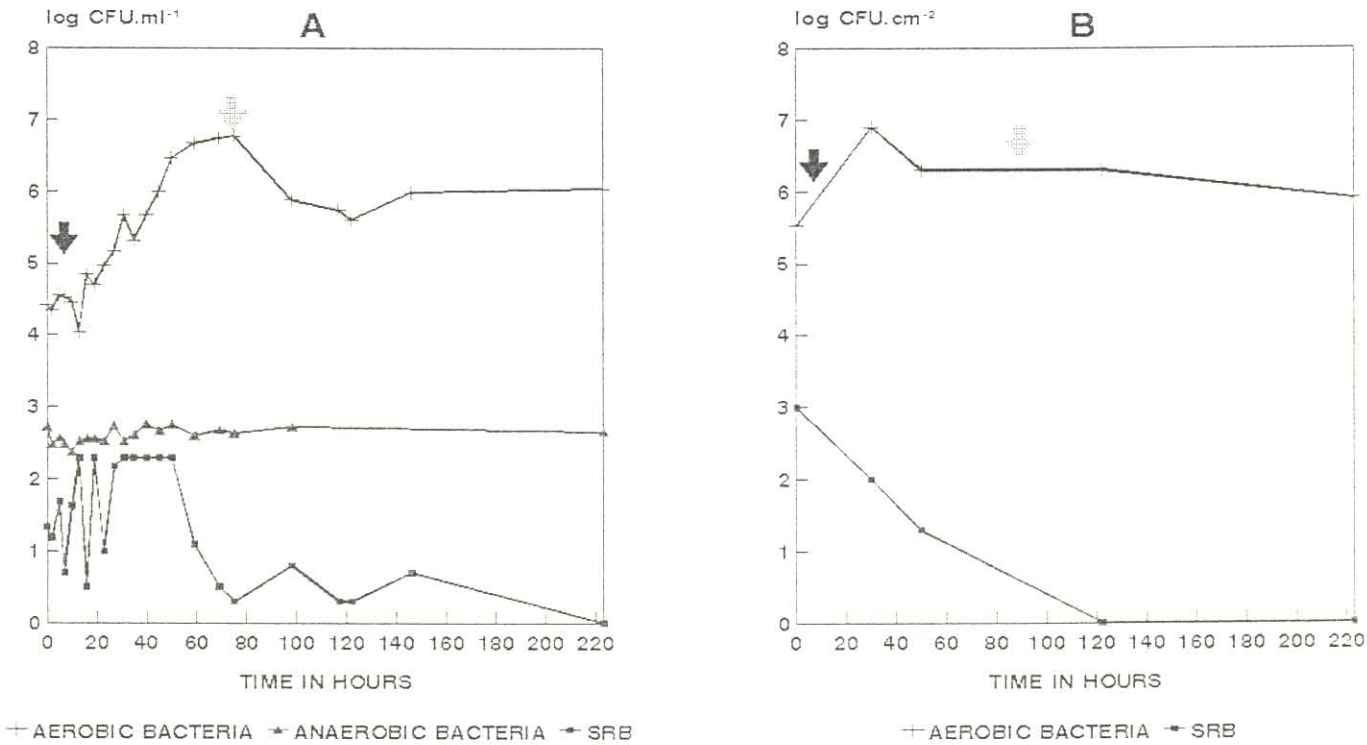


Figure 4.2 : Microbiological analysis of bulk water (A) and Robbins Device studs (B) at Lethabo Power Station. ↓ indicates biodispersant addition and ✛ biocide addition.

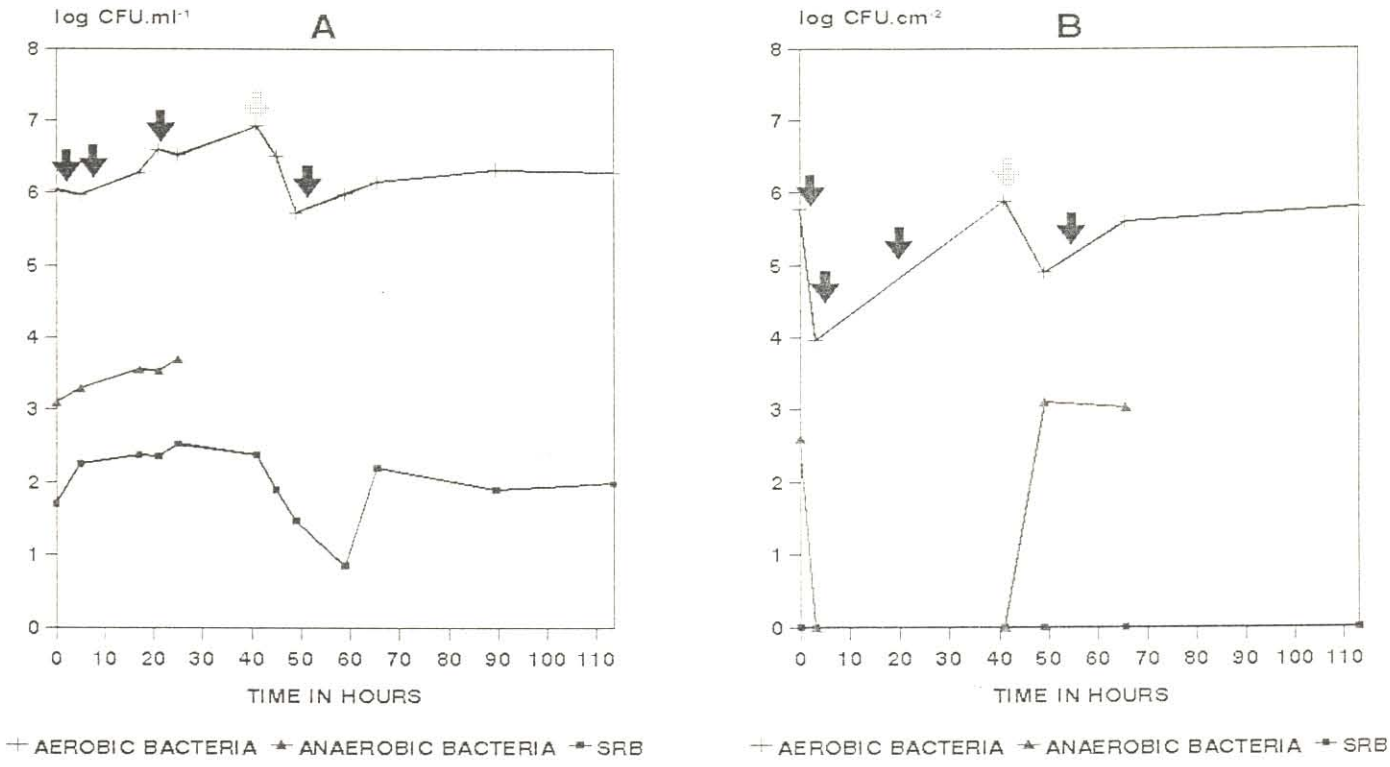


Figure 4.3 : Microbiological analysis of bulk water (A) and Robbins Device studs (B) at Matimba Power Station. ↓ indicates biodispersant addition and + biocide addition.

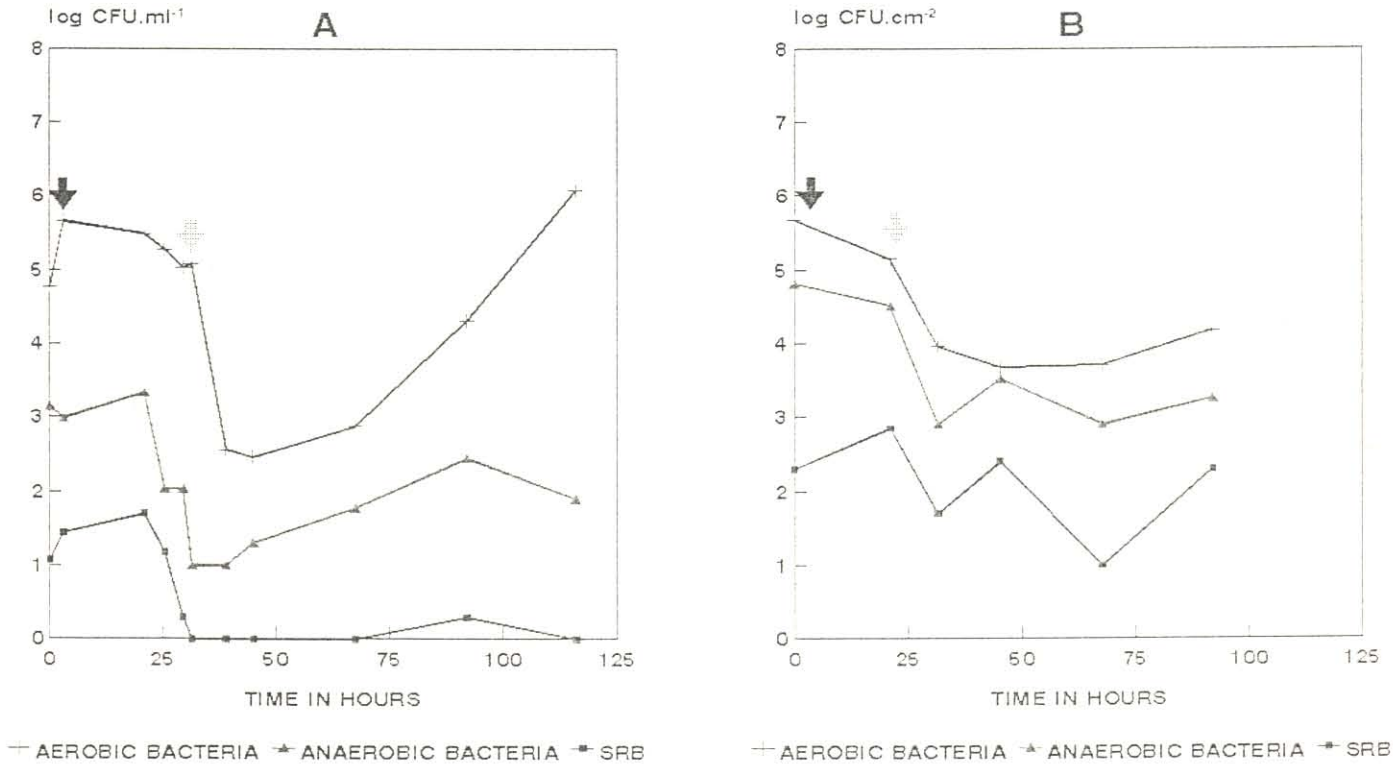


Figure 4.4 : Microbiological analysis of bulk water (A) and Robbins Device studs (B) at Tutuka (W) Power Station. ↓ indicates biodispersant addition and + biocide addition.

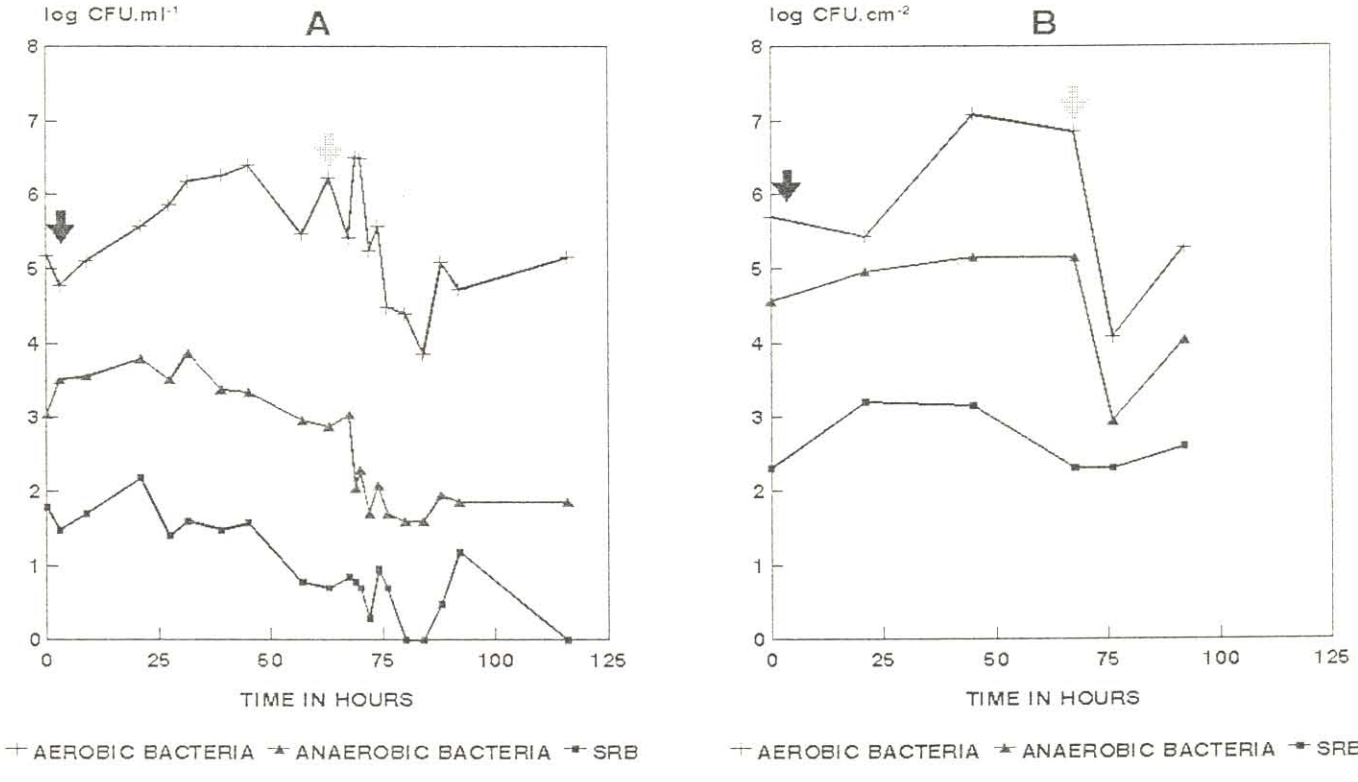


Figure 4.5 : Microbiological analysis of bulk water (A) and Robbins Device studs (B) at Tutuka (E
Power Station. ↓ indicates biodispersant addition and ✛ biocide addition.

Table 4.6 : Planktonic and sessile bacteria numbers in the four open recirculating cooling water systems treated with biodispersant/biocide combinations.

		BIODISPERSANT (% increase, planktonic) (% decrease, sessile)			BIOCIDE (% kill)		
	POWER STATION	Aerobic Bacteria	Anaerobic Bacteria	SRB	Aerobic Bacteria	Anaerobic Bacteria	SRB
PLANKTONIC	1[a]	21718.0	1000.0	7005.0	99.8	NM[b]	100.0
	2	22592.0	650.0	90.0	92.0	NC[c]	100.0
	3	654.0	287.0	576.0	83.2	NM	91.0
	4	667.0	57.0	316.0	97.2	99.5	100.0
	5	1033.0	573.0	2400.0	99.9	96.4	100.0
SESSILE	1	26.0	NM	ND[d]	98.0	NM	ND
	2	NC	NM	98.0	60.0	NM	100.0
	3	98.3	100.0	ND	89.9	0.0	ND
	4	70.2	49.0	NC	96.6	97.6	92.9
	5	46.0	NC	NC	99.8	99.4	NC

[a] For key to figures see Table 4.1
NM[b] = not monitored
NC[c] = no change or increase
ND[d] = not detected

Changes in planktonic bacteria numbers with the addition of a biodispersant to the bulk water

Little published information is available on the effects of biodispersants on sessile microorganisms in cooling water systems. However, in all the systems monitored, the addition of a biodispersant when slug or continuously dosed, resulted in appreciable increases in the numbers of planktonic microorganisms. These increases varied from 22592% for total aerobic bacterial counts at Lethabo Power Station, to 654% at Matimba Power Station (Table 4.6). The lowest percentage increase in total aerobic bacterial counts (654%), occurred at Matimba Power Station, over a 42 h period (Table 4.6). The dominant bacterial genus in South African cooling water systems is reported to be *Pseudomonas* (Cloete *et al.*, 1989). The minimum recorded generation time for *P. putida*, under ideal conditions, is 45 minutes (Stanier *et al.*, 1986). As a cooling water system is a low nutrient environment, it is unlikely that bacterial growth would be occurring at the maximum division rate (McCoy, 1980). Thus, the increases in the numbers of planktonic bacteria in the bulk water may be attributed to the action of the biodispersant. This assumption is supported by the fact that increases in the numbers of planktonic, total anaerobic bacteria and SRB were also recorded. As it is unlikely that anaerobic bacteria would multiply in the aerobic bulk water, these bacteria must have been released from biofilms. This indicated that the biodispersants were able to penetrate not only the upper aerobic regions of a biofilm, but also the underlying anaerobic areas (Lutey and Allison, 1991).

Although increases in planktonic bacteria numbers were recorded each time a particular biodispersant was added to the bulk water, these increases were not comparable to each other. For example, the same biodispersant (A), was added continuously to the cooling water systems at Lethabo, Grootvlei and Tutuka (East) Power Stations at 7, 12 and 8ppm respectively and slug dosed at Matimba Power Station at 21ppm (Table 4.3). The corresponding increases in planktonic aerobic bacteria numbers observed at these power stations were 22592%, 21718%, 1033% and 654%, respectively (Table 4.6). However, parameters such as the chemical composition of the water, ambient conditions, extent of initial fouling and raw water source varied from one system to another. These differences in system conditions may account for the variations in the effects of a particular biodispersant.

Changes in the planktonic bacteria numbers with the addition of a biocide to the bulk water

Percentage kills of the planktonic bacteria of between 83 - 100% were achieved by all of the biocides evaluated (Table 4.6). As for the biodispersants, the same biocide did not always achieve the same effect in different systems. A combination of biocides A and B was added to the cooling water at Grootvlei Power Station at concentrations of 12ppm of each product and

at Matimba Power Station at concentrations of 49ppm of biocide A and 84ppm of biocide B (Table 4.3). However, a percentage kill of 99,8% of the planktonic, aerobic bacteria was recorded at Grootvlei Power Station and only 83,2% at Matimba Power Station (Table 4.6). At Tutuka Power Station (east) where only biocide A was added, a percentage kill of 99.9% of aerobic bacteria was achieved (Table 4.6). The variations in the numbers of planktonic microorganisms as a result of biocide addition, was again attributed not only to the different products and dosage regimes, but also to the extent of fouling already established in the systems. It was noted that after the initial decrease in planktonic bacterial numbers, following the addition of a biocide, a subsequent increase was recorded. This phenomenon has been reported by other researchers and may be due to the recovery of resistant bacteria, or a as a result of the low retention time of a slug dose of biocide in a cooling water system (Cloete *et al.*, 1989). In those systems where a biodispersant was continuously added, this increase may also have been due to the continuing action of the biodispersant.

Changes in the sessile bacteria numbers with the addition of biodispersants or biocides to the bulk water

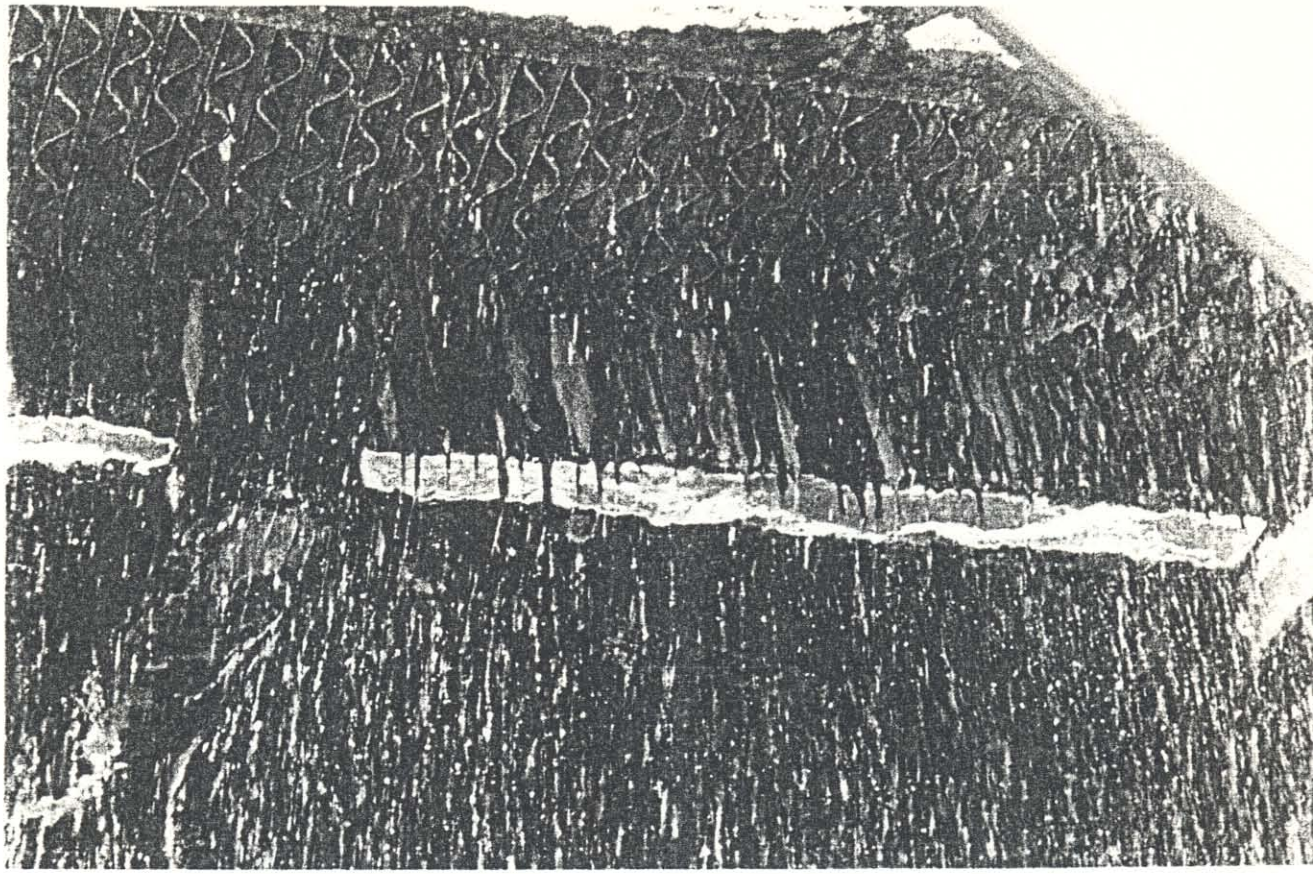
As with the planktonic bacteria, considerable variations in the effect of a particular biodispersant or biocide on sessile bacteria, were noted. Biodispersant A achieved a 26% decrease in attached bacterial numbers at Grootvlei (12ppm), a 98.3 % decrease at Matimba (21 and 14ppm) while an increase in sessile bacteria was recorded at Lethabo Power Station (7ppm) (Tables 4.3 and 4.6). The combination of biocides A and B achieved percentage kills of sessile aerobic bacteria of 98% at Grootvlei Power Station and 89.9% at Matimba Power Station (Table 4.6). Biocide A achieved a 99.8% kill of sessile aerobic bacteria at Tutuka Power Station (Table 4.6). These variations could be due to the differences in system conditions or to the inaccuracy of the monitoring device. For example, SRB were not detected on the studs removed from the Robbins Device at two of the power stations. This could be due to the fact that tearing of the biofilm may occur when studs are removed from the Robbins Device. Furthermore, it has been shown that biofilms may be unevenly distributed over metal surfaces in recirculating cooling water systems (Characklis *et al.*, 1990; Donlan *et al.*, 1990). This uneven distribution could affect the detection of not only SRB, but the total number of sessile bacteria detected by biofouling monitors with a small sample surface area, such as the Robbins Device. The accuracy of the Robbins Device will be addressed in a later chapter.

Visual Inspections

The results of the visual inspections are detailed in Table 4.7. and in Figures 4.6 - 4.10.

Table 4.7 : Visual inspections of the open recirculating cooling water system at Grootvlei Power Station before and during the implementation of a biodispersant/biocide treatment programme.

TIME OF INSPECTION	LOCATION	OBSERVATIONS
Before initiation of treatment	Cooling towers	Biofouling deposits consisting primarily of blue green algae attached to the support columns and hanging in strands from the packing (Figure 4.6).
After three weeks	"	Virtually all biofouling deposits removed or lost green colouration (Figure 4.6).
After nine months	"	Slight regrowth of algae in spray area. Packing and support columns free of algae (Figure 4.7).
Before initiation of treatment	Strainer boxes	Hard nodules on mild steel, covering shallow pits filled with a black liquid. All of the 10 nodules sampled contained SRB (Figure 4.8).
After three weeks	"	Nodules softened, could be brushed off the surface by hand. Many of the pits had lost the black colouration. Half of the 10 nodules sampled contained SRB (Figure 4.9).
After nine months	"	The majority of the nodules removed from metal surface. Only nodules in low flow areas contained SRB (Figure 4.10).



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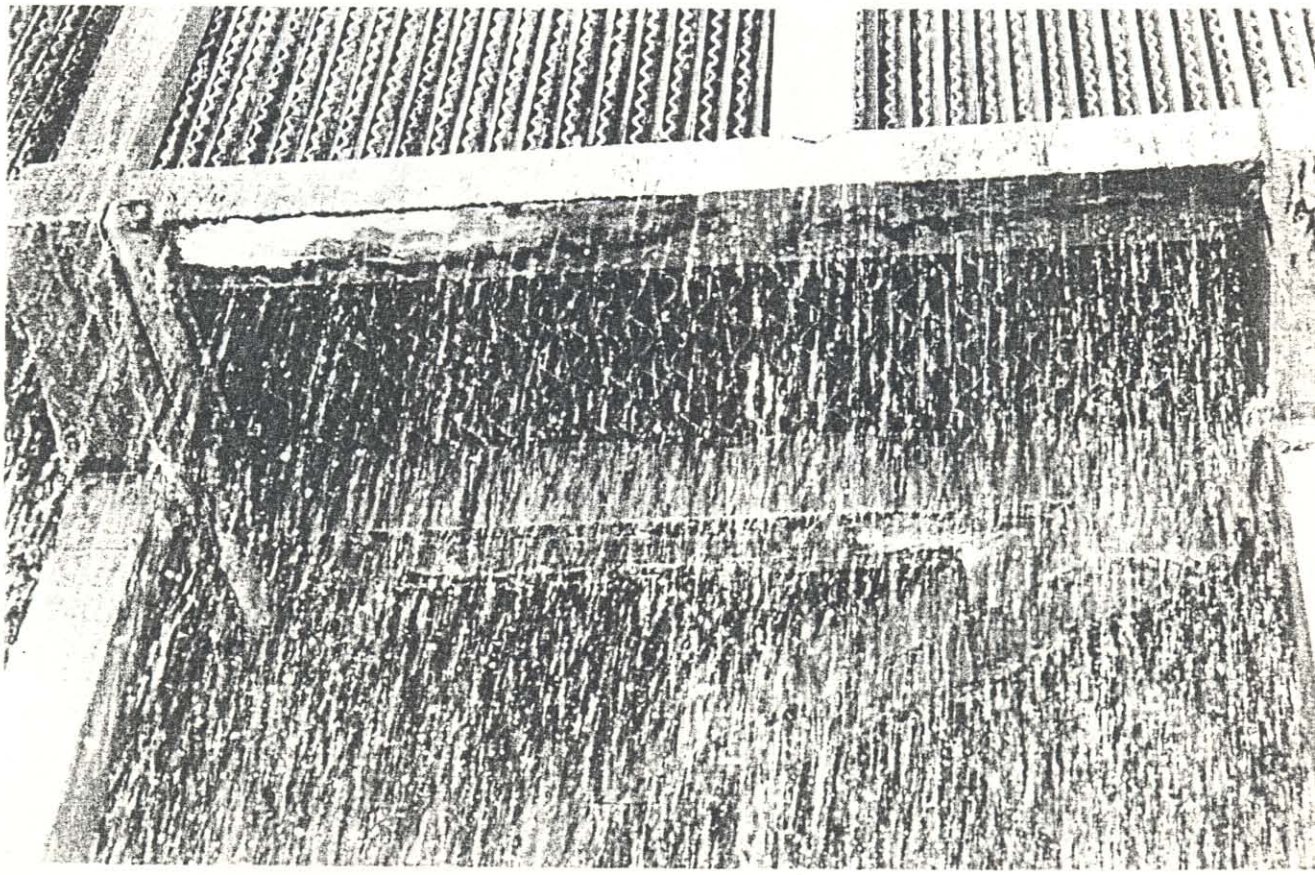

Figure 4.6: Biofouling deposits at Grootvlei Power Station on cooling tower packing before biodispersant/biocide treatment (A) and packing clear of biofouling deposits after three weeks of treatment (B).

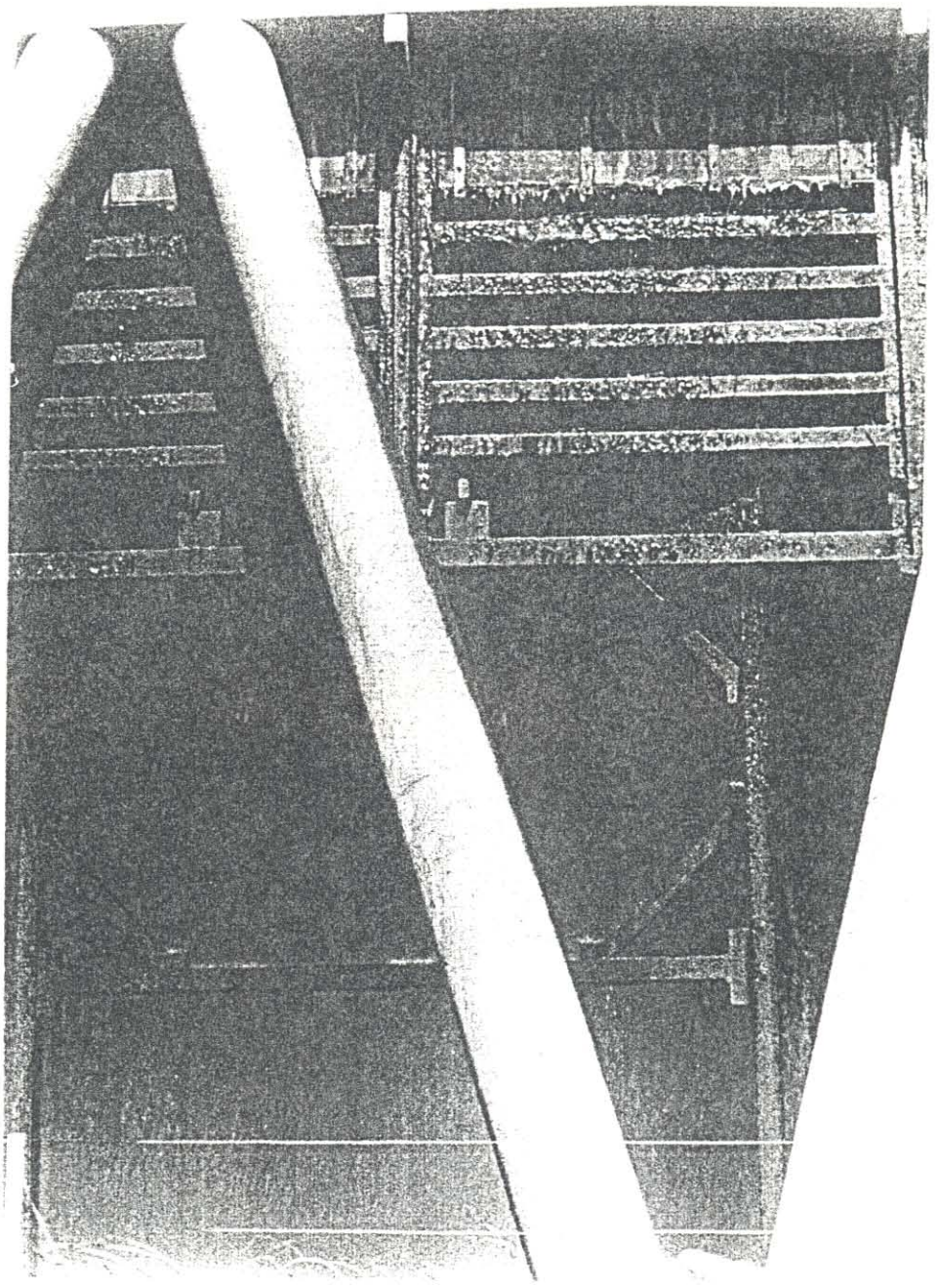

Figure 4.7: Slight algal regrowth in the spray area of the cooling tower at Grootvlei Power Station, after nine months of biodispersant/biocide treatment.

B

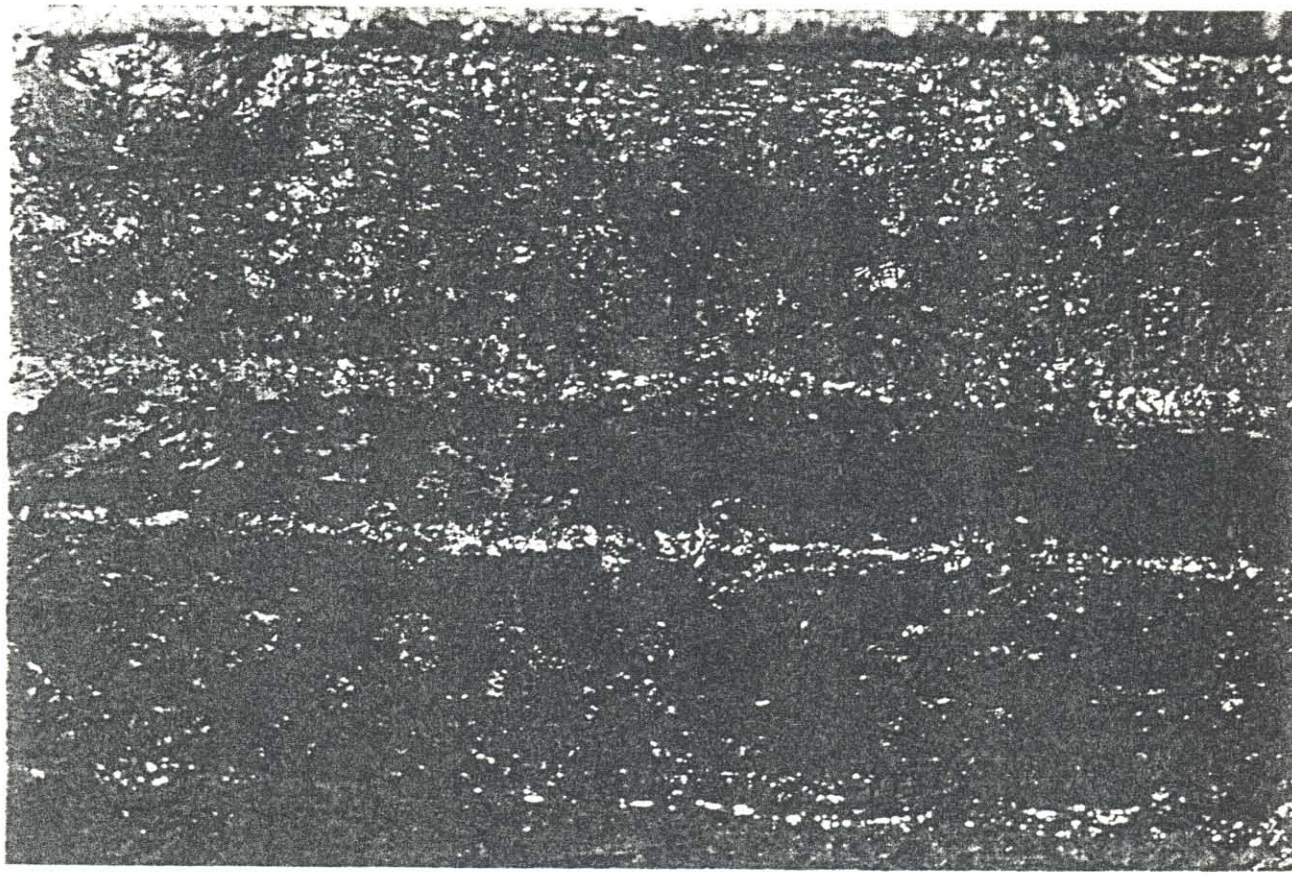

Figure 4.8 : Strainer box at Grootvlei Power Station before the initiation of biodispersant/biocide treatment showing hard nodules on surface (A) and underlying pits filled with black liquid (B).

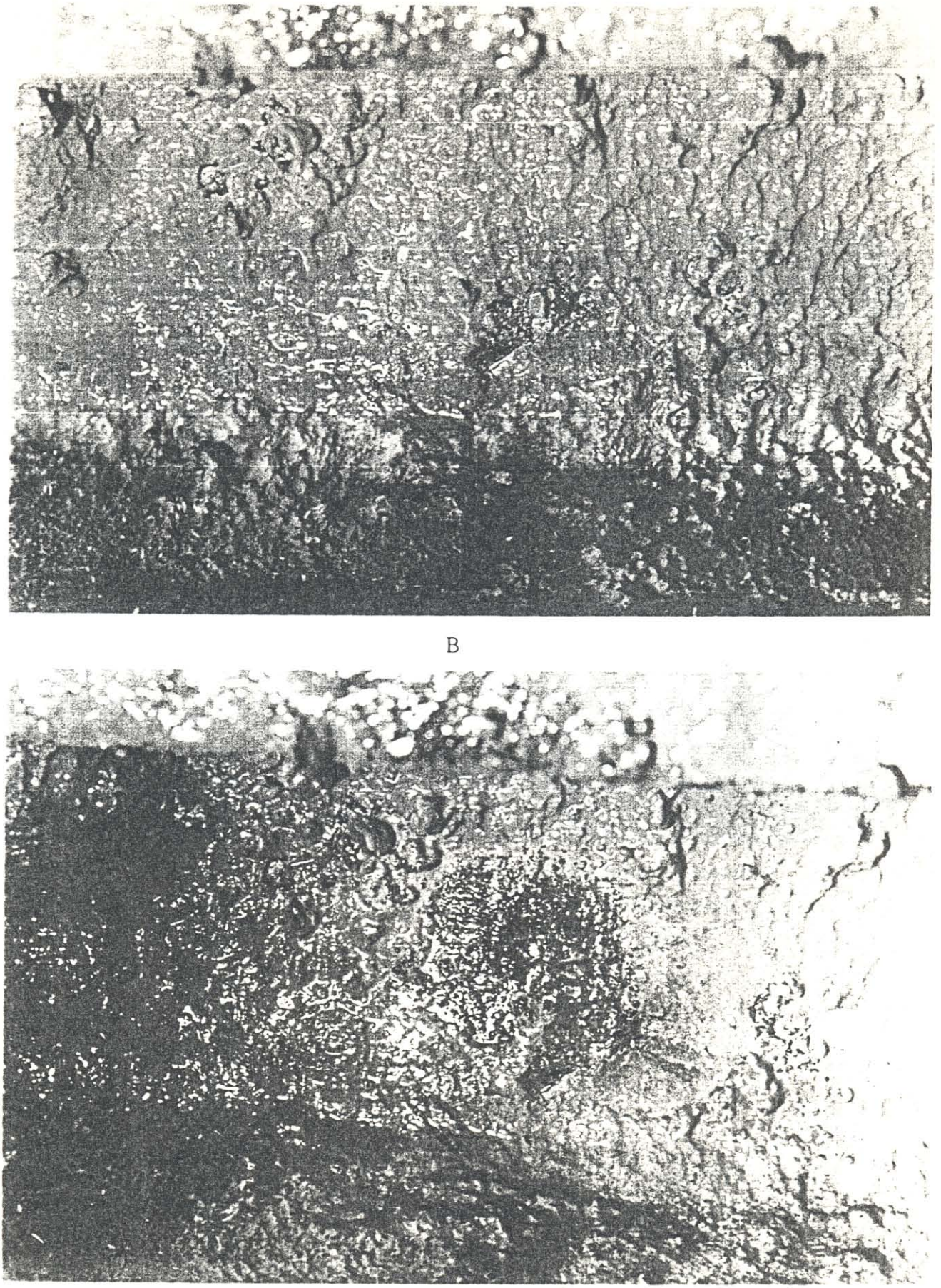

Figure 4.9 : Strainer box at Grootvlei Power Station after three weeks of biodispersant/biocide treatment showing softened nodules on surface (A) and loss of black colouration in underlying pits (B).

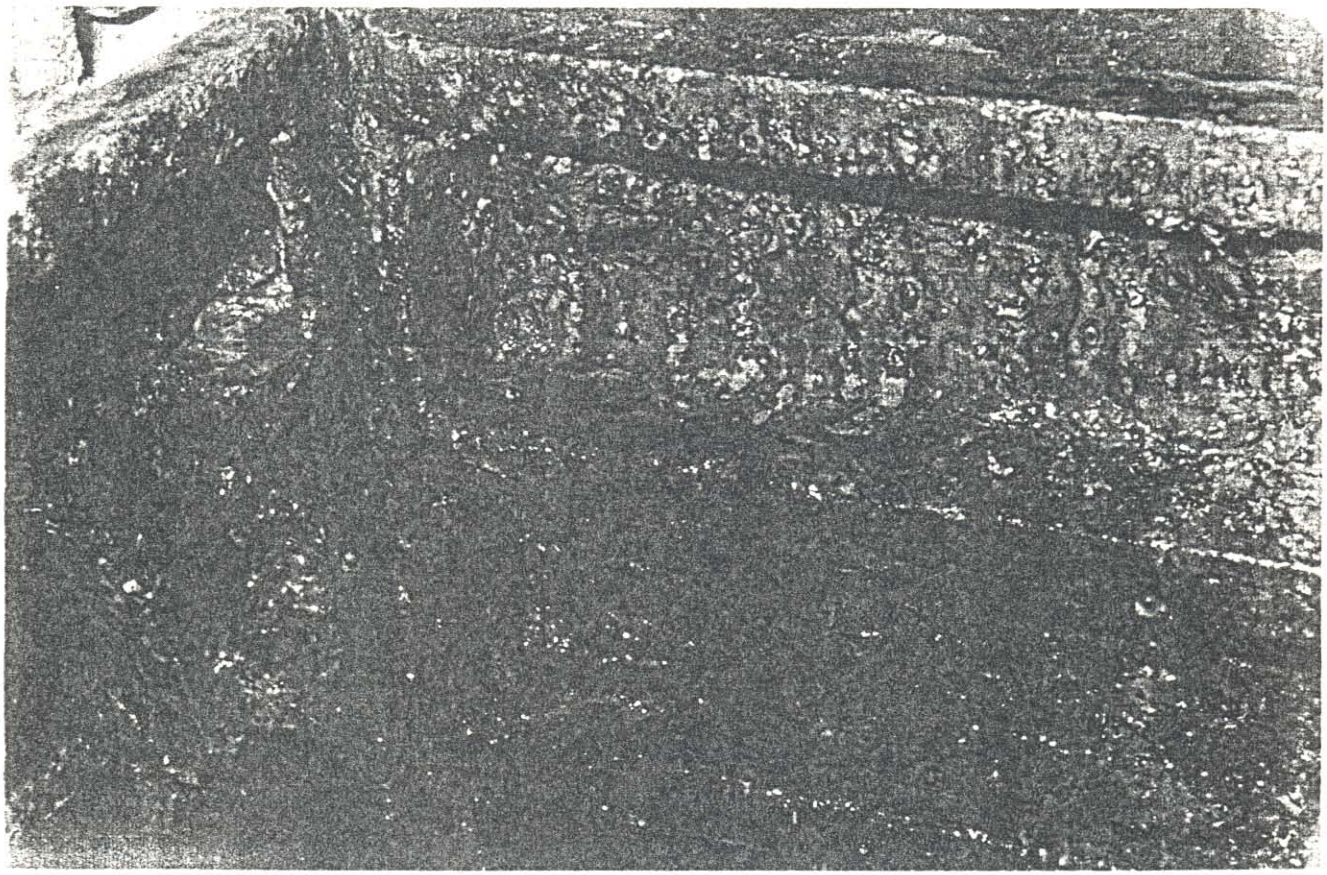

Figure 4.10 :Strainer box at Grootvlei Power Station after nine months of biodispersant/biocide treatment showing almost complete removal of nodules.

The visual inspections confirmed that a combination of a biodispersant and biocides was effective in removing biofilms, biofouling deposits and nodules of iron oxide, thus assisting in the mitigation of MIC (Table 4.7). After three weeks, the biofouling deposits on the cooling tower packing and clarifiers were either removed or had lost their green colouration, indicating cell death. In addition, little algal regrowth occurred over the nine month observation period. Thus the biodispersant/biocide programme was effective not only in the removal of biofouling deposits, but also in preventing any reattachment. The softening and removal of the nodules in the strainer boxes occurred over a longer time period. After three weeks of treatment, the nodules had been softened and only half of them contained SRB. However, it was only after nine months that almost complete removal of the nodules and thus mitigation of MIC occurred. These results were similar to those reported by Lutey *et al*. (1989), where a biodispersant was evaluated. This indicates that the biodispersant was the primary cause of biofouling deposit removal and mitigation of MIC, and not the biocide. However, the use of biocides, particularly in the "clean-up" phase of a treatment can assist with the control of those microorganisms dispersed into the bulk water, where they are more susceptible to the action of biocides (Blenkinsopp and Costerton, 1991).

CONCLUSIONS

The use of biodispersants in conjunction with biocides to control biofouling and MIC in cooling water systems operating at high cycles of concentration, was shown to be more effective than the use of biocides alone. The addition of a biodispersant aided in the dispersion of sessile bacteria into the bulk water where they are susceptible to the action of biocides. The accurate prediction of the effect of a particular biodispersant or biocide on the microbial populations in a cooling water system is not possible. In addition, the relative efficacy of different treatment products could not be determined. Therefore, biodispersants and biocides must be evaluated for each individual system.

ACKNOWLEDGEMENTS

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