Microbiological survey of open recirculating cooling water systems and their raw water supplies at twelve fossil-fired power stations

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Abstract

Raw water supplies utilised at 12 fossil-fired power stations, as well as the corresponding open recirculating cooling water systems were surveyed. Visual inspections were carried out and total aerobic and anaerobic bacteria, anaerobic acid-producing bacteria, *Thiobacillus* spp., *Nitrobacter* spp., sulphate-reducing bacteria (SRB) and algae were quantified. All raw water supplies and recirculating cooling waters contained all of the above groups of micro-organisms, with the exception of the two potable raw water supplies. In 75% of the systems, the numbers of SRB in the recirculating cooling waters were higher than in the corresponding raw water supplies and in 92% of the systems, the numbers of total aerobic bacteria were higher in the recirculating cooling waters than in the raw water supplies. However, no relationship between the sulphate levels in the recirculating cooling waters and the numbers of SRB could be distinguished, or between the percentage increase in the numbers of total aerobic bacteria and the cycles of concentration at which the system was operated. The frequency polygons of the occurrences of total aerobic and anaerobic bacteria in the raw water supplies and recirculating cooling waters did not follow normal distribution patterns. Visible biofouling deposits were observed at six of the power stations surveyed and the predominant algal group was the blue-green algae. However, in the raw water supplies, the predominant algal groups were green algae and diatoms. Microbiologically influenced corrosion was identified in all five of the condensers inspected. Each system was found to be unique and no generalisations in terms of presence or activity of micro-organisms could be made.

Introduction

The Department of Water Affairs and Forestry of South Africa has requested that dry-cooled power stations be constructed preferentially, as this type of power station utilises only 22% of the volume of water required by a wet-cooled station. Higher capital expenditure is, however, required for the construction of dry-cooled stations and operating costs are also elevated when compared with wet-cooled power stations. It is therefore possible that wet-cooled power stations may still be constructed in the future. It is estimated that by the year 2010, a total of 900 x 10^6 m^3 /a of water will be required for power generation, as compared with the 282 x 10^6 m^3 of water consumed during 1980 (Anon, 1986). Thus the need for water conservation and reuse will be of extreme importance in the future.

Awareness of microbially related problems in open recirculating cooling water systems has increased over the last few years and has been extensively reviewed (Soracco et al., 1988; Cloete et al., 1992). It has been widely reported that in aqueous systems, micro-organisms attach themselves to available surfaces by means of extracellular polymers, forming biofilms or biofouling deposits (Duddridge and Pritchard, 1983; Characklis et al., 1990). The attachment of micro-organisms to surfaces enables them to function as a multicellular tissue (Costerton et al., 1987). The physical presence of such deposits in cooling water systems can result in decreased heat transfer and increased frictional resistance (Characklis, 1973; Ferguson, 1981). In addition, discrete microbial colonies within biofilms or biofouling deposits on metal or concrete structures, can give rise to microbiologically influenced corrosion (MIC). The major groups of micro-organisms responsible for this phenomenon are the sulphate reducing bacteria (SRB), aerobic acid producing bacteria such as *Thiobacillus* spp. and *Nitrobacter* spp., anaerobic acid producing bacteria such as *Clostridium* spp. and iron bacteria such as *Gallionella* spp. (Tatnall, 1981; Pope et al., 1988). Algae are also responsible for numerous problems in cooling water systems, for example, reduction in heat transfer across cooling towers (McCoy, 1980).

Due to the intensified demand on limited water resources for a wide variety of industrial and domestic uses, the quality of water supply in South Africa is degenerating (Anon, 1986). The incidence of MIC and biofouling in industrial water systems in South Africa is increasing, resulting in costly control programmes and down-time (Poulton and Nixon, 1990). Iverson (1987), estimated that MIC constituted 10% of all metallic corrosion while the estimated direct cost of MIC in South Africa is approximately R400 million (Von Holy and Cloete, 1988). As the presence of potentially troublesome groups of micro-organisms can have profound effects on cooling water system operation and integrity, it is essential to determine their presence, activity and source.

The aim of this study was therefore to survey open recirculating cooling water systems at 12 fossil-fired power stations and their corresponding raw water make-up supplies. It was anticipated that this survey would not only reveal the extent of microbial contamination in these systems, but would also indicate which make-up supplies contained undesirable micro-organisms.

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TABLE 1
POWER STATIONS WHERE MICROBIOLOGICAL SURVEYS OF THE RECIRCULATING COOLING WATER AND RAW WATER SUPPLY WERE CARRIED OUT AND THEIR CORRESPONDING OPERATIONAL PARAMETERS

Power station	Raw water supply	System volume (Megalitres)	Cycles of concentration
1.	Nooitgedacht	50	12 - 15
2.	Jerico Dam	50	10
3.	Komati/Naauwpoort	128	10
4.	Vaal Dam	36	10
5.	Vygeboom/Komatipoort	60	7 - 10
6.	Potable water	0.7	11
7.	Komati River	40	7
8.	Usutu scheme	128	15 - 20
9.	Vaal River	128	15 - 20
10.	Potable water	0.7	5
11.	Grootdraai Dam	128	10
12.	Grootdraai Dam	128	20

TABLE 2
CHEMICAL ANALYSES OF THE RECIRCULATING COOLING WATERS AT THE 12 POWER STATIONS WHERE MICROBIOLOGICAL SURVEYS WERE CARRIED OUT

Power station	pH at 25°C ($\mu S \cdot cm^{-1}$)	Conductivity at 25°C	Total hardness ($mg \cdot \ell^{-1}$ $CaCO_3$)	Sulphate ($mg \cdot \ell^{-1}$)
1.	8.4	1 200	350	350
2.	8.4	1 040	56	21
3.	8.3	2 100	350	830
4.	8.3	1 310	206	470
5.	8.3	1 490	400	330
6.	8.6	450	120	50
7.	8.5	960	350	300
8.	8.5	1 500	500	400
9.	8.5	2 700	318	900
10.	8.6	800	200	20
11.	8.6	2 350	550	500
12.	8.6	4 700	428	1 300

Materials and methods

Description of power stations surveyed

The 12 power stations surveyed and their operational parameters are shown in Table 1.

Details of relevant chemical parameters of the recirculating cooling waters are shown in Table 2. It should be noted that no real difference in the pH of the recirculating waters was evident. There were however, large variations in conductivity, total hardness and sulphate concentrations.

Sampling points

At each power station, recirculating cooling water was sampled from the cooling tower sump and raw water from the inlet pipe into the cooling tower sump. Visual inspections were carried out on the cooling towers, clariflocculators and condensers. Samples of visible deposits on the cooling tower or areas of the clariflocculators, together with visible deposits or nodules in the condensers, were collected.

Sampling procedure

The 12 power stations were surveyed over a three-month period during summer. One power station was surveyed per week. The same sampling procedure was followed for both the raw water supplies and recirculating cooling waters. Four 550 mℓ aliquots of each water type were sampled in sterile Whirl Pak bags (Nasco, USA). One of the aliquots was purged with nitrogen before transportation and was utilised for the quantification of anaerobic micro-organisms. Air was trapped in the remaining Whirl Pak bags which were utilised for the quantification of the aerobic micro-organisms and algae.

TABLE 3
TECHNIQUES USED TO QUANTIFY BACTERIA IN THE RECIRCULATING COOLING WATERS AND RAW WATER SUPPLIES

Microbial type	Technique	Incubation time(d)	Atmosphere	Growth medium
Total aerobic bacteria	Pour plate	2	aerobic	Nutrient Agar (Biolab)
Total anaerobic	Pour plate	3	anaerobic	Nutrient Agar (Biolab)
Anaerobic acid-producing bacteria	Spread plate	3	anaerobic	Dextrose Tryptone Agar (*Oxoid*)
Thiobacillus spp.*	Spread plate	7	aerobic	Clesceri et al., 1989
Nitrobacter spp.*	Spread plate	7	aerobic	Martin et al., 1988
SRB	Agar tubes	14	anaerobic	SABS method 1497-1989 (1989)

* Bacterial morphology observed and Gram stain carried out

Deposits were removed by sterile forceps and immediately placed into Whirl Pak bags. Whirl Pak bags containing deposits that may have contained SRB were purged with nitrogen before transportation. All samples were kept at 4°C during transportation to the laboratory and analysed within 6 h of sampling.

Quantification of micro-organisms in water samples

The samples were diluted in sterile, quarter strength Ringer's solution and subjected to duplicate plate counts. As the samples were taken from highly aerated waters, no reducing agent was added to the diluent used in the quantification of anaerobic bacteria. However, the oxygen in the diluent was minimised prior to its use (ASTM D4412-84, 1992). All incubation was at 37°C. Anaerobic incubation occurred in an anaerobic incubator (Forma Scientific Anaerobic System, Labotec, SA), where the atmosphere consisted of 5% hydrogen, 15% carbon dioxide and 80% nitrogen. The techniques used to quantify bacteria in the raw water supplies and recirculating cooling waters are detailed in Table 3. Plates containing between 30 and 300 colonies, or the highest number if under 30, were counted.

The presence of algae in the recirculating and raw waters was determined by analysis of chlorophyll *a* according to the method of Sartory (1982). For each analysis, 500 mℓ of water was filtered.

Calculations

The following calculation was used to determine the percentage increase in the numbers of total aerobic bacteria (TAB) in the recirculating cooling water as compared to the raw water supply:

$$\frac{(\text{number of TAB in recirculating water} - \text{number of TAB in raw water})}{\text{number of TAB in raw water}} \times 100$$

Microscopic examination of deposits and water

All deposits were examined under a light microscope at 500 x magnification. If the deposits contained mostly algae, they were classified into unicellular or filamentous green algae, blue-green algae or diatoms (Palmer, 1962). If a deposit appeared to be primarily inorganic in composition, it was treated with dilute (0.1N) hydrochloric acid and examined under a light microscope at 500 x magnification for the presence of *Gallionella* spp. (ASTM D932-85, 1992).

One hundred mℓ of each of the raw water supply and recirculating cooling water samples were filtered through an 0.45µm pore size cellulose acetate filter (Millipore) and the filters were air-dried. A drop of immersion oil was placed onto each filter to clear it and the surface examined under a light microscope at 500 x magnification, for the presence of *Gallionella* spp. and planktonic algae.

Condenser inspections

When a system was off-line, condensers were visually examined. The bare metal or coated metal surfaces in the condensers were examined for signs of MIC e.g. nodules of iron oxides or blisters in the coating, with underlying shiny metal pits, filled with a black liquid (McCoy, 1980). Inspections were carried out within 12 h after the system had been drained, to ensure that the surfaces were still moist. Deposits were sampled and examined under a light microscope at 500 x magnification for the presence of *Gallionella* and cultured to determine the presence of SRB as described in Table 3.

TABLE 4
MICROBIOLOGICAL ANALYSES OF THE 12 RAW WATER SUPPLIES USED IN THE OPEN RECIRCULATING COOLING WATER SYSTEMS

Power station	Total aerobic bacteria	Total anaerobic bacteria	Anaerobic acid-producing bacteria	*Thio-bacillus*	*Nitro-bacter*	SRB	Algae
1.	$2.9x10^3$	$4.0x10^2$	Positive	$1.0x10^1$	$2.9x10^1$	$2.0x10^1$	3.7
2.	$2.0x10^2$	$6.0x10^1$	Positive	$1.0x10^1$	$2.9x10^1$	$1.0x10^0$	8.6
3.	$5.1x10^2$	$1.5x10^2$	Positive	$1.2x10^2$	$3.7x10^1$	$9.0x10^0$	12.3
4.	$7.3x10^2$	$3.5x10^2$	Positive	$4.1x10^2$	$3.0x10^0$	$5.0x10^0$	2.7
5.	$4.8x10^2$	$2.0x10^2$	Positive	$1.6x10^1$	$4.0x10^0$	$1.8x10^1$	11.4
6.	$5.0x10^0$	$<1.0x10^0$	$<1.0x10^0$	$1.3x10^1$	$1.0x10^0$	$<1.0x10^0$	<1.0
7.	$4.2x10^2$	$3.4x10^2$	Positive	$7.0x10^1$	$1.0x10^1$	$5.0x10^0$	2.7
8.	$1.0x10^2$	$2.0x10^1$	Positive	$6.0x10^0$	$<1.0x10^0$	$3.2x10^1$	9.3
9.	$7.0x10^3$	$8.8x10^2$	Positive	$1.3x10^2$	$3.3x10^1$	$3.0x10^0$	4.3
10.	$1.0x10^0$	$1.0x10^0$	$<1.0 x10^0$	$<1.0x10^0$	$<1.0x10^0$	$<1.0x10^0$	<1.0
11.	$1.0x10^3$	$2.1x10^3$	Positive	$7.1x10^1$	$9.0x10^1$	$1.5x10^1$	14.8
12.	$1.4x10^3$	$2.4x10^2$	Positive	$1.3x10^1$	$2.2x10^1$	$9.0x10^0$	1.6

All bacterial counts are reported as mean colony forming units (CFU)·mℓ^{-1}
Algae are reported as mg·ℓ^{-1} chlorophyll *a* (means of duplicates)

TABLE 5
MICROBIOLOGICAL ANALYSES OF THE 12 COOLING WATERS FROM THE OPEN RECIRCULATING COOLING WATER SYSTEMS

Power station	Total aerobic bacteria	Total anaerobic bacteria	Anaerobic acid-producing bacteria	*Thio-bacillus*	*Nitro-bacter*	SRB	Algae
1.	$3.0x10^3$	$8.0x10^2$	Positive	$5.0x10^1$	$6.9x10^1$	$1.0x10^0$	6.9
2.	$5.9x10^4$	$2.3x10^2$	Positive	$7.1x10^3$	$6.9x10^1$	$5.2x10^1$	32.6
3.	$2.2x10^3$	$3.2x10^3$	Positive	$9.5x10^2$	$1.2x10^2$	$3.1x10^1$	26.6
4.	$3.2x10^3$	$1.5x10^3$	Positive	$1.0x10^3$	$7.9x10^1$	$5.0x10^0$	16.0
5.	$4.0x10^2$	$4.1x10^2$	Positive	$3.5x10^1$	$1.4x10^1$	$2.0x10^1$	21.3
6.	$3.0x10^2$	$4.4x10^1$	Positive	$1.6x10^1$	$6.0x10^0$	$4.0x10^0$	17.3
7.	$1.8x10^3$	$1.3x10^3$	Positive	$7.0x10^1$	$1.9x10^1$	$2.0x10^0$	2.1
8.	$2.9x10^4$	$2.1x10^3$	Positive	$7.2x10^2$	$1.1x10^2$	$1.5x10^2$	29.8
9.	$3.0x10^5$	$3.6x10^3$	Positive	$2.2x10^3$	$2.2x10^3$	$1.6x10^1$	14.5
10.	$4.4x10^2$	$2.4x10^2$	Positive	$3.0x10^1$	$1.3x10^1$	$5.0x10^0$	1.5
11.	$2.2x10^3$	$1.1x10^3$	Positive	$7.4x10^1$	$1.1x10^2$	$1.1x10^1$	10.4
12.	$8.5x10^4$	$7.5x10^2$	Positive	$1.4x10^2$	$9.5x10^1$	$1.1x10^2$	6.2

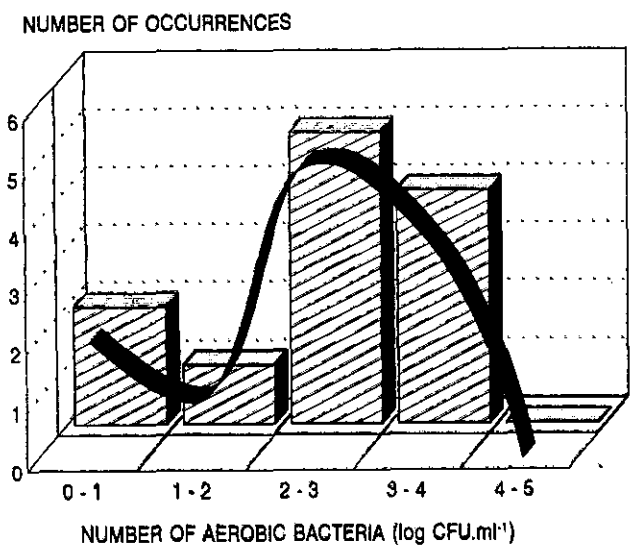
All bacterial results are reported as mean CFU·mℓ^{-1}
Algae are reported as μg·ℓ^{-1} chlorophyll *a* (means of duplicates)

Results and discussion

Quantification of micro-organisms in water samples

Microbial numbers quantified in the raw waters are detailed in Table 4.

The raw water supplies contained all groups of micro-organisms, with the exception of the potable waters at Power Stations 6 and 10 (Table 4). As these potable waters are chlorinated, low numbers of micro-organisms were expected. Although Power Stations 11 and 12 obtained their raw water from the same source, variations in the numbers of micro-organisms were noted. For example, the raw water used by Power Station 11 contained $2.1x10^3$ CFU·mℓ^{-1} anaerobic bacteria, whereas the water used by Power Station 12 contained $2.4x10^2$ CFU·mℓ^{-1} (Table 4). It is generally accepted that a variation in microbial numbers of one log order, indicates a significant difference. The raw water used by Power Station 11 also contained 4.8 μg·ℓ^{-1} of chlorophyll *a*, considerably more than the 1.6 μg·ℓ^{-1} recorded at Power Station 12 (Table 4). In addition, higher numbers of *Thiobacillus*, *Nitrobacter* and SRB were noted. The number of aerobic bacteria in the raw water used by Power Station 11 was slightly lower than the number



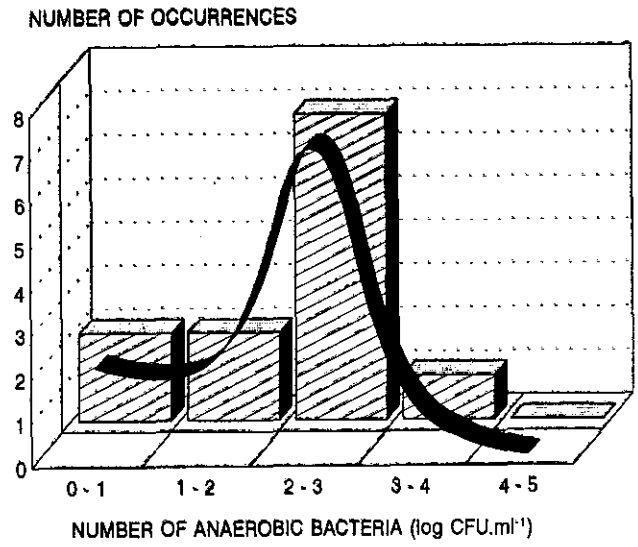
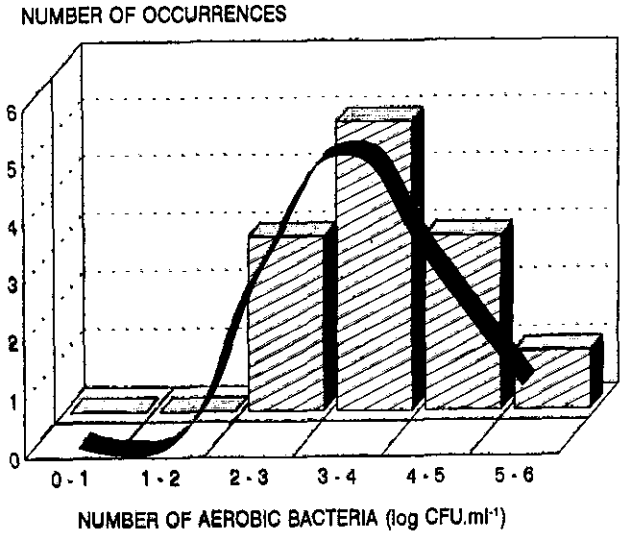


Figure 1
Frequency polygons of aerobic and anaerobic planktonic bacterial counts in the raw water supplies for the 12 power stations surveyed



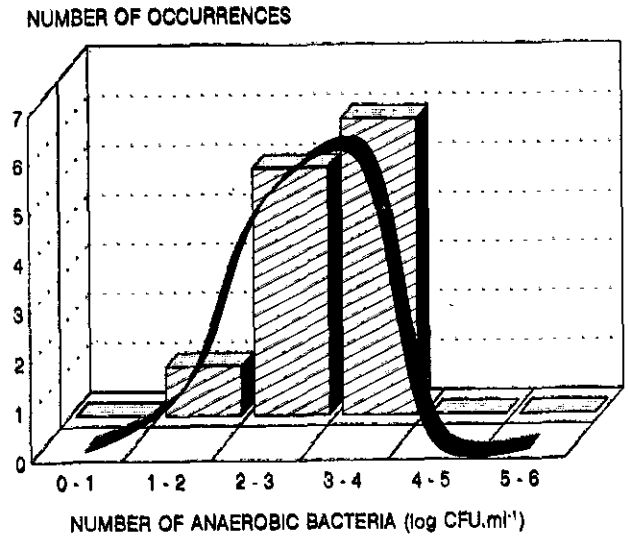


Figure 2
Frequency polygons of planktonic aerobic and anaerobic bacterial counts in the recirculating cooling waters at the 12 power stations surveyed

recorded in Power Station 12's water, 1.1×10^3 CFU·mℓ$^{-1}$ as compared with 1.4×10^3 CFU·mℓ$^{-1}$ (Table 4). These variations could be due to the fact that these power stations are not equidistant from the shared water supply and changes in the water may occur during transport to the power stations. Alternatively, the variations may be due to the samples not being taken on the same day.

Figure 1 shows the frequency polygons of the aerobic and anaerobic bacteria in the raw water supplies.

The frequency polygons for both the aerobic and anaerobic bacteria did not follow normal distribution patterns. However, in both cases, bacterial numbers most frequently fell into the range 1.0×10^2 to 1.0×10^3 CFU·mℓ$^{-1}$ (Fig. 1). As these raw waters were taken from a number of different sources, a normal distribution pattern would not be expected. In addition, the potable water supplies had been treated, thus changing the original microbiological composition.

All groups of micro-organisms were present in all the recirculating cooling waters. Again, differences in the microbial numbers quantified at Power Stations 11 and 12 were noted. The number of aerobic bacteria quantified in the recirculating cooling water at Power Station 12 was 8.5×10^4 CFU·mℓ$^{-1}$, while in Power Station 12's recirculating cooling water only 2.2×10^3 CFU·mℓ$^{-1}$ were recorded (Table 5). Whereas in Power Station 11's raw water the numbers of *Thiobacillus* spp., *Nitrobacter* spp. and SRB were higher than in Power Station 12's water, these bacteria were present in higher numbers in Power Station 12's recirculating water when compared to Power Station 11's recirculating water. A possible explanation for this could be that Power Station 12's cooling water system was operated at 20 cycles of concentration and Power Station 11's system at 10 cycles (Table 1). Thus, not only micro-organisms, but also nutrients would be more concentrated, in Power Station 12's water, due to system operation.

The frequency polygons for aerobic and anaerobic bacteria in

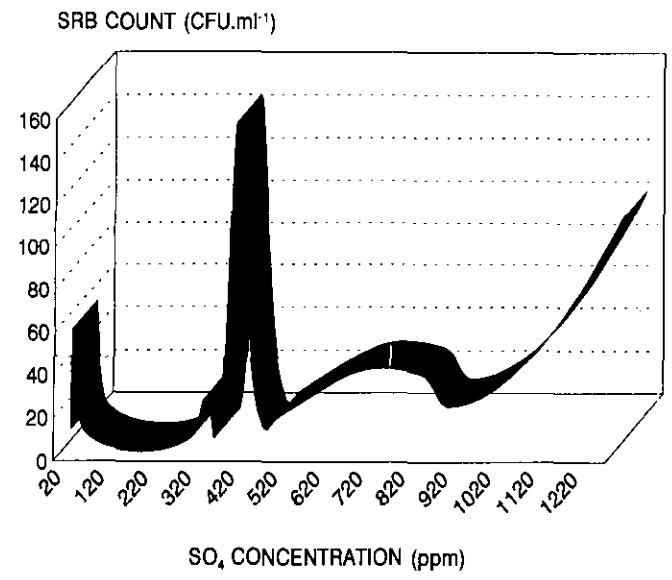


Figure 3
Numbers of SRB compared to corresponding sulphate concentrations in the recirculating cooling waters at the 12 power stations surveyed

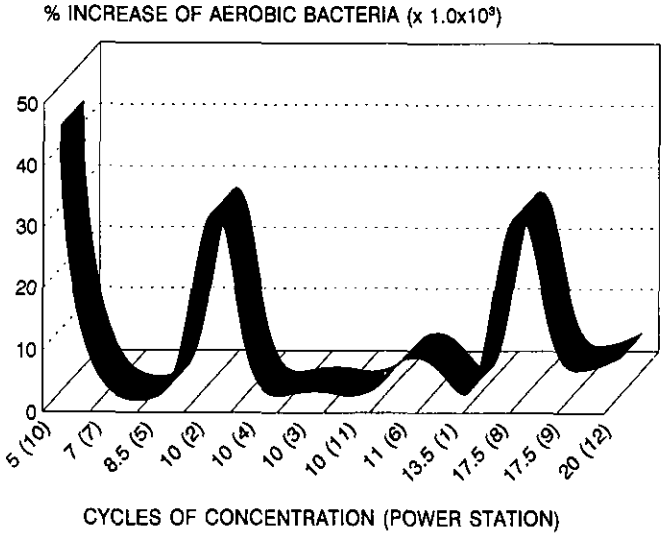


Figure 4
Effect of cycles of concentration on the percentage increase in the numbers of aerobic bacteria in the raw water supplies and corresponding recirculating cooling waters

the recirculating cooling waters are shown in Fig. 2.

As with the frequency polygons for the raw water supplies, the distribution of the aerobic and anaerobic bacteria in the recirculating cooling waters did not follow normal distribution patterns. However, the highest number of occurrences shifted to the range $1.0x10^3$ to $1.0x10^4$ CFU·mℓ^{-1} as compared with $1.0x10^2$ to $1.0x10^3$ CFU·mℓ^{-1} in the raw water supplies (Figs. 1 and 2). This shift can be explained by the fact that conditions are more favourable for microbiological growth in open recirculating cooling water systems when compared to raw water supplies (Strauss and Puckorius, 1984; Thierry, 1987).

In 75% of the systems, the numbers of SRB in the recirculating cooling waters were higher than in the raw waters. However, a number of disparities were noted. For example, the numbers of SRB in the raw water supply to Power Station 2 were 1.0×10^0 CFU·mℓ^{-1} and 5.2×10^1 CFU·mℓ^{-1} in the recirculating water. In direct contrast, 2.0×10^1 CFU.mℓ^{-1} SRB were quantified in the raw water supply to Power Station 1 and only 1.0×10^0 CFU·mℓ^{-1} in the corresponding recirculating cooling water (Tables 4 and 5). Numbers of SRB in the recirculating cooling waters vs. the corresponding sulphate concentration are illustrated in Fig. 3.

Numbers of SRB did not consistently increase with increasing concentrations of sulphate. Thus it appears that sulphate concentration is not the only factor that determines SRB activity (Postgate, 1981). In addition, as SRB are likely to preferentially migrate to anaerobic areas in the system, the quantification of their numbers in the bulk water cannot be used to accurately predict their activity (Postgate, 1981).

Other inconsistencies included minor changes between the numbers of aerobic bacteria in the raw and recirculating waters at Power Stations 1 and 5. Numbers of aerobic bacteria in the recirculating cooling water at Power Station 1 had increased by only 3% when compared to the raw water supply. At Power Station 5, numbers of aerobic bacteria in the recirculating water were lower than those in the corresponding raw water supply. In addition, the number of anaerobic bacteria in the recirculating cooling water at Power Station 11 was 53% of the number quantified in the raw water supply (Tables 4 and 5). In 92% of the cases, however, numbers of aerobic bacteria in the recirculating cooling waters were higher than those in the raw water supplies.

Percentage increases in the numbers of aerobic bacteria between the raw water supplies and recirculating cooling waters were thus compared to the cycles of concentrations at which the corresponding power stations operated (Fig. 4).

No obvious relationship between the percentage increase in aerobic bacteria and cycles of concentration could be distinguished. At five cycles of concentration, the aerobic bacteria at Power Station 10 increased by 43400%, whereas at Power Station 1, which is operated at 12 to 15 cycles, a 3% increase occurred (Fig. 4).

Microscopic examination of biofouling deposits and filtered water samples

In all biofouling deposits examined (Table 6), the predominant algal group was filamentous blue-green algae. Unicellular and filamentous diatoms and green algae were also observed, at irregular intervals. *Gallionella* spp. were not detected in any of the samples. When the results of the chlorophyll *a* content of the waters were examined, in relation to the presence of biofouling deposits, again no correlation could be found. The raw water supplies for Power Stations 3 and 11 contained the highest chlorophyll *a* content, (12.3 and 14.8 µg·ℓ^{-1} respectively) and biofouling deposits were present in these systems (Table 4). Although biofouling deposits were observed at Power Stations 4 and 7, the chlorophyll *a* content of both the raw water supplies for those power stations was only 2.7 µg·ℓ^{-1} (Table 4). Evidence of sessile algal growth was observed in 50% of the cooling towers and clariflocculators (Table 6). The microscopic examination of these algal deposits and the recirculating waters determined that they consisted predominantly of filamentous blue-green algae. The predominant algal groups in the raw waters were, however, green algae and diatoms. It has been reported that blue-green algae are the most prominent group of algae found in cooling systems, as was found during this study (McCoy, 1980). However, no explanation is given for this phenomenon.

Condenser inspections

Condenser inspections were carried out at all power stations where general maintenance was in progress, thus allowing entrance into the cooling water systems (Table 7). SRB were identified as detailed in Table 3 and *Gallionella* spp. as per ASTM D932-72 (1972).

All of the condenser inspections revealed evidence of MIC. Evidence of MIC was shown at Power Station 4 even though only 5 SRB·mℓ^{-1} were enumerated in the recirculating cooling water (Table 5). SRB were isolated from condenser pipework which had been protected with an epoxy coating. Epoxy coatings do offer a measure of protection against MIC. However, where there are defects in the coating, MIC attack of the underlying mild steel can still occur (Severyn, 1990).

The reasons for the inconsistencies in the results and observations made during this study could encompass a number of environmental and physiological changes that occur when raw water enters a cooling water system. The temperature of the water in certain areas of a cooling system is 10 to 20°C higher than it would be under ambient conditions, thus increasing the growth rate of micro-organisms (McCoy, 1980). Due to cycling of the water, nutrients are more freely available and the pH of the water is increased. Oxygen is also freely available as oxygenation of the water also occurs as a result of turbulence, and the mechanism by which heat exchange is achieved in the cooling tower (Strauss and Puckorius, 1984). These changes in environmental conditions are expected to result in changes in the numbers of micro-organisms (McCoy, 1980). However, sessile microbiological populations are predominant in aqueous environments (Costerton et al., 1985). More than 1.0 x 10^4 sessile bacteria have been quantified for each planktonic cell (Geesey et al., 1978). Furthermore, sessile micro-organisms form highly organised microbial communities, in which nutrients may be cycled (Costerton et al., 1985). This phenomenon could explain why no direct correlation could be found between sulphate levels in the recirculating cooling water and SRB numbers, and between total aerobic bacteria and cycles of concentration. However, in some studies, plantonic micro-organisms have been monitored (Cloete et al., 1989). The recirculating cooling water can also be further contaminated by windborne micro-organisms (Bott et al., 1983).

TABLE 6
MICROSCOPE EXAMINATION OF BIOFOULING DEPOSITS REMOVED FROM THE OPEN RECIRCULATING COOLING WATER SYSTEMS SURVEYED

Power station	Location of deposit	Predominant algal groups (Palmer, 1962)
3.	Clariflocculator outlet	Filamentous blue-green algae
4.	Clariflocculator outlet Cooling tower	Filamentous blue-green algae Filamentous green and blue-green algae Filamentous and unicellular diatoms Unicellular green algae
5.	Cooling tower	Filamentous blue-green algae Unicellular diatoms
7.	Cooling tower	Filamentous blue-green and green algae Unicellular diatoms
9.	Clariflocculator	Filamentous blue-green algae Unicellular diatoms and green algae
11.	Clariflocculator	Filamentous blue-green algae

TABLE 7
VISUAL INSPECTIONS OF CONDENSERS AT FIVE POWER STATIONS

Power station	Inspection point	Observations
3.	Cross-over loop of condenser 3.	Blisters in epoxy coating, shallow pitting of mild steel, SRB present.
4.	Cooling water strainer boxes.	Numerous nodules overlying shallow pits in the mild steel, SRB present.
5.	Cross-over loops of condensers 1, 3 and 5.	Numerous nodules overlying shallow pits in the mild steel, SRB present. *Gallionella* spp. in 20% of the 10 nodules sampled.
8.	Cross-over loop of condenser 6.	Blisters in epoxy coating, shallow pitting of mild steel, SRB present.
9.	Cross-over loop of condenser 3.	Blisters in epoxy coating, shallow pitting of mild steel, SRB present.

Evidence of this type of contamination, is the number of micro-organisms isolated from the recirculating cooling waters at Power Stations 6 and 10. The recirculating waters contained all groups of micro-organisms, whereas the raw water supply to both these systems was potable water which had been chlorinated and thus contained low numbers of all the groups of micro-organisms. These micro-organisms could therefore have been introduced into the recirculating cooling water from the surrounding environment.

Changes in the environmental condi-

tions that micro-organisms are exposed to on entering a cooling water system, could also explain the shifts in the frequency polygons for aerobic and anaerobic bacteria between the raw water supplies and the recirculating cooling waters. Higher numbers of bacteria were enumerated in the recirculating cooling waters. In addition, the environmental conditions in each system are unique. Thus a normal distribution pattern would not be expected due to variations in operating temperatures and chemical parameters.

Conclusions

The quality of the raw waters may contribute to the microbiological composition of the recirculating cooling water. However, other prevailing environmental and system conditions such as temperature and pH appeared to have a greater influence on the extent of microbiological contamination in any given system. This study emphasised the fact that each system was unique and thus no generalisations could be made in terms of the presence or activity of micro-organisms. The need to monitor and evaluate the microbiology of each individual system was highlighted.

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