4351

Summary   An investigation of the corrosion of swimming pool hall heat recovery exchangers at eight different sites has shown that exchangers using copper for both tubes and fins have adequate corrosion resistance, and can be expected to remain efficient and structurally sound for more than ten years. On the other hand, aluminium was found to be less suitable as a fin material because of its tendency to suffer localised dissimilar metal corrosion in contact with the copper tubes. Though the survey was limited, these findings are likely to apply to other pools using similar systems.

Corrosion of heat recovery exchangers in swimming pool hall ventilation systems

T L BIRD BA
Electricity Council Research Centre, Capenhurst, Chester CH1 6ES, UK

1 Introduction

The use of heat pumps to recover heat from swimming pool hall ventilation systems is now well established; over 250 units are operating. The heat recovery exchangers operate in a hostile environment: they recover latent as well as sensible heat from the warm and humid air extracted from the pool hall; these damp and wet conditions encourage corrosion. The condensate is well oxygenated by the air stream and corrosion rates can be further enhanced by chlorine-containing species (or other entities) emanating from the pool water and present in the extract air. Corrosion can lead initially to a loss of heat transfer efficiency and eventually to structural collapse. This study aimed to obtain information on the corrosion resistance of the materials of construction of the heat exchangers. Heat input exchangers operate under dry conditions and are not usually prone to corrosion except in extremely aggressive conditions (such as marine atmospheres); they are not considered in this paper.

There are two main methods of sterilising swimming pool water in the UK, one using chlorine, the other using ozone with chlorine at a lower concentration. A potentially important difference between the procedures from the point of view of the corrosivity of the atmosphere is the higher proportion of chlorine-containing species in chlorine-sterilised pool water. These levels, together with other factors such as the quality and temperature of the pool water, ventilation rates and whether air recirculation is practised, affect the concentration of contaminants in the pool hall atmosphere.

Chlorine-sterilised pools are more common at present. Chlorine-containing compounds are added to the water to give 1–2 ppm of 'free chlorine' (the sum of hypochlorous acid and hypochlorite ion). In ozone-sterilised pools, the water is first completely disinfected by ozone treatment in the recirculatory circuit outside the pool. It is then de-ozonised. Finally, before being returned to the pool, the sterile water is dosed to a free chlorine concentration of about half that in a chlorine-sterilised pool. This leads to a lower concentration of combined chlorine (chloro-compounds) in an ozone-sterilised pool.

This paper describes an investigation at eight pools, five of them chlorine-sterilised, three ozone-sterilised. The heat recovery exchangers were examined, corrosion test samples were placed on them, and one of the exchangers was inspected in detail after withdrawing it from service. All the exchangers were of the fin-on-tube type. All the tubes were copper, but the fin material varied. At the chlorine pools, the fins were copper at two of them, tin plated copper at another two, and aluminium at the other one. Aluminium fins were used at the three ozone pools.

Heat recovery exchangers are operated with their tubes carrying either heat-pump refrigerant (as at the three ozone pools) or chilled water as a secondary system linked to the heat-pump evaporator coil. Air circulation practice also varies. At the three ozone-sterilised pools the air was recirculated, just a small proportion of the total flow being vented and replaced by fresh air. At the five chlorine-sterilised pools, on the other hand, only the one with the aluminium-finned exchanger had air recirculation; at the others, the extracted air was dumped to atmosphere after heat recovery. At two of these there was a further stage of heat recovery downstream, involving a run-around system with water circulated through air-to-water heat exchangers.

2 Experimental details

Two approaches were adopted. First, exchangers in service were periodically examined to assess their state of corrosion. Second, the corrosion rate of test samples was measured.

2.1 Examination of heat-recovery exchangers in service

The heat-recovery units and their associated components (condensate collection trays, exchanger framework, duct panelwork) were periodically inspected for corrosion.

Where access was possible, the fins and the tubes close to the faces of the exchanger were examined. Small samples of fin were removed for more detailed study: the surfaces were then inspected microscopically using optical and scanning electron instruments and the corrosion product was identified structurally by x-ray diffraction analysis of material

removed from the fins. Metallographic cross sections of the fin samples were prepared for optical microscopical examination to observe the type of corrosion and to quantify its amount.

A heat recovery exchanger serving the hall of a chlorine-sterilised pool was withdrawn from service, dismantled, and examined in detail.

2.2 Corrosion test samples

For these tests the usual materials of construction and alternative ones were assessed by attaching test samples to the face of the exchanger, thus exposing them to the same conditions of atmosphere and temperature as those experienced by exchangers in service. The various test samples were designed to determine the rate of general surface corrosion, to reveal any susceptibility to dissimilar metal corrosion and to detect crevice corrosion. The samples were in thermal contact with the heat recovery exchangers via sample holders which were attached mechanically to the exchangers. Precautions were taken to prevent unwanted dissimilar metal corrosion between the samples and their holders.

For the corrosion tests, coupons of copper, tin-plated copper, aluminium and vinyl-coated aluminium were used, and also tubes of copper and the six copper alloys detailed in Table 1. These copper alloys were candidates for replacing copper for both fins and tubes. All of them are presently used to manufacture heat exchangers, but not of the fin-on-tube type. After taking the samples off test, the corrosion product was removed chemically and the mass loss converted to a mean penetration rate.

3 Results of heat exchanger examination at chlorine-sterilised pools

3.1 Pool Cl-1: copper fins; 1.0 ppm free chlorine; combined chlorine concentration not known

This system consists merely of a heat recovery coil (with tubes carrying the refrigerant). The exchanger was withdrawn from service to permit dismantling and detailed examination. It had been in operation for four years, though other parts of the ventilation system had been in operation considerably longer.

A large part of the air-impact face was contaminated with a dark, greasy deposit deriving from human skin scales, hair and clothing fibres. It was not distributed uniformly, probably as a result of some unevenness of air distribution. It adhered to the fins and extended to a distance of about 5 mm into the exchanger. In the most heavily contaminated regions, the inter-fin spacing had been reduced to about half its original value of 3 mm, almost certainly enough to interfere with the free flow of air. The corrosive attack underneath the contaminating material was often considerable.

Representative sections were cut from the exchanger and the fins removed to bare the tubes for inspection. Altogether, just over half of the 72 exchanger tubes were examined for general surface corrosion. Some lengths were further scrutinised under low magnification to search for localised corrosion such as pits. About one tenth of the total tube length was examined in this way. Metallographic sections of the most important regions were prepared and examined microscopically.

Table 1 Copper and copper alloys used in corrosion and crevice corrosion tests

Alloy description	British Standard designation	Nominal composition
Phosphorus-deoxidised non-arsenical copper	C 106	99.85% Cu (min.), 0.013–0.050% P
Aluminium brass	CZ 110	76% Cu, 22% Zn, 2% Al, 0.04% As
Admiralty brass	CZ 111	70% Cu, 29% Zn, 1% Sn, 0.04% As
Special 70/30 arsenical brass	CZ 126	70% Cu, 30% Zn, 0.04% As
10% cupronickel	CN 102	87.5% Cu, 10% Ni, 1.5% Fe, 1% Mn
30% cupronickel	CN 107	68% Cu, 30% Ni, 1% Fe, 1% Mn
7% aluminium bronze	CA 102	7% Al, 1.0–2.5% (Fe + Ni + Mn), remainder Cu

Aluminium-to-copper dissimilar metal corrosion tests were conducted on aluminium and vinyl-coated aluminium coupons in contact with a copper component, and on copper-tubed model heat exchangers with fins made of plain aluminium, vinyl-coated aluminium or chromate-treated aluminium. After exposure, the samples were dismantled and the corrosion products removed to allow the surfaces to be inspected by optical microscopy.

Crevice corrosion tests, to assess susceptibility to corrosion in nooks and crannies such as exist between the fins and tubes, were made on copper and the six tabled copper alloys.

Painted steel and galvanised steel test coupons were tested to assess the efficacy of chlorinated rubber paint.

The tubes were found to be only slightly corroded. There was no evidence whatsoever of crevice corrosion, and the only corrosion was slight attack in the form of superficial circumferential rings of green and black corrosion product. The green rings were basic copper carbonate (malachite, $Cu(OH)_2 \cdot CuCO_3$) and the black ones cupric oxide (CuO).

By contrast, the fins were noticeably corroded, particularly towards the air-impact face. The green corrosion product was paratacamite, $Cu_2(OH)_3Cl$. The corrosion rate of the fins was of the order of $10 \mu m \, y^{-1}$ close to the air-impact face, but virtually zero at the air-exit face. The fin corrosion extended further into the exchanger in those areas where the air-impact face contamination was heaviest.

The galvanised steel floor of the expansion chamber in front of the heat exchanger had started to corrode under a mound of rust which had been blown there from the heavily corroded ductwork upstream.

3.2 Pool Cl-2: tin-plated copper fins; 1.5 ppm free chlorine; 2.5 ppm combined chlorine

The heat recovery system consists of a chilled-water coil and a run-around exchanger.

Fin corrosion at the air-impact face of the chilled-water coil was slight. After $3\frac{1}{2}$ years, remnants of the tin plating remained and corrosion of the underlying copper had only just begun. During the next $3\frac{1}{2}$ years, the copper corroded to give a thin coating of paratacamite, $Cu_2(OH)_3Cl$. On the leading edge of the fins, there was some contamination by greasy material, similar in nature to that at pool Cl-1 but smaller in amount.

On the fins at the air-impact face of the other coil (the run-around coil) the green corrosion product (again paratacamite) was much thicker. It also varied in thickness between regions. In one area, a copper corrosion rate of 15.2 $\mu m\ y^{-1}$ was measured over a 2 year period. In the subsequent $3\frac{1}{4}$ years this dropped to 8.0 $\mu m\ y^{-1}$. In a leass heavily corroded part, the corrosion rate again slowed down with time, the corresponding figures being 6.3 and 4.1 $\mu m\ y^{-1}$.

Several steel components such as condensate collection trays, exchanger framework and duct panels suffered corrosion. The galvanised steel condensate collection trays on the chilled-water heat recovery coil were perforated by corrosion after $4\frac{1}{2}$ years and had to be replaced. The painted framework of this exchanger was also attacked intensively in parts. Some of the bottom horizontal members were completely corroded away after 7 years' service. Elsewhere, the galvanised steel floor of the duct between the two exchangers was badly corroded after periodic flooding by condensate carried past the antispray baffles of the upstream coil. Some areas of the galvanised steel duct walls had been wetted by condensate spilling over from upper collection trays and were likewise corroded. The panels which had not been moistened were still in good condition.

3.3 Pool Cl-3: copper fins; 2.0 ppm free chlorine; 1.0 ppm combined chlorine

The heat recovery system comprises a chilled-water coil and a run-around exchanger. After 5 years the amount of fin corrosion was small. On the chilled-water coil, the air-impact face was barely corroded while the other face was but slightly corroded. Even on the run-around coil, the degree of corrosion at the air-impact face was much less than that at pool Cl-2 after a comparable period of operation. On the other hand, the painted steel framework of both exchangers showed marked corrosion in several places.

3.4 Pool Cl-4: tin-plated copper fins; 1.7 ppm free chlorine; 0.4 ppm combined chlorine

The system consisted of a heat recovery exchanger only. After 4 years' operation the amount of corrosion was very slight: tin plating was still present on the fins at the air-exit face, and at the air-impact face the rate of attack had been even smaller. The painted framework of the exchanger was slightly corroded.

3.5 Pool Cl-5: aluminium fins; 1.5 ppm free chlorine; 0.8 ppm combined chlorine

Most of the pool hall air was recirculated, and the heat recovery unit consisted of a dehumidifier coil only. After three years of operation, the exchanger was in good condition. Dissimilar metal corrosion of the aluminium fins was confined to just two regions.

4 Results of heat exchanger examination at ozone-sterilised pools

4.1 Pools O₃-1, O₃-2, O₃-3: aluminium fins; 0.7 ppm free chlorine; 0.3 ppm combined chlorine

At the three ozone-sterilised pools investigated, the pool hall air is recirculated, and the heat recovery exchangers thus act as dehumidifier coils. They had suffered differing amounts of dissimilar metal corrosion: serious at O₃-1, moderate at O₃-2, slight at O₃-3. At pool O₃-1 after 2 years of operation, the aluminium fins were severely corroded in the regions close to the copper tubes on the air-impact side. This corrosion had become pronounced at an early stage. After just one year, the collars were covered by a layer of corrosion product, while a year later some of the fins had become separated from the tubes (Figure 1). In contrast, the fin material remote from the tubes was in good condition. The corrosion product on the collars was predominantly hydrated Al_2O_3, with only small quantities of other materials; in particular it contained only a trace of chloride. On the other face of the exchanger, the air-exit side, there were merely the initial signs of attack even after 2 years, with a milky-coloured liquid exuding from the collars. At pool O₃-2 the fins had also suffered from dissimilar metal corrosion, but less than at pool O₃-1. For instance, the collars on the air-impact side took 4 years to become encrusted with corrosion product, while the air-exit side remained free from attack. At pool O₃-3, the dissimilar metal corrosion was very slight; on the air-impact side, the aluminium fins showed only the initial signs of dissimilar metal corrosion in the collar region some 4 years after commissioning.

Figure 1 Bimetallic corrosion on the two-year-old dehumidifier coil at pool O₃-1

At pools O₃-1 and O₃-2 the air-impact face of the exchanger became heavily contaminated by fluffy, fibrous material. It probably originated mainly from the bathers and their

garments (the air is extracted via the wet duct, that is the duct carrying the pool water from the pool overflow grilles to the water recirculation system). The contamination had seriously impeded the air flow and had probably also hastened the bimetallic corrosion of the fins. A disposable glass-fibre filter was subsequently fitted in front of the exchanger at each of these two pools to stop the contamination. In contrast, the rate of contamination at pool O_3-3 was minimal. The air is extracted through wall vents instead of through the wet duct.

5 Results from corrosion test samples

5.1 Corrosion coupons of current materials

The corrosion rates of copper and tin-plated copper test coupons at three chlorine and three ozone pools are given in Table 2.

in theory the rate should decrease still further with time. Indeed, the corrosion rates generally decreased with time.

At pool Cl-2 the corrosion rates for tin-plated copper were lower than those for plain copper. Nevertheless the layer of tin was thin (13 μm) and it was removed quite quickly under aggressive conditions. For example, the coupons on the run-around exchanger had lost most of their plating after $2\frac{1}{4}$ years.

On the other coil at pool Cl-2, i.e. the chilled-water coil, the coupon corrosion rates were much lower than on the run-around coil, reflecting the small amount of fin corrosion.

At pools Cl-3 and Cl-4 the rates of corrosion were minimal for both copper and tin-plated copper coupons. At the three ozone pools the corrosion rates were also very low.

Aluminium coupon corrosion rates at the chlorine pools were very low (the highest was 4 μm y^{-1}—still a low figure—on the run-around coil at pool Cl-2), and at the ozone pools

Table 2 Corrosion rates of test samples of copper and tin-plated copper at the chlorine-sterilised pools Cl-2, Cl-3 and Cl-4 and the ozone pools O_3-1, O_3-2 and O_3-3

Pool	Test position	Corrosion rate (μm y^{-1})					
		Copper			Tin-plated copper		
		Exposure time (y)			Exposure time (y)		
		1	$1\frac{1}{4}$	$2\frac{1}{4}$	1	$1\frac{1}{4}$	$2\frac{1}{4}$
Cl-2	Air-impact face of run-around exchanger:						
	Lightly corroded region	14.7		9.6	9.5		4.9
	Heavily corroded region	13.4		13.4	6.4		3.8
Cl-2	Air-impact face of chilled-water exchanger	1.7		0.7	0.6		0.5
Cl-3	Air-impact face of run-around exchanger	0.8			1.7		
	Air-impact face of chilled-water exchanger	0.2		0			
	Air-exit face of chilled-water exchanger	0.7			1.1		
Cl-4	Air-impact face	0		0			
O_3-1	Air-impact face		2.1			0.8	
	Air-exit face		0.5			1.2	
O_3-2	Air-impact face		0.6			0.6	
	Air-exit face		0.8			1.1	
O_3-3	Air-impact face		0.3			0	
	Air-exit face		0.8			1.8	

In the two test positions on the run-around coil at pool Cl-2, the rates of copper corrosion of 9.6 μm y^{-1} and 13.4 μm y^{-1} for the lightly and heavily corroded regions respectively, measured on copper coupons after $2\frac{1}{4}$ years' exposure, may be compared with the measured fin corrosion rates of 6.3 μm y^{-1} and 15.2 μm y^{-1} in these two regions after 2 years of copper corrosion. The corrosion rates on the run-around coil were much higher than those on the other coil and those at the other pools. However, even at these rates a reasonable lifetime would still be anticipated for copper fins: the highest corrosion rate for $2\frac{1}{4}$ years' exposure was 13.4 μm y^{-1}, and a copper fin typically 260 μm thick would therefore be corroded by half after 10 years. The amount of corrosion should be even less than this because

they were even lower. The rates for vinyl-coated aluminium were lower again than those for plain aluminium.

5.2 Copper alloys (candidate materials)

The corrosion rates for the tubular samples of copper and copper alloys tested at the chlorine-sterilised pools Cl-2 and Cl-3, and the ozone-sterilised pools O_3-2 and O_3-3, are given in Table 3.

The alloy 30% cupronickel resisted corrosion best, invariably coming first or second in the rankings. Copper performed well in mild corrosive conditions (at the chlorine-sterilised pool Cl-3 and at both ozone-sterilised pools, and also on the chilled water coil at the chlorine-sterilised pool Cl-2), and

Table 3   Comparison of corrosion rates (μm y^{-1}) of test samples of copper and copper alloys

Pool	Cl-2			Cl-3		O$_3$-3	O$_3$-2	
Exchanger	Chilled water	Run-around		Run-around	Chilled water	Dehumidifier	Dehumidifier	
Face	Impact	Impact		Impact	Exit	Exit	Impact	Exit
Sector		A	B					
Test time (y)	4	1	2	2	3	3$\frac{1}{4}$	2$\frac{1}{4}$	3$\frac{3}{4}$
Cu-30% Ni		4.1	3.6			0.4	0.4	0.4
Cu	0.2			0.9	0.6	0.6	0.6	0.4
Cu-30% Ni	0.4			1.3	1.0			
Cu-10% Ni							1.2	
Admiralty brass						0.7		
70/30 brass	0.7	5.2	3.9	1.7	1.2	0.8	1.4	0.7
Cu-10% Ni				1.7	1.5			0.8
Admiralty brass	0.8	6.2	4.5	2.0	1.5		1.5	1.0
Cu		7.0						
Aluminium brass	0.9	7.2	4.7	2.4	1.9	0.8	1.6	1.1
Cu			4.9					
Cu-10% Ni	1.4	9.4	9.4			0.8		
Aluminium bronze	1.4	16.0	12.9	2.6	2.7	1.0	1.9	1.4

was ranked either first or second. On the run-around coil at pool Cl-2, where the conditions were more aggressive, copper did not occupy such a high position, but its corrosion rate was tolerable nonetheless; over a 2 year period, its average rate of corrosion was 4.9 μm y^{-1}, only a third faster than that of 30% cupronickel, the most resistant material.

On the run-around coil at pool Cl-2, the alloys were tested for 1 and 2 years. The ranking was substantially independent of time and, for every material except 10% cupronickel, the corrosion rate decreased with time.

5.3 Dissimilar metal corrosion

Serious corrosion of aluminium components in bimetallic aluminium-to-copper test assemblies occurred at both ozone and chlorine pools. In the worst instances, corrosion perforated the 0.25 mm thick aluminium coupon in the region of contact with the copper fixture within six months. The intensity of attack reflected the aggressiveness of the environment as indicated by the copper test coupon corrosion rates. However, even the mildest conditions gave serious attack. For instance, at pool Cl-4 there was considerable dissimilar metal corrosion after one year's exposure. The test coupons also indicated that the contamination of the air-impact face at pool O$_3$-1 had hastened bimetallic corrosion. Figure 2 shows that the coupons which became contaminated were more heavily corroded than those which remained clear: the latter were placed on test after the air filter had been fitted in front of the exchanger to eliminate contamination.

Vinyl-coated aluminium coupons behaved similarly to those of uncoated aluminium.

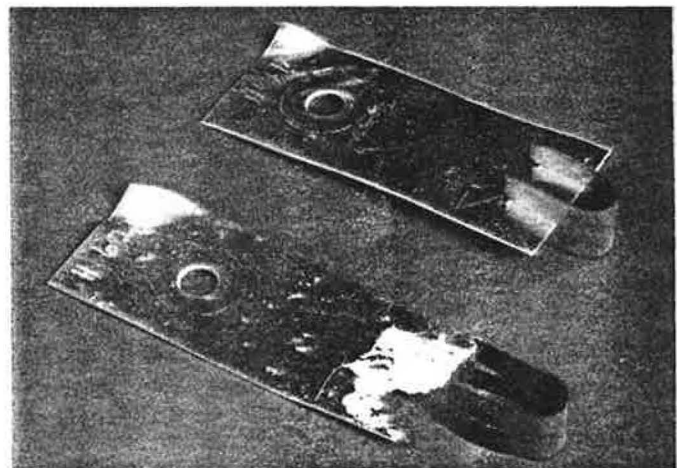On model exchangers, too, dissimilar metal corrosion was observed. Those with vinyl-coated and chromate-treated

Figure 2   Dissimilar metal corrosion suffered by test sample which had become contaminated during 5 months' exposure at pool O$_3$-1. The other sample was tested for the same length of time after an anti-fouling filter had been fitted.

aluminium fins resisted corrosion better than those with plain aluminium, but were still prone to an unacceptable degree of localised attack.

5.4 Crevice corrosion

No evidence of crevice corrosion was detected in the copper-based materials of Table 1 after up to 3 years on test.

5.5 Painted steel samples

After one year's exposure in the most aggressive environment (on the air-impact face of the run-around coil at pool Cl-2), the steel and galvanised steel test samples painted with

chlorinated rubber paint had resisted corrosion well. There were no signs of paint discolouration and the substrate remained free from attack. Meanwhile, the uncoated mild steel control samples had become heavily corroded but the galvanised steel control samples were still protected by their zinc coating.

6 Discussion

6.1 Copper

In any given installation the rate of general corrosion will vary through an exchanger. Of the several factors influencing the fin corrosion rate (such as the composition of the condensate, its film thickness and temperature), condensate film thickness will show a particularly wide variation. It can range from a 'just damp' condition near the front of the exchanger, where the relative humidity may be less than 100% and condensate is present only because of the hygroscopic nature of contaminating debris or previously formed corrosion product, to copious condensate flow further downstream within the body of the exchanger when the airstream temperature has been reduced enough for condensate to precipitate rapidly from the saturated air. If the fin corrosion pattern at pool Cl-1 is typical, corrosion is most rapid under 'just damp' conditions, whereas copious condensate flow gives less corrosion. Such a pattern is consistent with the known effect of humidity on atmospheric corrosion rates[1-4]. Below a threshold relative humidity (usually about 60 or 70%) corrosion is negligible. Above it, the corrosion rate depends strongly on the humidity, increasing sharply. The critical humidity is that at which a liquid film is just beginning to form on the surface of the metal. The onset of this stage is promoted by salts, corrosion products and contaminants on the surface. The rate of corrosion reaches a maximum when the surface is just damp, for the surface then carries a very thin liquid film which is capable of supporting the aqueous electrochemical corrosion reactions, yet is thin enough to allow rapid diffusion of oxygen to the corroding surface. Usually this condition is attained at some humidity well below 100%; thereafter the corrosion rate declines somewhat as the relative humidity increases to 100%.

Only general surface corrosion is of concern in relation to copper in swimming pool hall atmospheres. Localised corrosion is not likely to occur. In particular, the tubes in an all-copper exchanger would not be expected to suffer from pitting or crevice attack; none was found in the exchanger from service, and none was observed in test assemblies exposed at both chlorine- and ozone-sterilised pools.

To predict the life span of an all-copper exchanger, it is necessary to know the point in time at which exchanger efficiency would become unacceptable as a consequence of the fins becoming thinner and of their being covered by corrosion product. This information is not available. However, considering the maximum observed corrosion rate of copper—13.4 μm y^{-1}, representing 5% fin thickness per year—it would not seem unreasonable to expect a lifetime of at least 10 years, even for the most aggressive environment encountered in the present study, and even discounting the probable slowing of attack with time. In less corrosive environments the lifetime would be expected to be much longer. To achieve a less hostile environment, the pool water should be well managed so as to control the atmospheric concentration of any species emanating from the pool which could cause corrosion. The critical component in the atmosphere has not been identified, but clearly a chlorine-containing species is involved for a chlorine-sterilised pool since the copper corrosion product contains chloride. The atmospheric composition will be controlled *inter alia* by the pool composition, and there is fragmentary circumstantial evidence to suggest that a high combined chlorine level in the pool water is associated with increased corrosivity of the atmosphere. It is possibly desirable, therefore, to restrict the combined chlorine content of the pool water to a low level, say below 1.5 ppm. It is interesting to note that ozone-sterilised pools invariably operate well below this figure, with correspondingly low corrosion rates for copper test samples.

6.2 Tin-plated copper

Under the most severe conditions encountered, the tin layer was removed within a couple of years or so. In such cases, plating is probably not economically attractive because a plated exchanger is some 15–20% more expensive than a plain one, although some of the expense can be offset against the longer period between paying labour charges for removing the old exchanger and installing a new one. These costs can be quite high and can be an important consideration in economic assessment. Under mildly corrosive conditions, plain copper promises to be extremely durable, and there appears to be no need for tin plating.

6.3 Copper alloys

The alloy 30% cupronickel is the only one which can be considered seriously as a substitute for copper. It often resists corrosion better than copper, though under mild conditions copper is sometimes superior. Unfortunately its thermal conductivity is much poorer than that of copper, and a cupronickel exchanger having the same thermal performance as a copper one must be physically larger. This and the greater cost of the cupronickel makes the cost of an all-cupronickel exchanger much higher, more than double that of a copper one. Thus it is not economically attractive.

6.4 Aluminium

Aluminium, whether plain or coated, has been found to be prone to bimetallic corrosion when in contact with copper in all the swimming pool hall atmospheres studied. The general corrosion resistance of aluminium is good, but the localised nature of the dissimilar metal corrosion means that a relatively small total loss of metal from an aluminium fin close to a copper tube can lead to a considerable deterioration in heat transfer capability. The risk of bimetallic corrosion is present regardless of the type of pool sterilisation. The attack is most pronounced in those situations where copper test coupons corrode rapidly, but significant corrosion is observed even under milder conditions. Thus the use of aluminium-finned exchangers is always likely to be attended by the risk of dissimilar metal corrosion.

6.5 Steel

Mild steel components in the ventilation system need to be protected against corrosion. Those wetted by condensate are at greatest risk.

The steel should be galvanised (*BS 729:1971*) and subsequently painted with chemical-resistant paint (*BS 5493:1977*), since galvanising alone is often inadequate unless the surface is certain to remain dry, such as may

happen in the duct upstream of the heat recovery chamber. In the vicinity of the exchangers, however, it would be prudent to treat the duct panelwork fully. The framework of the exchanger and the condensate collection trays must be fully protected. For the trays and their drain pipes, it would be better to use non-corrodible materials such as a plastic.

7 Conclusions

The condition of the exchangers can be assessed only if ductwork access hatches are provided to allow regular inspection of each face of every exchanger. Designs should also provide for the eventual removal and replacement of exchangers.

Copper is a suitable fin material for the heat-recovery exchangers for the swimming pool halls investigated. This is likely to be the case for other pools using similar systems. The life predicted for a copper-finned exchanger with copper tubes is more than 10 years.

Test samples of other materials show that 30% cupronickel resists corrosion better than copper at some sites, but copper is preferred on economic grounds.

Tin plating confers only relatively short-term protection to the copper fins under the worst corrosive conditions encountered in the study, extending their life by just two years or so. This is not necessarily economically attractive. However, tin plating may be justified in some cases if the frequency of having to pay the labour costs (which can be considerable) for removing the old exchanger and reinstalling a new one is taken into account. Under milder corrosive conditions, copper has adequate corrosion resistance without plating.

The use of aluminium fins on copper tube is accompanied by the risk of dissimilar metal corrosion of the aluminium close to the copper. It was observed at all the pools studied.

Whether plain or coated, the fins can suffer localised corrosion, with the consequent risk of serious deterioration of thermal contact between fin and tube.

Steel components in and around the heat-recovery chamber corrode when in contact with condensate. Galvanising alone is often inadequate; additional protection can be provided by chlorinated rubber paint. For condensate collection trays and drain lines, construction from a plastic material (such as PVC) would obviate corrosion.

At some sites the exchanger can become deleteriously contaminated if the air from the pool hall is not filtered. A disposable glass-fibre filter in front of the exchanger is effective in preventing fouling.

References

1 Tomashov N D *Theory of corrosion and protection of metals* pp 367–398 (New York: McMillan) (1966)
2 Shreir L L *Corrosion* Vol. 1 pp 2.26–2.37 (London: Newnes-Butterworths) (1976)
3 Uhlig H H *Corrosion and Corrosion Control* pp 139–148 (Chichester: Wiley) (1967)
4 Evans U R *The Corrosion and Oxidation of Metals* Chapter XIII (London: Arnold) (1960)