DISMANTLING THE MYTHS ABOUT COLD CLIMATE CORROSION*

** This is an edited version of the paper, 'Studies in Antarctica help to better define the temperature criterion for atmospheric corrosion' by George King, Wayne Ganther (CSIRO Building, Construction & Engineering Australia, Janet Hughes (National Gallery of Australia), Paolo Grigioni and Andrea Pellegrini (ENEA Italian National Antarctic Research Program). The paper was presented to the NACE International Northern Area Region Conference, 'Shining a Northern Light on Corrosion', Anchorage, Alaska, February 2000.*

Long-held views about corrosion in cold climates have led to the development of almost mythological beliefs that have been dispelled by recent scientific endeavour.

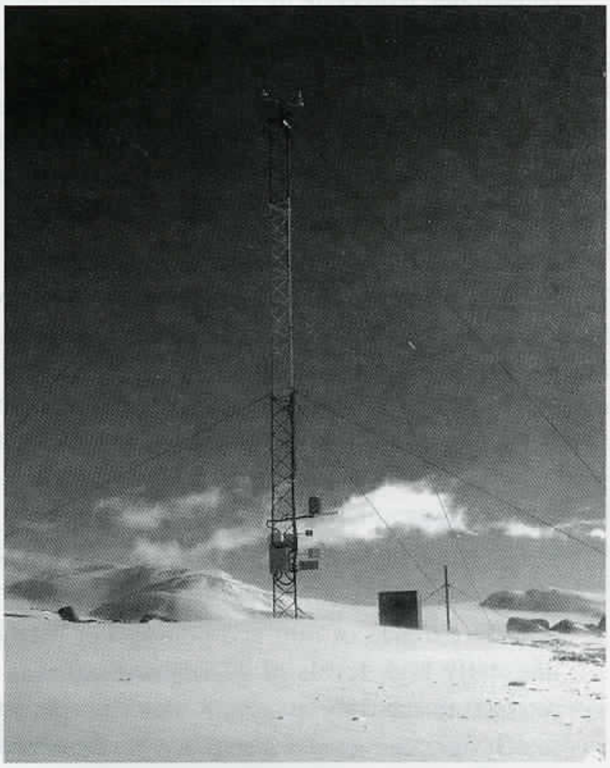
For example, a body of scientific evidence has now dispatched the view that cold dry climates such as those in Antarctica produce nil or extremely low corrosion. Now a new international scientific collaboration has shown that the methodology for calculating corrosion rates needs to be changed if we are to better protect our historic heritage in Antarctica, and valuable infrastructure. This view is implicit in ISO 9223, which effectively says that one estimate of the time of wetness of a surface can be used worldwide.

A new testing program just completed at Terra Nova Bay on the Ross Sea in the region known as Northern Victoria Land in eastern Antarctica, has shown that the accepted international standard for calculating corrosion does not in fact apply in these cold climates.

COLD CLIMATE CORROSION – BACKGROUND

Traditionally it has been long regarded that atmospheric corrosion is low in the very cold regions of the world because of the prevailing dry and cold climates. While this has been demonstrated for regions in Antarctica remote from the ocean, marked corrosion problems are observed on both historic and current buildings located close to the Antarctic coastline. Measurements of atmospheric corrosion rates at these sites have yielded results similar to some temperate environments. These observations are in conflict with the current international definition of the time that a metal surface is wet and can therefore corrode.

Antarctic corrosivity data thus raised fundamental questions about the time of wetness (TOW) criterion



Automatic weather station at enigma Lake near Terra Nova Bay station

in the International Standard ISO 9223. This is defined as 'the period during which a metallic surface is covered by adsorptive and/or liquid films of electrolyte that are capable of causing atmospheric corrosion'. The standard points out that 'wetting of surfaces is caused by many factors, for example dew, rainfall, melting snow and a high humidity level', and the calculated TOW of corroding surfaces can be estimated as the length of time when the relative humidity is greater than 80% at a temperature greater than 0°C.

A note in the standard qualifies this criterion and indicates that other factors such as metal type, object orientation, corrosion products and pollutants on the surface, may influence the TOW. However, the standard considers 'the criterion usually sufficiently accurate for the characterization of atmospheres'.

Recent experiments have thrown doubt on this. In a study conducted at temperate and tropical sites within Australia and three tropical Asian sites, TOW was measured directly on the surfaces of zinc specimens using the gold grid method discussed below (Experimental). The ISO criterion did not predict well the high TOW for tropical and temperate marine Australian sites and a tropical marine Asian site (Phuket, Thailand), nor a moderate TOW for an inland–tropical Australian site.

On the basis of meteorological data, the TOW for the Antarctic locations is much lower than at the comparable temperate locations previously studied. It has also been previously noted, however, that the long hours of sunlight in the Antarctic summer may raise the surface temperature of dark objects considerably above the surrounding air temperature, but that the temperature rise is inadequate to totally volatilise an electrolyte layer.

Confounding this is the observation that when the Scott expedition historic huts at Cape Evans (New Zealand Ross Dependency) were cleared of ice, the artefacts inside them which had suffered little corrosion in the previous 60 years started to corrode at significant rates without being subject to heating by direct solar gain.

Salt deposition

Examination of the role of salt deposition in Antarctic conditions has recently revealed that because of the general absence of rain and consequent leaching, unusually high levels of sulfate and chloride are retained in corrosion products. The chloride levels in rust from continental Antarctic sites far exceeded those for specimens from temperate marine sites, and the sulfur levels were comparable to those on specimens exposed at true industrial sites. The high concentrations of salts that could be found on a metal surface in the absence of regular washing by rain could logically be expected to increase corrosivity. In addition, the phenomenon of depression of the freezing point of salt solutions is well established by other researchers.

Given the significance of corrosion occurring unexpectedly in consistently cold conditions, particularly in the presence of salts, and given that the majority of Antarctic research stations are located close to the sea, corrosion could present an unforeseen risk for modern buildings which are generally designed presuming minimal corrosion rates.

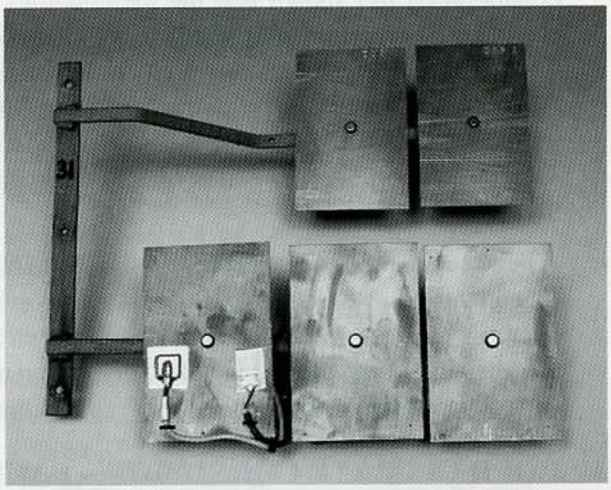
The information to be derived from this research is also believed to be of practical benefit in the preservation of historic metal artefacts and building components at the abandoned bases of the Scott (1902–1904, 1911–1914) and Shackleton (1907–1909) expeditions at Ross Island.

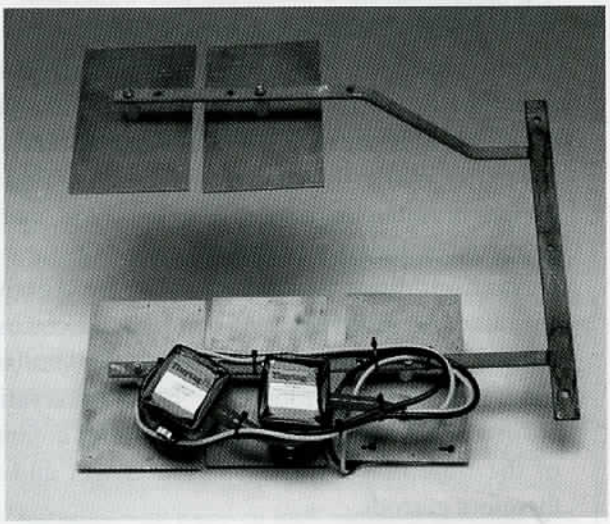
Hence, in order to better understand the conditions under which corrosion may occur in cold climates, an experimental program was devised which would demonstrate whether corrosion could occur when temperatures were too low for corrosion to occur according to ISO 9223.

THE EXPERIMENT SITE

It was decided that a suitable coastal site should be selected where temperatures are consistently low, but without any complicating factors such as anthropogenic pollutants from diesel generators that are generally used for producing electrical power. The Australian bases Mawson, Casey and Davis were unsuitable for the experiment as they all lie at latitudes of approximately 66–68°S, and maximum temperatures can exceed 0°C in the summer months, especially at Davis station.

The Italian research station at Terra Nova Bay in the Ross Sea area of Antarctica was chosen as a suitable





Zinc and steel plates mounted on bracket for exposure: (top) front view showing sensors for surface temperature and wetness; and (bottom) rear view showing data loggers for recording temperature and wetness.

location as detailed meteorological data suggesting that temperatures above 0°C were rare and several meteorological facilities were available which were specifically located away from potential sources of pollution.

DETAILS OF THE EXPOSURE SITE

The main feature of the region is the influence of the mountains – orography. The nearby trans-Antarctic mountain range represents the boundary of the polar ice cap. Orographic factors have a noticeable impact on the climate of the region, since they drive the atmospheric flows, giving rise to the dynamic systems prevailing in the area such as the katabatic and barrier winds. The katabatic winds originate over the polar plateau and blow down toward the coast following the valleys that intersect the trans-Antarctic range. In Terra Nova Bay these winds are particularly intense. Such winds usually blow toward the Ross Sea either from SW or NW. Nearby stations to Terra Nova Bay are New Zealand's Scott base and the US base at McMurdo Sound. The actual exposure site was at an automatic weather station near Terra Nova Bay station at an altitude of 21 m and approximately 1 km from the sea/sea ice.

The yearly mean and extreme values of temperatures (°C) of –15.1 to –24.5° (minimum) and –4° (maximum) showed it was ideal to test the ISO criterion of time of wetness.

EXPERIMENTAL MATERIALS AND METHODS

Materials exposed for corrosion measurements, unalloyed carbon steel ('mild steel') to Australian Standard AS 1594, a copper-bearing steel used as a standard for measuring corrosion, and high purity zinc (all 3mm thick) were used to measure the corrosion rate at the location.

Mounting specimens

For any atmospheric corrosion measurements, appropriate procedures have to be devised for each location for the mounting and exposure of specimens. The conventional methods of holding rectangular specimens on racks using porcelain insulators are often not possible as racks may not exist at any given location, and it may not even be possible to construct them.

Techniques have been developed at CSIRO to fix specimens to small brackets using thin bolts and machined plastic mounting spacers inserted into a central hole in the specimen.

Very compact assemblies can be made holding up to six standard specimens, and these can be easily fixed to suitable wooden or metal structural members. The technique has been employed very extensively for corrosivity surveys throughout Australia mounting the brackets onto low voltage power supply poles. Because of the logistical constraints of carrying out any work in Antarctica, especially when air transport of equipment is required, it is imperative that experimental assemblies be as compact and light as possible.

The CSIRO technique is ideal for this application, and the specimens and instruments can be packaged and sealed to ensure their integrity.

One bracket contained duplicate specimens of unalloyed carbon steel 150 x 100 mm, and a third specimen instrumented for surface temperature and TOW; duplicate specimens of zinc 150 x 100 mm were also mounted on this bracket. A second bracket carried duplicate specimens of the copper-bearing steel 100 x 50 mm. All specimens were mounted onto the bracket arms vertically (as opposed to exposure at angles of 45° or 30° which are usually employed).

Instrumentation

The additional unalloyed carbon steel plate was instrumented for the measurement of surface temperature and TOW. A temperature logger with an external thermistor was used for surface temperature. This can be seen on the left of the instrumented plate in Figure 1. A wetness logger with a gold grid sensor was used to measure when the metal surface was actually 'wet'. The gold grid sensor is on the right of the instrumented plate in the photo. The values produced by the wetness logger give a value for the conductivity of the surface of the gold grid. The conductivity is related to the thickness of the moisture film on the grid. It should also be noted that the specific conductivity will influence the values produced by the logger, i.e. a thin highly conductive layer may give the same value for wetness as a thicker and less conducting solution.

The loggers are extremely compact and are mounted directly on the bracket arms holding the specimens. Readings were recorded at intervals of one hour.

TRANSPORT AND EXPOSURE

The experimental set-up was assembled at CSIRO on 1 December 1999 and transported by air to Christchurch New Zealand in late December. It left for Antarctica on board the ENEA supply ship Italica on 6 January 2000 arriving in Terra Nova Bay on 15 January. Exposure of the assembly was not carried out at that time due to unforeseen circumstances, and it remained in storage at the station throughout the winter of 2000.

The record of wetness showed clearly that the specimens remained perfectly dry (inside the sealed bag) until after exposure on 29 October. Recovery was on 2 December 2000, giving an exposure period of 34 days. The assembly was returned by air to New Zealand and then Australia. The record of surface wetness showed that the specimens had remained dry in transit.

KEY DATA SUMMARY

Corrosion results

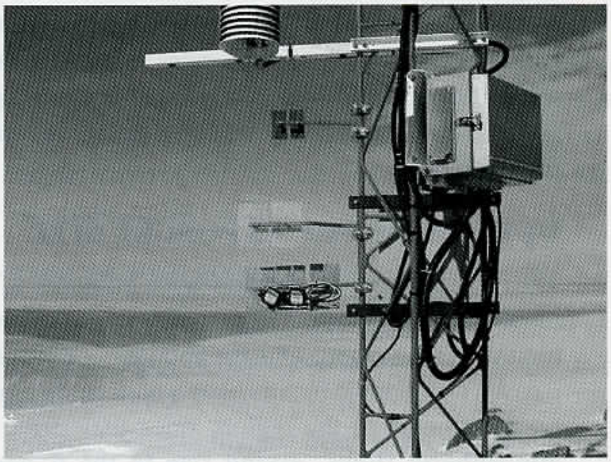
The average mass losses and equivalent corrosion rates for the three materials were as follows:

- unalloyed carbon steel 0.215 g, 9.3 *μm*/year;
- copper bearing steel 0.0174 g, 8.1 *μm*/year; and
- zinc 0.067 g, 3.2 *μm*/year.

While recognising that the exposure period is short, these corrosion rates are very much higher than one would expect in this environment. Support for the present results is provided by previous measurements at nearby Cape Evans (the site of Scott's hut) using the copper-bearing steel, with a result of 10.8 μm/year.

Climatic parameters and surface wetness

The prevailing winds for the duration of the experiment were overwhelmingly from the west. These are the katabatic winds blowing from the polar plateau towards the sea. This demonstrates that at this particular site, salt deposition on the corrosion specimens during the period of exposure would be minimal.



Specimens and instruments affixed to tower at exposure site

The surface temperature measured throughout the winter period varied from about –7 to –33°C, but for much of the time it was below –20°C.

The trend for air temperature increased from about –20°C to about –3 to –5°C during the exposure period but the relative humidity was nearly always below 80%. Table 1 presents key parameters derived from the meteorological data, and the measured surface temperature and wetness. At no time did the relative humidity exceed 80% and the air temperature exceed 0°C simultaneously and the ISO TOW was consequently zero. However, there were many events of wetness between relative humidities of 50% and 80%, and analysis showed that the measured time-of-wetness (28% of the total time) was almost

	RH		Ambient temp.		Surface Temp.	ISO TOW	TOW RH>50%; temp. –10°C	Grid TOW
	>80%	>50%	>0°C	>-10°C	>0°C			
Percent of exposure time	2.4	35.3	0.9	68.6	6.3	0	29.9	28.4

Table 1. Percentage of time for parameters derived from meteorological and measured data

identical to the time for which the relative humidity exceeded 50% and the air temperature exceeded –10°C.

CONCLUSION

Substantial corrosion has been measured in the specimens exposed at temperatures well below 0°C, which is in direct contradiction to the ISO criterion. The general conclusion from the experimental program is that the ISO 9223 criterion for estimating time of wetness (TOW) has been demonstrated to be totally incorrect for cold climates. It is proposed on the basis of the present results, that the TOW in these environments be estimated as the length of time that relative humidity exceeds 50% and the ambient temperature exceeds –10°C. This needs to be addressed in a revision of the standard.

A second identical experimental assembly was prepared in October 2000 and transported under similar conditions by air to New Zealand and then Terra Nova Bay for an exposure period of one year. This will allow the experiment to be conducted over a period during which the air temperature is below –15°C for over eight months. This experiment will provide solid validation for the first round of experiments and results will be available by early 2002.

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Editor.

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***Cover:** The photo montage on the cover reflects the contents of this issue. The failed fence highlights what loss of adhesion means to coated steel products. The oceanfront environment presents one of the greatest corrosion management challenges and corrosion mapping of these locations will allow better prediction of coating performance. The near 100-year old dairy building still has its original galvanized iron roof. A relatively thin coating of zinc has preserved the steel for almost a century, but where has the zinc gone?*

The decommissioned USS Reeves awaits the ultimate recycling in Newcastle Harbour. This old warship is destined to become a target in a joint naval exercise and will be sunk about 500 km off Australia's East Coast, returning several thousand tonnes of iron to the ocean floor, from where most iron deposits are believed to have developed.

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