The Relative Corrosion Severity of Laboratory Environments on Mild Steel, Medium Carbon Steel, Brass and Aluminium

J. I. Sodiki

Abstract—By the measurement of weight changes with time, the extents of corrosion on specimens of mild steel, medium carbon steel, brass and aluminum exposed to the laboratory atmosphere and 0.1M solutions of sodium chloride, ammonium hydroxide and hydrochloric acid were obtained. These solutions, respectively, represent salt, basic and acid environments that are usually encountered by the test metals in actual service. Corrosion – time graphs were then drawn for each exposure environment to facilitate the assessment of the relative aggressiveness of each environment on the test metals. A graphical illustration was further made to show the relative aggressiveness of the environments on any particular metal.

Index Terms—Laboratory environments, mild steel, medium carbon steel, brass, aluminum.

I. INTRODUCTION

In selecting a metal for a specific application, it is necessary to have a prior knowledge of its corrosion behavior in the particular environment. In some other circumstances, it may also be required to have a knowledge of the relative aggressiveness of different environments on a particular service metal; or of the relative aggressiveness of a particular environment on different metals. Such knowledge is important, for instance, in a situation where alternative metal containers are being contemplated to hold a particular corrosive liquid.

In nearly neutral aqueous environments, the corrosion of metals is a result of the oxidation of the metal by a reaction which in its simplest form may be written as [1].

$$M \rightleftarrows M^{2+} + 2e^-$$
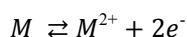
Assuming the metal to be bivalent as in the case of iron, copper and zinc; or as in the case of a trivalent metal such as aluminum.

$$M \rightleftarrows M^{3+} + 3e^-$$
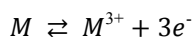
It is well known that the susceptibility of a metal to electrochemical corrosion, to a large extent, depends on the metal's position in the electrochemical series; and when metals and their alloys are in service their relative corrosion behavior is usually predictable by recourse to the galvanic series relevant to the service environment. There is, thus, the galvanic series for sea water, for instance [2], [3].

While the galvanic series are useful in predicting the corrosion behavior of unprotected metals, several other factors come into play in determining actual corrosion patterns. Such factors include the metal's exact composition; its dimensional properties such as surface area, shape, and surface roughness index; and its surface temperature. The actual relative aggressiveness of different service environments on metals would therefore be known only through controlled experiments.

In this paper, the relative extent of corrosion, after any given time of exposure of specimens of mild steel, medium carbon steel, brass and aluminum, in particular laboratory environments are assessed. The environments utilized are the laboratory atmosphere and 0.1M solutions of sodium chloride, ammonium hydroxide and hydrochloric acid. These solutions respectively represent salt, basic and acid environments that are usually encountered by the test materials in actual service.

For the sake of achieving the desired control in experimentation, factors which normally influence the extent of corrosion over time such as the specimen's dimensions (i.e. length and diameter), surface roughness index and temperature were fixed. This was achieved by making the specimens as identical as possible and by placing them as close as possible on the same laboratory bench.

Such tests as these would be useful for other test metals and exposure environments.

II. EXPERIMENTAL PROCEDURES

A. Test Material Composition

The chemical composition of the test materials obtained from the stockist are as shown in Table I.

TABLE I: CHEMICAL COMPOSITION OF TEST MATERIAL

Test Material	Main Element	Composition of Other Elements (Wt. %)	
Mild steel	Iron	Carbon	0.150
		Sulphur	0.023
		Phosphorus	0.030
		Manganese	0.500
		Silicon	0.250
Medium carbon steel	Iron	Carbon	0.350
		Sulphur	0.020
		Phosphorus	0.035
		Manganese	0.600
		Silicon	0.170
Brass	Copper	Zinc	30
Aluminium	Aluminium	Iron	0.7
		Manganese	0.1
		Silicon	0.5

B. Preparation of Exposure Environments

Standard laboratory methods were used to prepare 0.1M solutions of sodium chloride, ammonium hydroxide and hydrochloric acid [4], [5].

C. Preparation of Specimens

Cylindrical dimensions of 60mm length and 10mm diameter were chosen for all specimens of the test metals. The specimens were obtained by turning on a 'Colchester Chipmaster' lathe. Each specimen was degreased by washing with a piece of cotton wool in acetone immediately after turning.

As it is well known that specimens with rough surfaces corrode faster than those with smooth ones [6, 7], specimens whose surface finish indices were as close as possible were chosen for exposure in each environment. This was ensured by measuring the surface finish index of each specimen with a 'Talysurf 10' sylus instrument, and sorting accordingly.

Each specimen was subsequently stored in a desiccator (which had been designated for each exposure environment) until the first weighing prior to exposure in the relevant environment.

D. Corrosion Measurement

Among the several methods that abound [8, 9, 10, 11], the method of weight change determination was chosen for the measurement of relative aggressiveness of the test environments. This was due to the ready availability of the required laboratory apparatus.

Some degree of flaking off and washing off of corrosion products was inevitable in the course of the measurements. This was more severe with the specimens exposed in the solutions than with those in the laboratory atmosphere. This necessitated careful handling of the specimens exposed to the laboratory atmosphere, to obtain periodic weighings of the same specimen. A corrosion – time graph was thus drawn for each specimen.

In the case of the specimens exposed in liquid environments successive weighings on the same specimen were not done. Rather, a set of specimens, as close as possible in surface finish index, was required to obtain a corrosion-time graph; the mean surface finish index being the representative one for the set. After the 0.1M solutions had been prepared and all the specimens had been prepared and sorted, the first weighings were done and the specimens exposed in the relevant environments.

E. Exposure in Solution

75ml of the relevant solution were put in each of 75ml beakers which had been marked for identification. Each specimen was then immersed diagonally in the corresponding solution as shown in Fig. 1, and the time clock reading at the instant of immersion recorded. The top of the beaker was then covered with cardboard paper and the beaker rested on a table.

Subsequent clock readings and weighings were taken thereafter. Before any subsequent weighing, the specimen was washed in distilled water using a piece of cotton wool to scrub off any loose corrosion product. The used specimen was discarded after the weighing. The weight loss per unit surface area of specimen was thereby calculated for recorded times of exposure.

F. Atmospheric Exposure

For atmospheric exposure, the specimens were placed in a tray which could hold about 15 specimens at a time, as shown in Fig. 2. The wooden base support for the specimens was numbers, as shown, for easy identification.
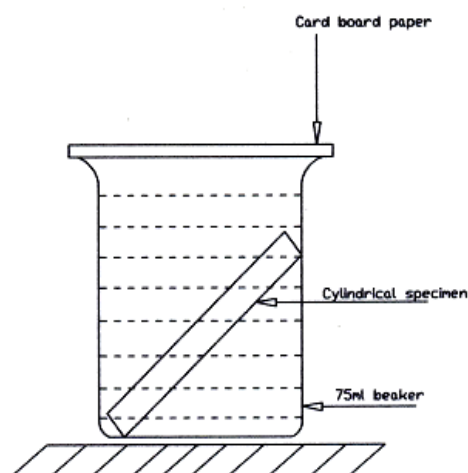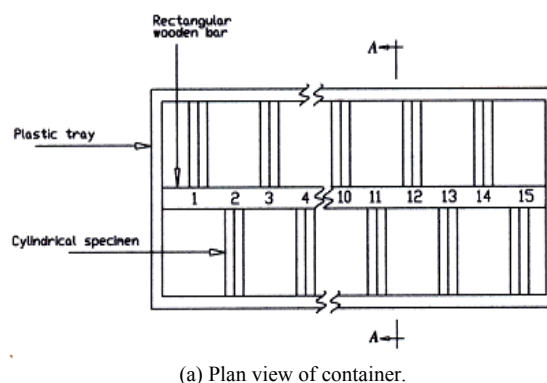

Fig. 1. Exposure in 01M solution.

(a) Plan view of container.
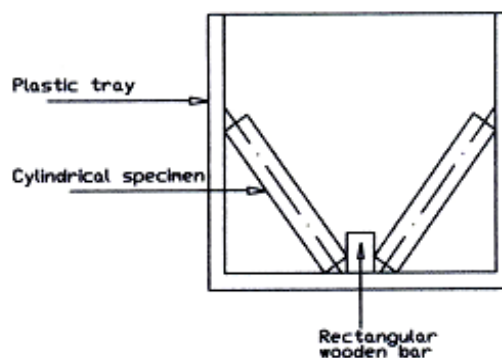
(b) View A-A.
Fig. 2. Atmospheric exposure.

III. RESULTS

Tables II to XVII show the results of the experiments. The results are also displayed as corrosion-time graphs in Figs. 3 to 7. Tables II to V show the results of the atmospheric exposure tests as weight increase per unit surface area of specimen; while Tables XI to XVII show the results of the tests for exposure in the solutions as weight loss per unit surface area.

TABLE II: ATMOSPHERIC EXPOSURE OF MILD STEEL (SURFACE FINISH VALUE 0.95μM)

Exposure Time		Weight Increase $(10^{-3}mg/mm^2)$
77h	20min	3.706
97h	20min	2.940
118h	40min	4.340
170h	0min	4.741
240h	20min	6.043
317h	48min	7.979
340h	50min	7.779

TABLE III: ATMOSPHERIC EXPOSURE OF MEDIUM CARBON STEEL (SURFACE FINISH VALUE 1.01 μM)

Exposure Time		Weight Increase $(10^{-3}mg/mm^2)$
44h	15min	0.318
110h	21min	0.636
163h	4min	0.636
187h	39min	0.509
255h	40min	0.573
286h	6min	0.527
318h	11min	0.730

TABLE IV: ATMOSPHERIC EXPOSURE OF BRASS (SURFACE FINISH VALUE 1.01 μM)

Exposure Time		Weight Increase $(10^{-3}mg/mm^2)$
70h	16min	0.423
105h	11min	0.446
138h	12min	0.678
191h	55min	0.593
237h	56min	0.568
301h	3min	0.689

TABLE V: ATMOSPHERIC EXPOSURE OF ALUMINUM (SURFACE FINISH VALUE 1.10 μM)

Exposure Time		Weight Increase $(10^{-3}mg/mm^2)$
28h	57min	1.382
46h	44min	1.682
94h	4min	1.562
122h	28min	2.223
168h	25min	1.581
216h	50min	2.068
272h	41min	1.784

TABLE VI: EXPOSURE OF MILD STEEL IN 0.1M HYDROCHLORIC ACID (SURFACE FINISH VALUE 1.17 μM)

Exposure Time		Weight Loss $(10^{-3}mg/mm^2)$
16h	35min	22.789
45h	19min	51.989
92h	44min	57.159
111h	42min	56.036
137h	26min	55.356
164h	33min	56.604
184h	20min	57.562

TABLE VII: EXPOSURE OF MEDIUM CARBON STEEL IN 0.1 M HYDROCHLORIC ACID (SURFACE FINISH VALUE 1.10 μM)

Exposure Time		Weight Loss $(10^{-3}mg/mm^2)$
2h	1min	28.433
22h	16min	45.646
48h	42min	50.574
73h	58min	51.408
144h	53min	59.673
192h	26min	64.302
235h	46min	67.719

TABLE VIII: EXPOSURE OF BRASS IN 0.1M HYDROCHLORIC ACID (SURFACE FINISH VALUE 1.20 μM)

Exposure Time		Weight Loss $(10^{-3}mg/mm^2)$
22h	48min	2.250
69h	35min	6.897
92h	48min	8.513
118h	27min	10.825
142h	14min	11.683
191h	42min	16.508

TABLE IX: EXPOSURE OF ALUMINUM IN 0.1 M HYDROCHLORIC ACID IN (SURFACE FINISH VALUE 1.16μM)

Exposure Time		Weight Loss $(10^{-3}mg/mm^2)$
3h	59min	0.718
28h	13min	1.618
94h	32min	5.423
117h	32min	6.636
143h	38min	7.924
194h	40min	9.893
218h	4min	10.957

TABLE X: EXPOSURE OF MILD STEEL IN 0.1M SODIUM CHLORIDE (SURFACE FINISH VALUE 1.09 μM)

Exposure Time		Weight Loss (10^{-3}mg/mm^2)
26h	9min	4.535
96h	59min	4.502
143h	15min	7.604
169h	39min	8.334
234h	22min	10.533
263h	55min	11.290
283h	29min	11.959

TABLE XI: EXPOSURE OF MEDIUM CARBON STEEL IN 0.1 M SODIUM CHLORIDE (SURFACE FINISH VALUE 1.17 μM)

Exposure Time		Weight Loss (10^{-3}mg/mm^2)
23h	10min	5.050
94h	10min	9.759
117h	37min	13.588
168h	40min	16.223
186h	30min	18.318
232h	56min	22.675
281h	22min	26.328

TABLE XII: EXPOSURE OF BRASS IN 0.1M SODIUM CHLORIDE (SURFACE FINISH VALUE 1.05 μM)

Exposure Time		Weight Loss (10^{-3}mg/mm^2)
21h	27min	0.307
68h	17min	0.893
91h	28min	1.250
124h	9min	1.429
142h	6min	1.421
189h	28min	1.440
240h	47min	1.428

TABLE XIII: EXPOSURE OF ALUMINUM IN 0.1M SODIUM CHLORIDE (SURFACE FINISH VALUE 1.13 μM)

Exposure Time		Weight Loss (10^{-3}mg/mm^2)
39h	28min	0.268
73h	2min	0.536
104h	36min	0.804
163h	49min	0.892
223h	2min	0.890
260h	32min	1.250

TABLE XIV: EXPOSURE OF MILD STEEL IN 0.1M AMMONIUM HYDROXIDE (SURFACE FINISH VALUE 1.21 μM)

Exposure Time		Weight Loss (10^{-3}mg/mm^2)
25h	26min	0.876
75h	50min	6.152
125h	21min	10.133
165h	18min	13.741
194h	51min	15.597
289h	33min	23.892
312h	34min	26.462

TABLE XV: EXPOSURE OF MEDIUM CARBON STEEL IN 0.1 M AMMONIUM HYDROXIDE (SURFACE FINISH VALUE 1.24 μM)

Exposure Time		Weight Loss (10^{-3}mg/mm^2)
15h	36min	1.139
44h	32min	4.050
110h	40min	8.814
139h	13min	12.534
162h	48min	15.775
187h	51min	16.984
208h	54min	18.915
259h	33min	24.020

TABLE XVI: EXPOSURE OF BRASS IN 0.1M AMMONIUM HYDROXIDE (SURFACE FINISH VALUE 1.15 μM)

Exposure Time		Weight Loss (10^{-3}mg/mm^2)
21h	19min	0.261
67h	59min	0.894
91h	13min	0.898
116h	51min	0.983
140h	10min	0.947
255h	6min	0.982

TABLE XVII: EXPOSURE OF ALUMINUM IN 0.1M EXPOSURE OF ALUMINUM IN 0.1M (SURFACE FINISH VALUE 1.09 μM)

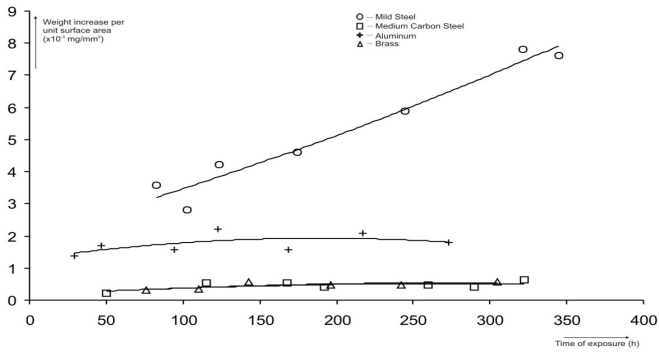| Exposure Time		Weight Loss (10^{-3}mg/mm^2)
25h	53min	0.334
76h	2min	0.121
125h	31min	0.569
146h	17min	0.412
217h	11min	0.360
283h	46min	0.714

Fig. 3. Corrosion-time graphs of test metals in the laboratory atmosphere.
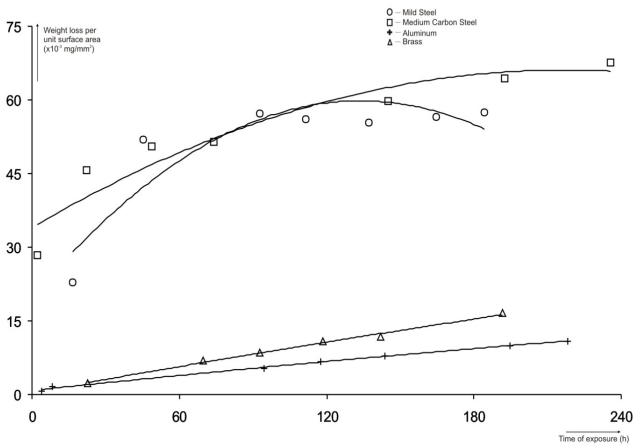

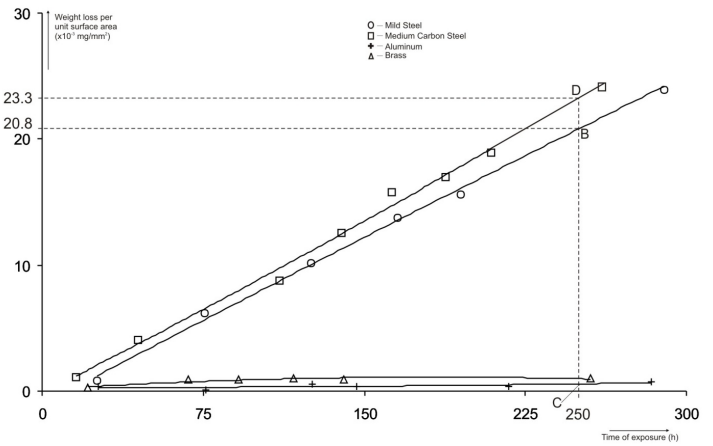Fig. 4. Corrosion-time graphs of test metals in 0.1M hydrochloric acid.

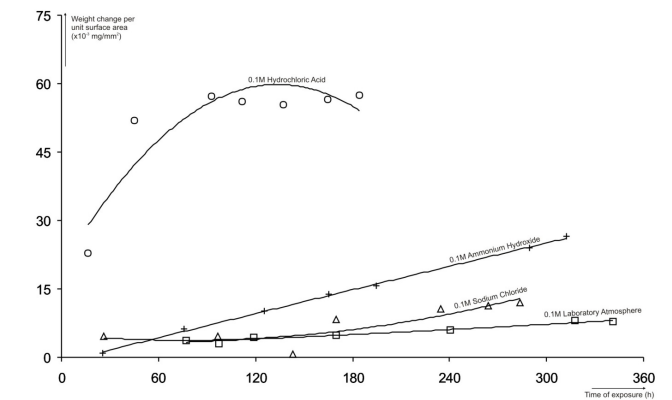Fig. 6. Corrosion-time graphs of test metals in 0.1M ammonium hydroxide.

Fig. 7. Corrosion-time graphs of mild steel in different environments.

IV. DISCUSSION OF RESULTS

A. Corrosion – Time Behaviour

Graphically, all the test materials show a general trend of increasing extent of corrosion with time of exposure, within the limits of exposure time utilized. There is also a general trend of decreasing slope, indicative of reducing corrosion rate, as time passed. This is expected as the initial corrosion products usually provide some surface protection against further attack. Another contributing factor to this trend, in the case of exposure in the 0.1M solutions, is the progressive reduction of the concentrations of the reactant constituents in the solutions. Such a reduction in concentration is not anticipated in the atmospheric tests as the laboratory atmosphere can be regarded to be of infinite extent.

However, some of the specimens and environments show almost constant slopes of the corrosion-time graphs due to the short exposure times utilized, in which the surface protection effect and the weakness of the exposure environments are not yet noticed.
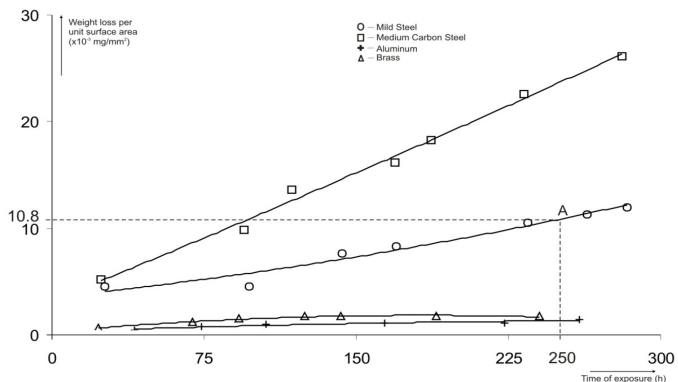

Fig. 5. Corrosion-time graphs of test metals in 0.1M sodium chloride.

B. Atmospheric Exposure

The corrosion action of the laboratory atmosphere on medium carbon steel and brass are equal in severity, within the limits of exposure time utilized, as the graphs of both metals coincide. The general trend is an increasing order on medium carbon steel (and brass), aluminium, and mild steel.

C. Exposure in 0.1M Hydrochloric Acid

Within the period of 100h and 120h the attack of 0.1M hydrochloric acid on mild steel and medium carbon steel appear to be equally aggressive. However, outside of this period, medium carbon steel becomes more severely attacked than mild steel. The severity of attack on the test metals follows a general increasing order of aluminium, brass, mild steel and medium carbon steel.

D. Exposure in 0.1M Sodium Chloride

The severity of attack of 0.1M sodium chloride on the test metals is in an increasing order of aluminium, brass, mild steel and medium carbon steel; as in the case of hydrochloric acid. However, the severity of attack (as observed from the weight loss values) for all the specimens is less for sodium chloride than for hydrochloric acid.

E. Exposure in 0.1M Ammonium Hydroxide

The general order of severity of attack on the test metals by this environment is the same as for 0.1M hydrochloric acid and 0.1m sodium chloride. Furthermore, for all exposure times, the order of magnitude of weight loss in 0.1M ammonium hydroxide is quite close to that in 0.1M sodium chloride, for all the test metals; except mild steel whose extent of corrosion is generally higher in 0.1M ammonium hydroxide than in 0.1M sodium chloride.

F. Experimental Constraints

As noted in an earlier paper which investigated the effect of surface finish on the extent of corrosion of mild steel, using a similar experimental set-up [2], possible experimental shortcomings include the following:

- The test materials are assumed to be homogenous and of standard composition. However, the inevitable heterogeneity of composition of the test materials could bring about unexpected corrosion patterns.
- For tests wherein weight increases were measured (i.e. the atmospheric exposure tests), flaking off of corrosion products from the metal surface in the course of the experiments might erroneously lower subsequent weight readings.
- Although weight changes have been presented in terms of unit surface area of specimen, there could have been discrepancies due to unequal dimensions within a set of specimens. This has arisen due to the difficulty in obtaining equal dimensions during machining.
- Due to the shortness in available exposure times resulting in a few numbers of points, many of the graphs only show approximate trends.

V. CONCLUSIONS

Within the limits of values utilized in the experiments, the following conclusions can be made:

- The test metals show a general increasing severity of corrosion (given as weight change per unit surface area) and decreasing corrosion rates (given as the slopes of the corrosion-time graphs) with increasing exposure times.
- The atmosphere exposure tests indicate an increasing severity of corrosion in the order of medium carbon steel and brass (whose graphs coincide), aluminium and mild steel; while for exposure in each of the 0.1M solutions there is a general severity increase in the order of aluminum, brass, mild steel and medium carbon steel.
- The test can be used to compare the aggressiveness of different environments on a given metal. Thus, after 250h, while the mild steel specimens corrode to an extent of only 10.8×10^{-3} mg/mm^2 weight loss in 0.1M sodium chloride, they corrode to an extent of 20.8×10^{-3} mg/mm^2 in 0.1M ammonium hydroxide. (See points A and B in Figs. 5 and 6, respectively). Fig. 7 shows the relative aggressiveness of different environments on mild steel, as an example of such comparisons. Such comparisons aid material selection for engineering applications.
- Furthermore, the corrosion severity of a particular

environment on different metals can be compared. If, for instance, it is intended to contain an ammonium hydroxide solution, this study indicates the preference for an aluminium container over one of steel. This is because while after about 250h the aluminium container would remain practically unattached, a medium carbon steel container would have corroded by 23.3×10^{-3} mg/mm^2 weight loss. (See points C and D in Fig. 6).

As many metals are usually exposed in fluid environments under flow conditions, suitable experiments can be done under such conditions. Such experiments would, for instance, indicate suitable metals and alloys for the piping of different fluids.

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J. I. Sodiki received his B.Sc. degree in mechanical engineering from University of Lagos, Nigeria in 1981 and M.Sc. degree in mechanical engineering from University of Lagos in 1986. He is working as a lecturer in Department of Mechanical Engineering at Rivers State University of Science and Technology, Port Harcourt, Nigeria. He has 19 years of teaching experience at university level. His areas of interest include thermo-fluids, building services, and corrosion control.