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ELECTRODE PASSIVATION STUDIES

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Air Force Aero-Propulsion
Laboratory
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Ohio

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FIGURE CAPTIONS

ABSTRACT

Studies of the passivation of Zn and Zn-alloys in KOH at 30°C have been made potentiostatically. Zinc shows the characteristic active-passive current-potential curve although the passive current is too high for use in the passive reserve mode in Zn-AgO batteries. Studies of the corrosion of Co, Cu, Fe, Mg, Mn, and Ti in alkaline solutions show them as possible choices for alloying with Zn to improve its standby characteristics. Cu-Zn alloys are not acceptable, however, since the addition of Cu lowers the Zn critical current but does not lower the passive current sufficiently. Zn-Mg solid solutions show the formation of an inactive surface layer and are therefore not suitable. Cu-plating of Zn may be suitable for its protection on standby.

Studies of the passivation of Mg from pH 2 to 14 were carried out with a view toward using the high energy density characteristics of the Mg-m-dinitrobenzene battery. In neutral and alkaline solutions Mg is passive on open circuit and cannot be used in the passive reserve mode. A secondary passivation may be present in mildly acid fluoride solutions.

I. INTRODUCTION

During this quarter we have concentrated our studies on the Zn and Mg anodes. Dissolution and passivation of Zn and its alloys have been investigated in alkaline solutions with particular reference to the use of the zinc-silver battery as a passive reserve system. Mg has been investigated with a view toward using the Mg-m-dinitrobenzene (m-DNB) system in acid solutions.

With respect to the Zn system, we have investigated the active-passive transition of zinc and its alloys in 1N and 6N KOH. The 1N alkali is less aggressive than the normal battery electrolyte and allows us to establish whether a given system has sufficient promise to merit attempted exploitation either by changing the alloy composition or by modifying the electrolyte. (An example would be adding neutral salt to increase conductivity while controlling the corrosion resistance by not changing the pH.) The 6N KOH better simulates the battery electrolyte as it is presently constituted. Corrosion resistance to these electrolytes of a number of elements which might be suitable for alloying with zinc has been examined and where appropriate the behavior of alloys has been investigated.

The corrosion behavior of pure Mg in a number of different electrolytes in the range of pH from 2-14 has been investigated with a view toward discovering whether its normal dissolution is trans-passive. If so, the simple concept of passive storage is not feasible.

II. WORK COMPLETED UNDER CONTRACT

A. Zinc and its Alloys

The behavior of zinc and its alloys in alkaline solutions has been investigated with a view toward using the zinc-silver battery in the passive reserve mode.

1. Factors Governing Selection of Alloying Elements

The factors governing the choice of suitable elements for alloying with Zn have been considered in some detail in this period. One important factor governing the selection must be that the alloying element is as non-noble as possible so that it will not raise the potential of the anode and reduce the power density of the battery. Information about this is readily available (Latimer, Oxidation Potentials (1952) or Pourbaix, Atlas of Electrochemical Equilibria (1963), although in very alkaline solutions it is of dubious reliability. Another important characteristic of the alloying constituent then must be the ability to form a passive layer in a potential region below the AgO/Ag_2O potential (~ 1.35 v vs. R. H. E.). This passive layer must be readily removable for activating the battery. Accurate information about these aspects, i. e. the actual kinetic behavior of elements in alkaline solutions, is scarce and even less reliable than the theoretical (thermodynamic) information mentioned above. On the basis of thermodynamic considerations and on general electrochemical corrosion grounds, we might attempt to alloy with V, Ti, Zr, Hf, Nb, Ta, Cr, Mn, Fe, Co, Ni, Cu, Cd, In, and Mg. However, alloying Zn with Ti, Zr, Hf, V, Nb, Ta, Cr, and In is either very difficult or impossible. This leaves Mn, Fe, Co, Ni, Cu, Cd, and Mg as reasonable possibilities. Some of these elements are more noble than zinc itself, and this may turn out to be a problem.

2. Experimental

The experimental arrangement for the study of the current potential curves involves the typical three-electrode system (working, counter, and reference) in a Pyrex cell. The working and counter-electrode compartments are blanketed in "pre-purified" N_2. In the reference compartment we use "tagged" H_2 to fix the potential of our Pt/H_2 reference system. We avoided the use of a calomel reference electrode because of the danger of contamination with Cl^-, a well known passive film destroyer. Potentials are given against the reversible hydrogen electrode in the working solution (R.H.E.). The working electrode is usually a polished cylinder ($\sim 1\ cm^2$ area) which is tapped, threaded, and mounted on a Teflon gasket. Some alloys are too brittle to be threaded, and are, therefore, soldered to a Pt wire sealed through soft glass. The Pt and Pt-alloy contacts were covered with melted Kel-F or with irradiated polyolefin. Experiments were carried out at $30 \pm 0.2°C$ in KOH or in other electrolytes as indicated.

It was decided to do most of the experiments without stirring in KOH containing no zincate since these conditions best simulate the conditions in a primary battery. The absence of stirring is obvious (zinc dissolution is sensitive to stirring), but the absence of zincate perhaps requires some explanation. In a secondary battery the zincate aids recharge and also lessens corrosion on standby. Neither of these is relevant in a primary battery, particularly a reserve battery.

Where appropriate, the potential was stepped (via an electronic potentiostat) so as to evolve H_2 in between each point. During this treatment any passive films formed previously tend to be reduced. Also, the solution is vigorously stirred for one minute to carry previously dissolved zincate into the bulk of the solution. The stirring is discontinued for one minute to allow the solution to become quiescent and then the potential of the electrode is raised to the next

potential of interest. This procedure is to obtain reproducible
and appropriate surface and solution conditions. It is not
valuable for some materials since passive film reduction is
sluggish. At the potential of interest, we record the current as
a function of time and observe any changes in the appearance of
the electrode. When the current is steady (after ~ 60 seconds
over most of the potential region of interest for zinc itself. but
observed for at least another 5 min), we revert back to the H_2-
evolution potential (~ - 0.8 to 1.0 v vs. R.H.E.) in preparation
for the next point. In this way we are able to obtain currents at a
fixed potential which reproduce from sample to sample and during
the course of an extended experiment, to within 10% for Zn.

3. Corrosion of Zinc

Typical current-potential curves for Zn is unstirred
1N and 6N KOH at 30°C are shown in Fig. 1. The curves show the
characteristic active-passive transition with increasing potential
above about - 0.1 v vs. R.H.E. The currents were stable with time
in the active dissolution region (less than 10% change from 1 - 10 min
at each potential) but less so in some parts of the passive region.
For example, in 1N KOH, at + 0.1 v, $i_{1\ min}$ was 3.9 mA and $i_{7\ min}$
was 3.7 mA. The electrode was white under these conditions
(probably $Zn(OH)_2$). Similarly at 0.6 v. where the electrode becomes
brown, $i_{1\ min}$ was 6.0 mA. $i_{7\ min}$ was 5.5 mA and $i_{45\ min}$ was
4.5 mA. The largest change with time is seen in the transition region
between the active and the passive regions (- 0.35 to - 0.1 v). For
example at - 0.1 v, $i_{1\ min}$ was 7 mA and $i_{10\ min}$ was 3.7 mA. The
variation with time in 6N KOH, where the dissolution rate is much
higher, was even less. The colors which the electrode took under
the various conditions of polarization are also indicated on the graph.

As indicated, these curves show that Zn in KOH has the
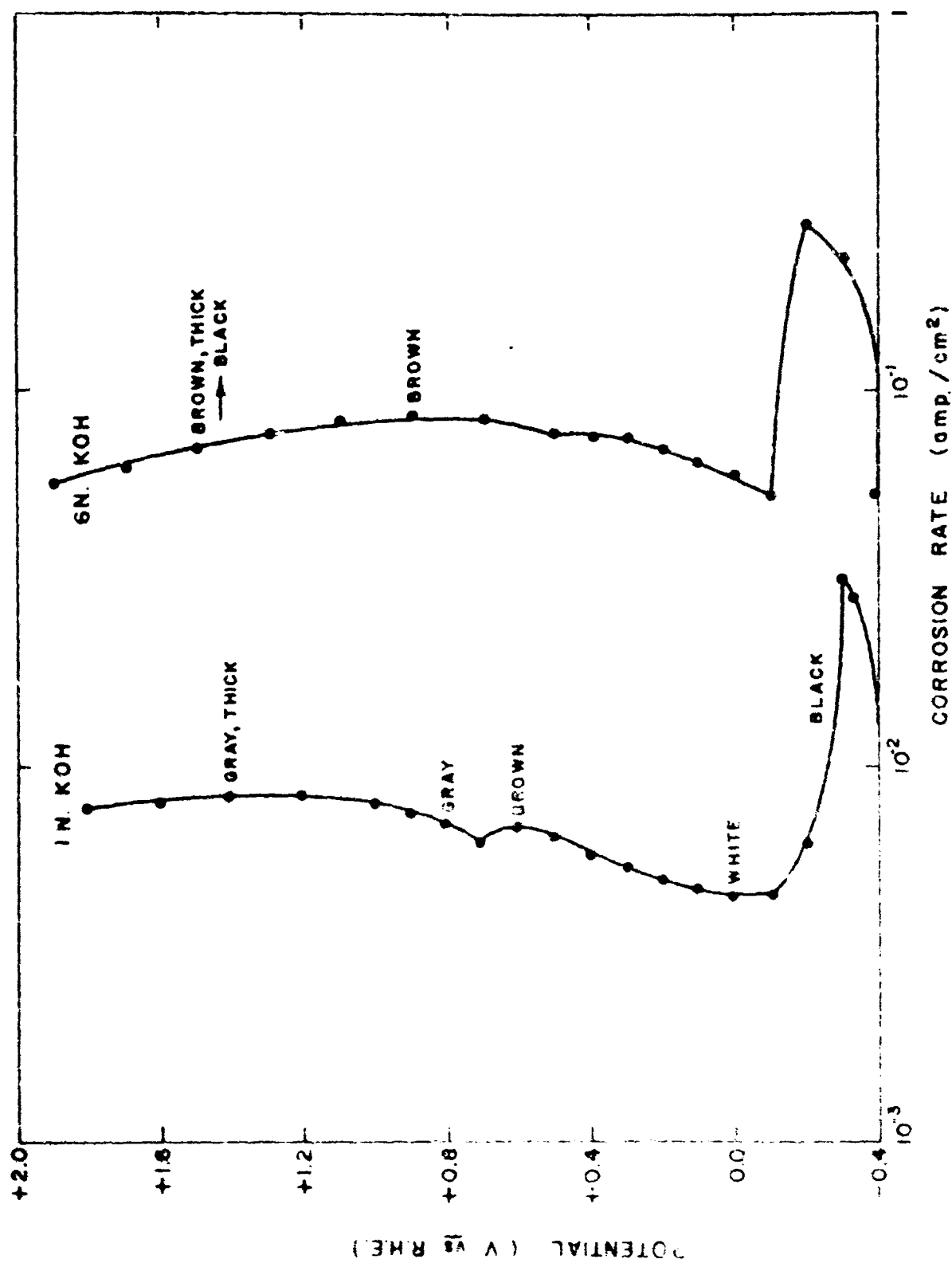characteristic active-passive dissolution curve and the one required

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Fig. 1 Corrosion of Zn in KOH

for the present purpose. However, while the active dissolution
rate is suitably high, the passive dissolution rate is much too
high (~ 4.5 mA/cm^2 in 1N KOH and 55 mA/cm^2 in 6N KOH under
the best conditions). An appropriate passive dissolution rate is
perhaps one microampere per cm^2. To achieve this, one can
alloy the zinc (either as a solid solution or as in an intermetallic
compound) with an element which passivates better in KOH but
which still dissolves readily at the anode potential of the Zn-AgO
battery.

4. Tests of Possible Alloying Elements

Corrosion tests on a number of elements were
carried out in KOH to test appropriateness for alloying with Zn.

The current potential curve for Mg in 1N KOH is shown in
Fig. 2. This metal approaches the desired passive current but is
not readily activated; indeed, we have not really found any significant
potential region of active dissolution.

The corrosion of Cu was investigated in 1N and 6N KOH
(Figs. 3 and 4). In 1N KOH, Cu shows a typical active-passive
transition, being active at ~ 0.8 v vs. R.H.E. and showing a
minimum of passive current at 1.1 v. The currents depended very
strongly on time. For example, after 45 minutes at 1.0 v, the
corrosion rate was 0.6 μA/cm^2 and the electrode was covered with
a dull brown film.

Activation was readily achieved with a cathodic galvanostatic
pulse, and a number of potential arrests were seen before H$_2$-
evolution. The charges involved in these potential arrests were
dependent on the current density, suggesting the reduction of solution
species rather than (or in addition to) surface oxides. Under some
circumstances the electrode acquired black, velvety films which could
not be reduced galvanostatically.

Figure 2

Anodic Dissolution of Mg in 1N KOH at 30°C, unstirred
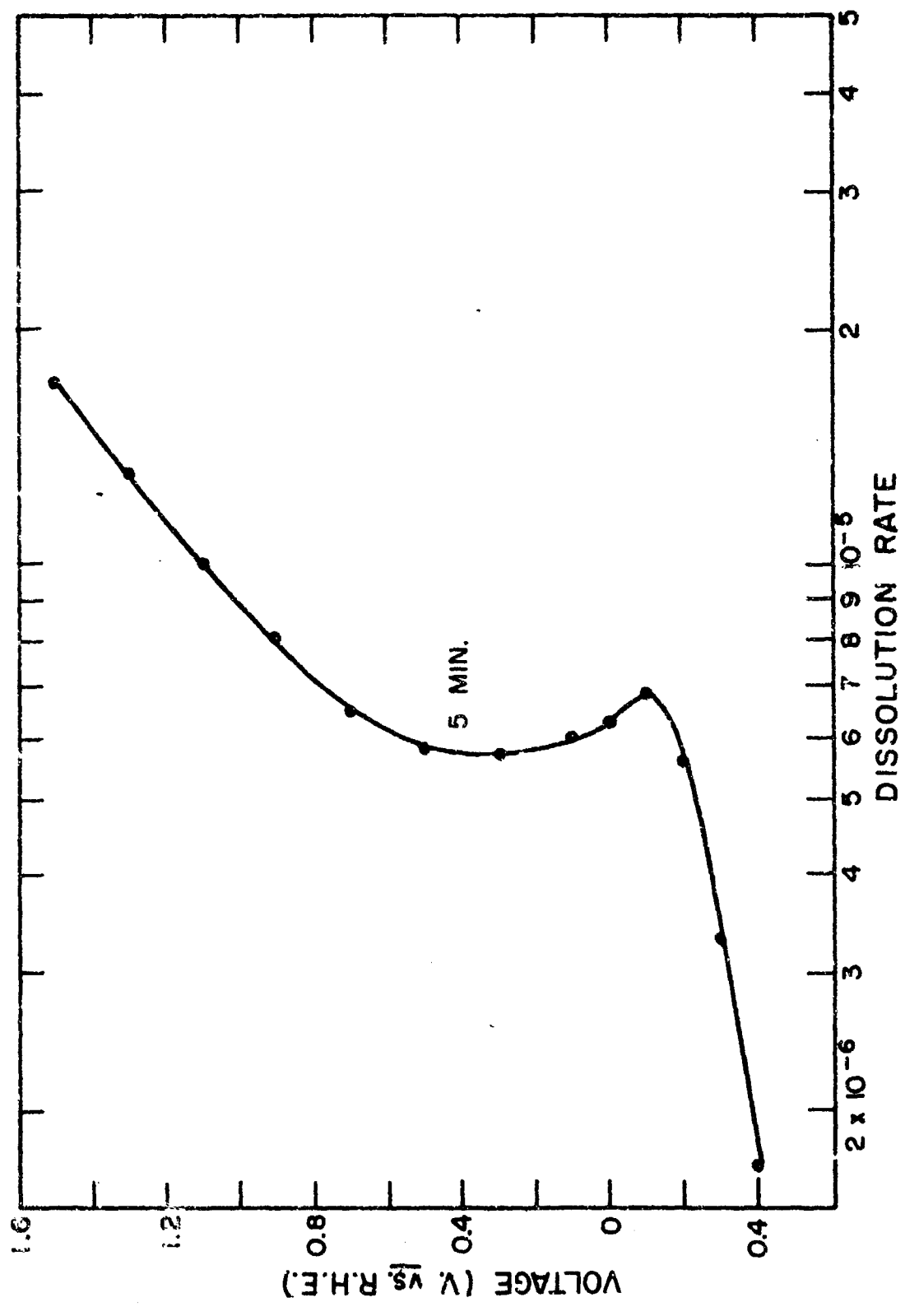
Figure 3

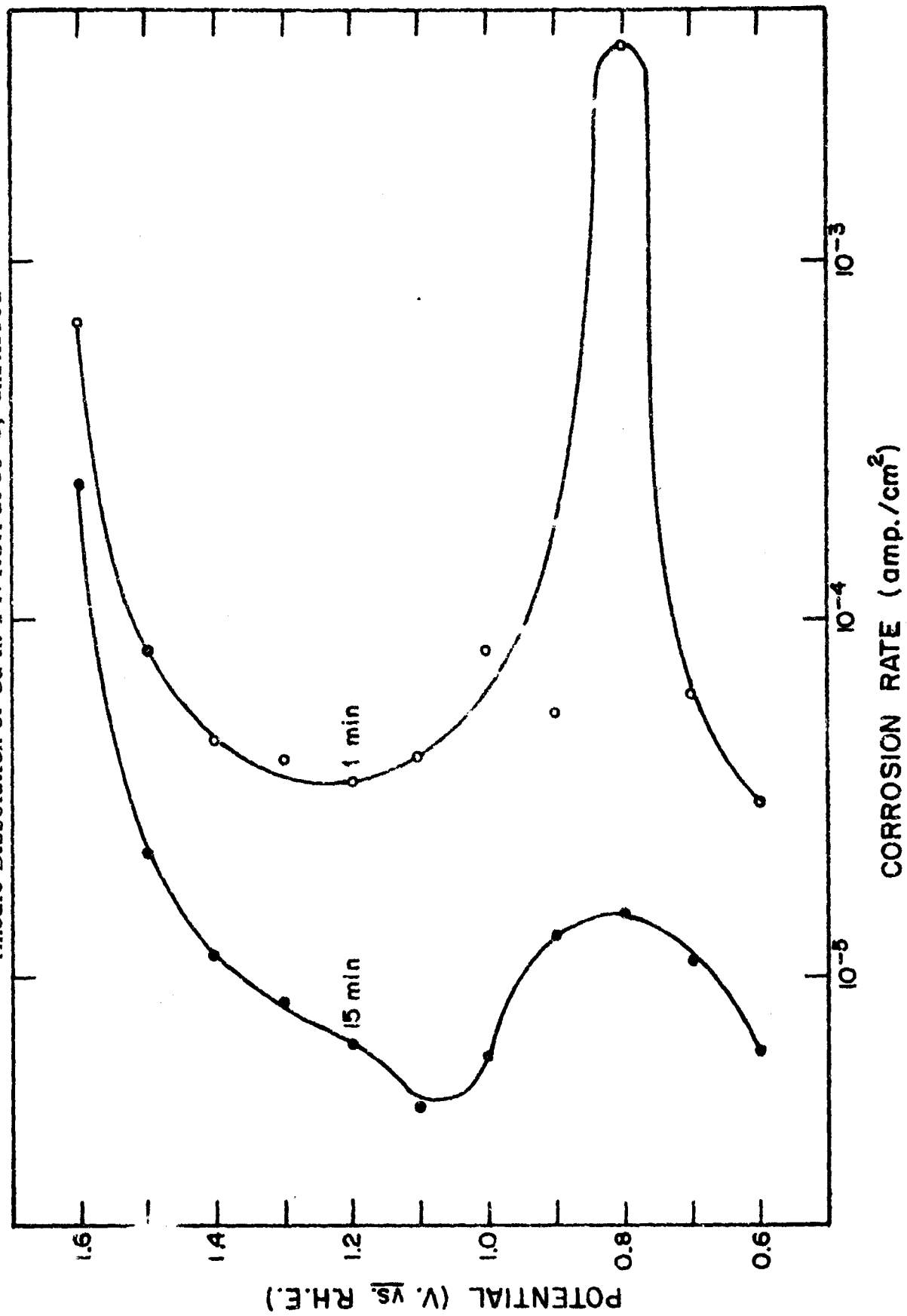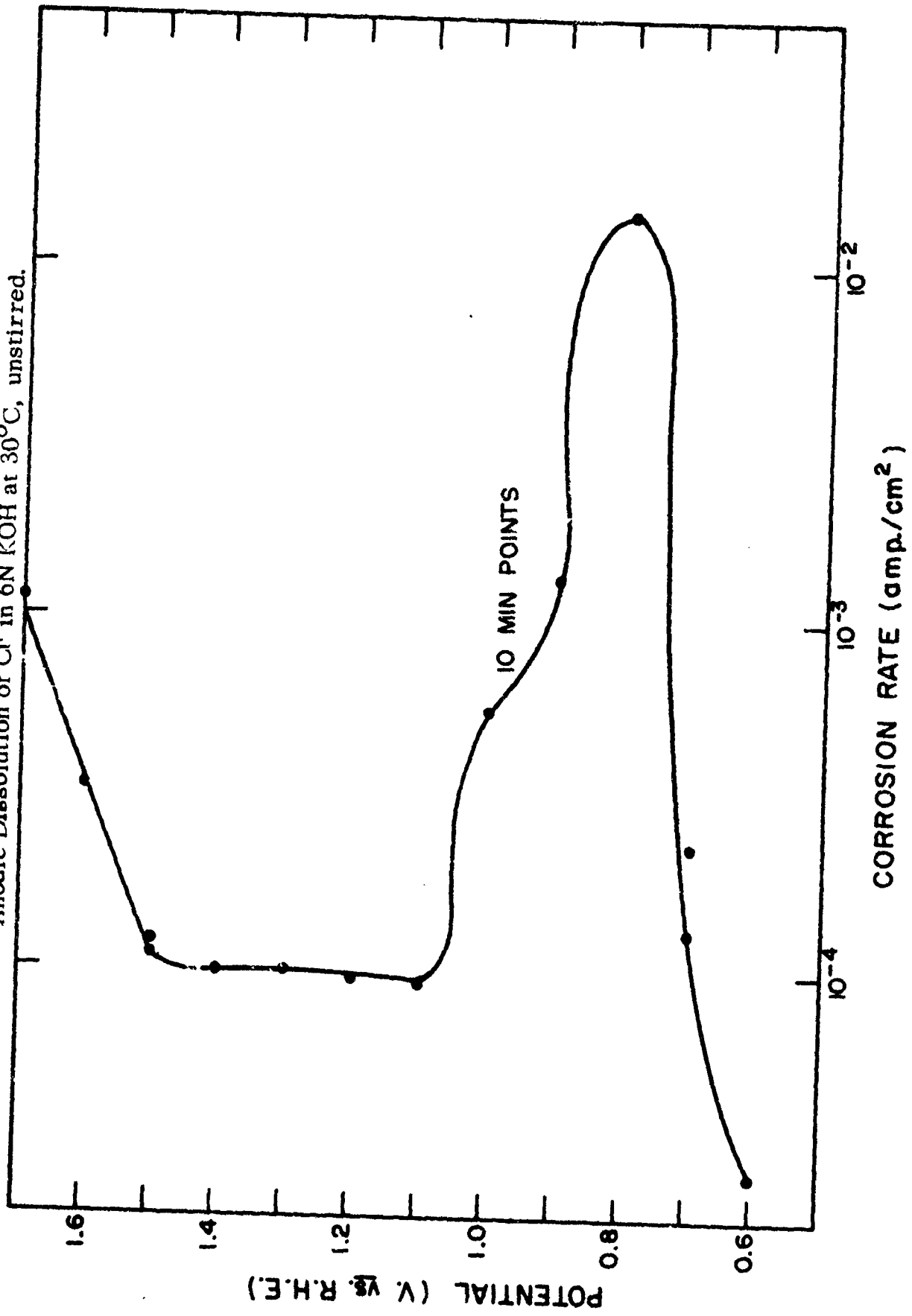Anodic Dissolution of Cu in 1 N KOH at 30°C, unstirred

Figure 4

Anodic Dissolution of Cr in 6N KOH at 30°C, unstirred.

In 6N KOH (Fig. 4) the currents were much steadier, but the dissolution rate was considerably higher. For example, the passive current was 10^{-4} amp/cm^2. Again, the electrode went through various color stages in different potential regions. The greater corrosion rate of Cu in 6N KOH is related to complexing of $Cu(OH)_2$ by KOH; for example, we found that $Cu(OH)_2$ is relatively insoluble in 1N KOH and soluble in 6N KOH.

It was thought inappropriate at this juncture to investigate the corrosion of Cu in greater detail. It is clear from Fig. 5 that Cu does have suitable corrosion characteristics in 1N KOH for our purposes.

The corrosion of Ti in 1N KOH is of the right order for the present purpose (Fig. 5) although the active dissolution region is so low that activation after standby passivation would be difficult. The passive current is fairly low and, for example, after one hour at 1.0 v falls to about 2.5 $\mu A/cm^2$. After being taken to 1.6 v in an extended run, the Ti looks little different from its original condition but reduction of what is certainly a passivating film is very difficult since there are no potential arrests at - 1 mA/cm^2 before H_2-evolution. In 6N KOH, Ti tarnished after a short while at potentials above the hydrogen potential. Currents were unsteady but low enough to suggest the possible usefulness of Ti in this medium (a few $\mu A/cm^2$ after several minutes at 1.0 v). One of the problems with the Ti system is that although compounds with Zn have been reported (Hansen, Constitution of Binary Alloys), they are apparently very difficult to make. We are investigating this.

The corrosion of Mn in KOH has also been investigated. Corrosion currents were low. (Fig. 6 shows 5 min. points) and rather unsteady, declining rapidly with time. For example, in one experiment at 0.8 v, the current fell from 150 to 50 $\mu A/cm^2$ going from 1 to 5 min; at 1.4 v it fell a similar factor in this time range. On reduction from high potentials (e.g. 1.4 v) there was a long

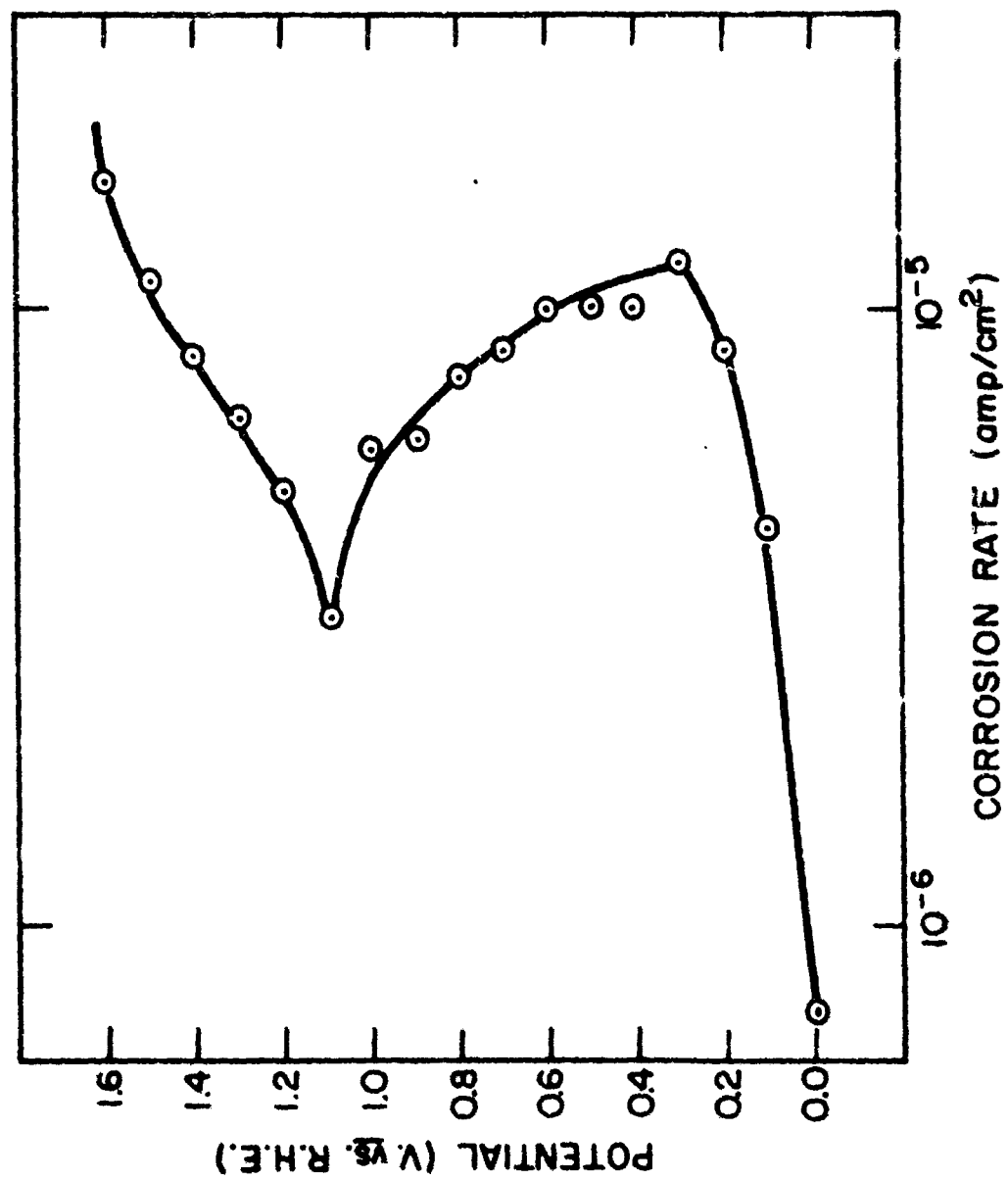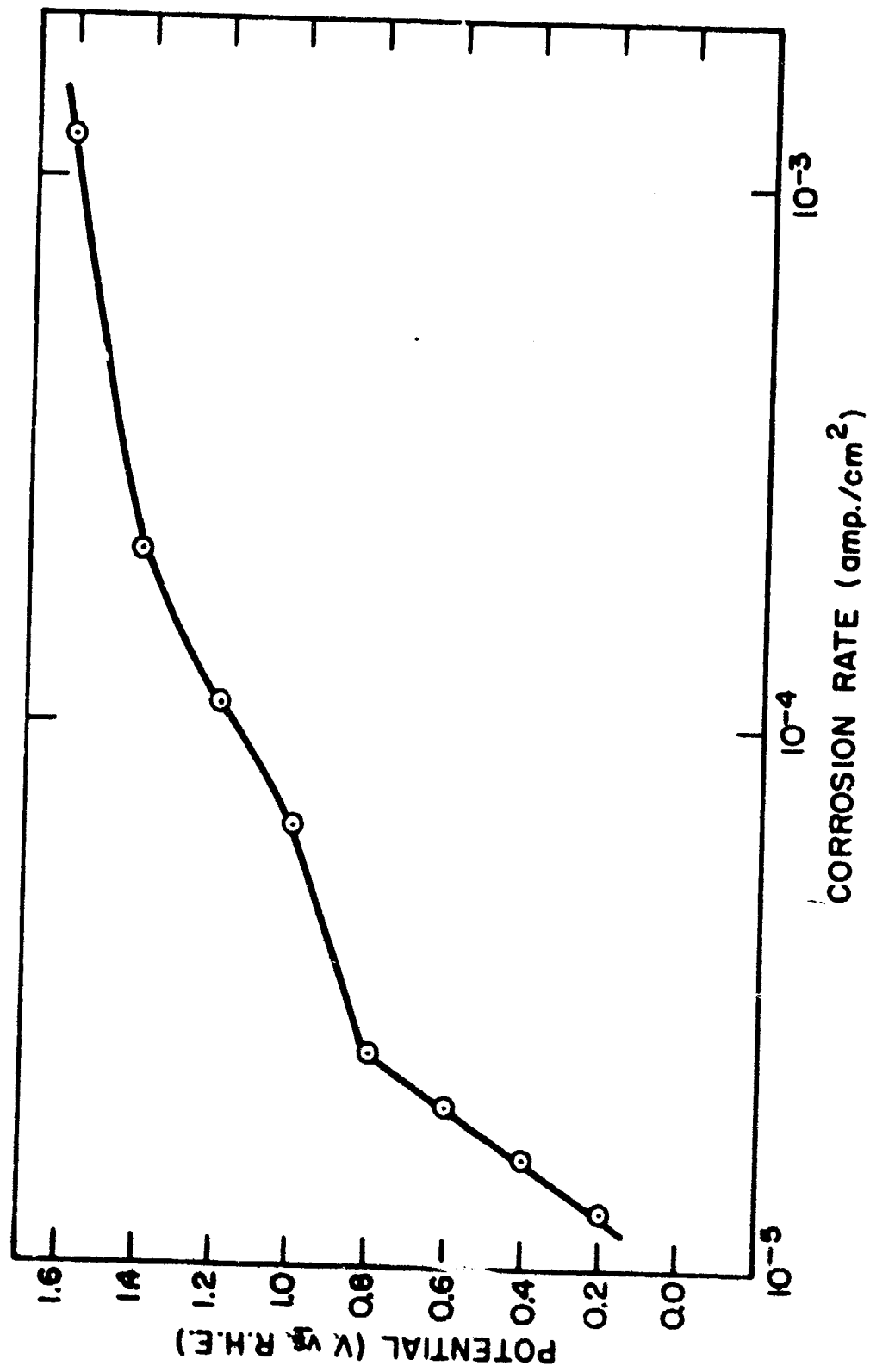Fig. 5 Anodic dissolution of Ti in 1N KOH at 30°C, unstirred

Fig. 6 Anodic dissolution of Mn in 1N KOH at 30°C, unstirred

POTENTIAL (V vs. R.H.E.)

CORROSION RATE (amp./cm^2)

potential arrest, suggesting the presence of a surface oxide.
Below 0.6 v, the currents were much steadier but still quite low.
The potential of the Mn returns to the H_2-evolution region on
cathodic treatment and the metal behaves pretty much as before.
The implication is that Mn would be suitable for alloying with Zn.

The corrosion of Co in KOH was also investigated. Since
the currents were low and unsteady, it was not possible to obtain
a meaningful current-potential curve. The electrode did not
tarnish but the rest potential was very sensit've. Probably this
potential was controlled by air films of Co oxides ($\sim +0.25$ v) but
when these had been reduced (after a few minutes at $+0.3$ v), minor
contamination with oxygen in the solution was able to control the
potential at much higher values ($+0.98$ v). Co appears promising
for alloying with Zn.

The corrosion of Fe in KOH was investigated and the passive
current was found to be very low, although erratic. Alloying with Fe
will, therefore, be tried.

5. Corrosion of Zinc-Magnesium Alloys

Magnesium has good corrosion resistance in alkaline
solutions (Fig. 2) and an alloy of 97 Zn - 3 Mg (wt %, not at % as
in our previous reports) was therefore tested in KOH. Figure 7
compares curves in 1N KOH (stirred) for Zn and 97 Zn - 3 Mg.

The dissolution of the Zn-Mg is similar to Zn but about three
times less. An important characteristic of the proposed system is
not only the low passive corrosion rate but also the ready activation
on demand. Zn in both 1N and 6N KOH readily activates either under
cathodic galvanostatic driving or on open circuit. The cathodic
chronopotentiogram thus taken has a delay corresponding principally
to the reduction of dissolved zincate. To test the suitability or
otherwise of the Zn-Mg system in this respect, we carried out the
following experiment. The electrode was left at + 1.2 v, well into the
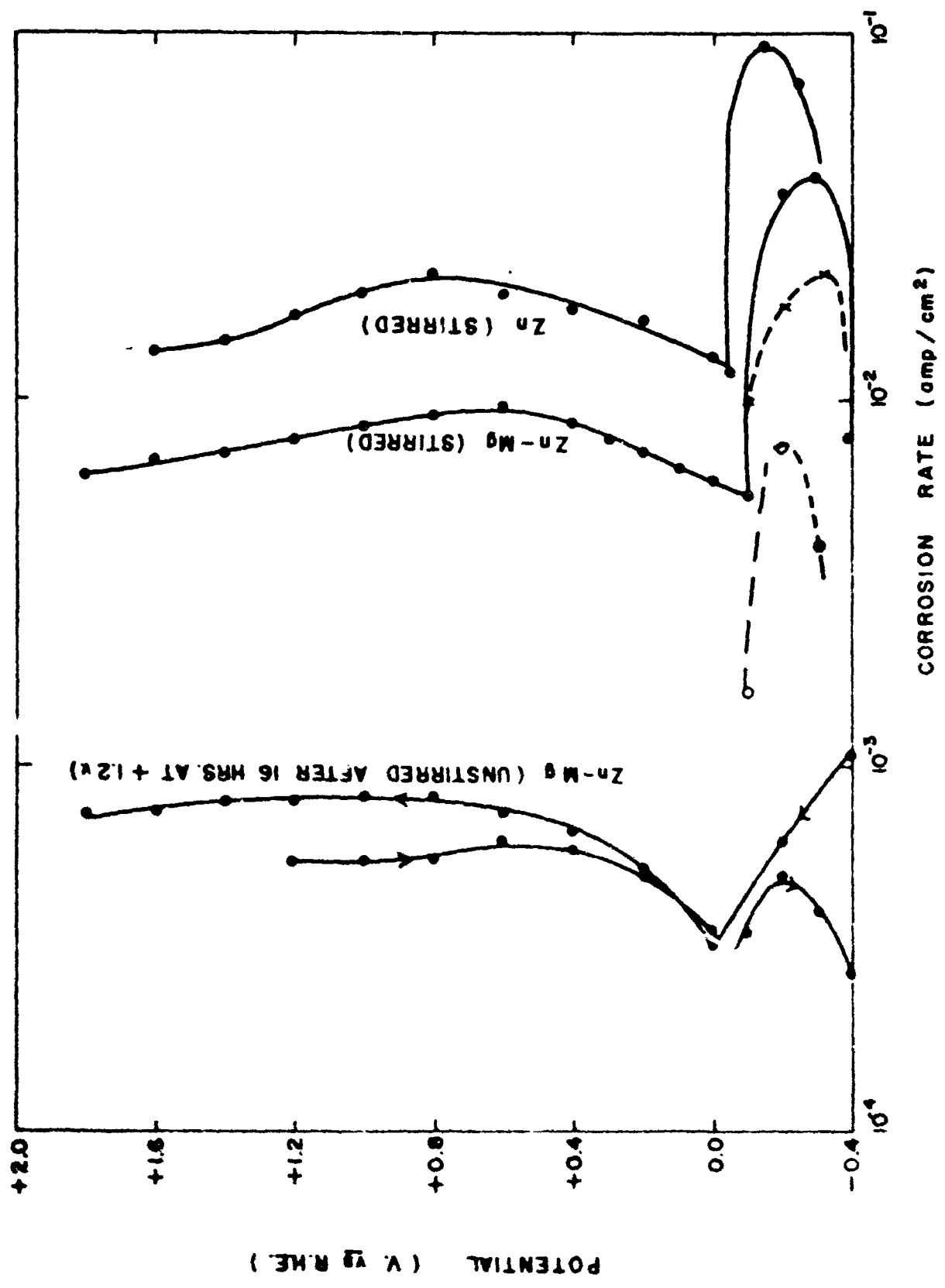
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Fig. 7 Corrosion of Zn and 97 Zn - 3 Mg in N KOH at 30°C

passive region, without stirring (Fig. 7). During this time
(~ 16 hours), the current fell from 7.9 mA/cm^2 (stirred) to
0.56 mA/cm^2 (unstirred). Then the oxidation rate of the electrode
was studied as before and the electrode, which was black, was
inactive as shown in Fig. 7. Although the open circuit potential was
still in the zinc dissolution region (- 0.37 v) and was rapidly attained
on breaking the circuit, it was not possible to activate this electrode
again either by vigorous H$_2$-evolution (attempting to reduce the
passive film) or by vigorous O$_2$-evolution (attempting to reach the
transpassive region). In fact, the passive layer behaved like an
ohmic film with a resistance (measured with a current interrupter)
of about 21.5 ω.

In a subsequent experiment the electrode was repolished and
run through the active dissolution regime (unstirred) as shown in
Fig. 8 (crosses). Then, we waited 45 min. at 0.1 v, which is the
beginning of the passive region. During this time (5 min. to 15 min)
the current fell from 10 to 3.3 mA/cm^2. The aim of this experiment
was to investigate just where in the passive region the black ohmic
layer is produced. Subsequently, the electrode was rather inactive
(even after 10 mA/cm^2 of H$_2$-evolution for 20 min.); for example,
the maximum dissolution rate of the alloy was down to 7.5 mA/cm^2
from 22 mA/cm^2 (unstirred) and extended for a range of less than
0.1 v (in the vicinity of - 0.2 v vs. R.H.E.). Such a curve, taken
in the active dissolution region of the alloy, is shown dotted in Fig. 7
(black circles). Repetition of this procedure lowered the maximum
dissolution current to 4 mA/cm^2. From this experiment it appears
that deactivation of Mg-Zn occurs even as low as - 0.1 v vs. R.H.E.

Reactivation of the alloy by cathodic galvanostatic pulses was
attempted. Such activation is possible, although it did not remove the
loose black material covering the surface. The possibility of zinc
plating from solution onto the alloy electrode during the cathodic
pulse was considered, and it was concluded that it did not affect the

results appreciably. Therefore, activation is not due to oxidation of Zn plated out from the solution during the cathodic "activation". We are sure of this because the extra charge due to active dissolution at say - 0.3 v is much larger than could be accounted for by plated zinc. For example, after one minute of a cathodic activation at - 1 mA, no more than 60 mcoul of Zn could be plated onto the electrode. (This assumes no H_2-evolution, there is some however.) This is then the maximum excess charge which could be attributed to plated zinc in subsequent oxidation of the alloy. In practice, we find at least 1200 mcoul (Fig. 8). Cathodization for longer times gives a more long-lived activation.

It is evident that we are partially reducing a very refractory surface layer which is forming at the active dissolution potential and that this cannot be the black and rather porous-looking layer which the electrode acquires after some time under active dissolution. Deactivation of the corrosion, both in the "active" dissolution potential region (Fig. 9) and in the subsequent "passive" region, evidently occurs. because of formation of a surface layer which is difficult to remove. Presumably, this is complicated by loss of zinc from the surface layers, but it is not certain that this is a predominant effect. The Mg-Zn solid solution system does not look very promising because the presence of Mg seems to limit the active dissolution of Zn rather more than it lowers the passive current.

Experiments with $MgZn_2$ are planned since the compound should have quite different active-passive characteristics from the constituent elements. Also, although the loss of Zn from the surface layers may be a problem in the solid solutions, the compound is expected to be more coherent in this respect.

6. Corrosion of Zinc-Copper Alloys

Cu has good corrosion resistance to 1N KOH (Fig. 3) and therefore its alloys with Zn were tested.

Figure 8

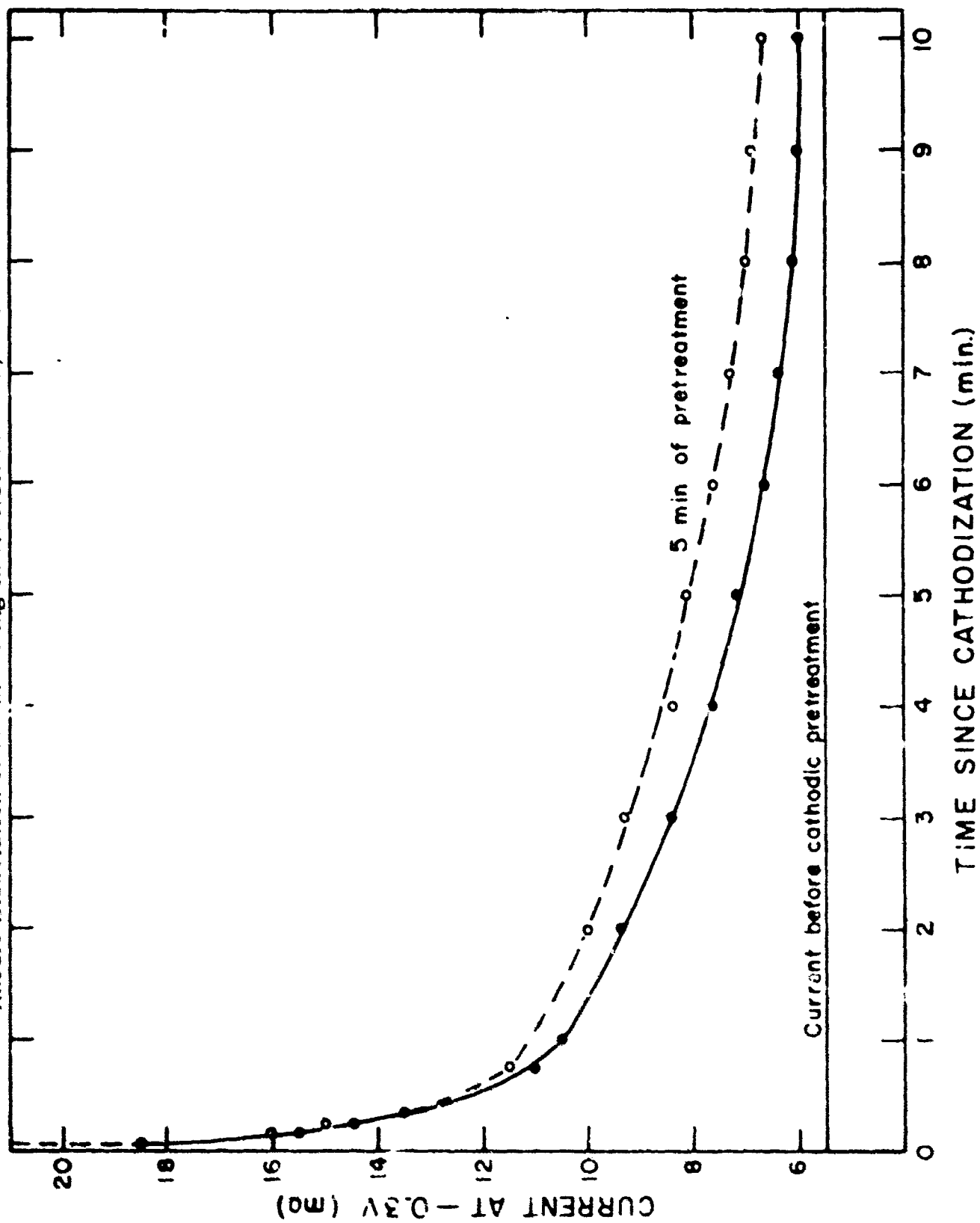Anodic Dissolution of 97 Zn – 3 Mg in 6N KOH at 30°C, unstirred

CURRENT AT –0.3V (ma)

TIME SINCE CATHODIZATION (min.)

5 min of pretreatment

Current before cathodic pretreatment

Figure 9

Anodic Dissolution of 97 Zn – 3 Mg in 6N KOH at 30°C., unstirred
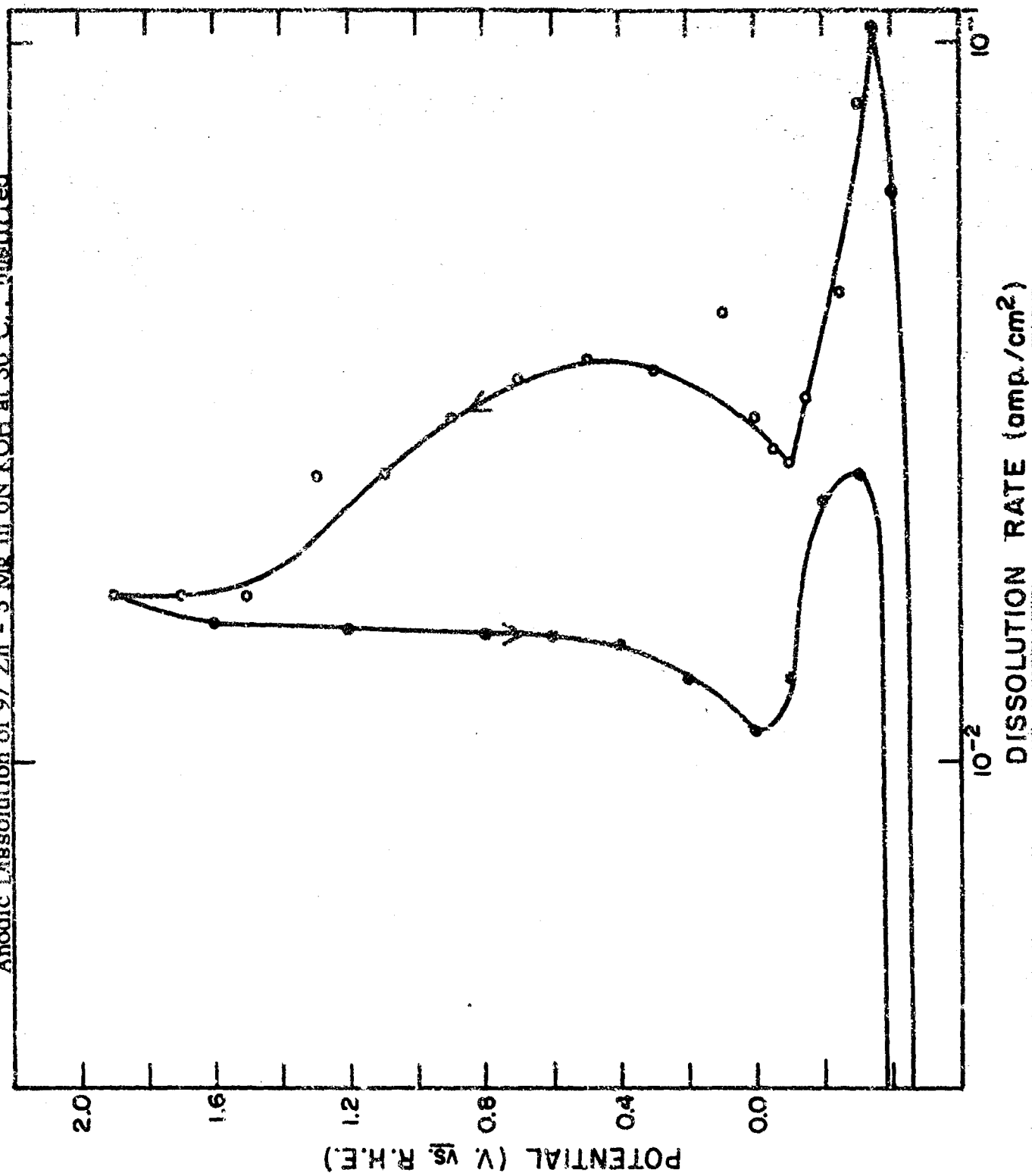
Fig. 10 shows the dissolution of 67-33 Zn in 1N KOH. The passive current is about ten times higher than that of Cu. After 17 hours at 1.2 v, this decreased to 15 $\mu A/cm^2$ and the electrode became black. The electrode was fairly readily activated but, as can be seen from Fig. 10, the over-all behavior does not show the Zn active dissolution region.

The corrosion of 80 Zn - 20 Cu (wt %) in 1N KOH is shown in Fig. 11. This curve shows currents taken point by point after 5 minutes at each potential. The currents were fairly steady; e.g. at - 0.2 v there is no change from 1 min to 5 min and between 0.5 and 0.7 v, the worst region, it decreased by < 30% in this time range. The diagram shows that the active dissolution of Zn has been pushed from ~ - 0.3 v to ~ 0.1 v and that the critical current is ~ 10 mA/cm^2 (vs. ~ 60 mA/cm^2 for pure Zn at - .3 v. This undoubtedly reflects the lowering of Zn "activity" in the alloy. After the first passivation at ~ 0.3 v, the electrode shows another active peak at 0.55 v and another at 0.85 v. Another peak is seen at 1.1 v. This complex corrosion behavior cannot be fully accounted for at this time and it appears inappropriate to investigate the system more fully in this context. The lowest passive current is at ~ 1.0 v; this is 1.7 mA/cm^2 after 5 min and still 0.9 mA/cm^2 after 17 hours.

The conclusion from these studies is that Cu-Zn alloys do not have suitable corrosion properties for the primary reserve battery. This is because the effect of the added Cu is both to raise the active dissolution potential of the Zn and to decrease its critical current, not to lower its passive current enough.

As an alternative to alloying Cu with Zn, we considered briefly the possibility of protecting the Zn by plating Cu onto it. In this configuration the Zn electrode would be stored Cu-plated. Cu does not corrode at open circuit once O_2 in this electrolyte has been consumed. To activate the battery a pulse is applied to dissolve Cu. One possible disadvantage of this procedure is that it could not

Figure 10

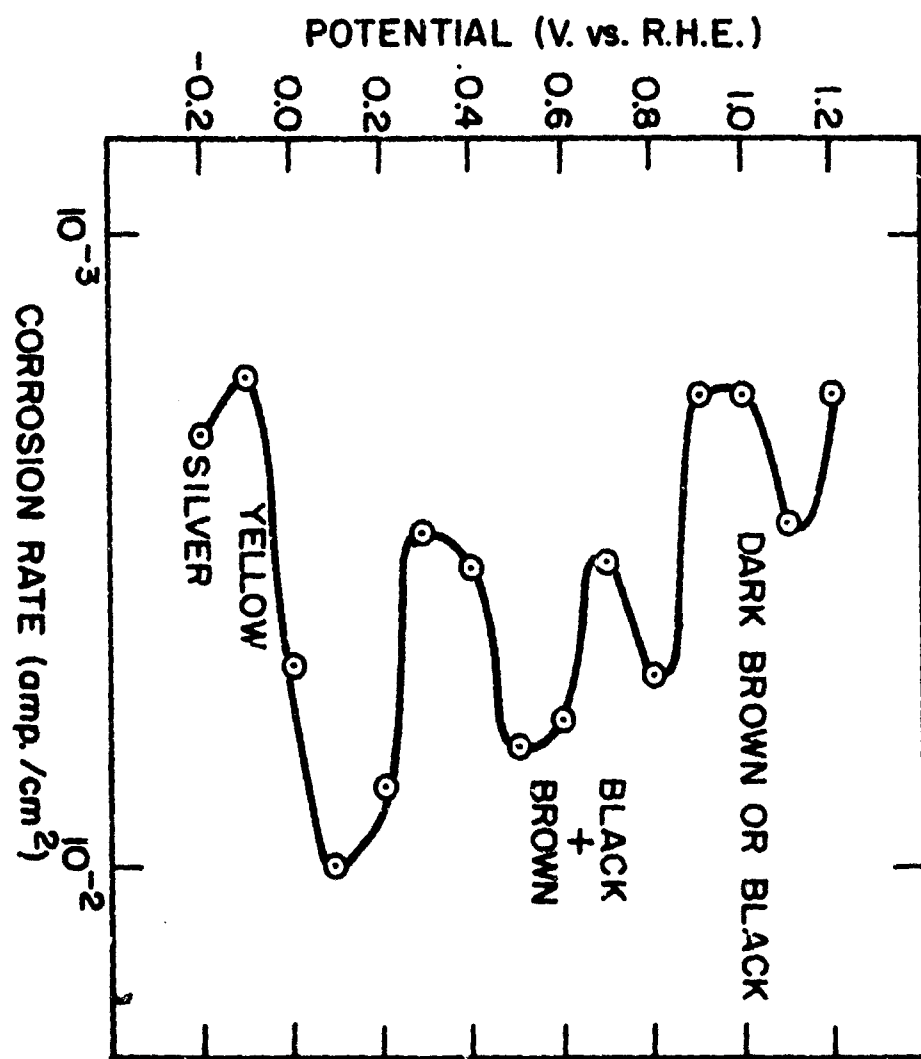Anodic Dissolution of 67 Cu - 33 Zn in 1N KOH at 30°C. unstirred

Fig. 11   Anodic dissolution of 80 Zn - 20 Cu in 1N KOH at 30°C, unstirred

be used for porous Zn (high rate) anodes, only for smooth ones. Another possible problem is that in order to protect the Zn we might have to put a large thickness of Cu onto the Zn (e.g. say microns). This would make activation difficult. Even worse, once the Cu had been removed during the activation procedure, it might plate back onto the Zn, which will now be well negative of the Cu reversible potential ($\sim$ +0.55 v).

To test this notion, we attempted to plate Cu onto Zn. The minimum successful plate used so far involves about 1 coul/cm^2 from a cyanide bath and about 10 coul/cm^2 from an acid sulfate bath ($\sim$ 6000 Å in all). This amount of Cu on Zn gave the Cu potential in 6N KOH. However, although it can be removed by anodic dis-charge, activation is lengthy because of the large charge involved. Cu, once removed, will tend to plate back onto the Zn thus deactivating it. Thus, the activated Zn could only be used while dissolving very rapidly, e.g. - 0.2 v in 6N KOH. We conclude that further develop-ment will be necessary to make this procedure suitable for the com-plete protection of Zn anodes.

B. Corrosion of Mg

Mg has a very active dissolution potential (- 2.4 v vs. R.H.E. at pH = O) and is a highly desirable anode material. Unfortunately, its performance is limited by a high open circuit corrosion rate, by rapid H_2-evolution on discharge, and by rather higher open circuit potentials than one would expect (above - 1.2 v). If Mg could be used as an anode, one would achieve cells with very large potential and with very high energy density (equivalent weight of Mg is 12). We have sought to overcome one of the big problems of the Mg anode - its high open circuit corrosion rate, using the passive battery concept.

We have investigated the corrosion of Mg in a number of solutions where it might be used as an anode. In Fig. 12 we show the current-potential curves for Mg in these solutions. The results are somewhat approximate at the high current densities because of

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Fig. 12 Anodic dissolution of Mg at 30°C. (a) 1N NaClO₄ buffered to pH 7 with NaH₂PO₄; (b) 1N NaClO₄ unbuffered; (c) 0.2M NaF at pH 2 (using HF).

iR drops. These occur not only in the solution, between the working electrode and the tip of the Luggin capillary, but also in the layer of corrosion products which accumulate on the electrode. This latter makes automatic electronic iR compensation very difficult. The results are presented without correction and the errors are considerable since, for example at + 1.0 v vs. R.H.E., H_2 is still being rapidly evolved from the electrode. In all cases, thick white precipitates of corrosion products formed on the electrode. Despite these strictures, the curves in Fig. 12 are representative of what would actually be found for a battery anode.

Since the reversible potential of Mg^{+2}/Mg is - 2.4 v and the open circuit potential is typically -0.8 v, it is apparent that the open circuit potential is a mixed potential between the H^+/H_2 reaction and the Mg/Mg^{+2} reaction. The major question is whether the intersection of the current-potential curves for these reactions occurs in the active part of the Mg/Mg^{+2} dissolution reaction or where the reaction is impeded by the formation of a passivating oxide. If the latter is true (as suggested by King for neutral and alkaline solutions, J. Electrochem. Soc., 110, 1113 (1963)), the dissolution of a Mg anode must occur transpassively and the passive reserve configuration is not possible. According to Fig. 12 this is the case in pH7 $NaClO_4$ and pH7 $NaClO_4$, NaH_2PO_4. In the more acid F^- solution there is some evidence for active-passive transformation but it may reflect the accumulation of macroscopic amounts of MgF_2 which block the surface, rather than the formation of a thin passivating film. Evidence for this was obtained with cathodic galvanostatic pulses from which it appeared that after a few minutes at 1.0 v vs. R.H.E., the ohmic drop was 40 ω and the double layer capacity was only $\sim$ 15 $\mu F/cm^2$ although the electrode was very badly etched. Further experiments to investigate the behavior of Mg in mildly acid solutions, where it does not form an insoluble product, are in progress.

Al shows the same phenomena in dilute acid solutions as does Mg. Thus, the open circuit potential is very high: current-potential curves similar to those in Fig. 12 are found, and as with Mg, H_2 evolution increases as the potential increases (the "negative difference effect"). Studies on Al are not being continued at this time.

III. CONCLUSIONS

Zn and Zn alloys show the appropriate current-potential characteristic in alkaline solutions for possible use in the passive reserve mode. Possible elements for alloying with Zn which appear to have appropriate passive currents are Co, Cu, Fe, Mg, Mn, and Ti. Alloys of Zn-Cu are not suitable, however, as the addition of Cu lowers the Zn critical current and does not lower the passive current enough. Zn-Mg solid solutions show the formation of an inactive surface layer and are not suitable. Cu plating of Zn may be suitable for its protection on standby.

Mg is in the passive state on open circuit in neutral and alkaline solutions. A secondary passivation may be found in mildly acid fluoride solutions.

IV. FUTURE WORK

Studies to confirm whether Mg shows a secondary passivation in acid solutions will be continued and possible alloying constituents to enhance any such passivation will be considered. Studies of Zn alloys - notably Zn-Fe, $ZnMg_2$, Zn-Co, and Zn-Mn - will be continued.

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13. ABSTRACT

Studies of the passivation of Zn and Zn-alloys in KOH at 30°C have been made potentiostatically. Zinc shows the characteristic active-passive current-potential curve although the passive current is too high for use in the passive reserve mode in Zn-AgO batteries. Studies of the corrosion of Co. Cu. Fe Mg Mn, and Ti in alkaline solutions show them as possible choices for alloying with Zn to improve its standby characteristics. Cu-Zn alloys are not acceptable however, since the addition of Cu lowers the Zn critical current but does not lower the passive current sufficiently. Zn-Mg solid solutions show the formation of an inactive surface layer and are therefore not suitable. Cu-plating of Zn may be suitable for its protection on standby.

Studies of the passivation of Mg from pH 2 to 14 were carried out with a view toward using the high energy density characteristics of the Mg-m-dinitro-benzene battery. In neutral and alkaline solutions Mg is passive on open circuit and cannot be used in the passive reserve mode. A secondary passivation may be present in mildly acid fluoride solutions.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Primary Batteries						
Reserve Batteries						
Anode Passivation						
Zinc-Silver Batteries						
Zinc Alloy Corrosion in alkali						
Magnesium Anodes						
Magnesium Corrosion						

INSTRUCTIONS