Name ______________

Student No ____________

University of Toronto

Final Exam
MMS 315 Environmental Degradation of Materials
April 2001

Examiner: D.W. Kirk

You may remove the data sheet and graph papers from the exam. Be sure to record your name on each page used.

Marks

1 Pourbaix Diagram

Tin has 2 principal solid phases Sn and SnO_2. The principal aqueous phases are Sn^{2+}, Sn^{4+}, and SnO_3^{2-}.

10 a)Construct a simplified Pourbaix diagram for the tin water system using the following information and graph paper provided. T= 25°C

5 b) Identify the regions of corrosion, immunity and passivation

5 c)Using the diagram give the pH limit for SnO_2 stability in acid and alkali for a 1×10^{-6} M dissolved tin. pH = ____________, pH = ____________

Assume the dissolved species have a concentration of 1×10^{-6} M
Convert the following data to equations of lines for the Pourbaix diagram

i) $Sn^{4+} + 2e^- \rightarrow Sn^{2+}$ $E° = 0.15V$ vs SHE

ii) $Sn^{2+} + 2e^- \rightarrow Sn$ $E° = -0.136V$ vs SHE

iii) $SnO_2 + 4H^+ + 4e^- \rightarrow Sn + 2H_2O$ $E° = -0.106V$ vs SHE

iv) $SnO_2 + 4H^+ \rightarrow Sn^{4+} + 2H_2O$ $K = 2.089 \times 10^{-8}$

v) $SnO_2 + H_2O \rightarrow SnO_3^{2-} + 2H^+$ $K = 6.918 \times 10^{-32}$

Name ________

Student No ________

10 2 Corrosion Kinetics - Evans Diagram

Part A

A steel vessel is used to contain an aqueous fluid having a pH of 7.8. The vessel is open to the atmosphere and has an oxygen content of 0.376 x 10^{-3} mol/L in the aqueous phase.

a) Using the graph paper provided, determine the corrosion rate of the steel based on the folowing kinetic parameters.

Oxygen reduction: b_c = -0.045 volts/ decade , i_o = 1 x 10^{-5} A/m^2
$O_2 + 2H_2O + 4e^- = 4OH^-$ E° = +0.401 V vs SHE

Steel oxidation: b_a = 0.04 volts/ decade , i_o = 1 x 10^{-4} A/m^2
$Fe = Fe^{2+} + 2e^-$ E° = -0.44 V vs SHE
(Assume an iron concentration of 1 x 10^{-5} mol/L)

b) If after several months the potential of the steel vessel is measured with respect to a Saturated Copper- copper sulphate electrode and is found to be -0.5 V, what is the new corrosion rate?

i_{corr} = ________

c) What may have caused the change in corrosion rate?

10 Part B

What would be the effect on the corrosion rate if the following changes were made. Explain your answer.

a) the fluid conductivity was decreased

b) the fluid was stagnant

c) the fluid temperature was cooled by 10°C

d) the vessel was operated under vacuum

Name ____________

Student No. ____________

3. General material properties and behaviour

10 Part A

Provide the best match of the following 6 materials with the 6 specified environments. You may use each material only once. Briefly justify your choice. (cost is not a consideration)

Materials: polypropylene, SS304, carbon steel, aluminum alloy, tin alloy, copper alloy

a) Exterior application exposed to industrial atmosphere

b) in-ground application with anaerobic environment

c) flowing seawater application

d) concrete structural support

e) food contact application room temperature

Name ____________

Student No. ____________

Qu 3 Part B

10

Briefly describe **2 of the following** forms of corrosion. Identify the mechanism and effects on the material: intergranular corrosion, filiform corrosion, hydrogen embrittlement. Make a sketch if it will help your explanation.

i)

ii)

Name ________________

Student No. ________

4 Resistance Polarization

A sample of zinc coated steel is to be tested for corrosion in an acidified fluid containing salt.

The polarization method is used but only one measurement is taken
A cathodic current of 10 $\mu A/cm^2$ is applied and the steady state voltage measured is 2.7 mV from E_{corr}
The kinetic parameters for the coated steel were determined to be $b_a = 30$ mV, $b_c = -118$ mV
An AC impedance technique was used to determine the solution resistance of 1000Ω.

10

a) Determine the expected corrosion rate of the sample in the fluid.

5

b) Show a schematic polarization plot of a metal that passivates. Identify i_{active}, i_{crit}, $i_{passivation}$, $E_{passivation}$, $i_{transpassive}$

5

c) Show on the same plot a polarization curve of a metal that pits. Identify E_{pit}, $E_{repassivation}$, E_{corr}

Name ______ ______ . . .

Student No. ____________

5 Steel alloy tubes are being considered for a hot furnance application at 1000°C.
One of these has been surface treated with aluminum and the manufacturer claims has ~~better~~ corrosion resistance (but at a higher cost). Measurements of the untreated and treated steel alloy materials in the environment have been conducted and are presented below.

untreated alloy		treated alloy	
% wt gain	time (hr)	% wt gain	time (hr)
7.5	10	1.0	10
		1.2	20
16.5	30	1.3	30
22.0	50	1.35	60
36.0	175	1.88	175

10 a) determine the nature/type of corrosion using the graph paper provided.

5 b) linearize the data and extrapolate to end of life. Determine end of life (40% wt gain)

untreated alloy life __________ , treated alloy life ____________

5 c) speculate why aluminum treatment is effective

Data Page

The information provided below may be used in any of the questions as required.

DATA:

$R=8.314$ J/K·mol;
$F=96{,}487$ c/mol e^-;
$\ln x = 2.303 \log x$

Ideal Gas Law $PV = n_{mol}RT$

Nernst Equ. $E=E^{\circ} - RT/nF \ln (a_{i\,prod}/a_{i\,react})$
at 25°C $RT/F \ln (x) = 0.0591 \log (x)$

Tafel Equ. $\eta = a + b \log i$ or
$\eta = b \log(i/i_o)$

Overpotential $\eta = E - E_{equilibrium}$

Linear Polarization
$Rp = \Delta E/\Delta i = b_a b_c / (2.3\, i_{corr}(b_a + b_c))$
($R = V/I$ for simple electrical circuit)
Total $R = R_{solution} + R_{polarization}$

Butler Volmer $i = i_o[\exp(\alpha\eta zF/RT) - \exp((1-\alpha)\eta zF/RT)]$

Mass transfer limitation

$i_{lim} = zFD(C_b - C_s)/\delta$
where δ is 0.05 cm in unstirred, 0.001 cm in stirred conditions

$D_{O_2} = 2.0 \times 10^{-9}$ m^2/s 25°C

Reference Electrodes

SCE =	+ 0.242 V vs SHE
Ag/AgCl =	+0.222 V vs SHE
$CuSO_4$ =	+0.330 V vs SHE
HgO =	+0.910 V vs SHE

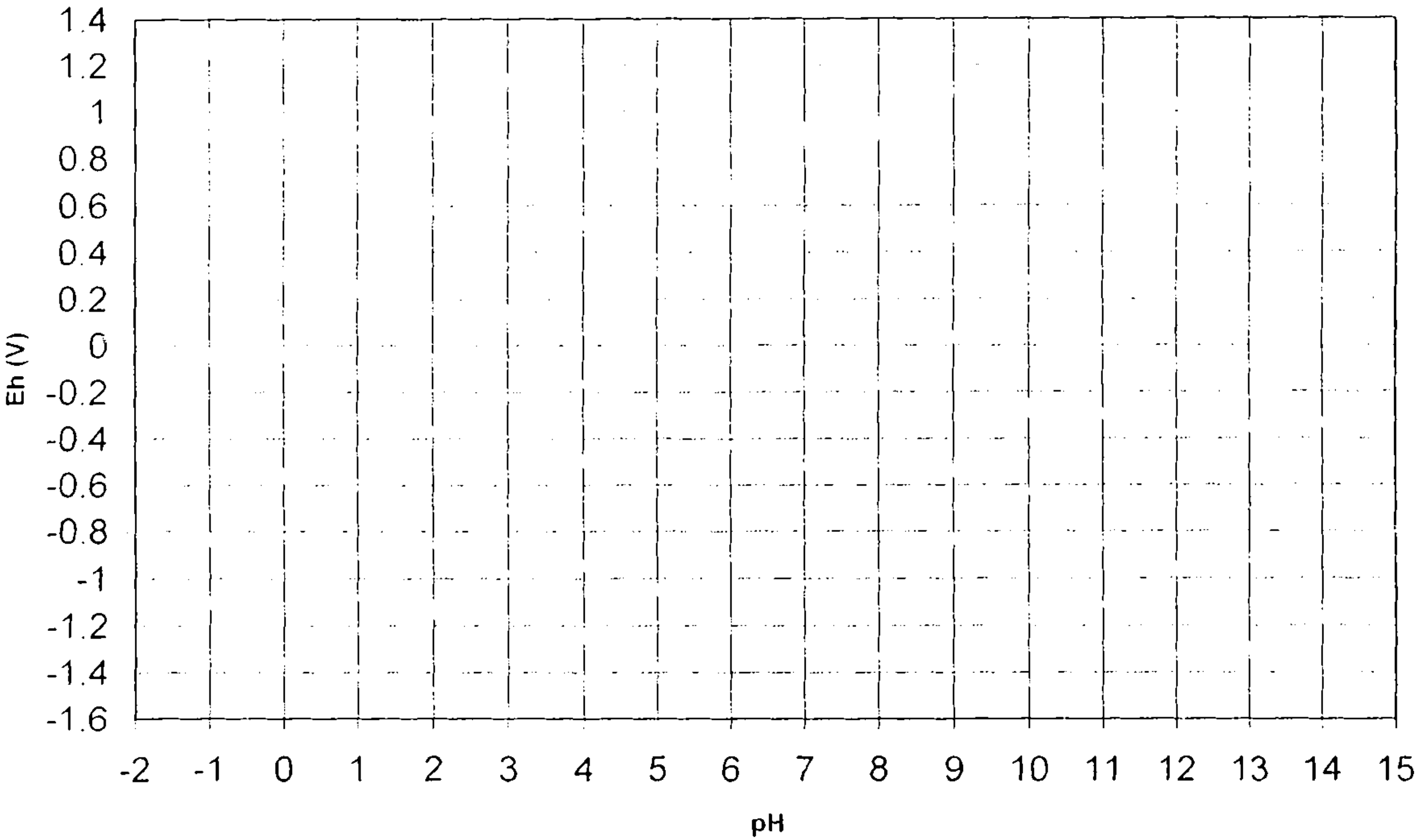
$pH = -\log [H^+]$

$[H^+][OH^-] = 1 \times 10^{-14}$

Units: 1 inch = 2.54 cm
1 mpy = 1×10^{-3} inch/year

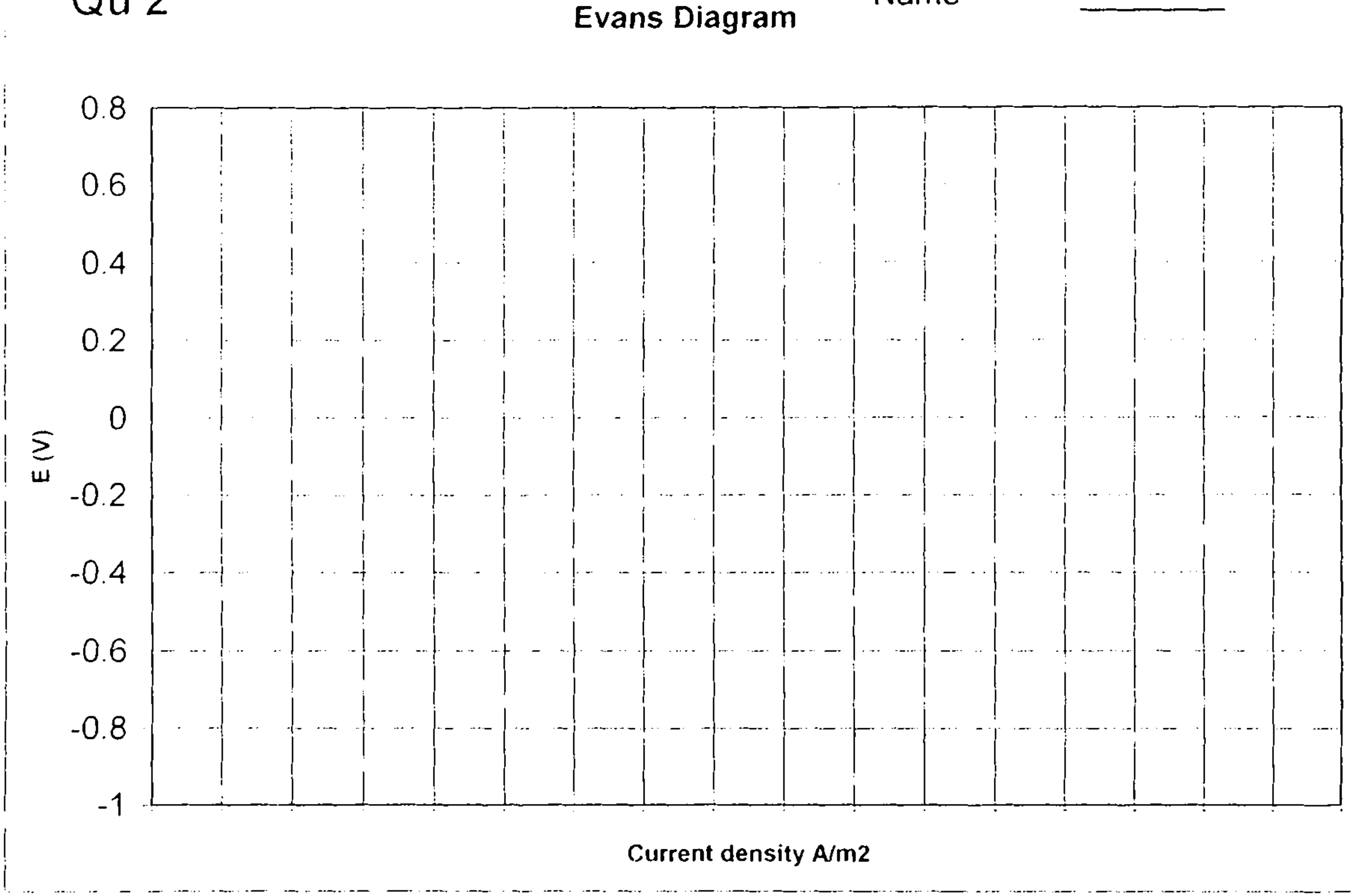
Qu. 1

Pourbaix Diagram Name



Qu 2

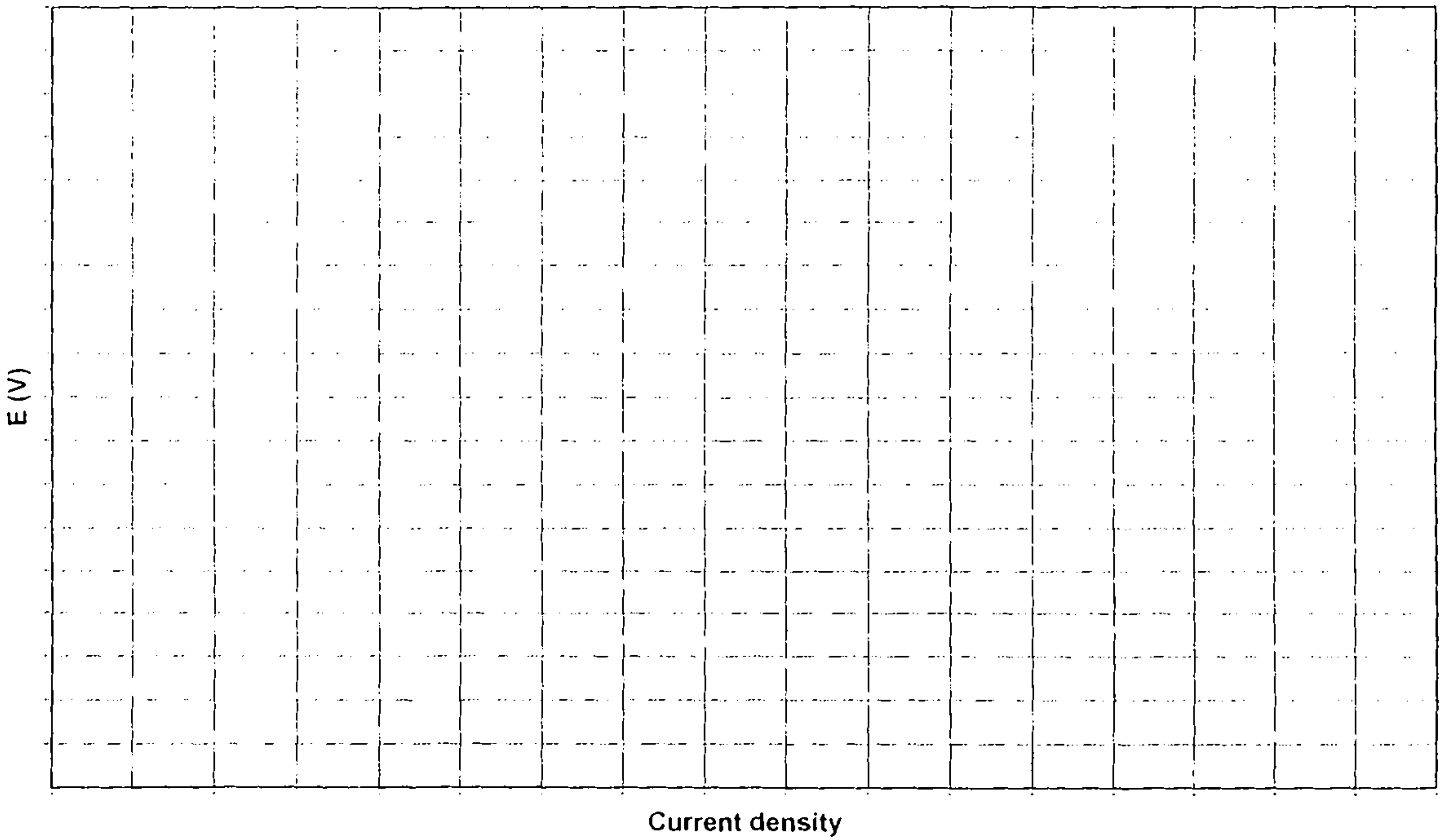
Name ________



Qu 4

Name ________

polarization



Qu 5

Name ____________

Corrosion rate