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APPENDICES

Appendix A Corrosive Solution Composition and Preparation

From Table 3.2 where the analysis of composition of produced water is given, the amount of chemicals for simulating this water is calculated and given in Tables A.1 and A.2 within a vicinity of 1% error. This composition was used for the experiments in section 4.2 and 4.4 whereas others are specified in Table A.3, A.4, and A.5.

Table 3.2 The analysis of produced water provided by Chevron Energy Technology Company

Composition	pH	Ca^{2+}	Mg^{2+}	K^+	Na^+	HCO_3^-	Cl^-
Value (mg/L)	7.7	1.65	0.35	41	1682.5	2317.75	615.75

Table A.1 The amount of chemicals for simulating produced water

Chemical	Amount (mg/L)			Cation (mg/L)			Anion (mg/L)		
	Min.	Desired	Max.	min	Desired	max	min	Desired	max
NaCl	937.53	947.00	956.47	368.80	372.52	376.25	568.73	574.48	580.22
KCl	77.52	78.30	79.08	40.66	41.07	41.48	36.86	37.23	37.61
$CaCl_2$	4.52	4.57	4.62	1.63	1.65	1.67	2.89	2.92	2.95
$MgCl_2.6H_2O$	2.87	2.90	2.93	0.34	0.35	0.35	1.00	1.01	1.02
$NaHCO_3$	3159.09	3191.00	3222.91	864.61	873.35	882.08	2294.48	2317.65	2340.83

Table A.2 The composition of simulated produced water

	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-
Desired	1245.87	41.07	1.65	0.35	2317.65	615.64
min	1233.41	40.66	1.63	0.34	2294.48	609.49
max	1258.33	41.48	1.67	0.35	2340.83	621.80

For the experiments in section 4.3 where chloride concentration was varied, NaCl was increased to 1%wt and 3.5%wt and compositions are given in Table A.3 and A.4

Table A.3 The amount of chemicals for simulating produced water used in section 4.3

Chemical	Amount (mg/L)	Cation (mg/L)	Anion (mg/L)
NaCl (1%wt)	10000	3933.7	6066.3
NaCl(3.5%wt)	35000	13768.04	21231.96
KCl	78.30	41.07	37.23
$CaCl_2$	4.57	1.65	2.92
$MgCl_2.6H_2O$	2.90	0.35	1.01
$NaHCO_3$	3191.00	873.35	2317.65

Table A.4 The concentration of Na^+ and Cl^- of simulated produced water used in section 4.3

	Na^+ (mg/L)		Cl^- (mg/L)	
	1%wt	3.5%wt	1%wt	3.5%wt
Desired	4807.05	14641.39	6107.44	21273.12
min	4759.00	14494.98	6046.36	21060.39
max	4855.14	14787.80	6168.51	21485.85

When mercury(II) was observed, section 4.6, mercuric chloride ($HgCl_2$) was used as the representative. However, to eliminate the influence of chloride, NaCl had to be reduced whereas other chemicals were kept constant as given in Table C.5.

Table A.5 The amount of NaCl and $HgCl_2$ for conducting the experiment in section 4.6

Chemicals	[mercury(II)] (ppm)					
	0	3	6	12	100	1000
NaCl (mg/L)	947	946.50	946.00	944.50	927.50	749.00
$HgCl_2$ (mg/L)	0	4.05	8.10	16.20	135.50	1354.00

Appendix B Corrosion Rate Calculation Step for Immersion Testing

Corrosion rate is determined as the mass loss rate which is calculated based on the equation (B.1).

$$\text{Mass loss rate (g/cm}^2\text{.yr)} = \frac{\text{(initial weight - final weight)}}{\text{exposed area} \times \text{time exposure}} \quad \text{(B.1)}$$

For example, 13Cr immersed in simulated produced water saturated with CO_2 at 60°C. Parameters going to be calculated are,

Initial weight, W_i, g = 24.1331 g

Final weight, W_f, g = 24.1185 g

Exposed area, rectangular coupon, cm^2

$$= 2(12.80 \times 76.50) + 2(76.50 \times 3.35) + 2(12.80 \times 3.35)$$

$$= 2556.71 \text{ mm}^2$$

$$= 25.5671 \text{ cm}^2$$

Time exposure, days = 14 days

Therefore,

$$\text{Mass loss rate} = \frac{24.1331 - 24.1185}{25.5671 \times 14}$$

$$= 4.08 \times 10^{-5} \frac{\text{g}}{\text{cm}^2 \cdot \text{days}}$$

$$= 0.0150 \frac{\text{g}}{\text{cm}^2 \cdot year}$$

Table B.1 Data from immersion testing of 13Cr in various conditions

Condition			Coupon No.	Dimension			Area (mm^2)	Weight	Weight	Corrosion rate	AVG	STDEV
Temp.	Solution	PCO2		W	L	T		(before)	(after)	$g/cm^2.yr$	$g/cm^2.yr$	
30	SPW	1	420_02	12.85	76.45	3.3	2554.15	24.0766	24.0664	0.0104	0.0104	
60	SPW	1	420_03	12.8	76.5	3.35	2556.71	24.1331	24.1185	0.0149	0.0150	0.0002
60	SPW	1	420_04	12.8	76.4	3.35	2553.48	24.0526	24.0378	0.0151		
50	SPW	1	420_05	12.7	76.4	3.25	2519.71	23.9702	23.9469	0.0241	0.0185	0.0080
50	SPW	1	420_06	12.8	76.6	3.35	2559.94	24.2309	24.2183	0.0128		
60	1%NaCl	1	420_07	12.8	76.6	3.35	2559.94	24.1816	24.1241	0.0585	0.0481	0.0148
60	1%NaCl	1	420_08	12.7	76.55	3.35	2542.35	24.1669	24.1302	0.0376		
60	3.5%NaCl	1	420_09	12.8	76.6	3.35	2559.94	24.4725	24.3484	0.1264	0.1096	0.0238
60	3.5%NaCl	1	420_10	12.6	76.6	3.3	2519.04	23.9958	23.9062	0.0928		
60	SPW	0	420_13	12.65	76.6	3.3	2527.03	24.2453	24.2432	0.0022	0.0037	0.0021
60	SPW	0	420_14	12.65	76.6	3.3	2527.03	24.1721	24.1671	0.0052		
60	SPW	0.5	420_21	12.7	76.4	3.2	2510.8	24.1536	24.1422	0.0127	0.0137	0.0014
60	SPW	0.5	420_22	12.7	76.3	3.15	2498.72	24.1366	24.1235	0.0147		
60	6 Hg(II)	1	420_11	12.65	76.6	3.3	2527.03	24.7946	24.7615	0.0342	0.0400	0.0082
60	6 Hg(II)	1	420_12	12.65	76.6	3.3	2527.03	24.1314	24.0870	0.0458		
60	12 Hg(II)	1	420_15	12.8	76.7	3.35	2563.17	24.3772	24.2158	0.1642	0.1075	0.0802
60	12 HG(II)	1	420_16	12.8	76.7	3.35	2563.17	24.0394	23.9895	0.0508		
60	pH = 11.16	1	420_17	12.8	76.7	3.35	2563.17	24.1752	24.1485	0.0272	0.0197	0.0105
60	pH = 11.16	1	420_18	12.7	76.7	3.35	2547.16	23.7601	23.7481	0.0123		
60	pH = 5.12	1	420_19	12.7	76.6	3.3	2535.02	24.3797	24.3177	0.0638	0.0588	0.0071
60	pH = 5.12	1	420_20	12.7	76.5	3.25	2522.9	24.1884	24.1364	0.0537		

Table B.2 Data from immersion testing of L80 in various conditions

Condition			Coupon No.	Dimension			Area (mm^2)	Weight	Weight	Corrosion rate	AVG	STDEV
Temp.	Solution	PCO2		W	L	T		(before)	(after)	$g/cm^2.yr$	$g/cm^2.yr$	
30	SPW	1	L80_31	12.75	76.6	3.35	2551.945	24.2951	24.2819	0.0691	0.0604	0.0122
30	SPW	1	L80_32	12.8	76.6	3.3	2551	23.2139	24.3534	0.0518		
60	SPW	1	L80_05	12.65	76.6	3.3	2527.03	24.2309	24.1498	0.0837	0.0804	0.0046
60	SPW	1	L80_06	12.65	76.6	3.3	2527.03	24.3011	24.2263	0.0772		
50	SPW	1	L80_03	12.8	76.6	3.3	2551	24.3441	24.2703	0.0754	0.0779	0.0035
50	SPW	1	L80_04	12.85	76.7	3.35	2571.175	24.1066	24.0273	0.0804		
60	1%NaCl	1	L80_07	12.65	76.5	3.35	2532.755	24.2757	24.2120	0.0656	0.0653	0.0005
60	1%NaCl	1	L80_08	12.65	76.5	3.35	2532.755	24.2524	24.1893	0.0649		
60	3.5%NaCl	1	L80_09	12.7	76.7	3.3	2538.22	24.2806	24.1969	0.0925	0.1016	0.0128
60	3.5%NaCl	1	L80_10	12.6	76.5	3.3	2515.86	24.2399	24.1407	0.1107		
60	SPW	0	L80_13	12.75	76.6	3.35	2551.945	24.2730	24.2157	0.0585	0.0479	0.0150
60	SPW	0	L80_14	12.75	76.6	3.35	2551.945	24.2593	24.2228	0.0373		
60	SPW	0.5	L80_21	12.8	76.7	3.4	2572.12	24.2045	24.1502	0.0593	0.0560	0.0046
60	SPW	0.5	L80_22	12.8	76.7	3.4	2572.12	24.2517	24.2034	0.0527		
60	6 Hg(II)	1	L80_11	12.65	76.6	3.3	2527.03	24.2280	24.1753	0.0544	0.0503	0.0058
60	6 Hg(II)	1	L80_12	12.65	76.6	3.3	2527.03	24.2746	24.2298	0.0462		
60	12 Hg(II)	1	L80_15	12.65	76.45	3.3	2522.245	24.4823	24.3496	0.1477	0.1165	0.0441
60	12 HG(II)	1	L80_16	12.65	76.45	3.3	2522.245	24.2121	24.1354	0.0854		
60	pH = 5.12	1	L80_19	12.8	76.7	3.4	2572.12	24.7274	24.6673	0.0609	0.0511	0.0138
60	pH = 5.12	1	L80_20	12.8	76.7	3.4	2572.12	24.3856	224.3448	0.0414		
60	pH = 11.16	1	L80_17	12.65	76.45	3.3	2522.245	24.3474	24.1023	0.2533	0.2576	0.0060
60	pH = 11.16	1	L80_18	12.75	76.6	3.35	2551.945	24.2506	23.9943	0.2618		

Appendix C Corrosion Rate Calculation Step for Potentiodynamic Polarization Technique

The polarization curve of 13Cr in simulated produced water saturated with CO_2 at 60°C is used to illustrate the Tafel extrapolation technique to obtain the corrosion current.

Open circuit potential or E_{corr} is shown by a vertical line whereas Tafel extrapolation lines were drawn and shown by slope line. The intersection between tafel slopes and E_{corr} is drawn across the figure horizontally and known as the corrosion current density.

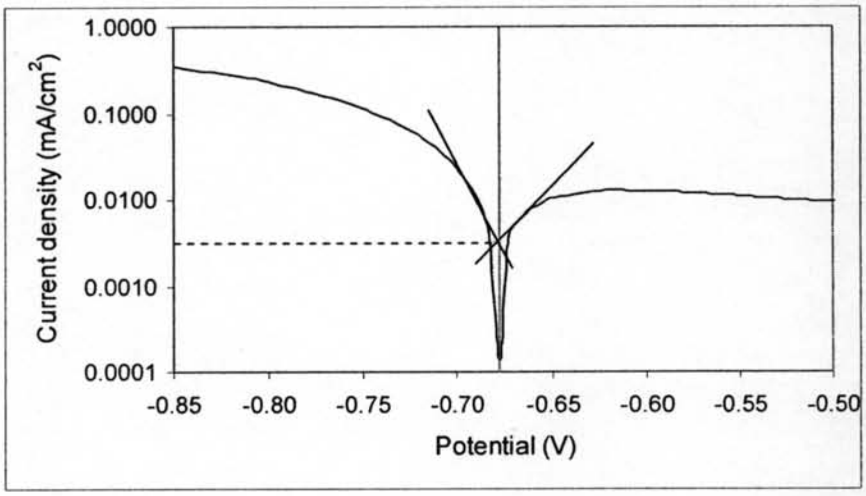

Figure C.1 Close up of polarization curve of 13Cr in simulated produced water at 60°C.

Once the corrosion current density is obtained, in this example is 0.0033 mA/cm^2, the corrosion rate is then calculated by equation (2.32)

$$r = \frac{m}{tA} = \frac{ia}{nF} \qquad 2.32$$

Where,

r	=	Corrosion rate in term of mass loss rate,
i	=	Current density,
F	=	Faraday's constant, 96,500 coulomb/equivalent,
a/N	=	Equivalent weight, EW, which is calculated by equation (2.33)

$$EW^{-1} = N_{EQ} = \Sigma\left(\frac{f_i}{a_i / n_i}\right) = \Sigma\left(\frac{f_i n_i}{a_i}\right) \tag{2.33}$$

Where f_i, n_i and a_i are mass fraction, electrons exchanged, and atomic weight, respectively. Calculation of equivalent weight for type 420 stainless steel composed of 12.94%Cr and 85.62%Fe is given in the equation (C.1) which gives the equivalent weight in the reciprocal form. Other elements with a composition less than 1% wt are considered to be negligible. Thus, the final value of equivalent weight is given in equation (C.2).

$$EW^{-1} = N_{EQ} = \Sigma\left(\frac{0.1294 \times 3}{52.01} + \frac{0.8562 \times 2}{55.84}\right) \tag{C.1}$$

$$EW = 26.2260 \; g_{alloys}/mol \tag{C.2}$$

Then, the corrosion rate is

$$r = \frac{(0.0033 mA / cm^2) \times (26.2260 g / mol \cdot e^-)}{96{,}500 C / mol \cdot e^-} \times \left(\frac{1A}{1000 mA}\right) \times \left(\frac{1C}{1A \times s}\right)$$

$$r = 8.9684 \times 10^{-10} (g / cm^2 \cdot s) = 0.0283 (g / cm^2 \cdot yr)$$

On the contrary, the equivalent weight (EW) of L80 (1.24%Mn and 97.85%Fe) is

$$EW^{-1} = N_{EQ} = \Sigma\left(\frac{0.0124 \times 2}{54.93} + \frac{0.9785 \times 2}{55.84}\right)$$

$$EW = 28.1706\ g_{alloys}/mol\ e^{-}$$

Hence, for the same condition of 13Cr, corrosion current density of L80 in solution of 60°C is 0.041 mA/cm^2. The corrosion can be calculated as shown in equation

Table C.1 Corrosion potential (V), corrosion current density (mA/cm^2), and corrosion rate (g/cm^2.yr) of L80 in various conditions

Condition			E_{corr}	i_{corr}	EW	Corrosion rate
Temp.	Solution	P_{CO2}	(V)	(mA/cm^2)		(g/cm^2.yr)
30	SPW	1	-0.7364	0.0094	28.1707	0.0865
50	SPW	1	-0.7315	0.0390	28.1707	0.3590
60	SPW	1	-0.7350	0.0410	28.1707	0.3774
60	1%NaCl	1	-0.7410	0.0275	28.1707	0.2532
60	3.5%NaCl	1	-0.7330	0.0690	28.1707	0.6352
60	SPW	0	-0.8730	0.0034	28.1707	0.0313
60	SPW	0.5	-0.7510	0.0107	28.1707	0.0985
60	pH 5.37	1	-0.7220	0.1200	28.1707	1.1047
60	pH 11.336	1	-0.7470	0.0240	28.1707	0.2209
60	3Hg(II)	1	-0.7400	0.0180	28.1707	0.1657
60	6Hg(II)	1	-0.7220	0.0183	28.1707	0.1685
60	12Hg(II)	1	-0.7370	0.0220	28.1707	0.2025
60	100Hg(II)	1	-0.7344	0.0310	28.1707	0.2854
60	1000Hg(II)	1	-0.4630	0.1100	28.1707	1.0126
30	3Hg(II)	1	-0.7120	0.0037	28.1707	0.0341
30	6Hg(II)	1	-0.7025	0.0043	28.1707	0.0396
30	12Hg(II)	1	-0.7260	0.0049	28.1707	0.0451
60	3Hg(II)	0	-0.741	0.0023	28.1707	0.0212
60	3Hg(II)	0.5	-0.74	0.0180	28.1707	0.1657

Table C.2 Corrosion potential (V), corrosion current density (mA/cm^2), and corrosion rate (g/cm^2.yr) of 13Cr in various conditions

Condition			E_{corr}	i_{corr}	EW	Corrosion rate
Temp.	Solution	P_{CO2}	(V)	(mA/cm^2)		($g/cm^2.yr$)
30	SPW	1	-0.6690	0.0014	26.2262	0.0120
50	SPW	1	-0.6827	0.0022	26.2262	0.0189
60	SPW	1	-0.6778	0.0033	26.2262	0.0283
60	1%NaCl	1	-0.6980	0.0023	26.2262	0.0197
60	3.5%NaCl	1	-0.7020	0.0019	26.2262	0.0163
60	3.5%NaCl	1	-0.6970	0.0035	26.2262	0.0300
60	SPW	0	-0.8780	0.0015	26.2262	0.0129
60	SPW	0.5	-0.7250	0.0023	26.2262	0.0197
60	11.336	1	-0.7120	0.0012	26.2262	0.0099
60	5.54	1	-0.6480	0.0043	26.2262	0.0369
60	3Hg(II)	1	-0.7110	0.0024	26.2262	0.0206
60	3Hg(II)	1	-0.7150	0.0032	26.2262	0.0274
60	6Hg(II)	1	-0.7169	0.0025	26.2262	0.0214
60	6Hg(II)	1	-0.7050	0.0029	26.2262	0.0249
60	12Hg(II)	1	-0.7016	0.0031	26.2262	0.0266
60	100Hg(II)	1	-0.025	0.078	26.2262	0.6685
60	1000Hg(II)	1	-0.0137	0.3000	26.2262	2.5711
60	1000Hg(II)	1	-0.0186	0.1900	26.2262	1.6284
30	0	1	-0.6690	0.0014	26.2262	0.0120
30	3	1	-0.6773	0.0013	26.2262	0.0107
30	6	1	-0.6700	0.0013	26.2262	0.0111
30	12	1	-0.6720	0.0015	26.2262	0.0129
60	3	0	-0.711	0.002	26.2262	0.0171
60	3	0.5	-0.712	0.0027	26.2262	0.0231

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