

## APPENDIX A : LIST OF SYMBOLS

$x_1 = m(\text{Fe}_{(S)}),$ mass of solid iron	[kg]
$x_2 = m(\text{Fe}_{(L)}),$ mass of liquid steel	[kg]
$x_3 = m(\text{C}),$ carbon in solution in steel	[kg]
$x_4 = m(\text{Si}),$ silicon in solution in steel	[kg]
$x_5 = m(\text{Slag}_{(S)}),$ solid slag mass	[kg]
$x_6 = m(\text{Slag}_{(L)}),$ liquid slag mass	[kg]
$x_7 = m(\text{FeO}),$ FeO in slag	[kg]
$x_8 = m(\text{SiO}_2),$ SiO <sub>2</sub> in slag	[kg]
$x_9 = m(\text{CO}),$ carbon-monoxide	[kg]
$x_{10} = m(\text{CO}_2),$ carbon-dioxide	[kg]
$x_{11} = m(\text{N}_2),$ nitrogen in gas-phase	[kg]
$x_{12} = T(\text{fluid group}),$ temperature	[K]
$x_{13} = T(\text{solid group}),$ temperature	[K]
$x_{14} = P(\text{furnace})$ relative pressure	[Pa]
$x_{15}, x_{16}, x_{17}$ comprise the off-gas flow	
$y_1 =$ relative pressure measurement	[Pa]
$y_2 =$ liquid steel temperature	[K]
$y_3 =$ off-gas %CO	[%]
$y_4 =$ off-gas temperature	[K]
$u_1 = \dot{m}(\text{turb}),$ Off-gas turbine flow	[kg/s]
$u_2 = w(\text{slipgap}),$ Slip gap width	[m]
$v_1 = \dot{m}(\text{Oxy}),$ oxygen fuel flow	[kg/s]
$v_2 = p(\text{Arc}),$ Electric arc power	[kW]
$v_3 = \dot{m}(\text{DRI}),$ DRI addition flow	[kg/s]
$w_1 = \dot{m}(\text{slag}),$ Slag addition	[kg/s]
$w_2 = \dot{m}(\text{graphite}),$ Graphite injected	[kg/s]

Table A.1 gives the values of dimensionless constants. Table A.2 gives the air and area constants. Table A.3 gives the rate and thermal constants. Four constant temperatures were assumed to be at 300 K:  $T_{\text{DRI}}, T_{\text{slag}}, T_{\text{O}_2}, T_{\text{AIR}}$ . Thermodynamic data such as latent heat, specific heat or enthalpy of formation were obtained from Kubaschewski *et al* [32] except where a reference in the chapters would indicate a different source.

Table A.1 Dimensionless Constants

$K_{\text{er}}$	$k_{\text{IJ}}$	$k_{\text{XC}}$	$k_{\text{XSi}}$	$k_{\text{PR}}$
15.0	8.44	$491 \cdot 10^{-6}$	$8.08 \cdot 10^{-8}$	0.2

Table A.2 Air and Area Constants

Air [ $\text{mol} \cdot \text{kg}^{-1}$ ]		Area [ $\text{m}^2 \cdot \text{kg}^{-1}$ ]	
$k_{\text{AIR1}}$	$k_{\text{AIR2i}}$	$k_{\text{area1}}$	$k_{\text{area2}}$
7.3	27.4	0.005	0.12

Table A.3 Rate and Thermal Constants

Rate [ $\text{kg} \cdot \text{s}^{-1}$ ]		Thermal [ $\text{kW} \cdot \text{K}^{-1} \cdot \text{m}^{-2}$ ]	
$k_{\text{dC}}$	$k_{\text{dSi}}$	$k_{\text{ther1}}$	$k_{\text{ther5}}$
12	144	0.4	0.2

$M$  = manipulation horizon

$P$  = prediction horizon

$U$  = input cost function weight matrix (diagonal)

$Y$  = output cost function weight matrix (diagonal)

$K_I$  = integral cost function weight

$\gamma_C$  = activity coefficient of carbon in liquid steel

$\gamma_{FeO}$  = activity coefficient of FeO in slag

$\bar{\gamma}$  = error vector used in cost function of MPC

$\bar{r}$  = output setpoint vector

$\bar{y}$  = output vector

$\psi$  = cost function

Time	Date	Time	Temp	T(Calcium)	WtC
12:00	3280	0	0	0	0
12:01	3280	0	0	0	0
12:02	3280	0	0	0	0
12:03	3280	0	0	0	0
12:04	3280	0	0	0	0
12:05	3280	0	0	0	0
12:06	3280	0	0	0	0
12:07	3280	0	0	0	0
12:08	3280	0	0	0	0
12:09	3280	0	0	0	0
12:10	3280	0	0	0	0
12:11	3280	0	0	0	0
12:12	4841	110	237	247	0
12:13	5686	138	306	444	0
12:14	6735	186	374	543	0
12:15	8120	159	445	647	0
12:16	8820	232	522	784	0
12:17	9870	266	595	861	0
12:18	10820	288	660	908	0
12:19	11970	332	740	1075	0
12:20	13017	366	815	1162	0
12:21	14064	399	890	1289	0
12:22	15111	432	964	1390	0
12:23	16158	465	1037	1570	0
12:24	17205	498	1111	1810	0
12:25	18252	530	1185	1717	0
12:26	19299	560	1258	1824	0
12:27	20346	590	1332	1931	0
12:28	21393	637	1405	2136	0
12:29	22440	695	1478	2145	700
12:30	23487	800	1551	2212	1070
12:31	24534	720	1627	2269	1500
12:32	25582	707	1700	2487	2000
12:33	26630	800	1774	2574	2600
12:34	27678	824	1848	2692	3000
12:35	28726	808	1921	2788	3200
12:36	29774	900	1995	2987	4000
12:37	30822	938	2069	3034	4300
12:38	31870	995	2142	3077	5070
12:39	32918	1032	2216	3150	5500
12:40	33966	1038	2222	3258	6900
12:41	35014	1070	2286	3386	8500
12:42	36062	1104	2370	3474	9700
12:43	37110	1138	2410	3548	7000
12:44	38158	1172	2450	3522	6000
12:45	39206	1206	2480	3686	8500
12:46	40254	1241	2520	3770	6000
12:47	41302	1275	2560	3845	9500

## Appendix B: Plant Data

Minutes	Time	Electricity		Oxygen		DRI	Antra	Dolo	Lime	Foam	T(Celcius)	%C
		Kwh	Nm3	Nm3	Nm3							
1	11:54	680	0	0	0	0	0	0	0	0		
2	11:55	1360	0	0	0	0	0	0	0	0		
3	11:56	2310	0	0	0	0	0	0	0	0		
4	11:57	3260	0	0	0	0	0	0	0	0		
5	11:58	3260	0	0	0	0	0	0	0	0		
6	11:59	3260	0	0	0	0	0	0	0	0		
7	12:00	3260	0	0	0	0	0	0	0	0		
8	12:01	3260	0	0	0	0	0	0	0	0		
9	12:02	3260	0	0	0	0	0	0	0	0		
10	12:03	3260	0	0	0	0	0	0	0	0		
11	12:04	3260	0	0	0	0	0	0	0	0		
12	12:05	3260	0	0	0	0	0	0	0	0		
13	12:06	3260	0	0	0	0	0	0	0	0		
14	12:07	3260	0	0	0	0	0	0	0	0		
15	12:08	3260	0	0	0	0	0	0	0	0		
16	12:09	3260	27	32	58	0	0	0	0	0		
17	12:10	3593	54	100	155	0	0	0	0	0		
18	12:11	3594	82	169	251	0	0	0	0	0		
19	12:12	4641	110	237	347	0	0	0	0	0		
20	12:13	5688	138	306	444	0	0	0	0	0		
21	12:14	6735	166	374	540	0	0	0	0	0		
22	12:15	8120	199	448	647	0	0	0	0	0		
23	12:16	8829	232	522	754	0	0	0	50	0		
24	12:17	9876	266	595	861	0	0	0	100	0		
25	12:18	10923	299	669	968	0	0	0	150	0		
26	12:19	11970	332	743	1075	0	0	0	200	0		
27	12:20	13017	366	816	1182	0	0	0	250	0		
28	12:21	14064	399	890	1289	0	0	0	300	0		
29	12:22	15111	432	964	1396	0	0	0	350	0		
30	12:23	16158	466	1037	1503	0	0	0	400	0		
31	12:24	17205	499	1111	1610	0	0	0	450	0		
32	12:25	18252	532	1185	1717	0	0	0	500	0		
33	12:26	19299	566	1258	1824	0	0	0	550	0		
34	12:27	20346	599	1332	1931	0	0	0	600	25		
35	12:28	21393	632	1406	2038	0	0	0	650	50		
36	12:29	22440	666	1479	2145	500	0	0	700	75		
37	12:30	23487	699	1553	2252	1000	0	0	750	100		
38	12:31	24534	733	1627	2359	1500	0	0	800	100		
39	12:32	25582	767	1700	2467	2000	0	0	850	100		
40	12:33	26629	800	1774	2574	2500	0	0	900	100		
41	12:34	27676	834	1848	2682	3000	0	0	950	100		
42	12:35	28723	868	1921	2789	3500	0	0	1000	100		
43	12:36	29770	902	1995	2897	4000	0	0	1050	100		
44	12:37	30817	936	2069	3004	4500	0	0	1100	100	1551	
45	12:38	31864	969	2108	3077	5000	0	0	1150	100	1551	0.056
46	12:39	32911	1002	2148	3150	5500	117	50	1200	100	1551	0.056
47	12:40	33958	1036	2222	3258	6000	233	100	1250	100	1551	0.056
48	12:41	35005	1070	2296	3366	6500	350	150	1300	100	1551	0.056
49	12:42	36052	1104	2370	3474	7000	467	200	1350	100	1551	0.056
50	12:43	37099	1138	2410	3548	7500	467	250	1400	100	1551	0.056
51	12:44	38146	1172	2450	3622	8000	467	300	1450	100	1551	0.056
52	12:45	39193	1206	2489	3696	8500	467	350	1500	100	1605	0.056
53	12:46	40240	1241	2529	3770	9000	467	400	1550	100	1605	0.048
54	12:47	41287	1275	2569	3845	9500	467	450	1600	100	1605	0.048



55	12:48	42334	1310	2610	3919	10000	467	500	1650	100	1605	0.048
56	12:49	43381	1344	2650	3994	10500	467	550	1700	100	1605	0.048
57	12:50	44428	1379	2690	4069	12333	467	600	1750	100	1605	0.048
58	12:51	45475	1413	2731	4144	14167	467	650	1800	100	1630	0.048
59	12:52	46522	1448	2771	4219	16000	467	700	1850	100	1630	0.035
60	12:53	47569	1448	2771	4219	17833	467	750	1900	100	1630	0.035
61	12:54	48616	1448	2771	4219	19667	467	800	1950	100	1630	0.035
62	12:55	49664	1448	2771	4219	20667	467	850	2000	100	1630	0.035
63	12:56	50711	1448	2771	4219	21667	467	900	2050	100	1602	0.035
64	12:57	51758	1448	2771	4219	22667	467	950	2100	100	1602	0.03
65	12:58	52805	1448	2771	4219	23667	467	1000	2150	100	1602	0.03
66	12:59	53852	1448	2771	4219	24667	467	1050	2200	100	1602	0.03
67	13:00	54899	1448	2771	4219	25667	467	1100	2250	100	1602	0.03
68	13:01	55946	1448	2771	4219	26667	467	1150	2300	100	1602	0.03
69	13:02	56993	1448	2771	4219	27667	467	1200	2350	100	1609	0.03
70	13:03	58040	1448	2771	4219	28667	467	1250	2400	100	1609	0.03
71	13:04	59087	1448	2771	4219	29667	467	1300	2450	100	1609	0.03
72	13:05	60134	1448	2771	4219	30667	467	1350	2500	100	1609	0.03
73	13:06	61181	1448	2771	4219	31667	467	1400	2550	100	1609	0.03
74	13:07	62228	1448	2771	4219	33433	467	1450	2600	100	1609	0.03
75	13:08	63275	1448	2771	4219	35200	467	1500	2650	100	1625	0.03
76	13:09	64322	1448	2771	4219	35200	467	1500	2700	100	1625	0.03
77	13:10	65369	1448	2771	4219	35200	467	1500	2750	100	1625	0.03
78	13:11	66416	1448	2771	4219	35200	467	1500	2750	100	1625	0.03
79	13:12	67463	1448	2771	4219	35200	467	1500	2750	100	1625	0.025
80	13:13	68510	1448	2771	4219	35200	467	1500	2750	100	1625	0.025
81	13:14	69557	1448	2771	4219	35200	467	1500	2767	100	1625	0.025
82	13:15	70605	1448	2771	4219	35200	467	1500	2767	100	1627	0.025

## Appendix C: Linear system

A

-8E-04	0	0	0	0	0	0	0	0	0	0	0	-8E-04	-5E-04	0	0	0	0	
0.0008	-1E-05	0.0058	0.0086	0	-7E-05	0.0008	-7E-05	0	0	0	0.0008	0.0005	0	0	0	0	0	
0	3E-06	-0.002	6E-06	0	1E-05	-8E-05	1E-05	0	0	0	0	0	0	0	0	0	0	
0	1E-07	7E-07	-0.002	0	1E-07	-7E-07	1E-07	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	-1E-03	0	0	0	0	0	0	0	-6E-05	-3E-04	0	0	0	0	
0	0	0	0	0.001	0	0	0	0	0	0	0	6E-05	0.0003	0	0	0	0	
0	1E-05	-0.006	-0.009	0	7E-05	-8E-04	7E-05	0	0	0	0	0	0	0	0	0	0	
0	-3E-07	-1E-06	0.0046	0	-2E-07	1E-06	-2E-07	0	0	0	0	0	0	0	0	0	0	
5E-08	-2E-07	5E-05	-4E-07	0	-9E-07	5E-06	-9E-07	-0.001	0.0013	0.0013	-5E-06	-1E-05	0.0012	-0.006	0.0055	0	0	
0	0	0	0	0	0	0	0	0.0006	-0.002	0.0006	-1E-06	3E-06	-0.002	-0.003	0.0026	0	0	
0	0	0	0	0	0	0	0	0.0007	0.0007	-0.002	-1E-06	3E-06	-0.002	-0.003	0.0031	0	0	
-8E-06	-6E-07	-2E-04	0.0006	-1E-05	2E-06	-2E-05	1E-06	0	0	0	-1E-04	1E-04	0.0016	0	0	0	0	
4E-07	0	0	0	-1E-06	0	0	0	0	0	0	0.0006	-8E-04	0	0	0	0	0	
-4E-04	-6E-04	0.1379	0.0308	-5E-04	-0.003	0.0139	-0.003	9E-16	6E-16	1E-15	-0.006	0.0054	-8.599	-31.67	31.672	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.093	-1.287	-2.194

C

0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4981	-0.498	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7361	-0.736	0	0
0	0	0	0	0	0	0	0	0.0011	-2E-04	-1E-04	0.0002	0	-6E-04	0.0005	-5E-04	0	0
0	0	0	0	0	0	0	0	0	0	0	0.3229	0	0	55.591	-55.59	0	0

B

0	0	0	0	0	0	0	0
0	0	-3.5	0	0.825	0	10.392	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0
0	0	3.5	0	0.13	0	-13.36	0
0	0	0	0	0.045	0	0	0
0	0.0775	0.0187	0	0	0	0.07	0
0	0.0361	-0.005	0	0	0	0	0
0	0.0431	-0.005	0	0	0	0	0
0	0	0.0945	1E-05	-0.007	-0.006	-0.203	0
0	0	0	0	0	0	0	0
0	442.75	5.2881	0.0006	-0.368	-0.359	186.41	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0

D

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	-5.224	0	0	0	0	0
0	-7.72	0	0	0	0	0
0	-0.904	0	0	0	0	0
0	-934.2	0	0	0	0	0