Final Report
For
Minnesota Department of Natural Resources
Iron Ore Cooperative Research

ANALYSIS OF OXYGEN INJECTION
IN THE KEEWATIN TACONITE
KILN TRANSFER CHUTE
USING MEDUSA HEAT
AND MASS BALANCE SIMULATION
AND MINI-POT FIRING TESTS

COLERAINE MINERALS RESEARCH LABORATORY

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Objective:
Perform Medusa modeling and simulation of the Keewatin Taconite Line 2 furnace, simulating oxygen injection in the first few feet of the kiln to determine oxygen required to achieve magnetite oxidation levels equivalent to ported kiln performance, greater than 95% complete at the kiln discharge point.

Introduction:
The hybrid-Medusa heat and mass balance program with CFD cooler model linear equations was modified to simulate oxygen injection at the kiln transfer chute of the Line 2 furnace. Specifically, the CFD equations were modified to accept lower magnetite contents expected with oxygen injection, because the original cooler CFD relations were not established at the lower levels of magnetite. Parallel flow and recoup gas temperature relationships for decreased oxidation in the cooler were approximated based on CFD models established for the Line 7 ported kiln installation at Minntac. Results presented are an estimation of the expected outcome. At additional cost, a more exact solution could be obtained by performing additional CFD runs on the KeeTac cooler operating under ported kiln conditions, but this was beyond the scope of this initial investigation.

The simulations indicated that oxidation levels in excess of 95% could not be achieved within the short length of kiln and preheat zone, even when oxygen levels approached three times the stoichiometric amount required, for an assumed production rate of 640 LTPH of product. In an attempt to validate these findings, 16 mini-pot tests were performed using a grate cycle based on 670 LTPH of product. The pellets were quenched with nitrogen in the pot and assayed for ferrous iron in top, center and bottom samples from which average oxidation at the end of the grate was estimated. These tests confirmed the simulation results, that excessive amounts of oxygen would be required given the very short contact time between gas and bed on the furnace grate.

Mini-Pot Tests:
The mini-pot test apparatus which was acquired from the former Cliffs Research Laboratory in Hibbing was used to simulate the effect of increased oxygen levels on the grate in the preheat zone. Two samples of green balls were collected from KeeTac on June 9 and June 23, respectively.

The grate cycle was based on a combination of a grate speed of 309 in/min, a bed depth of nominal 5 inches, and bulk density of 130 lbs/ft^3, to yield a fired pellet production rate of 670 LTPH. Test conditions are summarized in Table 1. The mini-pot is equipped with data logging, for on-gas and bed temperatures and estimated air flow to the burner, based on a burner pressure drop correlation supplied by the burner manufacturer. The airflow at the burner is the combined flow of air plus injected oxygen.

Inlet gas oxygen content is monitored through an oxygen sensor; output is manually logged, as there is no electronic signal available for data logging. Oxygen levels were recorded every 15 seconds during the test. Immediately following the end of the test, airflow was shut off and nitrogen was introduced to the pot via the burner air delivery system. Nitrogen flow continued until bottom of the bed temperatures fell below 250°C. At this point, the pot was opened up and samples taken of top, center and bottom of the bed for total and ferrous iron assays. A green ball head sample was also assayed to provide the starting ferrous iron content. The bed was divided as follows, top = 5-3.5 inches above grate, center = 3.5-1.5 inches above grate, and bottom = 1.5 – 0 inches above grate. Weights were established for total green balls charged and for each of the top, center, and bottom samples and were kept constant throughout all 16 tests.

Initially the oxygen was added in the time period correlating to the last wind box of the preheat zone, which was the last 23 seconds of the 1:56 (min:sec) preheat residence time. Problems were encountered, in that the inlet gas delivery to the oxygen sensor was too slow, making oxygen content control difficult. Beginning with test 7, elevated oxygen levels were performed for the entire preheat zone. Gas delivery to the sensor was modified for tests 10-16, providing for significantly faster response time at the sensor. However, tests 10-14 were carried out with added oxygen for the entire preheat zone, to be consistent with earlier tests. In tests 15 and 16, oxygen was added again, simulating the last wind box of the preheat zone. While oxygen control and sensing improved in the second test series, the test apparatus does not have a sufficiently fast response time to achieve adequate control and repeatability for a 23 second time period.

Table 2A contains the time averaged inlet gas oxygen contents by zone for all tests, along with the percent oxidation completed in the bed at the end of the grate cycle. The average oxidation completed is the average of the top, center, and bottom values. Percent oxidation is calculated as the difference between green ball ferrous and remaining ferrous iron, divided by green ball ferrous iron. Several temperature conditions for the preheat zone were tested initially. Table 2B breaks out the tests that have the same time and temperature conditions with varied oxygen contents. Table 2C provides the ferrous iron assays.

Figure 1 plots the time averaged **target** oxygen content for the preheat zone against the time averaged **measured** oxygen content during the test. The plot in Figure 1 provides a relative indication of ability to achieve and control the target oxygen content. Overall, the correlation is acceptable; the scatter most likely results from the combination of limited readings and the response time variability. Figure 2 plots average bed oxidation completed against the averaged measured oxygen content in the inlet gas. Here the scatter is due partially to response time variability and several tests with different preheat temperatures. Figure 3 plots results from Table 2B, where time and temperature conditions are constant and only oxygen content is variable.

From Figure 3, one can see that the baseline oxygen content of 16-17 percent resulted in an average oxidation of 66-73%, which is thought to be a reasonable approximation of plant conditions. The highest degree of oxidation, 85%, was achieved with 29% oxygen during the entire preheat zone, which falls short of the target by 10 percentage points. Keep in mind that the stoichiometric volume of oxygen, if well mixed with the entire preheat flow in the plant, would raise oxygen content from 16-17% to 17-18%. On this basis, the tests in the 18-20% O2 range produced a maximum oxidation of 78%, well below the target.

The mini-pot tests simulated how much additional oxidation might be completed on the grate. It is recognized that the total pellet oxidation would be higher when allowing for the additional oxidation on the transfer chute. The Medusa simulations address the combined oxidation levels on the grate and in the kiln. The simulations and the mini-pot tests appear to be in agreement that stoichiometric volumes of oxygen will not achieve the target oxidation >95%.

Medusa-Hybrid Simulations:
Table 3 gives the calculation for estimating the stoichiometric amount of oxygen required to achieve 100% oxidation in the pellets, assuming an average starting value of 65% completed on the grate under baseline conditions. For 640 LTPH of product, the volume of oxygen required is on the order of 3300 SCFM at 90% O2 purity. The Medusa simulations were carried out at this single production

rate. Variables investigated were the number of kiln injection ports, the oxygen volume flow, purity, and temperature.

Thirty-one simulations were performed and the results are tabulated in Table 4. The simulations approximate the injection point by limiting the number of ports in the model. The injection point in the plant will have a shallower bed with less contact time between gas and solids, relative to the Medusa simulations, and, on this basis, the simulated results may be overestimating the degree of oxidation achieved. In the model, the kiln length is divided into 100 divisions, which are approximately 1.3 feet long in the case of the KeeTac kiln. Thus the relative length of kiln used for injection is 1.3*# ports. Three injection ports simulate an injection zone in the kiln 4.2 feet long.

The simulations show that percent oxidation completed is strongly influenced by the number of ports; injecting the same amount of gas through more ports will raise the degree of oxidation. Increasing the gas flow through fewer ports was evaluated and found to be ineffective. Three ports were considered the minimum and nine were required to achieve target levels of oxidation at volumes approaching stoichiometric requirements.

Figure 4 is based on the Medusa simulations and summarizes oxygen injection effect on preheat inlet gas oxygen content, assuming a well-mixed reactor. This provides for comparison to the mini-pot simulations. For flow rates between 3000 and 4000 SCFM (@ 100% purity) oxygen content in the preheat gases ranges between 17 and 18 percent. In Figure 5, the same numbers are reworked to show impact on oxygen content reporting to the last wind box of preheat. The relation in Figure 5 is based on the assumption that injected gas reports to the last wind box on the grate and is not uniformly mixed over bed. The total gas flow to the last wind box is proportioned by the number of wind boxes, which in these simulations amounts to 20%, to which the injected oxygen is added.

Figure 6 is a crude statistical model derived from the simulations. Its purpose is to show that oxidation on the grate is primarily influenced by port volume flow, whereas in the kiln, oxidation is primarily influenced by the number of ports. Thus, grate oxidation increases mainly with increasing volume flow, and oxidation in the kiln increases with increasing number of ports. The total oxidation achieved in the process at or near stoichiometric additions falls short of the target by 7-10 percentage points.

It may be possible to achieve the goal of 95% oxidation by increasing the length of the injection zone from 4 feet to 9 plus feet, i.e. adding more ports. This might still achieve the weight reduction necessary for the injection equipment required by the kiln bearing limitations, while meeting the oxidation target with reasonable volumes of gas. This evaluation would require additional funding to complete, if interest exists.

Table 1
Mini Pot Test Firing Conditions

	DD1			DD2			Preheat					
							WB1-4	WB 5	WB1-5	WB1-4	WB 5	Time Wt'd
Test #	Time, Min:Sec	Temp, F	% O2	Time, Min	Temp, F	% O2	Time, Min:Sec	Time, Min:Sec	Temp, F	% O2	% O2	Ave % O2
1	1:56	625	As Is	1:33	1460	20	1:33	0:23	1950	16.5	16.5	16.5
2	1:56	625	As Is	1:33	1460	20	1:33	0:23	1950	16.5	26.0	18.4
3	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	16.5	16.5	16.5
4	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	16.5	23.0	17.8
5	1:56	625	As Is	1:33	1460	20	1:33	0:23	2100	16.5	16.5	16.5
6	1:56	625	As Is	1:33	1460	20	1:33	0:23	2100	19.0	19.0	19.0
7	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	20.5	20.5	20.5
8	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	22.0	22.0	22.0
9	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	22.0	22.0	22.0
10	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	16.0	16.0	16.0
11	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	19.0	19.0	19.0
12	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	23.0	23.0	23.0
13	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	27.0	27.0	27.0
14	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	30.0	30.0	30.0
15	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	16.0	25.0	17.8
16	1:56	625	As Is	1:33	1460	20	1:33	0:23	2025	16.0	30.0	18.8

Green balls sampled on 6/9/04 Tests 1-9 and 6/23/04 Tests 10-16
Bed Depth = Approx 5", green ball charge per test = 2160 gms,
Cycle time based on grate speed =309.4 in/min, 140 Ft grate, 5"inch bed,

Grate cycle time, min=	5.43
Simulated product rate,LTPH	671
Tests 1-9 Moisture %wt	9.04
Tests 10-16 Moisture %wt	9.13

Table 2A

Test #	Time Averaged Inlet Gas Oxygen Content %			Oxidation Completed End Of Pheat			
	DD1	DD2	Pheat	Top	Middle	Bottom	Bed Ave
1	19.04	18.20	18.09	88.23	85.61	61.57	78.47
2	18.44	17.73	18.55	91.10	87.78	72.30	83.73
3	18.08	17.35	16.66	84.22	76.95	59.05	73.41
4	18.06	18.83	19.69	87.98	79.77	65.63	77.79
5	30.01	18.57	16.80	83.14	76.11	54.50	71.25
6	18.41	18.57	18.86	87.34	80.22	62.41	76.66
7	18.70	17.70	20.51	87.04	79.18	57.02	74.41
8	19.46	15.60	20.51	89.96	78.19	58.26	75.47
9	18.83	19.68	21.01	83.88	77.89	59.10	73.62
10	17.58	18.97	16.31	79.35	71.61	48.08	66.35
11	17.95	19.95	19.03	85.78	79.81	60.78	75.46
12	18.04	19.23	22.46	83.10	77.23	53.04	71.12
13	17.99	20.02	27.01	93.98	84.11	67.41	81.83
14	17.74	18.75	27.56	93.17	89.37	71.46	84.67
15	17.75	17.93	18.14	84.11	77.99	59.41	73.84
16	17.86	19.00	20.06	85.17	81.17	61.84	76.06

Table 2B

Tests with Common Time and Temperature Conditions

Test #	Time Averaged Oxygen			Oxidation Completed End Of Pheat			
	DD1	DD2	Pheat	Top	Middle	Bottom	Bed Ave
3	18.08	17.35	16.66	84.22	76.95	59.05	73.41
4	18.06	18.83	19.69	87.98	79.77	65.63	77.79
7	30.01	18.57	16.80	83.14	76.11	54.50	71.25
8	18.41	18.57	18.86	87.34	80.22	62.41	76.66
9	18.70	17.70	20.51	87.04	79.18	57.02	74.41
10	19.46	15.60	20.51	89.96	78.19	58.26	75.47
11	18.83	19.68	21.01	83.88	77.89	59.10	73.62
12	17.58	18.97	16.31	79.35	71.61	48.08	66.35
13	17.95	19.95	19.03	85.78	79.81	60.78	75.46
14	18.04	19.23	22.46	83.10	77.23	53.04	71.12
15	17.99	20.02	27.01	93.98	84.11	67.41	81.83
16	17.74	18.75	27.56	93.17	89.37	71.46	84.67

Table 2C

Ferrous Iron Assays

Test #	Green Ball Head	Top	Middle	Bottom
1	20.22	2.38	2.91	7.77
2	20.22	1.80	2.47	5.60
3	20.22	3.19	4.66	8.28
4	20.22	2.43	4.09	6.95
5	20.22	3.41	4.83	9.20
6	20.22	2.56	4.00	7.60
7	20.22	2.62	4.21	8.69
8	20.22	2.03	4.41	8.44
9	20.22	3.26	4.47	8.27
10	19.76	4.08	5.61	10.26
11	19.76	2.81	3.99	7.75
12	19.76	3.34	4.50	9.28
13	19.76	1.19	3.14	6.44
14	19.76	1.35	2.10	5.64
15	19.76	3.14	4.35	8.02
16	19.76	2.93	3.72	7.54

Table 3

Conditions For Medusa Simulations

Estimated Volume of O2 Required for production rate of 640 DLTPH

LTPH Magnetite to Oxidize from 65 to 100%		195.68
	lb mols/hr	1894.21
O2 Required	lb mols/hr	473.55
Approx Stoichiometric volume required @ 90% purity	SCFM	3323.63

Table 4 Medusa-CFD Simulation Results

1 of 3

RUN #	File Name	PORT SCFM	O2 Deg F	% O2	Kiln Port Range	3A lbs/min	3B lbs/min	Rec By-pass lbs/min	Rec Out Prs inH2O	KILN FUEL SCFM	FEED WLTPH	INLET AIR DEG K	Green Ball %WT Magnetite	DD1 Ave Pellet Deg F	DD2 Ave Pellet Deg F
1	**Pretest_magadj_1**	**0**	**70**	**0**	**0**	**15000**	**17500**	**500**	**-1.7**	**3615**	**735**	**280**	**75.45**	**174**	**956**
2	Pretest_magadj_2	6000	70	90	3	15000	17500	500	-1.7	3200	735	280	75.45	159	882
3	Pretest_magadj_3	7000	70	90	3	15000	17500	500	-1.7	3200	735	280	75.45	164	886
4	Pretest_magadj_4	10000	70	90	3	15000	17500	500	-1.7	3200	735	280	75.45	176	897
5	Pretest_magadj_5	10000	70	90	6	15000	17500	500	-1.7	3200	735	280	75.45	168	883
6	Pretest_magadj_6	7000	70	90	9	15000	17500	500	-1.7	3200	735	280	75.45	153	860
7	Pretest_magadj_7	4000	70	90	9	15000	17500	500	-1.7	3100	735	280	75.45	137	823
8	Pretest_magadj_8	3500	70	90	9	15000	17500	500	-1.7	2850	735	280	75.45	123	759
9	Pretest_magadj_9	4500	70	90	9	15000	17500	500	-1.7	2850	735	280	75.45	125	758
10	Pret_magadj_10	4500	70	90	9	13000	17500	500	-1.7	2975	735	280	75.45	115	738
11	Pret_magadj_11	4500	70	90	9	16000	13500	500	-1.7	2975	735	280	75.45	128	741
12	Pret_magadj_12	4500	250	90	5	16000	13500	500	-1.7	2975	735	280	75.45	132	757
13	Pret_magadj_13	4500	250	90	3	16000	13500	500	-1.7	2975	735	280	75.45	135	769
14	Pret_magadj_14	15000	250	90	3	16000	13500	500	-1.7	3275	735	280	75.45	203	893
15	Pret_magadj_15	4500	1500	90	3	16000	13500	500	-1.7	2800	735	280	75.45	126	726
16	Pret_magadj_16	4500	1000	90	3	16000	13500	500	-1.7	2935	735	280	75.45	132	755
17	Pret_magadj_17	4500	750	90	3	16000	13500	500	-1.7	2995	735	280	75.45	136	772
18	Pret_magadj_18	4500	500	90	3	16000	13500	500	-1.7	3075	735	280	75.45	141	794
19	Pret_magadj_19	4500	250	90	3	16000	13500	500	-1.7	3150	735	280	75.45	147	815
20	Pret_magadj_20	8000	1200	40	3	16000	13500	500	-1.7	3125	735	280	75.45	164	856
21	Pret_magadj_21	8000	1200	43	3	16000	13500	500	-1.7	3125	735	280	75.45	164	855
22	Pret_magadj_22	8000	1200	46	3	16000	13500	500	-1.7	3050	735	280	75.45	157	836
23	Pret_magadj_23	8000	1200	50	3	16000	13500	500	-1.7	2975	735	280	75.45	151	816
24	Pret_magadj_24	8000	1200	55	3	16000	13500	500	-1.7	2975	735	280	75.45	151	814
25	Pret_magadj_25	8000	1200	60	3	16000	13500	500	-1.7	2975	735	280	75.45	150	812
26	Pret_magadj_26	8000	1200	65	3	16000	13500	500	-1.7	2975	735	280	75.45	150	810
27	Pret_magadj_27	8000	1300	65	3	16000	13500	500	-1.7	2975	735	280	75.45	150	812
28	Pret_magadj_28	10000	1200	50	3	16000	13500	500	-1.7	2975	735	280	75.45	159	832
29	Pret_magadj_29	10000	1350	50	3	16000	13500	500	-1.7	2975	735	280	75.45	160	836
30	Pret_magadj_30	10000	1425	50	3	16000	13500	500	-1.7	2975	735	280	75.45	161	839
31	Pret_magadj_31	10000	1525	50	3	16000	13500	500	-1.7	2975	735	280	75.45	162	841

Kiln has 100 divisions over 130 Ft, @ 1.3 ft/division

3 ports = 4.2 ft distance into kiln

9 ports = 11.7 ft distance into kiln

Table 4 Medusa-CFD Simulation Results
2 of 3

DD2 Ave %FE3O4	PHeat Ave Pellet Deg F	PHeat Ave % Fe3O4	PHeat OBed % O2	Kiln Pell Disch Deg F	KILN %FE3O4	KILN SOL LTPH	DD1 GAS IN lbs/min	DD1 GAS IN Deg F	DD2 GAS IN lbs/min	DD2 GAS IN Deg F	HEAT GAS IN lbs/min	PH OBED Deg F	KILN GAS IN lbs/min
56.70	**1758**	**24.53**	**16.5**	**2247**	**23.04**	**675.72**	**21652**	**689**	**12657**	**1496**	**14560**	**1780**	**11594**
58.76	1710	23.82	18.8	2227	10.43	678.92	22002	657	12671	1403	14935	1733	11609
58.56	1709	23.30	19.2	2219	10.14	679.00	22089	666	12675	1397	15031	1726	11614
57.99	1707	21.87	20.3	2196	9.32	679.20	22348	690	12686	1380	15317	1710	11631
58.55	1720	22.45	20.0	2263	3.29	680.74	22247	676	12682	1375	15205	1738	11583
59.42	1726	24.38	18.6	2327	0.10	681.55	21925	641	12668	1388	14846	1769	11537
60.73	1696	26.62	17.5	2316	1.09	681.29	21695	598	12658	1386	14568	1761	11545
62.68	1627	28.47	17.6	2230	2.27	680.99	21725	549	12658	1344	14551	1705	11606
62.59	1632	27.98	18.0	2234	1.05	681.31	21792	556	12662	1338	14629	1705	11604
63.45	1567	30.55	17.4	2213	1.82	681.11	20505	473	12251	1457	13235	1670	10203
62.97	1658	28.06	17.9	2273	1.11	681.29	22285	568	11993	1319	15204	1741	12163
62.52	1662	27.46	18.1	2244	4.42	680.45	22324	580	11995	1326	15261	1734	12184
62.10	1656	26.86	18.4	2188	9.77	679.09	22403	592	11998	1332	15358	1713	12224
57.73	1725	20.08	21.9	2208	6.60	679.90	23236	734	12034	1329	16338	1722	12211
63.39	1644	28.29	18.1	2248	1.54	684.10	22293	558	11993	1308	15202	1730	12181
62.51	1668	27.41	18.1	2257	3.72	680.63	22305	580	11994	1328	15241	1743	12175
62.00	1677	26.93	18.2	2253	5.32	680.22	22319	592	11995	1337	15270	1743	12178
61.37	1690	26.35	18.2	2252	7.16	679.76	22335	608	11996	1351	15303	1749	12178
60.75	1701	25.76	18.2	2248	9.35	679.20	22357	625	11997	1364	15342	1751	12181
59.41	1715	25.23	17.6	2239	11.70	678.60	22616	664	12008	1376	15635	1751	12188
59.44	1717	25.15	17.7	2246	10.94	678.79	22606	663	12007	1375	15626	1754	12183
60.01	1702	25.46	17.9	2228	10.37	678.94	22611	650	12007	1361	15624	1741	12196
60.67	1686	25.81	18.1	2214	9.59	679.14	22616	634	12008	1347	15618	1729	12206
60.73	1689	25.70	18.2	2224	8.44	679.40	22603	633	12007	1345	15605	1733	12198
60.79	1692	25.58	18.4	2234	7.35	679.71	22592	632	12007	1343	15593	1737	12191
60.83	1695	25.45	18.6	2244	6.31	679.97	22581	632	12006	1341	15582	1740	12184
60.77	1699	25.41	18.5	2253	5.82	680.10	22569	633	12006	1343	15571	1745	12178
60.08	1693	24.98	18.4	2212	9.20	679.24	22763	654	12014	1344	15790	1726	12207
59.96	1702	24.89	18.4	2228	8.53	679.41	22746	657	12013	1349	15772	1736	12195
59.87	1706	24.83	18.4	2236	8.20	679.49	22736	658	12013	1351	15764	1740	12190
59.80	1711	24.77	18.4	2246	7.79	679.59	22725	661	12013	1354	15754	1746	12183

Table 4 Medusa-CFD Simulation Results

KILN GAS IN Deg F	DD1 GAS OUT lbs/min	DD1 GAS OUT Deg F	DD2 GAS OUT lbs/min	DD2 GAS OUT Deg F	PH GAS OUT lbs/min	PH GAS OUT Deg F	KILN GAS OUT lbs/min	KILN GAS OUT Deg F	% Oxidation Kiln Disch	TOT WASTE GAS lbs/min	AVE WASTE GAS Deg F	BTU/LT
2063	**25122**	**225**	**14367**	**329**	**20347**	**733**	**13356**	**1920**	**69.5**	**39489**	**263**	**320,991**
1985	25410	219	14455	310	20703	698	13731	1864	86.2	39865	252	282,802
1977	25526	222	14427	311	20795	707	13827	1857	86.6	39953	254	282,769
1955	25860	230	14359	315	21074	733	14113	1838	87.6	40219	260	282,686
1978	25715	226	14403	311	20963	718	14002	1868	95.6	40118	257	282,046
2014	25287	215	14499	305	20618	680	13643	1905	99.9	39786	248	281,711
2010	24918	203	14618	297	20369	634	13365	1897	98.6	39536	238	273,012
1947	24791	192	14755	285	20384	581	13349	1835	97.0	39546	227	251,105
1944	24882	194	14735	285	20455	588	13427	1835	98.6	39617	228	250,987
1930	23210	169	14665	285	19124	499	12033	1805	97.6	37875	214	262,072
1974	25443	200	13985	267	21046	601	14001	1870	98.5	39428	224	262,003
1967	25525	203	13951	269	21092	614	14058	1862	94.1	39476	226	262,326
1949	25646	206	13919	271	21176	626	14155	1838	87.1	39565	229	262,852
1948	26901	248	13551	303	22081	780	15134	1844	91.3	40452	266	289,013
1956	25420	198	14009	264	21052	590	14000	1857	98.0	39429	221	245,578
1973	25504	203	13953	269	21072	614	14038	1870	95.1	39457	226	258,731
1979	25561	206	13917	272	21089	627	14067	1872	92.9	39478	229	264,179
1987	25626	210	13877	276	21110	645	14100	1878	90.5	39503	233	271,419
1995	25694	214	13839	280	21138	662	14138	1880	87.6	39533	237	278,269
1999	26078	225	13736	289	21416	704	14432	1879	84.5	39814	247	276,304
2001	26067	225	13737	289	21406	704	14423	1882	85.5	39804	247	276,227
1983	26037	222	13771	285	21409	689	14421	1869	86.3	39808	244	269,538
1968	25998	218	13809	280	21409	672	14415	1855	87.3	39807	240	262,832
1971	25982	218	13812	280	21396	671	14402	1859	88.8	39794	240	262,732
1974	25966	217	13814	279	21384	669	14389	1864	90.3	39780	239	262,612
1976	25952	217	13816	279	21372	669	14379	1868	91.6	39768	239	262,512
1981	25943	221	13814	279	21360	670	14367	1873	92.3	39757	241	262,461
1965	26212	224	13756	284	21569	694	14587	1852	87.8	39968	245	262,794
1974	26198	224	13752	285	21550	696	14569	1862	88.7	39950	245	262,728
1979	26192	225	13748	286	21542	698	14561	1867	89.1	39940	246	262,697
1985	26183	225	13746	286	21530	701	14550	1873	89.7	39929	246	262,658

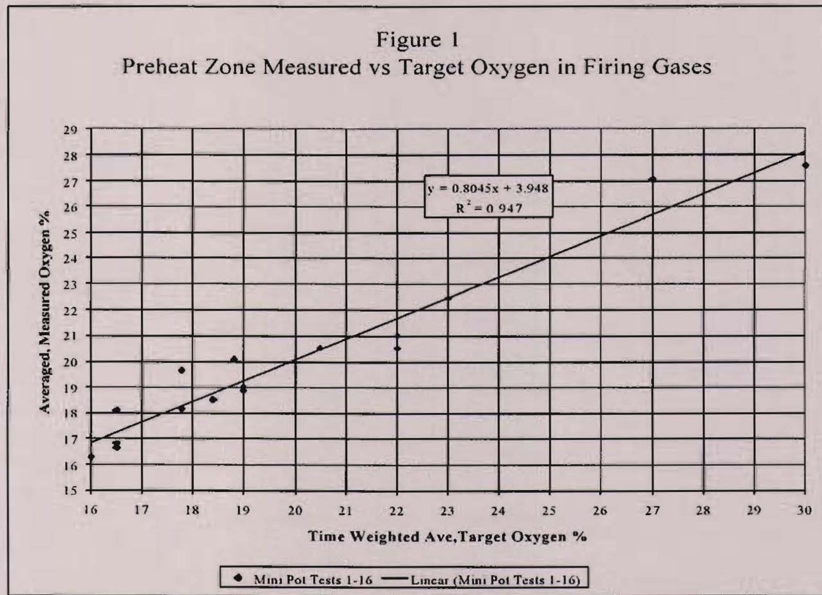


Figure 1
Preheat Zone Measured vs Target Oxygen in Firing Gases
y = 0.8045x + 3.948
R² = 0.947
Averaged, Measured Oxygen %
Time Weighted Ave,Target Oxygen %
Mini Pot Tests 1-16
Linear (Mini Pot Tests 1-16)

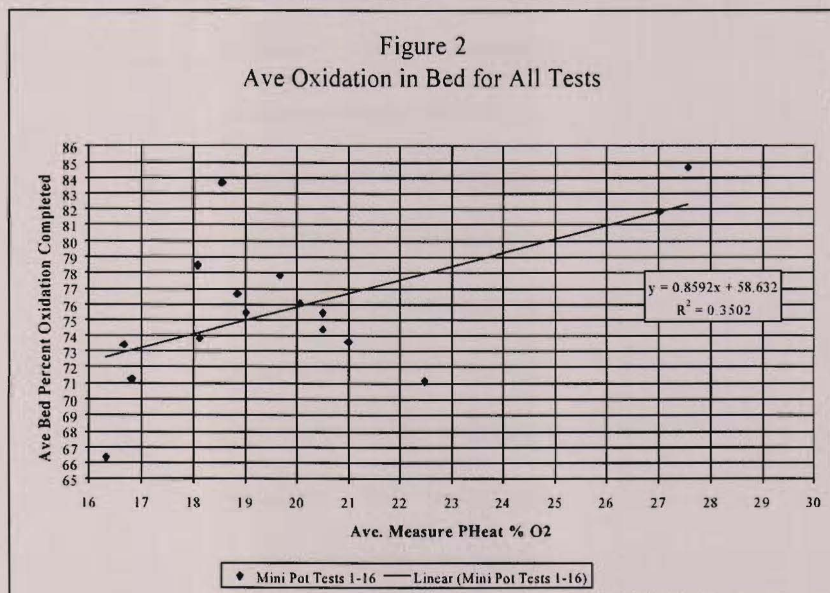


Figure 2
Ave Oxidation in Bed for All Tests
y = 0.8592x + 58.632
R² = 0.3502
Ave Bed Percent Oxidation Completed
Ave. Measure PHeat % O2
Mini Pot Tests 1-16
Linear (Mini Pot Tests 1-16)

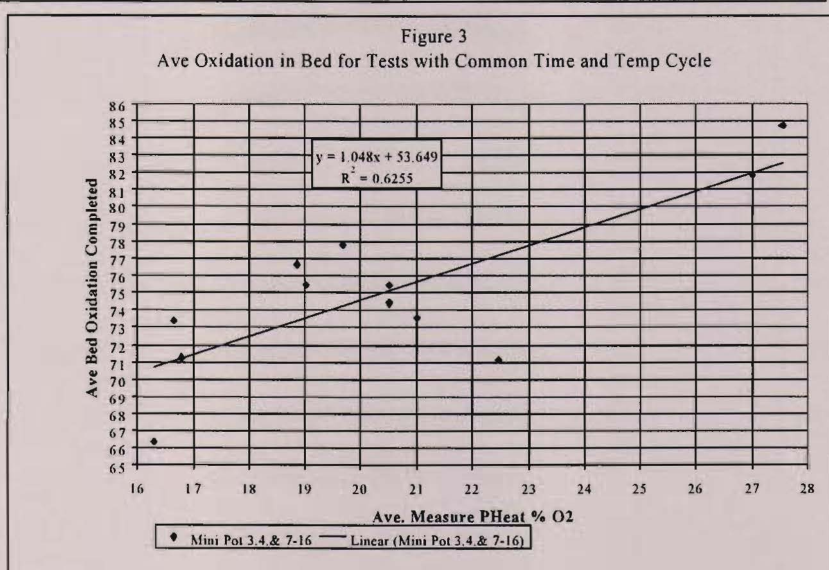
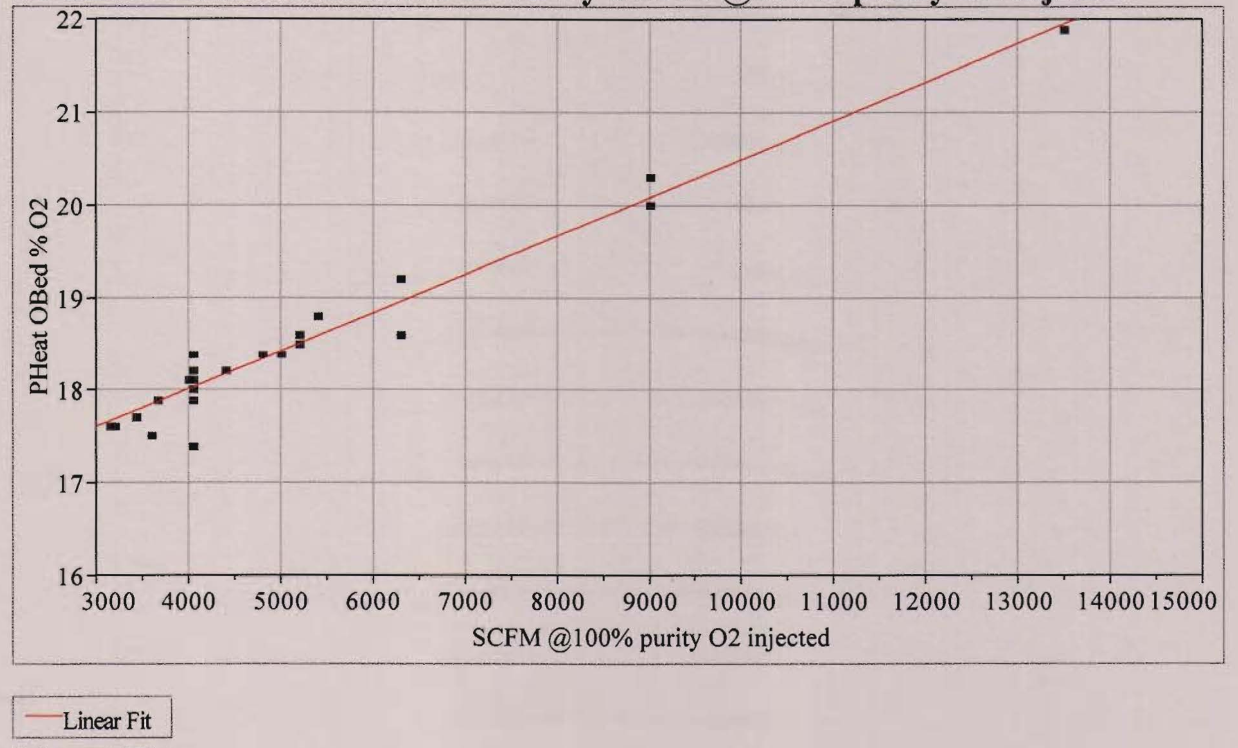


Figure 3
Ave Oxidation in Bed for Tests with Common Time and Temp Cycle
y = 1.048x + 53.649
R² = 0.6255
Ave Bed Oxidation Completed
Ave. Measure PHeat % O2
Mini Pot 3,4,& 7-16
Linear (Mini Pot 3,4,& 7-16)

Figure 4

DataTable=KEETac O2 RESULTS,Design=Central Composite Design,Model=,Fit Model 2=

Bivariate Fit of PHeat OBed % O2 By SCFM @100% purity O2 injected



Linear Fit

PHeat OBed % O2 = 16.366148 + 0.0004132 SCFM @100% purity O2 injected

Summary of Fit

RSquare	0.959563
RSquare Adj	0.958169
Root Mean Square Error	0.196385
Mean of Response	18.37419
Observations (or Sum Wgts)	31

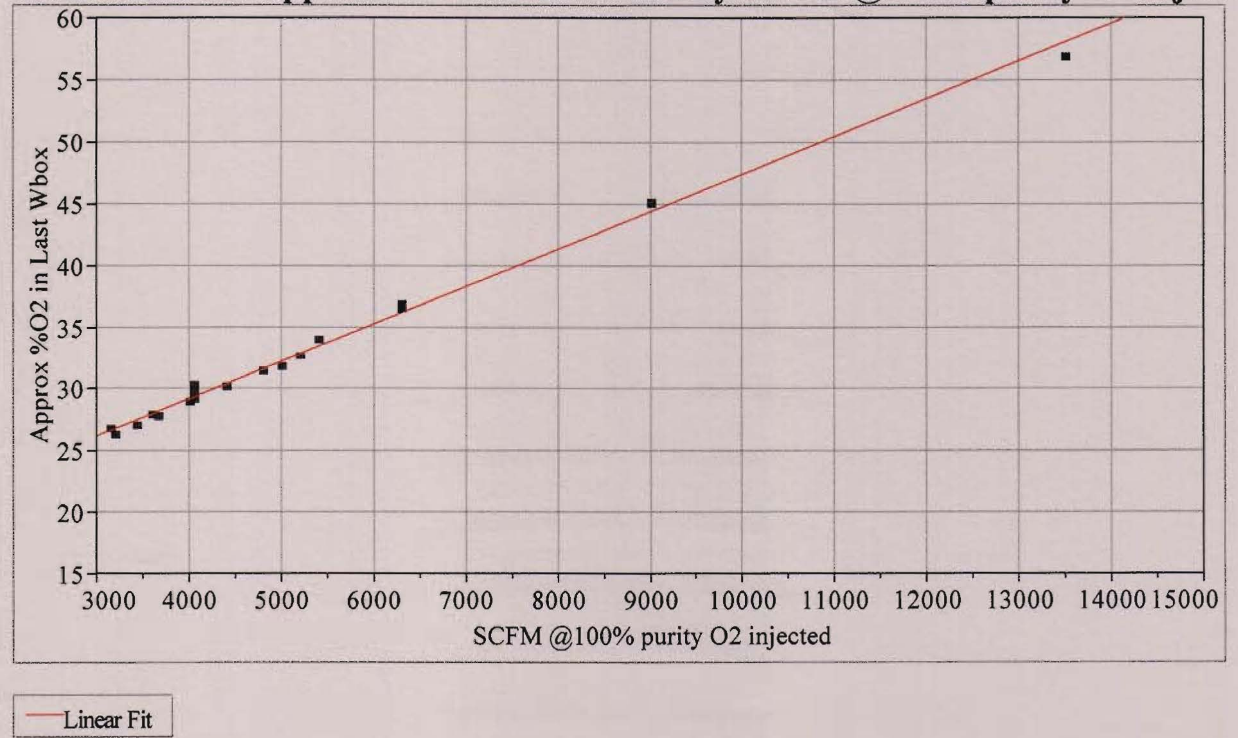
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	16.366148	0.084282	194.18	<.0001
SCFM @100% purity O2 injected	0.0004132	0.000016	26.23	<.0001

Figure 5

DataTable=KEETac O2 RESULTS,Design=Central Composite Design,Model=,Fit Model 2=

Bivariate Fit of Approx %O2 in Last Wbox By SCFM @100% purity O2 inject



Linear Fit

Approx %O2 in Last Wbox = 16.99129 + 0.003045 SCFM @100% purity O2 injected

Summary of Fit

RSquare	0.995398
RSquare Adj	0.995239
Root Mean Square Error	0.479418
Mean of Response	31.79085
Observations (or Sum Wgts)	31

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	16.99129	0.20575	82.58	<.0001
SCFM @100% purity O2 injected	0.003045	0.000038	79.20	<.0001

Figure 6

Prediction Profiler