coal-rate effects being smaller--followed the same general pattern. (See fig. 31.) The coal requirement was minimum in the region of 11 std. c.f. of oxygen per pound coal. For the two middle pressures, 100 and 150 p.s.i.g., the coal requirement at the two lower coal rates almost coincided. For the three lower pressures, the coal requirement at the highest coal rate was higher than for the other two coal rates, whereas the reverse was true for the 300-pound pressure. Again, the probable cause of this change was the opposing effects of residence time and heat loss. The coal requirement at a coal rate of 400 pounds per hour changed only slightly with change in pressure, but at the 1,000-pound-per-hour coal rate the coal requirement increased as the pressure decreased.

Exit-Gas Temperature, Calculated, ° F.

Efforts to develop equipment to measure the temperature of the gases leaving the reaction zone were unsuccessful. The temperatures in figure 32 were calculated from heat balances. The figure shows that exit-gas temperatures increased with an increase in coal rate and oxygen-to-coal ratio and with a decrease in pressure. Either a decrease in pressure or an increase in coal rate decreases the residence time and therefore decreases the amount of heat absorbed by the gasification reaction, which, in turn, increases the exit-gas temperature.

Heat Loss

The exit-gas temperature and the average temperature of the gasifier are not directly related; thus, although the exit-gas temperature decreased with an increase in pressure, the heat loss (B.t.u. per pound of coal)--shown graphically in figure 33-- was essentially independent of pressure. Heat loss, which increased with an increase in oxygen-to-coal ratio because the average temperature of the gasifier was higher at the higher rates, decreased with an increase in coal rate, as a lower heat loss per unit of fuel input results at higher throughputs.

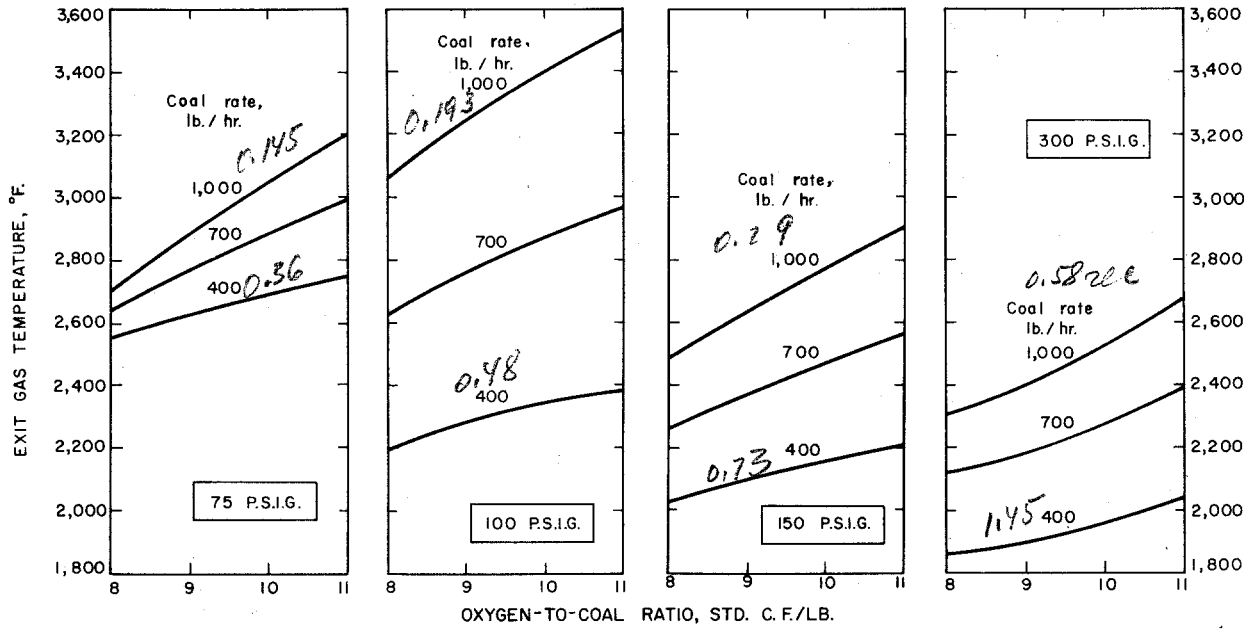

FIGURE 32. - Effect of Oxygen-to-Coal Ratio on Exit-Gas Temperature; Gasifier Pressure, 75, 100, 150, and 300 p.s.i.g.

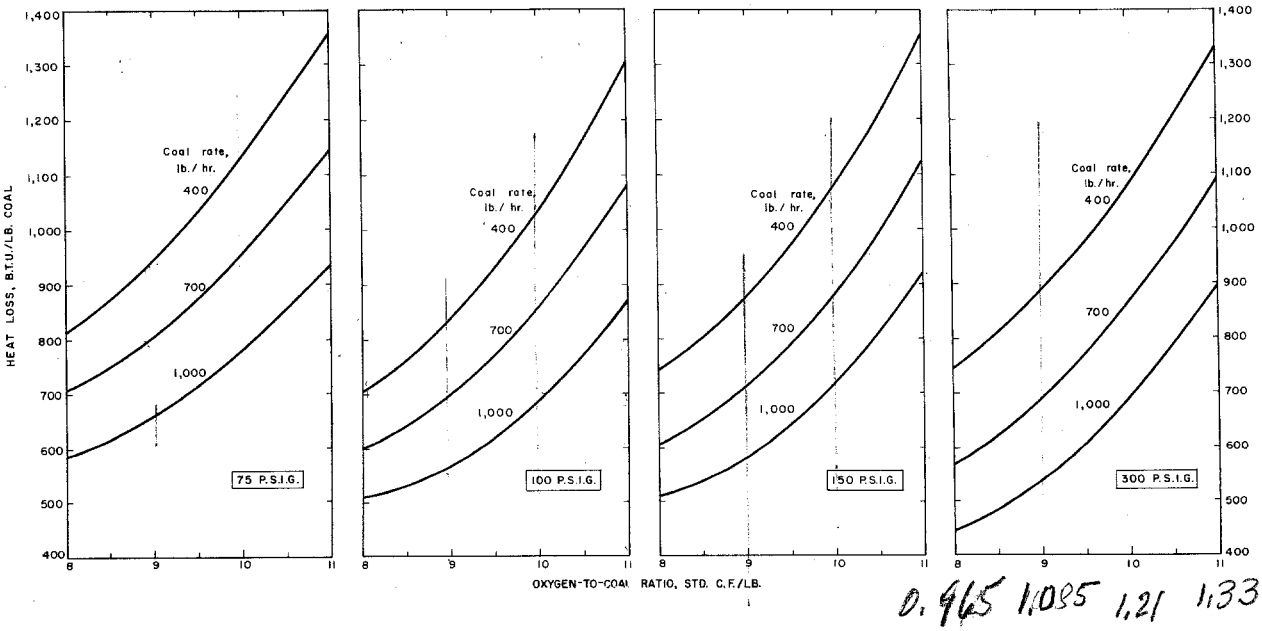

FIGURE 33. - Effect of Oxygen-to-Coal Ratio on Heat Loss; Gasifier Pressure, 75, 100, 150, and 300 p.s.i.g.

Coal 70.9% C

APPENDIX I

TABLE 5. - Operating conditions and principal results, Gasifier 3

Run and period	Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	O_2-to-coal ratio, std. c.f./lb.	Steam-to-coal ratio, lb./lb.	Carbon gasified, percent	Requirements per M std. c.f. CO + H_2		Heat loss, B.t.u. per lb. of coal	Calculated exit-gas temp., ° F.
						Coal, lb.	Oxygen, std. c.f.		
54H...	77	438	8.85 1.06	0.27	76.8	43.1	380	913	2,555
54I...	77	438	9.46 1.13	.27	80.0	39.8	377	984	2,700
54J...	75	365	10.55 1.26	.33	84.2	43.5	459	1,381	2,560
54L...	75	365	9.52 1.14	.33	81.7	43.7	416	1,184	2,750
42A...	300	1,002	10.92 1.30	.33	94.1	34.6	378	728	2,765
42B...	300	1,002	10.17 1.21	.33	88.4	35.8	364	589	2,540
42C...	300	1,002	9.37 1.12	.33	83.7	37.4	350	479	2,480
40C...	300	831	10.88 1.31	.32	90.3	38.0	414	1,069	2,570
43D...	300	647	10.89 1.31	.32	90.3	36.3	395	998	2,065
44I...	300	1,054	10.50 1.25	.31	92.4	35.5	372	647	2,595
44J...	300	1,054	9.63 1.15	.31	88.1	36.6	353	522	2,555
44K...	300	692	8.66 1.04	.30	80.4	39.0	337	565	2,155
47C...	300	1,062	10.40 1.24	.31	93.8	36.2	376	732	2,530
47D...	300	1,062	8.81 1.05	.31	84.9	38.0	335	402	2,150
47F...	300	730	9.72 1.16	.24	87.2	39.6	385	956	2,335
47G...	300	730	8.92 1.06	.24	84.2	39.6	353	742	2,245
49B...	100	765	9.06 1.08	.28	78.6	43.6	395	710	2,925
49C...	100	765	9.78 1.17	.28	84.8	42.0	411	869	3,095
49E...	105	1,011	9.01 1.07	.33	81.8	43.6	393	596	3,205
50K...	100	741	9.37 1.12	.29	84.5	39.9	374	667	2,800
51S...	101	715	10.48 1.25	.31	89.4	39.8	416	947	2,885
51T...	101	715	8.72 1.04	.32	78.9	41.8	364	632	2,795
51U...	101	715	10.50 1.25	.32	85.8	41.0	430	958	2,815
52A...	76	1,062	8.60 1.03	.29	69.4	49.3	424	544	2,775
52B...	78	1,062	9.63 1.15	.29	77.6	45.5	438	724	2,880

TABLE 5. - Operating conditions and principal results, Gasifier 3 (Con.)

Run and period	Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	O_2-to-coal ratio, std. c.f./lb.	Steam-to-coal ratio, lb./lb.	Carbon gasified, percent	Requirements per M std. c.f. CO + H_2		Heat loss, B.t.u. per lb. of coal	Calculated exit-gas temp., ° F.
						Coal, lb.	Oxygen, std. c.f.		
52C...	75	1,062	10.39	0.29	81.7	44.2	460	761	3,170
52D...	70	701	8.89	.30	73.5	45.8	408	1,011	2,685
52E...	70	701	9.89	.30	83.1	41.6	412	920	2,960
52F...	70	701	10.72	.30	85.1	42.4	455	1,088	3,115
53M...	78	740	9.45	.29	77.4	44.3	419	657	3,205
53N...	78	740	8.43	.29	70.0	47.5	400	766	2,975
53P...	75	1,072	9.49	.29	77.2	44.5	422	628	3,075
53Q...	75	1,072	8.56	.29	71.3	46.6	399	583	2,930
61B...	73	966	11.39	.32	87.0	46.6	531	1,014	3,315
60S...	73	1,119	9.86	.28	77.2	46.9	463	746	3,110
60T...	155	931	9.80	.34	83.5	41.0	402	696	2,615
39A...	300	1,200	12.90	.32	96.2	40.0	515	1,308	3,210
39B...	300	1,200	12.29	.32	94.5	39.9	490	1,250	3,110
39C...	300	1,108	12.85	.32	93.3	41.7	535	1,431	3,055
40A...	300	831	13.03	.32	100.0	38.1	497	1,407	3,025
40B...	300	831	11.38	.32	95.2	37.0	422	1,144	2,680
57D...	153	409	10.22	.30	84.2	39.4	403	1,112	2,110
59L...	154	684	9.17	.31	83.3	38.3	351	702	2,315
59M...	154	684	10.16	.31	91.6	35.6	362	781	2,430
59N...	154	684	10.96	.31	92.4	38.3	420	1,092	2,475
61A...	73	966	9.45	.32	72.8	50.3	476	710	2,960
53R...	75	1,072	10.24	.29	84.7	41.1	421	743	3,200
55B...	100	443	8.79	.27	79.2	42.0	369	795	2,305
56G...	72	404	8.64	.29	72.9	47.5	410	894	2,430
56H...	72	404	10.27	.30	83.5	42.5	437	1,047	2,570
56N...	100	429	9.69	.28	80.1	44.7	433	1,002	2,570
56P...	102	429	9.67	.28	83.6	41.1	397	909	2,345

TABLE 5. - Operating conditions and principal results, Gasifier 3 (Con.)

Run and period	Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	O_2-to-coal ratio, std. c.f./lb.	Steam-to-coal ratio, lb./lb.	Carbon gasified, percent	Requirements per M std. c.f. CO + H_2		Heat loss, B.t.u. per lb. of coal	Calculated exit-gas temp., ° F.
						Coal, lb.	Oxygen std. c.f.		
57A...	100	390	10.64	0.31	88.8	39.1	416	1,221	2,490
57B...	154	409	8.53	.30	72.3	44.0	375	795	2,160
57C...	153	409	9.44	.30	79.1	40.6	384	907	2,065
57E...	153	401	9.65	.30	81.8	39.8	385	958	2,105
58F...	156	401	10.42	.30	84.4	40.3	420	1,289	2,125
58G...	156	401	8.67	.30	72.3	44.3	384	845	2,025
58I...	74	692	9.01	.31	75.3	43.9	395	811	2,480
58J...	75	692	10.06	.31	83.8	40.3	405	954	2,830
58K...	75	692	10.75	.31	85.4	41.1	442	1,159	2,665
59O...	150	703	9.93	.30	86.4	39.0	387	899	2,500
59P...	150	703	8.95	.30	81.9	38.8	347	693	2,330
59Q...	151	703	10.78	.30	87.9	38.9	419	1,151	2,505
60R...	70	1,119	8.16	.28	67.8	49.3	402	526	2,680
60U...	156	931	10.91	.34	87.3	41.1	448	876	2,870
61C...	155	705	8.92	.30	79.0	41.9	391	823	2,335
61D...	156	705	9.94	.30	87.2	39.0	387	840	2,545
61E...	155	705	10.70	.32	87.1	40.6	404	1,112	2,570
62F...	157	1,019	9.00	.31	73.9	45.4	409	609	2,430
62G...	159	1,019	10.71	.31	88.7	40.2	431	862	2,725
62I...	158	981	10.30	.32	86.8	40.7	419	776	2,695
62J...	158	981	9.28	.32	80.3	43.5	404	645	2,755
63I...	151	986	10.35	.32	86.3	43.2	446	870	2,960
63J...	155	986	9.24	.32	75.1	45.3	418	605	2,675
65A...	155	1,085	8.44	.29	75.3	45.5	384	563	2,590
$65A_r$..	155	1,087	8.43	.29	74.0	45.3	382	480	2,655
65B...	155	1,085	9.34	.29	83.4	41.3	386	571	2,830
65C...	70	1,008	10.88	.31	85.4	42.9	466	895	2,990
65D...	70	1,008	9.05	.31	70.5	48.8	442	714	2,695
67F...	300	396	8.81	.30	88.2	38.1	336	927	1,955

TABLE 5. - Operating conditions and principal results, Gasifier 3 (Con.)

Run and period	Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	O_2-to-coal ratio, std. c.f./lb.	Steam-to-coal ratio, lb./lb.	Carbon gasified, percent	Requirements per M std. c.f. CO + H_2		Heat loss, B.t.u. per lb. of coal	Calculated exit-gas temp., ° F.
						Coal, lb.	Oxygen std. c.f.		
67G...	300	396	9.87	0.30	83.3	41.4	409	1,098	2,125
67I...	298	402	10.52	.30	82.7	42.7	449	1,276	2,175
66E...	300	745	10.22	.29	78.9	43.8	447	1,070	2,385
$66E_r$..	295	675	11.32	.32	89.8	38.8	439	1,342	2,370
68I...	300	415	10.08	.29	87.0	39.4	397	1,060	1,885
68J...	300	415	9.28	.29	78.2	41.9	389	978	1,915
68K...	299	415	8.37	.29	75.1	42.5	356	677	1,940
57H...	100	390	10.62	.31	87.8	38.4	408	1,172	2,370
47E...	300	730	8.29	.24	75.8	42.5	353	667	2,055
48B...	300	1,341	9.49	.34	87.8	41.2	391	637	3,125
48E...	300	1,341	11.17	.34	94.1	36.2	405	754	2,870
48F...	300	1,341	10.28	.34	91.5	34.9	359	589	2,585
49A...	100	765	8.16	.28	70.0	48.1	392	618	2,610
49D...	105	1,011	10.10	.33	84.7	44.9	452	820	3,375
43E...	300	647	10.15	.32	89.2	34.9	354	781	2,170
43F...	300	1,437	8.95	.31	79.7	39.1	350	335	2,385
44G...	300	1,437	9.63	.31	86.2	38.1	367	475	2,665
44H...	300	1,437	10.41	.31	89.7	37.7	392	501	2,890
50L...	100	741	10.10	.29	83.9	41.6	422	803	2,870
53O...	78	740	10.20	.29	79.7	44.4	453	1,012	3,250
54G...	76	438	7.96	.27	67.3	48.7	387	854	2,620
55A...	100	475	7.23	.25	63.7	51.0	369	621	2,175
55C...	100	443	9.38	.27	84.5	39.7	372	810	2,325
55E...	100	456	7.60	.26	72.2	45.2	432	618	2,275
55F...	100	456	9.07	.26	83.0	40.1	364	735	2,365
$65B_r$..	151.5	1,087	9.31	.29	79.2	42.8	399	583	2,785
66A...	156	971	9.43	.32	81.2	40.3	380	598	2,595
66B...	156	971	10.45	.32	86.5	39.3	411	769	2,770

TABLE 6. - Deviations[1] of dependent variables for tests at 75 and 100 p.s.i.g.

Run and period	Values of independent variables			Values and deviations of dependent variables													
	Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	O_2-to-coal ratio, std. c.f./lb.	Carbon gasified, percent			Requirements per M std. c.f. CO + H_2						Heat loss, B.t.u. per lb. of coal			Exit-gas temp., ° F.		
							Coal, lb.			Oxygen, std. c.f.								
				Exp.[2]	Calc.[3]	Dev.[4]	Exp.[2]	Calc.[3]	Dev.[4]	Exp.[2]	Calc.[3]	Dev.[4]	Exp.[2]	Calc.[3]	Dev.[4]	Exp.[2]	Calc.[3]	Dev.[4]
54G.....	76	438	7.96	67.3	68.9	-1.6	48.7	47.7	1.0	387	396	-9	854	788	66	2,620	2,546	74
54H.....	77	438	8.85	76.8	75.9	.9	43.1	44.2	-1.1	380	395	-15	913	899	14	2,555	2,607	-52
54I.....	77	438	9.46	80.0	79.7	.3	39.8	42.7	-2.9	377	403	-26	984	999	-15	2,700	2,653	47
54J.....	75	365	10.55	84.2	84.8	-.6	43.5	41.6	1.9	459	435	24	1,381	1,274	107	2,560	2,699	-139
54L.....	75	365	9.52	81.7	80.0	1.7	43.7	42.7	1.0	416	406	10	1,184	1,058	126	2,750	2,646	104
56G.....	72	404	8.64	72.9	73.6	-.7	47.5	45.4	2.1	410	398	12	894	908	-14	2,430	2,668	-238
56H.....	72	404	10.27	83.5	83.0	.5	42.5	42.0	.5	437	428	9	1,047	1,201	-154	2,570	2,776	206
53O.....	78	740	10.20	79.7	83.0	-3.3	44.4	42.5	1.9	453	431	22	1,012	952	60	3,250	2,942	308
52D.....	70	701	8.89	73.5	73.4	.1	45.8	45.6	.2	408	404	4	1,011	817	194	2,685	2,766	-81
52E.....	70	701	9.89	83.1	79.8	3.3	41.6	43.4	-1.8	412	425	-13	920	962	-42	2,960	2,882	78
52F.....	70	701	10.72	85.1	83.8	1.3	42.4	42.9	-.5	455	457	-2	1,088	1,115	-27	3,115	2,967	148
53M.....	78	740	9.45	77.4	78.7	-1.3	44.3	43.5	.8	419	409	10	657	833	-176	3,205	2,855	350
53N.....	78	740	8.43	70.0	71.3	-1.3	47.5	46.5	1.0	400	395	5	766	710	56	2,975	2,723	252
58I.....	74	692	9.01	75.3	75.2	.1	43.9	44.8	-.9	395	402	-7	811	784	27	2,480	2,775	-295
58J.....	75	692	10.06	83.8	81.8	2.0	40.3	42.7	-2.4	405	426	21	954	971	-17	2,830	2,892	-62
58K.....	75	692	10.75	85.4	85.0	.4	41.1	42.4	-1.3	442	454	-12	1,159	1,102	57	2,665	2,961	-296
52A.....	76	1,062	8.60	69.4	70.6	-1.2	49.3	48.1	1.2	424	413	11	544	595	-51	2,775	2,853	-78
52B.....	78	1,062	9.63	77.6	78.8	-1.2	45.5	45.2	.3	438	435	3	724	676	48	2,880	3,081	-201
52C.....	75	1,062	10.39	81.7	82.7	-1.0	44.2	44.6	-.4	460	465	-5	761	795	-34	3,170	3,142	28
53P.....	75	1,072	9.49	77.2	77.2	.0	44.5	45.8	-1.3	422	433	-11	628	674	-46	3,075	2,995	80
53Q.....	75	1,072	8.56	71.3	70.1	1.2	46.6	48.4	-1.8	399	414	-15	583	592	-9	2,930	2,825	105
61B.....	73	966	11.39	87.0	86.7	.3	46.6	44.6	2.0	531	511	20	1,014	1,047	-33	3,315	3,196	119
60S.....	73	1,119	9.86	77.2	79.9	-2.7	46.9	45.8	1.1	463	451	12	746	699	67	3,110	3,025	85
61A.....	73	966	9.45	72.8	76.9	-4.1	50.3	45.3	5.0	476	425	51	710	736	-26	2,960	2,915	45
53R.....	75	1,072	10.24	84.7	81.8	2.9	41.1	44.8	-3.7	421	459	-38	743	767	-24	3,200	3,123	77
60R.....	70	1,119	8.16	67.8	65.2	2.6	49.3	50.9	-1.6	402	401	1	526	576	-50	2,680	2,616	64
65C.....	70	1,008	10.88	85.4	84.1	1.3	42.9	44.7	-1.8	466	488	-22	895	935	-40	2,990	3,086	-96
65D.....	70	1,008	9.05	70.5	73.2	-2.7	48.8	46.9	1.9	442	422	20	714	687	27	2,695	2,796	-101
55A.....	100	475	7.23	63.7	65.7	-2.0	51.0	49.8	1.2	369	392	-23	621	620	1	2,175	2,208	-33
55C.....	100	443	9.38	84.5	84.4	.1	39.7	41.2	-1.5	372	388	-16	810	898	-88	2,325	2,352	-27
55E.....	100	456	7.60	72.2	69.3	2.9	45.2	47.7	-2.5	432	386	46	618	656	-38	2,275	2,218	57
55F.....	100	456	9.07	83.0	80.8	2.2	40.1	41.8	-1.7	364	383	-19	735	840	-105	2,365	2,352	13
55B.....	100	443	8.79	79.2	78.9	.3	42.0	42.7	-.7	369	381	-12	795	804	-9	2,305	2,306	-1
56N.....	100	429	9.69	80.1	84.5	-4.4	44.7	40.5	4.2	433	394	39	1,002	961	41	2,570	2,348	222
56P.....	102	429	9.67	83.6	84.7	-1.1	41.1	40.4	.7	397	392	5	909	952	-43	2,345	2,325	20
57A.....	100	390	10.64	88.8	88.1	.7	39.1	39.7	-.6	416	421	-5	1,220	1,185	35	2,490	2,325	165
57H.....	100	390	10.62	87.8	88.9	-1.1	38.4	39.7	-1.3	408	422	-14	1,172	1,180	-8	2,370	2,324	46
49A.....	100	765	8.16	70.0	72.2	-2.2	48.1	46.1	2.0	392	382	10	618	596	22	2,610	2,757	-147
50L.....	100	741	10.10	83.9	85.7	-1.8	41.6	40.9	.7	422	414	8	803	855	-52	2,870	2,966	-96
49B.....	100	765	9.06	78.6	79.3	-.7	43.6	42.9	.7	395	389	6	710	689	21	2,925	2,881	44
49C.....	100	765	9.78	84.8	83.9	.9	42.0	41.4	.6	411	405	6	889	789	100	3,095	2,972	123
50K.....	100	741	9.37	84.5	81.4	3.1	39.9	42.0	-2.1	374	394	-20	667	742	-75	2,800	2,880	-80
51S.....	101	715	10.48	89.4	87.8	1.6	39.8	40.5	-.7	416	427	-11	947	937	10	2,885	2,958	-73
51T.....	101	715	8.72	78.9	77.1	1.8	41.8	43.7	-1.9	364	382	-18	632	669	-37	2,795	2,755	40
51U.....	101	715	10.50	85.8	87.9	-2.1	41.0	40.5	.5	430	428	2	958	942	16	2,815	2,960	-145
49D.....	105	1,011	10.10	84.7	85.6	-.9	44.9	42.2	2.7	452	430	22	820	677	143	3,375	3,504	-129
49E.....	105	1,011	9.01	81.8	78.4	3.4	43.6	44.3	-.7	393	399	-6	596	549	47	3,205	3,325	-120

1/ Deviation = experimental value minus calculated value.
2/ Exp. = experimental value.
3/ Calc. = calculated value.
4/ Dev. = deviation.

TABLE 7. - Deviations[1] of dependent variables for tests at 100 and 150 p.s.i.g.

Run and period	Values of independent variables			Values and deviations of dependent variables													
	Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	O_2-to-coal ratio, std. c.f./lb.	Carbon gasified, percent			Requirements per M std. c.f. CO + H_2						Heat loss, B.t.u. per lb. of coal			Exit-gas temp., ° F.		
							Coal, lb.			Oxygen, std. c.f.								
				Exp.[2]	Calc.[3]	Dev.[4]	Exp.[2]	Calc.[3]	Dev.[4]	Exp.[2]	Calc.[3]	Dev.[4]	Exp.[2]	Calc.[3]	Dev.[4]	Exp.[2]	Calc.[3]	Dev.[4]
55A.....	100	475	7.23	63.7	64.9	-1.2	51.0	49.8	1.2	369	396	-27	621	625	-4	2,175	2,191	-16
55C.....	100	443	9.38	84.5	81.7	2.8	39.7	41.4	-1.7	372	393	-21	810	872	-62	2,325	2,410	-85
55E.....	100	456	7.60	72.2	68.3	3.9	45.2	47.9	-2.7	432	392	40	618	643	-25	2,275	2,227	48
55F.....	100	456	9.07	83.0	79.8	3.2	40.1	42.1	-2.0	364	388	-24	735	807	-72	2,365	2,403	-38
55B.....	100	443	8.79	79.2	77.8	1.4	42.0	43.0	-1.0	369	388	-19	795	768	27	2,305	2,358	-53
56N.....	100	429	9.69	80.1	83.4	-3.3	44.7	40.9	3.8	433	398	35	1,002	944	58	2,570	2,410	160
56P.....	102	429	9.67	83.6	83.2	.4	41.1	40.8	.3	397	397	0	909	941	-32	2,345	2,395	-50
57A.....	100	390	10.64	88.8	87.5	1.3	39.1	40.1	-1.0	416	423	-7	1,221	1,333	-1	2,490	2,387	103
57H.....	100	390	10.62	87.8	87.4	.4	38.4	40.2	-1.8	408	422	-14	1,172	1,216	-44	2,370	2,387	-17
49A.....	100	765	8.16	70.0	74.2	-4.2	48.1	45.3	2.8	392	377	15	618	588	30	2,610	2,724	-114
50L.....	100	741	10.10	83.9	87.0	-3.1	41.6	40.5	1.1	422	408	14	803	853	-50	2,870	2,944	-74
49B.....	100	765	9.06	78.6	80.9	-2.3	43.6	42.3	1.3	395	385	10	710	667	43	2,925	2,864	71
49C.....	100	765	9.78	84.8	84.7	.1	42.0	40.9	1.1	411	400	11	889	777	112	3,095	2,923	172
50K.....	100	741	9.37	84.5	83.0	1.5	39.9	41.5	-1.6	374	390	-16	667	721	-54	2,800	2,866	-66
51S.....	101	715	10.48	89.4	88.8	.6	39.8	40.1	-.3	416	418	-2	947	957	-10	2,885	2,919	-34
51T.....	101	715	8.72	78.9	78.6	.3	41.8	43.0	-1.2	364	379	-15	632	649	-17	2,795	2,728	67
51U.....	101	715	10.50	85.8	88.8	-3.0	41.0	40.1	.9	430	419	11	958	962	-4	2,815	2,920	-105
49D.....	105	1,011	10.10	84.7	85.6	-.9	44.9	42.8	2.1	452	433	19	820	709	-111	3,375	3,344	31
49E.....	105	1,011	9.01	81.8	79.1	2.7	43.6	44.4	-.8	393	402	-9	596	570	26	3,205	3,175	30
57D.....	153	409	10.22	84.2	85.0	-.8	39.4	39.0	.4	403	395	8	1,112	1,114	-2	3,110	2,166	-56
57B.....	154	409	8.53	72.3	74.6	-2.3	44.0	42.7	1.3	375	375	0	795	772	23	2,160	2,042	118
57C.....	153	409	9.44	79.1	80.8	-1.7	40.6	40.1	.5	384	381	3	907	928	-21	2,065	2,124	-59
57E.....	153	401	9.65	81.8	81.9	-.1	39.8	39.8	.0	385	384	1	958	978	-20	2,105	2,131	-26
58F.....	156	401	10.42	84.4	85.8	-1.4	40.3	38.8	1.5	420	400	20	1,289	1,177	112	2,125	2,156	-31
58G.....	156	401	8.67	72.3	75.6	-3.3	44.3	42.3	2.0	384	375	9	845	796	49	2,025	2,045	-20
59L.....	154	684	9.17	83.3	80.7	2.6	38.3	40.4	-2.1	351	369	-18	702	744	-42	2,315	2,339	-24
59M.....	154	684	10.16	91.6	86.4	5.2	35.6	38.9	-3.3	362	392	-30	781	927	-146	2,430	2,439	-9
59N.....	154	684	10.96	92.4	89.7	2.7	38.3	38.8	-.5	420	421	-1	1,092	1,133	-41	2,475	2,492	-17
59O.....	150	703	9.93	86.4	85.3	1.1	39.0	39.2	-.2	387	387	0	899	865	34	2,500	2,461	39
59P.....	150	703	8.95	81.9	79.3	2.6	38.8	41.1	-2.3	347	367	-20	693	704	-11	2,330	2,350	-20
59Q.....	151	703	10.78	87.9	89.1	-1.2	38.9	38.8	.1	419	415	4	1,151	1,068	83	2,505	2,521	-16
61C.....	155	705	8.92	79.0	79.1	-.1	41.9	41.1	.8	391	366	25	823	702	121	2,335	2,321	14
61D.....	156	705	9.94	87.2	85.3	1.9	39.0	39.1	-.1	387	386	1	840	868	-28	2,545	2,432	113
61E.....	155	705	10.70	87.1	88.8	-1.7	40.6	38.8	1.8	404	411	-7	1,112	1,046	66	2,570	2,497	73
$65B_r$.....	151.5	1,087	9.31	79.2	79.5	-.3	42.8	43.7	-.9	399	407	-36	583	591	-8	2,785	2,798	-13
66A.....	156	971	9.43	81.2	81.4	-.2	40.3	41.9	-1.6	380	393	-13	598	653	-55	2,595	2,652	-57
66B.....	156	971	10.45	86.5	86.8	-.3	39.3	40.9	-1.6	411	427	-16	769	821	-52	2,770	2,789	-19
60T.....	155	931	9.80	83.5	83.8	-.3	41.0	40.9	.1	402	399	-3	696	724	-28	2,615	2,668	-53
60U.....	156	931	10.91	87.3	88.9	-1.6	41.1	40.6	.5	448	442	6	876	950	-74	2,870	2,788	82
62F.....	157	1,019	9.00	73.9	78.2	-4.3	45.4	43.3	2.1	409	389	20	609	591	18	2,430	2,624	-194
62G.....	159	1,019	10.71	88.7	87.4	.3	40.2	41.6	-1.4	431	445	-14	862	849	13	2,725	2,857	132
62I.....	158	981	10.30	86.8	86.0	.8	40.7	41.1	-.4	419	422	-3	776	786	-10	2,695	2,769	-74
62J.....	158	981	9.28	80.3	80.4	-.1	43.5	42.2	1.3	404	390	14	645	632	13	2,755	2,625	130
63I.....	151	986	10.35	86.3	86.2	.1	43.2	41.2	2.0	446	426	20	870	791	79	2,960	2,833	127
63J.....	155	986	9.24	75.1	80.1	-5.0	45.3	42.4	2.9	418	391	27	605	625	-20	2,675	2,646	29
65A.....	155	1,085	8.44	75.3	73.4	-.1	45.5	45.9	-.4	384	388	-4	563	540	23	2,590	2,599	-9
$65A_r$.....	155	1,087	8.43	74.0	73.3	.7	45.3	45.9	-.6	382	388	-6	480	539	-59	2,655	2,599	56
65B.....	155	1,085	9.34	83.4	79.7	3.7	41.3	43.5	-2.2	386	406	-20	571	596	-25	2,830	2,772	58

1/ Deviation = experimental value minus calculated value.
2/ Exp. = experimental value.
3/ Calc. = calculated value.
4/ Dev. = deviation.

TABLE 8. - Deviations[1] of dependent variables for tests at 150 and 300 p.s.i.g.

Run and period	Values of independent variables: Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	O_2-to-coal ratio, std. c.f./lb.	Values and deviations of dependent variables: Carbon gasified, percent: Exp.[2]	Calc.[3]	Dev.[4]	Requirements per M std. c.f. CO + H_2: Coal, lb.: Exp.[2]	Calc.[3]	Dev.[4]	Oxygen, std. c.f.: Exp.[2]	Calc.[3]	Dev.[4]	Heat loss, B.t.u. per lb. of coal: Exp.[2]	Calc.[3]	Dev.[4]	Exit-gas temp., ° F.: Exp.[2]	Calc.[3]	Dev.[4]
57D...	153	409	10.22	84.2	82.4	1.8	39.4	37.0	2.4	403	401	2	1,112	1,150	-38	2,110	2,181	-71
57B...	154	409	8.53	72.3	73.2	-.9	44.0	42.4	1.6	375	364	11	795	839	-44	2,160	2,080	+80
57C...	153	409	9.44	79.1	80.7	-1.6	40.6	40.3	.3	384	379	5	907	992	-85	2,065	2,125	-60
57E...	153	401	9.65	81.8	81.8	.0	39.8	40.0	-.2	385	385	0	958	1,032	-77	2,105	2,130	-25
58F...	156	401	10.42	84.4	85.2	-.8	40.3	39.4	.9	420	409	11	1,289	1,203	+86	2,125	2,180	-55
58G...	156	401	8.67	72.3	76.1	-3.8	44.3	42.0	2.3	384	366	18	845	859	-14	2,025	2,070	-47
59L...	154	684	9.17	83.3	80.6	2.7	38.3	40.8	-2.5	351	373	-22	702	752	-52	2,315	2,380	-65
59M...	154	684	10.16	91.6	85.7	5.9	35.6	39.4	-3.8	362	399	-37	781	933	-152	2,430	2,473	-43
59N...	154	684	10.96	92.4	88.7	3.7	38.3	39.4	-1.1	420	429	-9	1,092	1,100	-8	2,475	2,595	-120
59O...	150	703	9.93	86.4	83.6	2.8	39.0	39.8	-.8	387	393	-6	899	876	+23	2,500	2,477	+33
59P...	150	703	8.95	81.9	79.1	2.8	38.8	41.4	-2.6	347	371	-24	693	709	-16	2,330	2,388	-58
59Q...	151	703	10.78	87.9	88.0	-.1	38.9	39.4	-.5	419	423	-4	1,151	1,061	+90	2,505	2,573	-68
61C...	155	705	8.92	79.0	79.1	-.1	41.9	41.4	.5	391	369	22	823	702	+121	2,335	2,375	-40
61D...	156	705	9.94	87.2	84.8	2.4	39.0	39.6	-.6	387	392	-5	840	874	-34	2,545	2,465	+80
61E...	155	705	10.70	87.1	87.9	-.8	40.6	39.3	1.3	404	419	-15	1,112	1,039	+73	2,570	2,555	+15
$65B_r$..	151.5	1,087	9.31	79.2	80.2	-1.0	42.8	43.2	-.4	399	402	-3	583	569	+14	2,785	2,693	+92
66A...	156	971	9.43	81.2	81.8	-.6	40.3	41.7	-1.4	380	392	-12	598	636	-38	2,595	2,624	-30
66B...	156	971	10.45	86.5	86.8	-.3	39.3	40.6	-1.3	411	422	-11	769	817	-48	2,770	2,759	+16
60T...	155	931	9.80	83.5	83.9	-.4	41.0	40.9	.1	402	399	3	696	717	-21	2,615	2,642	-27
60U...	156	931	10.91	87.3	88.6	-1.3	41.1	40.3	.8	448	438	10	876	941	-65	2,870	2,795	+75
62F...	157	1,019	9.00	73.9	79.0	-5.1	45.4	42.9	2.5	409	387	22	609	556	53	2,430	2,603	-173
62G...	159	1,019	10.71	88.7	87.8	.9	40.2	40.8	-.6	431	434	-3	862	844	18	2,725	2,830	-105
62I...	158	981	10.30	86.8	86.4	.4	40.7	40.6	.1	419	416	3	776	781	-5	2,695	2,740	-45
62J...	158	981	9.28	80.3	81.0	-.7	43.5	41.9	1.6	404	388	16	645	609	+36	2,755	2,608	+147
63I...	151	986	10.35	86.3	86.1	.2	43.2	41.0	2.2	446	422	24	870	790	+80	2,960	2,768	+192
63J...	155	986	9.24	75.1	80.5	-5.4	45.3	42.2	3.1	418	390	28	605	602	+3	2,675	2,615	+60
65A...	155	1,085	8.44	75.3	74.5	.8	45.5	45.0	.5	384	387	-3	563	472	+91	2,590	2,585	+5
$65A_r$..	155	1,087	8.43	74.0	74.4	-.4	45.3	45.0	.3	382	387	-5	480	470	+10	2,655	2,585	+70
65B...	155	1,085	9.34	83.4	80.6	2.8	41.3	42.9	-1.6	386	400	-14	571	572	-1	2,830	2,687	+143
67F...	300	396	8.81	88.2	77.8	10.4	38.1	42.4	-4.3	336	377	-41	927	858	+69	1,955	1,882	+70
67G...	300	396	9.87	83.3	83.8	-.5	41.4	40.5	.9	409	399	10	1,098	1,055	+43	2,125	1,940	+185
67I...	298	402	10.52	82.7	86.6	-3.9	42.7	40.1	2.6	449	420	29	1,276	1,201	+75	2,175	2,000	+175
68I...	300	415	10.08	87.0	85.1	1.9	39.4	40.1	-.7	397	403	-6	1,060	1,086	-26	1,885	1,980	-95

See footnotes at end of table.

TABLE 8. - Deviation[1] of dependent variables for tests at 150 and 300 p.s.i.g. (Con.)

Run and period	Values of independent variables: Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	O_2-to-coal ratio, std. c.f./lb.	Values and deviations of dependent variables: Carbon gasified, percent: Exp.[2]	Calc.[3]	Dev.[4]	Requirements per M std. c.f. CO + H_2: Coal, lb.: Exp.[2]	Calc.[3]	Dev.[4]	Oxygen, std. c.f.: Exp.[2]	Calc.[3]	Dev.[4]	Heat loss, B.t.u. per lb. of coal: Exp.[2]	Calc.[3]	Dev.[4]	Exit-gas temp., ° F.: Exp.[2]	Calc.[3]	Dev.[4]
68J...	300	415	9.28	78.2	81.1	-2.9	41.9	41.2	0.7	389	383	6	978	923	+55	1,915	1,925	-10
68K...	299	415	8.37	75.1	75.2	-.1	42.5	39.5	3.0	356	370	-14	677	781	-104	1,940	1,885	+55
43E...	300	647	10.15	89.2	88.1	1.1	34.9	37.9	-3.0	354	384	-30	781	929	-148	2,170	2,240	-70
40C...	300	831	10.88	90.3	92.2	-1.9	38.0	36.7	1.3	414	403	11	1,069	970	+99	2,570	2,510	+60
43D...	300	647	10.89	90.3	90.8	-.5	36.3	37.8	-1.5	395	412	-17	998	1,101	-103	2,065	2,326	-261
44K...	300	692	8.66	80.4	80.1	.3	39.0	40.2	-1.2	337	358	-21	565	648	-83	2,155	2,155	0
47F...	300	730	9.72	87.2	86.7	.5	39.6	37.8	1.8	385	366	19	956	790	+166	2,335	2,275	+60
47G...	300	730	8.92	84.2	86.1	-1.9	39.6	39.3	.3	353	349	4	742	662	+80	2,245	2,203	+42
40A...	300	831	13.03	100.0	95.5	4.5	38.1	40.8	-2.7	497	525	-28	1,407	1,607	-200	3,025	2,887	+138
40B...	300	831	11.38	95.2	93.7	1.5	37.0	37.1	-.1	422	424	-2	1,144	1,096	+48	2,680	2,586	+94
66E...	300	745	10.22	78.9	79.2	-.3	43.8	37.2	6.6	447	385	62	1,070	879	+191	2,385	2,343	+42
$66E_r$..	295	675	11.32	89.8	92.3	-2.5	38.8	38.0	.8	439	430	9	1,342	1,193	+149	2,370	2,417	-47
47E...	300	730	8.29	75.8	77.6	-1.8	42.5	41.1	1.4	353	343	10	667	585	+82	2,055	2,160	-104
42A...	300	1,002	10.92	94.1	93.0	1.1	34.6	36.3	-1.7	378	399	-19	728	875	-147	2,765	2,667	+98
42B...	300	1,002	10.17	88.4	90.0	-1.6	35.8	36.4	-.6	364	371	-7	589	719	-130	2,540	2,552	-12
42C...	300	1,002	9.37	83.7	85.9	-2.2	37.4	37.5	-.1	350	349	1	479	586	-107	2,480	2,447	+33
44I...	300	1,054	10.50	92.4	91.6	.8	35.5	36.3	-.8	372	382	-10	647	756	-109	2,595	2,639	-44
44J...	300	1,054	9.63	88.1	87.4	.7	36.6	37.0	-.4	353	355	-2	522	601	-79	2,555	2,514	+41
47C...	300	1,062	10.40	93.8	91.2	2.6	36.2	36.3	-.1	376	379	-3	732	732	0	2,530	2,629	-99
47D...	300	1,062	8.81	84.9	82.3	2.6	38.0	38.8	-.8	335	339	-4	402	490	-88	2,150	2,419	-269
39A...	300	1,200	12.90	96.2	96.6	-.4	40.0	40.0	.0	515	514	1	1,308	1,300	+8	3,210	3,232	-22
39B...	300	1,200	12.29	94.5	96.2	-1.7	39.9	38.3	1.6	490	474	16	1,250	1,114	+136	3,110	3,091	+19
39C...	300	1,108	12.85	93.3	96.6	-3.3	41.7	39.7	2.0	535	509	26	1,431	1,342	+89	3,055	3,137	-82
48B...	300	1,341	9.49	87.8	85.7	2.1	41.2	38.2	3.0	391	361	30	637	473	+164	3,125	2,643	+482
48E...	300	1,341	11.17	94.1	93.4	.7	36.2	37.2	-1.0	405	419	-14	754	761	-7	2,870	2,948	-78
48F...	300	1,341	10.28	91.5	89.4	2.1	34.9	37.2	-2.3	359	383	-24	589	589	0	2,585	2,776	-191
43F...	300	1,437	8.95	79.7	81.5	-1.8	39.1	40.0	-.9	350	356	-6	335	389	-54	2,385	2,591	-106
44G...	300	1,437	9.63	86.2	85.9	.3	38.1	38.6	-.5	367	370	-3	475	462	+13	2,665	2,701	-36
44H...	300	1,437	10.41	89.7	89.9	-.2	37.7	37.8	-.1	392	394	-2	501	578	-77	2,890	2,832	+46

1/ Deviation = experimental value minus calculated value.
2/ Exp. = experimental value.
3/ Calc. = calculated value.
4/ Dev. = deviation.

TABLE 9. - Coding equations for variables

Independent variables

Designations and units for uncoded variables:	Coding equation Coded variable
P = Gasifier pressure, p.s.i.g.	$X_1 = (226 - 1.36\ P)/(P + 14.4)$
C.R. = Coal rate, lb./hr.	$X_2 = (C.R. - 795)/334$
O/C = Oxygen to coal ratio, std. c.f./lb.	$X_3 = (O/C - 9.82)/1.13$

Dependent variables

% C = Carbon gasified, percent	$Y_1 = (\%\ C - 90)/10$
C Req. = Coal requirement, lb./M std. c.f. CO + H_2.	$Y_2 = (C\ Req. - 41.3)/4$
O.R. = Oxygen requirement, std. c.f./M std. c.f. CO + H_2.	$Y_3 = (O.R. - 410)/50$
H.L. = Heat loss, B.t.u./lb. of coal	$Y_4 = \frac{(H.L. - 800)}{500}$
E.G.T. = Exit-gas temperature, ° F.	$Y_5 = (E.G.T. - 2,600)/457.5$

TABLE 10. - Coefficients (coded values)

Coefficients	Variables and pressure levels														
	Carbon gasified, percent			Coal requirement			Oxygen requirement			Heat loss			Exit-gas temperature		
	75-100	100-150	150-300	75-100	100-150	150-300	75-100	100-150	150-300	75-100	100-150	150-300	75-100	100-150	150-300
b_o	-0.0927	-0.5557	-0.5305	-0.5833	-0.4358	-0.4009	-0.4557	-0.4851	-0.4345	-0.2901	-0.0006	-0.0152	1.2474	-0.3110	-0.1984
b_1	-.6423	.1330	-.5068	.8035	.4835	1.0344	.5222	.4405	.7889	.3117	-.0780	.0797	-.3916	1.5277	.6285
b_2	-.1037	.0742	.0196	.4336	.5454	.2697	.3569	.4531	.2102	-.3831	-.3495	-.3961	2.4874	.7251	.6269
b_3	.6557	.6138	.5685	-.4017	-.3489	-.3333	.6897	.6232	.6314	.3453	.4088	.4143	.3100	.2769	.2740
b_{22}	.0045	.1851	-.1203	.1457	.4100	.2630	.1465	.3695	.2076	-.0024	.0226	.0536	.0459	.0580	-.0944
b_{33}	-.1093	.1066	-.1065	.2752	.2640	.2317	.2343	.1889	.1768	.0559	.1030	.0691	.0200	-.0552	.0395
b_{23}	.0655	.0046	.0252	-.0027	.0680	-.0236	.1090	.1747	-.0026	-.0836	-.1126	-.0544	.1362	.1251	.0851
b_{12}	-	-	-.3017	-	-	1.1147	-	-	.8744	-	-	-	-1.5186	.6538	-

TABLE 11. - Values of Student's t for coefficients

Coefficients	Variables and pressure levels														
	Carbon gasified, percent			Coal requirement			Oxygen requirement			Heat loss			Exit gas-temperature		
	75-100	100-150	150-300	75-100	100-150	150-300	75-100	100-150	150-300	75-100	100-150	150-300	75-100	100-150	150-300
b_o	0.59	7.08	9.94	2.07	3.10	4.19	1.99	3.96	5.57	3.11	0.01	0.49	12.82	4.25	4.36
b_1	5.06	1.04	4.61	3.53	2.12	5.25	2.81	2.81	4.91	4.13	1.03	1.23	4.86	11.60	6.64
b_2	1.52	.09	.32	3.54	3.79	2.49	3.57	3.04	2.38	9.41	7.32	16.01	17.32	9.47	17.39
b_3	10.74	9.14	12.24	3.67	2.90	4.01	7.73	7.03	9.30	9.51	10.24	15.33	8.92	4.76	6.97
b_{22}	.05	1.89	2.54	.94	2.33	3.10	1.16	1.02	3.00	.05	.39	2.18	.88	.64	2.64
b_{33}	2.10	1.89	3.67	2.95	2.61	4.45	3.08	2.84	4.17	1.80	3.07	4.01	.66	1.12	1.57
b_{23}	.94	.06	.49	.02	.47	.26	1.07	.93	0	2.01	2.36	1.80	3.44	1.82	1.94
b_{12}	-	-	6.58	-	-	13.56	-	-	13.04	-	-	-	14.12	3.77	-

TABLE 12. - Analysis of variance

	Variables and pressure levels														
	Carbon gasified, percent			Coal requirement			Oxygen requirement			Heat loss			Exit gas-temperature		
	75-100	100-150	150-300	75-100	100-150	150-300	75-100	100-150	150-300	75-100	100-150	150-300	75-100	100-150	150-300
Sum of squares about mean	19.0302	16.8933	25.2179	30.1598	24.2205	29.9770	21.2901	12.0186	42.6935	7.1550	6.9963	17.3718	20.7900	20.9818	31.8731
Reduction due to regression equation	17.3099	14.4247	20.1849	20.6220	16.5497	17.5639	14.6990	6.9528	34.6402	6.2756	6.4370	15.5220	19.3512	19.6583	27.9115
Residual sum of squares	1.7203	2.4686	5.0330	9.5378	7.6708	12.4131	6.5911	5.0658	8.0533	.8794	.5593	1.8498	1.4388	1.3235	3.9616
Error mean square	-	.0683	-	-	.2194	-	-	.1460	-	-	.0244	-	-	.0502	-
F test of equation	42	35	42	16	13	11	17	8	34	43	44	91	55	57	93
Average standard deviation, uncoded	-	2.6	-	-	1.9	-	-	19	-	-	78	-	-	100	-

APPENDIX II

Additional Details of Method of Calculating Experimental Results

As indicated in the text, the data were subjected to regression analysis. In inverting the matrices, the data were coded to obtain conformable matrices. The coding equations are given in table 9 and the regression coefficients of the coded variables in table 10. Table 11 gives the values of Student's t for each regression coefficient and table 12 the analysis of variance for each of the regression calculations. For details of the method of calculation, refer to texts on the subject.19/

The curves presented in this report are derived from the coefficients listed in table 10. How well the curves represent the data is shown in table 12 by (1) the standard deviation and (2) the values of F and the sum of squares accounted for by the equation and in figures 27 and 28 of the text, which compare the values calculated from the equation with the experimental value. The deviations from the 45° line are due to lack of fit of the equation and experimental error. As a rather narrow range was covered by the tests, the error from the lack of fit of the equation is expected to be small compared with the experimental error. Because the equations are based on a number of points, they should give more reliable results than ones based on single points, which are subject to random deviations, as shown in figures 27 and 28, pages 39 and 40.

Inherent variability in the operation of the gasifier causes the random variations. There are several reasons for this variability. For example, the thickness of the slag on the wall may change. Furthermore, coal is a natural product, so the composition of the ash, hence the slag, is not constant. Moreover, the flame may be deflected by slag adhering to the lip of the burner. Variations from such causes are uncontrollable and appear as random deviations in the data.

As stated in the text, there were also measurement errors. Product gas was difficult to meter accurately, because the gases contained considerable dust and moisture; both a positive-displacement- and an orifice-type meter were used to measure product-gas flow, and the standard deviation of the difference between the readings of these meters was about 5 percent of the gas-flow rate. The approximate standard deviation of the values for oxygen and coal requirement and carbon gasified (percent) from the equations was also about 5 percent of the average value (table 12). As the standard deviation of the results after fitting the equations is about the right magnitude for the inherent variation in the process, the expected variation of the data is largely accounted for by the equations, and an appreciable improvement in the fit could not be obtained by changing the form of the equations.

The curves express the average relationship and give a general picture of what happens as coal rate, oxygen-to-coal ratio, and pressure vary. When

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19/ Davies, Owen L., The Design and Analysis of Industrial Experiments: Hafner Publishing Co., New York, N.Y., 1954, pp. 552-561.

actual data points are compared the individual variability hides the general picture, but it is believed that the curves developed from the equations give a good general approximation of the results at various conditions. The significance of the curves is confirmed by the statistical significance of the coefficients of the equations, as well as by the foregoing analysis. Perhaps more points could have been taken at certain levels, but the time available for the tests was limited, and equipment that can operate under the stated conditions is no longer available.

As discussed previously, the coal rate could not be set at the desired value. Therefore, the actual results deviate somewhat from the nominal results presented in the graphs. This effect is shown in table 13, which lists the experimental value, the value calculated from the equation using the experimental conditions, and the value at the nominal conditions.

TABLE 13. - Oxygen requirement at 100 p.s.i.g. and a nominal coal rate of 700 pounds per hour

Run and period	Coal rate, lb./hr.	Oxygen-to-coal ratio, std. c.f./lb.	Experimental result	Calculated at-			
				Experimental conditions		Nominal conditions	
				75-100 pressure group	100-150 pressure group	75-100 pressure group	100-150 pressure group
49A.....	765	8.16	392	382	377	381	377
49B.....	765	9.06	395	389	385	386	383
49C.....	765	9.78	411	405	400	402	397
50K.....	741	9.37	374	394	390	391	388
50L.....	741	10.10	422	414	408	415	406
51S.....	715	10.48	416	427	418	426	418
51T.....	715	8.72	364	382	379	382	379
51U.....	715	10.50	430	428	419	427	419

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