OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS

INTERREGIONAL SYMPOSIUM ON THE APPLICATION OF MODERN TECHNICAL PRACTICES IN THE IRON AND STEEL INDUSTRY TO DEVELOPING COUNTRIES

11-26 NOVEMBER 1963

STEEL SYMP.1963/
Technical Paper/B.5
19 September 1963

Original: ENGLISH

D04783

THE SL DIRECT REDUCTION PROCESS

by

D.J. HAINS,
Hains Engineering Company Limited,
Toronto, Ontario, Canada

I. Synopsis of Process

1. The SL Direct Reduction Process is the result of the co-operative efforts of The Steel Company of Canada Limited, Hamilton, Ontario, Canada, and the LURGI Gesellschaft fuer Chemie und Huettenwesen m.b.H., Frankfurt/Main, Germany. The "SL" trade name is derived from the first letters of the STELCO and LURGI trade names.

2. The process can use high-grade iron ores or iron concentrates which have been agglomerated into the form of pellets. The iron ore or the pellets are fed into a rotary kiln along with coal and dolomite. The coal is used as a reductant and as a source of supplemental heat. The dolomite serves as an interface and absorbs sulphur which may be driven off from the coal or the iron-bearing materials.

3. Due to the mechanical construction features of the SL kiln very high reaction temperatures are possible without fusion of the materials within the kiln. One of the features of the SL kiln is mantle burners. The burners are supplied with air and gas and the total mix is combusted in the kiln. The burners act as a source of heat and in addition enable the control of the temperature and the composition of the gas atmosphere within the kiln. The control so exercised is accurate and temperature profiles of plus or minus a few degrees centigrade are attainable over long periods of time. The reduced iron, commonly referred to as sponge iron, is discharged via a gastight chute from the reducing kiln into a rotary cooler where the sponge, unburnt char and dolomite are cooled and discharged via an airtight seal to a conveying system. The discharged product generally has a temperature of 65°C and is non-pyrophoric. By means of screening and dry magnetic separation, the non-magnetic products are separated from the magnetic products, namely sponge iron. The non-magnetic products can be further separated to recover the char and this char returned to the system.

II. Process History and Application

4. In 1958, The Steel Company of Canada Ltd. commenced a programme of investigating direct reduction processes and based on their survey of existing processes came to the conclusion that there were serious technical and economic shortcomings in the available processes. At this time, they contacted the LURGI Companies and it was determined that mutual interests existed. An agreement was entered into and trials commenced in the autumn of of 1959, using the Lurgi pilot plant kiln in Frankfurt. The successful results of these preliminary tests warranted the building of a semi-industrial unit in Hamilton, Ontario, Canada, which started operation in the spring of 1961. The recent average production rate is approximately 100 net tons sponge per day.

5. The SL-sponge iron product produced since 1961 has been used:

a. in pilot blast furnace tests;

b. for electric furnace steel making;

c. as a coolant for oxygen steel making;

d. for cupola melting tests;

e. as a precipitant for copper solutions.

III. Raw Materials and their Preparation

6. Iron Ore

In the LURGI pilot plant in Frankfurt, Brazilian ore and Venesuelan ore has been crushed and screened so that the +¼" -1½" material was fed directly to the kiln. At the Steel Company of Canada in Hamilton the basic material, which has been used, is a magnetite ore which is crushed, ground and concentrated so that the concentrates contain approximately 66-68% Fe as Fe_3O_4. These concentrates are pelletised and indurated at the mine and the hardened pellets are transported to Hamilton for charging into the kiln. These pellets are screened to reject the -¼" and +5/8". The quantity which has been rejected as over and undersize has been very small, indicating good control of the pellet size at the mine.

7. Coal

The coal can vary from anthracite to lignite and should have non-coking characteristics. A desirable feature is to have the softening temperature of the ash of the coal as high as possible. The coal is usually crushed to -6.68 millimeters, the dolomite or limestone is usually crushed to -3.327 millimeters. These raw materials are received and placed in storage bins and are discharged from the storage bins by means of weigh feeders which are programmed and can be individually adjusted from a remotely situated central control panel. The weighing devices are fully integrated so that the total weight and ratio of pellets to coal to dolomite is kept.

IV. Process Equipment

8. The following description of the SL Process equipment is based on the Hamilton plant of the Steel Company of Canada. The LURGI Companies in Frankfurt/Main, Germany, were responsible for the design and supply of the process equipment. To minimize personnel, the plant was fully instrumented and practically all of the operations automated and controlled remotely from a single control center. In addition to being highly automated, the plant was designed to provide the maximum of process data.

9. The plant has been described by Mr. J.G. Sibakin in his paper entitled: "Development of the SL Direct Reduction Process", however, it is worth-while to again describe the equipment (a). The plant consists of four sections: raw material handling system, main kiln, rotary cooler and finished products handling system. A schematic layout of the plant may be seen in Fig. 1.

10. The raw materials consisting of pellets, dolomite and coal, are brought to the plant by rail and truck and are conveyed to their respective storage bins. Pellets and dolomite are screened to remove the oversized and undersized particles prior to their entering the bins. From the storage bins, the materials are fed continuously, by means of weighing feeders, in the desired portions onto a common collecting conveyor. The materials then pass through a rotary gate-feeding mechanism, which prevents escape of the kiln gases, down a feed spout into the kiln.

11. The kiln, excluding the two stationary heads, is 115 feet long, has an internal diameter of about 7½ feet and can be rotated at a constant speed over a wide range of speeds. It is lined with a double course of refractory bricks, making a lining thickness of about 8½ inches.

12. Ten burners are mounted on the shell of the kiln. The burners are evenly spaced with each offset in succession from the next by 72 degrees. The air and gas for the burners enter separate manifolds from opposite ends of the kiln. The transfer of gas and air from the stationary kiln heads to the rotating manifolds is accomplished through circular cavities enclosed by inner and outer labyrinth seals. The bearing surfaces of the seals are lubricated with a suitable grease having a drop point of 350°F. One axial burner is located at the discharge end of the kiln.

13. The materials gradually move through the hot kiln, until they are discharged and drop through a bricklined transfer chute onto a stone box which diverts them into the cooler. At this point, the materials are at a temperature of about 1090°C, but soon cool to about 65°C during passage through the rotary cooler.

14. The rotary cooler is mounted below the main kiln. It is 65½ feet long, has an outside diameter of 5 feet and can be rotated at a constant speed over a wide speed range. Only the first 28 feet of this cooler are refractory lined. Water sprays are directed against the outer shell surface along the unlined length. The atmosphere of the rotary cooler consists essentially of gases from the main kiln and prevent reoxidation of the reduced iron.

15. Both the main kiln and rotary cooler slope at an angle of about 2 degrees from the horizontal.

16. The materials discharge from the rotary cooler via another gate mechanism and are conveyed to the product bins. The materials are separated by means of a screen and two drum magnetic separators into three products: coarse sponge iron (plus 3/16 inches), fine sponge iron (minus 3/16 inches) and non magnetic mixture of calcined dolomite and coal char.

17. The gases generated in the process flow counter-current to the stationary charging head and into two multiclone dust collectors. The relatively dust free gases are then discharged through a short stack. The pressure of the gas in the kiln is regulated by means of adjustable louvres and an exhaust fan. Plants for the production of 700 and 1000 tons of sponge per day are presently being designed.

V. Operation

18. In all endothermic chemical reactions it is advantageous to have the reaction temperature as high as possible to obtain the maximum results. The controlling temperature in the SL Process is the lowest softening temperature of the various materials of the charge used. As a general practice the gas volume is kept constant and the air admission at each burner is varied to accommodate the materials in process and the temperature profile. The exit gases are analyzed continuously and generally contain less than 1.0% total combustibles (hydrogen + carbon monoxide).

19. During the past two years of operation there has been no ringing in the kiln which is indicative of the excellent temperature control available. A typical temperature profile of a 140 net ton test is indicated in Fig. 2.

20. The test data for five 140 net ton per day and one 150 net ton per day runs are detailed in Appendix I.

VI. Utilization of SL Sponge

21. Test results from the United States Bureau of Mines Experimental Blast Furnace at Bruceton, Pa., indicate that substantial increases in blast furnace productivity and much lower coke rates can be obtained by the use of prereduced pellets. A maximum decrease in coke rate of 44% and an increase in production rate of 55% were obtained by increasing the average iron content of the burden from 66.19% to 86.49% Fe by removal of 95% of the oxygen in the iron minerals (b).

22. The sponge iron product has been used in several different electric arc furnace steel making operations, making both normal carbon steel and low and high alloy steels.

23. In one steel plant all the electric furnace test heats were cast through the continuous casting process. This process requires a ladle temperature of about 1660°C for most grades of steel, which is about 50°C above normal ingot pouring temperatures. The power consumption for these tests was therefore about 50-100 KWH/ton above most other electric furnace operating results due to the additional thermal requirements of the steel for continuous casting application.

24. From the melting of 325 tons of SL pellets and 40 tons of SL briquettes in a 4700 K.V.A. furnace with up to 80 per cent of the charged material consisting of SL sponge iron, the following conclusions were made:

a. SL sponge iron significantly improves the electric furnace production of medium carbon steels through the acquisition of better control over the melt-down analysis of the steel. A decrease of up to 20 per cent in the finishing time for test heat may be realised using SL pellets.

b. The number of charges required to reach the furnace melting capacity are decreased 50 per cent with the increase in charge density provided by SL pellets. This provides a decrease of up to 11 per cent in total power consumption and an increase of about 10 per cent in the production rate.

c. The regular replacement of 30 to 50 per cent of the scrap by SL iron in the electric furnace is technically feasible and will improve operations over the long run.

d. It is estimated that a productivity increase of up to 40 per cent and power saving of up to 20 per cent over normal practice, may result from an efficient continuous charging operation utilizing SL pellets.

25. Electric furnace data from another plant test run on SL sponge pellets and sponge briquettes are shown in Appendix II and indicate favourable comparisons with scrap.

26. If the SL plant is in close proximity to the electric furnace, then sponge pellets may be considered. If a long storage life is required, then the SL pellets should be briquetted.

27. SL sponge has been used in a small-scale electric induction furnace with excellent results and further work in this direction is suggested.

28. Large-scale tests have been conducted in Hamilton on the use of SL sponge iron pellets as a scrap substitute in the LD steel making operation. It is contemplated under certain conditions to replace scrap with its wide range of composition and price with a material of known composition at a relatively fixed price. It is also considered that SL sponge pellets or briquettes can be handled easier than scrap through the existing flux handling system and charged by gravity to the LD vessel.

29. In the tests, up to 15% pellets as scrap substitute have been charged after ignition without difficulty.

30. Total pellet additions of up to 20% gave smooth operation during the blowing cycle.

31. The pellets gave better cooling control and are slightly more efficient than regular scrap.

32. Based on the satisfactory performance of the pellets future tests will be designed for faster and more continuous SL sponge additions, particularly for additions after ignition. The operating personnel anticipate trials using SL sponge as a complete substitute for scrap.

33. A partial summary of some of the test data is shown in Appendix III.

VII. <u>Investment Costs</u>

34. Assuming the pellets are available and delivered to the reduction plant along with the necessary coal and dolomite or limestone, then the investment costs for receiving these materials, the process equipment and separating the magnetics from the non-magnetics, including the briquetting of the magnetics to assure their long storage life, will vary between 25.00 and 12.[illegible] per annual ton of capacity depending on the size of plant.

VIII. Operating Costs

35. The operating costs are best illustrated in Fig. 3 as a percentage of the total cost per ton of sponge.

IX. Economic Developments

36. In highly industrialised areas the SL Process can produce sponge iron with known characteristics and chemical analyses, suitable for electric furnace melting to make the highest quality alloy steels.

37. In certain areas of industrial countries, where scrap commands a high price, due to transportation distances, local iron deposits can be worked economically to produce a substitute iron melting stock. In industrial areas where an increase in pig iron production is required, the use of partially reduced pellets will permit higher rates of production without additional blast furnaces or an increase in the number of coke ovens. The use of partially reduced pellets in blast furnaces will be the next step of beneficiation of the blast furnace burden, after the production possibilities of indurated pellets or self-fluxing sinter have been exhausted.

38. In non-industrial countries, the SL Process will permit the production of steel without the capital requirements of coke ovens and blast furnaces. The SL Process will also permit the use of local non-coking coals of various ranks.

39. From a capital cost point of view where new iron or steel production plants are being considered, or where existing iron production must be increased, the SL Process is highly competitive and worthy of closest examination by potential and current steel producers.

References

(a) SIBAKIN, J.G. Development of the SL Direct Reduction Process Preprint, General Meeting, The American Iron and Steel Institute, New York, May 23, 1962, 42 pp.

(b) MELCHER, N.B. Smelting Prereduced Pellets in an Experimental Blast Furnace, Twenty-Fourth Annual Mining Symposium, University of Minnesota and Annual Meeting of Minnesota Section, AIME 1963, pp 47-51.

APPENDIX I.

SL DIRECT REDUCTION TEST DATA

TRIAL	1-140 HB	1-150 HB	2 140 HB	3 140 HB	4 140 HB	5 140 HB
DATE	Apr. 30/62	May 7/62	May 27/62	May 27 28	May 29/62	May 30 31
TIME START	9:00 pm	1:00 am	2:00 am	10:00 pm	7:00 am	11 00 pm
END	9:00 am	1:00 pm	2:00 pm	10:00 am	7.00 pm	11 00 am
CHARGING RATES N.T./day						
Hilton Pellets	139.1	148.4	137.7	138.0	139.2	138.3
Anthracite	69.9	74.6	69.5	69.0	69.5	71.2
Dolomite	3.6	4.4	3.7	3.8	3.6	3.4
Coal/Ore Ratio	0.50	0.50	0.50	0.50	0.51	0.51
PRODUCTION RATES, N.T./day						
SL Pellets (+3/16")	80.0	82.91	65.7	66.6	55.6	74.0
SL Fines (-3/16")	22.5	25.23	32.9	33.3	46.5	27.0
Dolochar	35.3	38.59	31.1	34.1	33.7	32.2
Fines/Pellets Ratio	0.28	0.30	0.50	0.50	0.83	0.36
PERFORMANCE						
Kiln Speed r.p.m.	0.40	0.40	0.375	0.375	0.375	0.375
Cooler Speed r.p.m.	3.09	3.09	3.09	3.09	3.09	3.09
% Metallization	95.69	95.60	97.37	96.88	99.03	95.53
% Reduction	97.09	96.74	97.83	97.37	99.30	96.67
Carbon charged lb/N.T.H.	723.7	733.5	747.8	738.5	748.4	762.3
Carbon discharged lb/N.T.H.	381.1	405.9	356.8	398.0	379.6	363.5
Carbon consumed lb/N.T.H.	342.6	327.6	391.0	340.5	368.8	392.8
Waste Gas Combustibles: H_2	0.22	0.13	0.35	0.29	0.29	0.19
(% dry gas) CO	0.48	0.37	0.47	0.62	0.57	0.48
CH_4	0.13	0.12	0.22	0.22	0.28	0.16
O_2	0.11	0.28	0.13	0.16	0.17	0.16
Temperature Profile 11	2131	2124	2132	2124	2145	2127
(°F by Thermocouple no.) 10	2103	2134	2134	N.W.	N.W.	2131
9	2120	2128	2141	2128	2136	2145
8	2133	2059	N.W.	N.W.	N.W.	N.W.
7	2110	2150	2152	2139	2141	2142
6	2103	2125	2145	N.W.	N.W.	N.W.
5	1989	1955	2003	1998	1967	1918
4	1884	1882	1936	1925	1946	1897
3	1599	1609	1644	1645	1660	1616
2	1297	1344	1339	1328	1385	1319
1	1074	1081	1067	1051	1062	1061
Waste Gas	1231	1232	1220	1221	1220	1209
Heat Consumption, 10^6 BTU/NTH	8.488	8.394	8.922	8.430	8.743	8.553
% Degradation	29.6	33.7	47.0	41.7	[illegible]	[illegible]

TRIAL	1-140 HB	1-150 HB	2 140 HB	3-140 HB	4 140 HB	5 140 HB
Heat Consumption, 10^6 BTU/NTH	8.488	8.394	8.922	8.430	8.743	8.533
Heat Consumption, 10^6 BTU/NT Sponge	11.519	11.514	12.375	11.726	11.915	11.701
Heat Consumption, 10^6 BTU/NT Fe T	12.641	12.70	13.373	12.726	13.209	12.905
Heat Consumption, 10^6 BTU/NT Fe M	13.210	13.345	13.770	13.137	13.338	13.507
NATURAL GAS PROPERTIES						
Average Temperature, °F	49.0	56.0	56.0	60.0	56.0	71.5
Main Line Pressure p.s.i.	11.7	12.2	13.4	12.8	13.1	13.3
Header Pressure, in. w.g.	23.7	24.0	25.0	24.9	24.9	24.7
Specific Gravity	0.620	0.620	0.625	0.625	0.625	0.620
Heat Content, Gross BTU/ft.^{3}						
Net BTU/ft.^{3}	987	984	960	958	953	958
NATURAL GAS DISTRIBUTION						
Total Gas Flow c.f./N.T.H.	2300	2263	1972	1901	1823	1949
AIR PROPERTIES						
Average Temperature °F	45.6	47.0	64.5	53.7	62.2	68.1
Moisture % Vol.	0.98	0.64	0.92	0.97	1.29	1.69
AIR DISTRIBUTION						
Total Air Flow c.f./N.T.H.	47710	47868	47626	47971	46682	48061
WASTE GAS						
Volume (N.T.P.) c.f./N.T.H.	63139	64547	61048	62032	59517	60108
H_2O	18.66*	18.05*	18.7	18.9*	17.8*	19.1*
CO_2	20.3	19.8	20.2	19.9	19.9	19.9
N_2	60.3	60.2	60.1	60.1	61.2	60.1
O_2	0.09	0.22	0.11	0.13	0.14	0.15
H_2	0.18	0.10	0.28	0.24	0.24	0.15
CO	0.39	0.30	0.38	0.50	0.47	0.39
CH_4	0.11	0.10	0.18	0.18	0.22	0.13

* - Calculated from input moisture and hydrogen

[illegible]IAL		1-140 HB	1-150 HB	2-140 HB	3-140 HB	4-140 HB	5-140 HB
[illegible] PELLETS							
Screen Analysis	+5/8"	0	0	0.0	0.0	0.0	0.0
-5/8"	+1/2"	2.1	3.7	11.6	3.9	15.8	1.7
-1/2"	+3/8"	66.8	81.0	74.8	70.4	70.9	69.6
-3/8"	+1/4"	29.1	13.8	13.1	23.4	12.9	27.0
-1/4"		2.1	1.5	0.4	2.3	0.4	1.7
Bulk Density lb/cu.ft.							
Moisture % H_2O		0.1	0.1	0.7	0.9	0.02	0.03
Chemical Analysis (% dry)	Fe (tot)	67.10	65.80	66.40	66.10	66.10	66.00
	Fe ++	0.50	0.60	0.50	0.60	0.50	0.60
	S	0.007	0.009	0.015	0.014	0.009	0.008
	C	0.055	0.042	0.035	0.063	0.025	0.109
	Gangue	4.08	5.96	5.09	5.51	5.54	5.61
ANTHRACITE							
Screen Analysis	6M	31.8	35.4	32.3	33.0	32.8	35.2
-6M	10M	56.3	51.7	50.8	52.5	51.9	51.3
10M	20M	9.8	9.4	10.7	10.3	10.8	9.3
20M	35M	1.1	1.4	2.4	1.8	2.1	1.6
-35M	65M	0.3	0.6	1.2	0.8	0.9	0.7
-65M		0.7	1.5	2.7	1.5	1.6	1.8
Bulk Density lb/cu.ft.							
Moisture % H_2O		10.2	10.7	9.95	10.68	8.3	9.7
Heat Content B.T.U./lb.		12770	13231	13539	13785	13754	14370
Chemical Analysis (% dry)	Volatiles	7.70	6.68	6.84	6.90	7.12	6.68
	Fixed C	80.20	81.66	81.68	81.84	81.66	82.00
	S	0.75	0.61	0.70	0.71	0.71	0.70
	Ash	12.10	11.66	11.48	11.21	11.22	11.32

RAW MATERIALS

TRIAL		1-140 HB	1-150 HB	2-140 HB	3-140 HB	4-140 HB	5-140 HB
DOLOMITE							
Screen Analysis	+6M	0.1	0	0.0	0.0	0.0	0.0
-6M	+10M	47.0	21.5	12.3	9.9	10.4	14.8
-10M	+20M	50.0	61.8	60.9	61.8	61.9	62.1
-20M	+35M	2.2	11.2	17.8	20.1	18.9	14.7
-35M	+65M	0.1	3.2	4.8	4.5	3.7	3.7
-65M		0.6	2.2	4.2	3.7	5.1	4.7
Bulk Density lb/cu.ft.							
Moisture % H_2O		0.15	0.1	0.1	0.1	0.08	0.05
Chemical Analysis (% dry)	CaO		30.75		composite		30.65
	MgO		20.56				20.55
	S		.088		sample		0.086
	L.O.I		46.92				46.97

PRODUCTS

TRIAL		1-140 HB	1-150 HB	2 140 HB	3-140 HB	4-140 HB	5-140 HB
DOLOCHAR							
Screen Analysis	+6M	3.8	6.1	6.3	6.7	6.2	7.6
-6M	+10M	50.0	49.5	49.7	50.8	52.8	47.9
-10M	+20M	30.8	25.8	25.1	27.3	26.0	24.3
-20M	+35M	8.8	8.8	9.2	7.9	8.1	9.4
-35M	+65M	3.8	5.2	5.0	4.0	3.8	5.8
-65M		2.7	4.7	4.7	3.3	3.0	5.0
Bulk Density lb/cu.ft.		48.0	51.2	49.6	48.0	48.0	49.6
Heat Content B.T.U./lb.		10462	10985	11785	11938	11570	12185
Chemical Analysis	Fe (tot)	1.10	1.40	1.20	0.90	1.00	1.00
	Fe ++	0.50	0.43	0.35	0.30	0.38	0.30
	Fe (met.)	0.50	0.48	0.45	0.35	0.45	0.35
	S	1.15	0.83	0.89	0.87	0.88	0.82
	C (tot)	76.30	79.23	79.58	80.87	79.56	79.54
	Volatiles	1.38	1.39	1.21	1.20	1.13	1.48
	Gangue	21.77	18.69	18.06	17.16	18.38	18.40

PRODUCTS

[illegible]		1-140 HB	1-150 HB	2-140 HB	3-140 HB	4 140 HB	5 140 HB
SL [illegible]							
Screen Analysis	+5/8"	0	0	0.0	0.0	0.0	0.0
-5/8"	+1/2"	1.1	1.0	2.6	0.9	1.2	0.2
-1/2"	+3/8"	38.6	42.4	30.0	32.3	19.8	32.6
-3/8"	+1/4"	28.8	21.5	20.0	23.8	17.4	26.1
-1/4"	+3/16"	9.5	11.9	11.2	8.0	15.1	14.3
-3/16"	+6M	5.3	5.6	9.3	7.0	11.1	4.7
-6M	+10M	11.3	11.8	17.2	18.3	21.0	14.2
-10M	+20M	4.0	4.0	6.7	7.4	10.5	5.4
-20M	+35M	1.0	1.0	1.8	1.5	2.5	1.3
-35M	+65M	0.3	0.4	0.8	0.5	0.8	0.6
-65M		0.1	0.3	0.4	0.3	0.5	0.5
SL PELLETS (+1/4")							
Chemical Analysis	Fe (tot)	90.90	90.40	91.90	90.70	90.20	90.40
(%)	Fe ++	4.95	4.10	1.60	1.80	0.77	4.27
	Fe (Met.)	85.90	85.40	89.40	87.50	89.40	85.00
	S	0.012	0.010	0.020	0.013	0.010	0.014
	C	0.019	0.030	0.161	0.134	0.180	0.123
	Gangue	7.63	7.86	7.07	8.03	9.38	7.76
Gangue Pickup lb/100 lb. Fe		2.31	0	0			
% Metallization		94.50	94.46	97.27	96.47	99.11	94.02
% Reduction		96.30	95.48	97.85	97.13	99.41	95.58
Bulk Density lb/cu.ft.		106.0	110.6	110.4	108.8	105.6	107.2
Porosity		56.75	55.88	56.86	59.14	55.14	58.78
Apparent Density		3.53	3.60	3.53	3.45	3.41	3.49
True Density		6.84	6.80	6.86	6.99	6.37	7.05
SL FINES (-1/4")							
Chemical Analysis	Fe (tot)	91.60	89.90	92.50	90.60	90.20	91.10
	Fe ++	1.35	1.10	0.80	0.70	0.70	1.30
	Fe (Met.)	90.10	87.90	90.20	88.30	89.27	89.20
	S	0.015	0.009	0.013	0.012	0.011	0.014
	C	0.082	0.153	0.164	0.153	0.338	0.188
	Gangue	7.85	9.23	6.45	8.35	9.15	8.07
Gangue Pickup lb./100 lb.Fe		2.48	1.21	0.00	0.88	1.76	0.35
% Metallization		98.36	97.77	97.51	97.46	98.97	97.91
% Reduction		98.85	98.17	97.81	97.71	99.22	98.38
Bulk Density lb/cu.ft.		123.2	116.8	115.2	118.4	116.8	120.[illegible]

APPENDIX II.

MELTING TESTS

SL PELLETS AND BRIQUETTES

CHARGE MATERIALS (Pounds)	Control 4-23-62	SL 6 4-24-62	Control C 3925	SL C 3926
Mill Ends - Crops	2 000	2 000	2 000	1 000
R.R. Wheels (3.5%C)	2 100	3 500	2 100	2 800
Railroad #1	5 000	10 000	5 000	-
Auto	27 400	10 600	28 900	3 500
Bundles	9 000	3 400	7 500	--
SL Pellets	-	16 820	--	-
SL Briquettes	--	-	--	38 700
% SL	--	36.4	--	84.1
Total Scrap	45 500	46 320	45 500	46 000
Burnt Lime	500	500	--	--
Carbon	--	--	--	--
Ore	300	300	--	--
Limestone	--	--	1 500	1 000
FEED MATERIALS				
Ore	600	--	--	--
Burnt Lime	650	450	400	400
Limestone	500	400	200	--
All Other (incl. Alloys)	333	370	474	956
POWER				
TOTAL KWH				
To Melt Total Charge	9 200	9 300	9 200	9 200
Power on to Tap	10 900	10 600	11 400	11 900
KWH per Ton				
To Melt Total Charge	450	450	442	459
Power on to Tap	533	513	548	574
TIMES-ACTUAL				
Charge to all melted	$1^h\ 52^m$	$2^h\ 13^m$	$1^h\ 57^m$	$1^h\ 53^m$
Charge to Tap	$3^h\ 12^m$	$3^h\ 04^m$	$3^h\ 00^m$	$3^h\ 02^m$
Tap to Tap	$3^h\ 38^m$	$3^h\ 26^m$	$3^h\ 20^m$	$3^h\ 26^m$
TIMES-NET (Less Delays)				
Charge to all melted	$1^h\ 47^m$	$2^h\ 13^m$	$1^h\ 54^m$	$1^h\ 53^m$
Charge to Tap	$3^h\ 01^m$	$3^h\ 04^m$	$2^h\ 57^m$	$3^h\ 02^m$
NET TIME POWER TO FURNACE				
Power on to all melted	$1^h\ 36^m$	$2^h\ 00^m$	$1^h\ 52^m$	$1^h\ 51^m$
Power on to Tap	$2^h\ 57^m$	$2^h\ 35^m$	$2^h\ 55^m$	$3^h\ 00^m$
GOOD INGOTS PRODUCED (TONS)	20.42	20.65	20.82	20.03

	Control 4-23-62	SL-6 4-24 62	Control C 3925	SL C 3926
CHEMISTRY - STEEL %				
C	0.31	0.31	0.30	0.16
Mn	0.58	0.56	0.58	0.50
P	0.019	0.030	0.015	0.009
S	0.038	0.030	0.038	0.033
Si	0.13	0.12	0.10	0.09
Cu	0.39	0.23	0.32	0.09
METALLIC YIELD				
Total Charge (T)	22.75	23.16	22.75	23.00
Yield (%)	90.0	89.5	91.5	87.1%
Yield % @ 86.8% SL *	-		-	97.9%
@ 93 % SL	90.0	91.5	91.5	92.5%

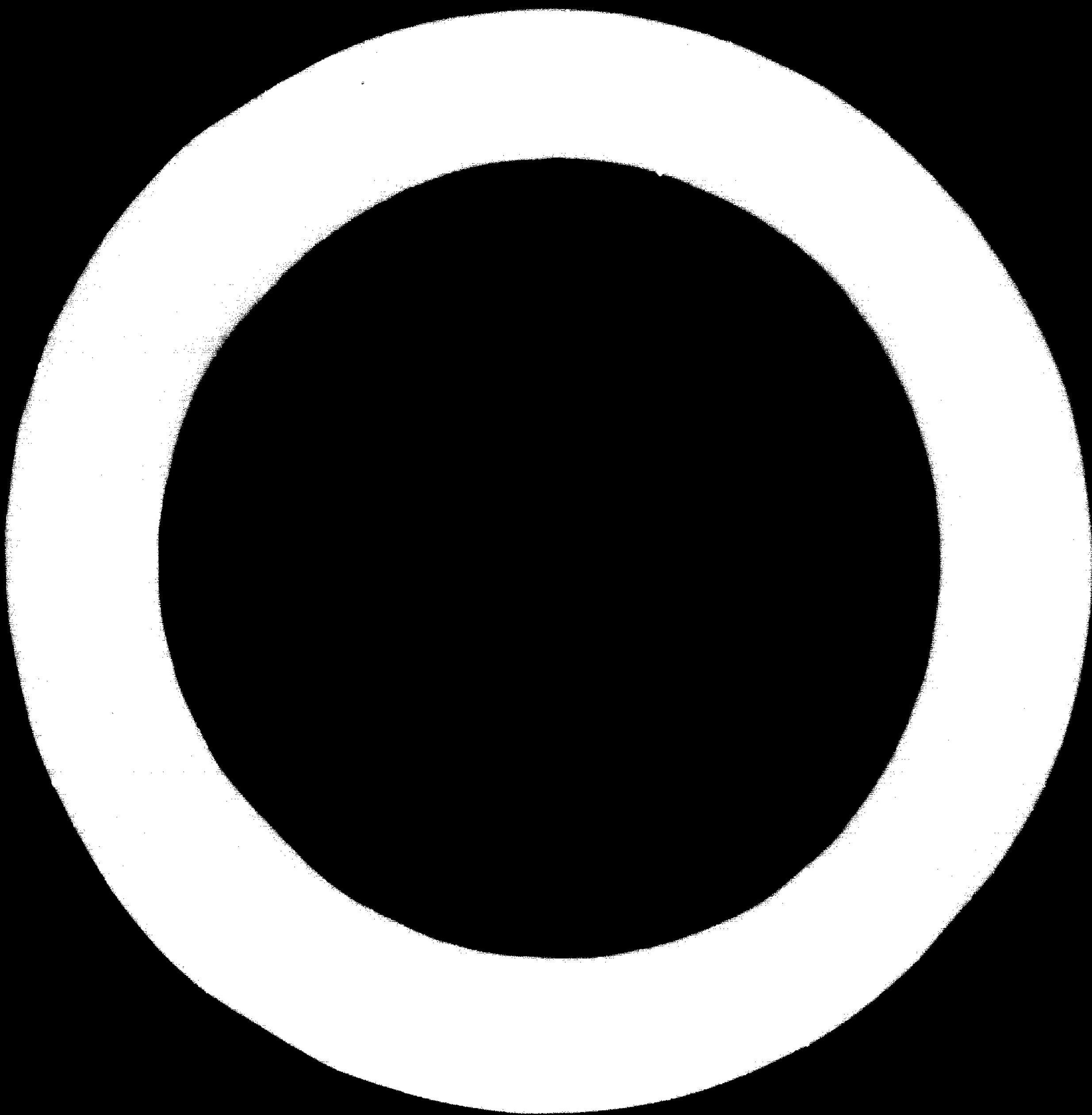
---

* 86.8% metallic Fe

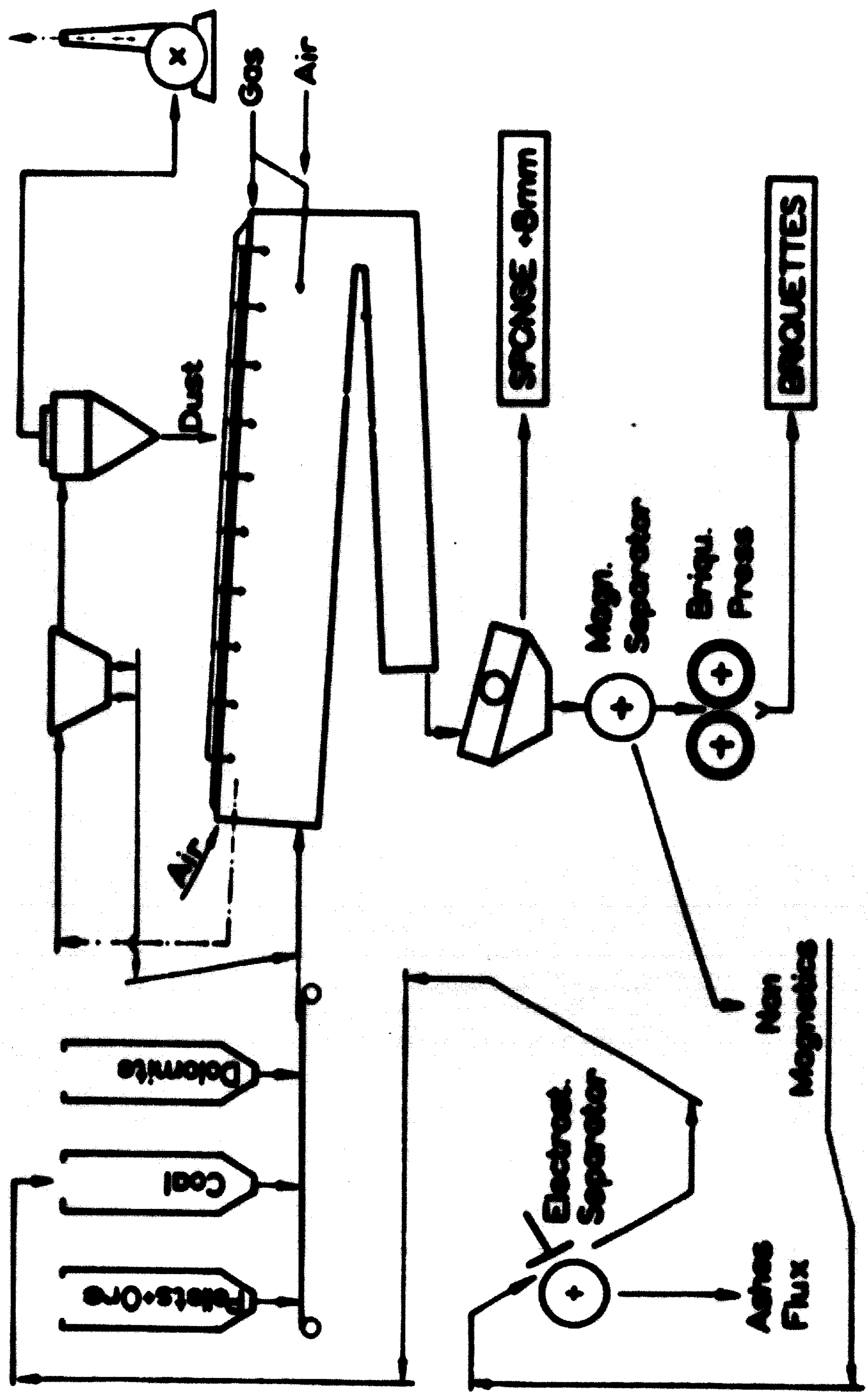
APPENDIX III

STEELMAKING DATA FROM HEATS USING SL PELLETS

Heat No.	66 204	66 306	66 340
Total charge pounds	239 500	276 800	257 000
Weight SL	24 000	41 000	48 000
SL % of charge	10	15	20
Added with scrap	10	-	5
After ignition	--	15	15
Scrap weight	40 800	30 000	20 800
% scrap	17	10.8	8.1
Total coolant	62 400	68 000	63 000
% coolant	26	24.5	24.5
Hot metal weight	177 100	209 900	193 000
% hot metal	74	75.7	75.2
Fce operation sparking	Nil	Nil	Nil
Slag	Fluid	Fluid	Fluid

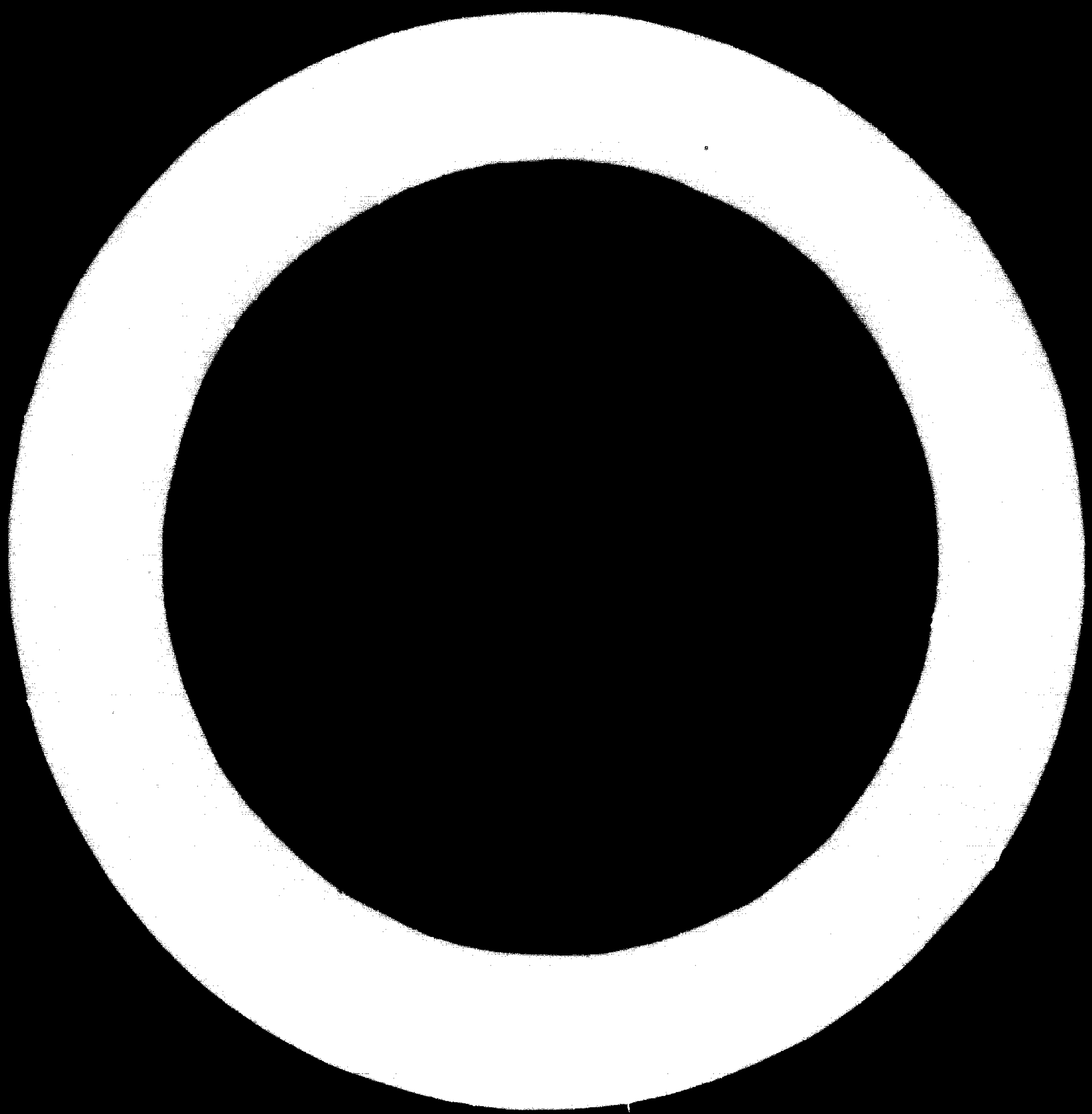


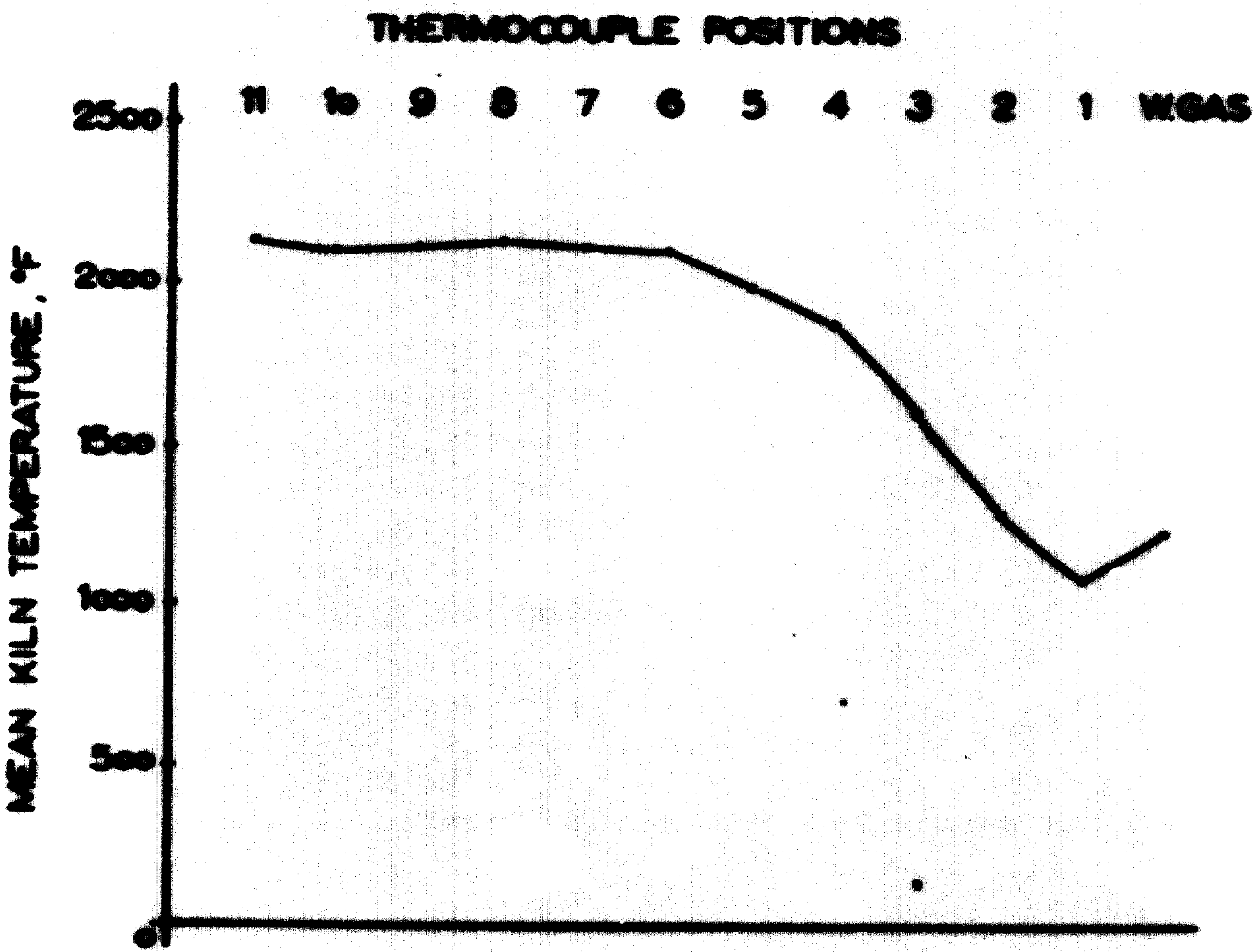
FIGURES



SL - PROCESS

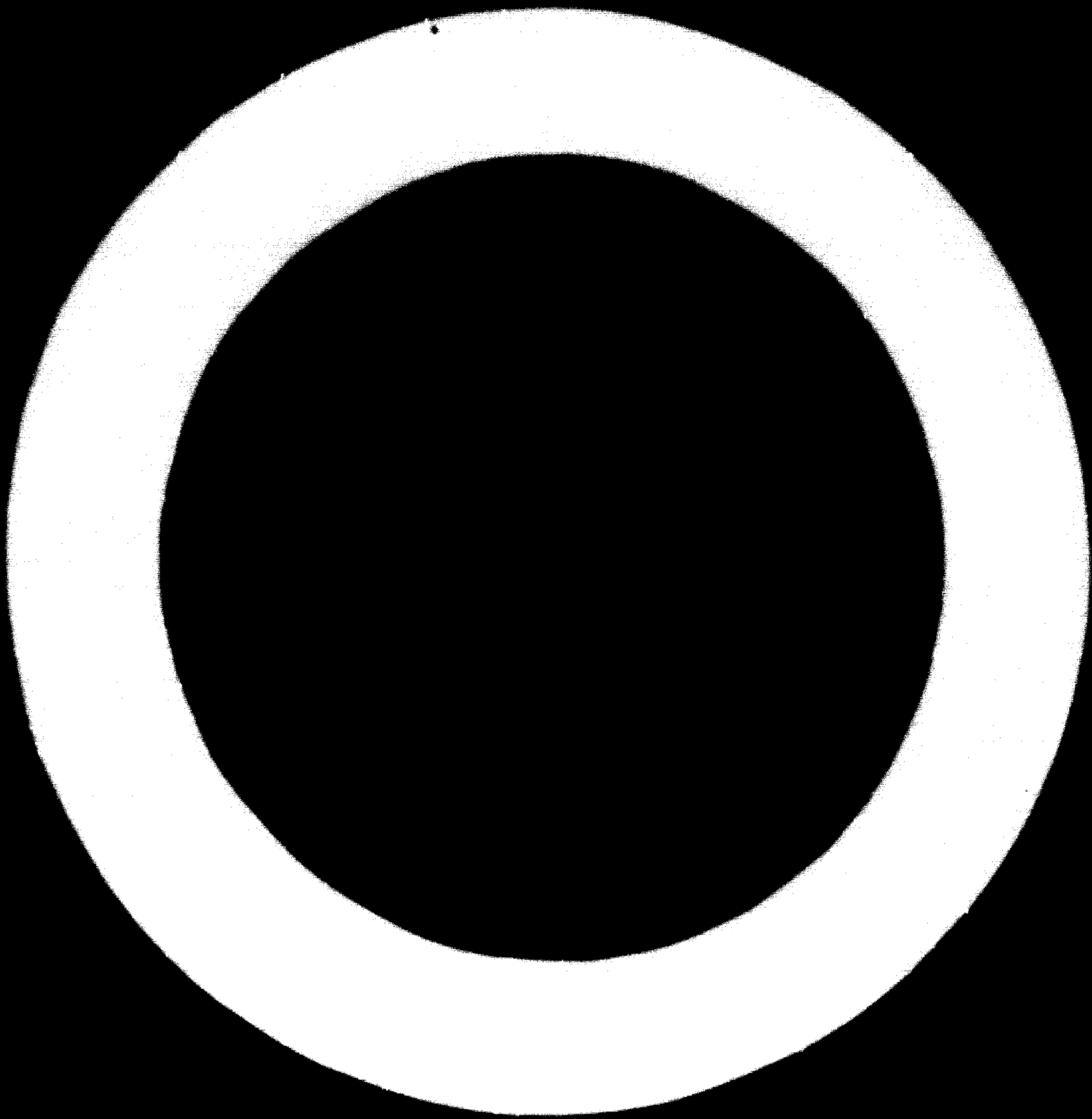
FIG. 1

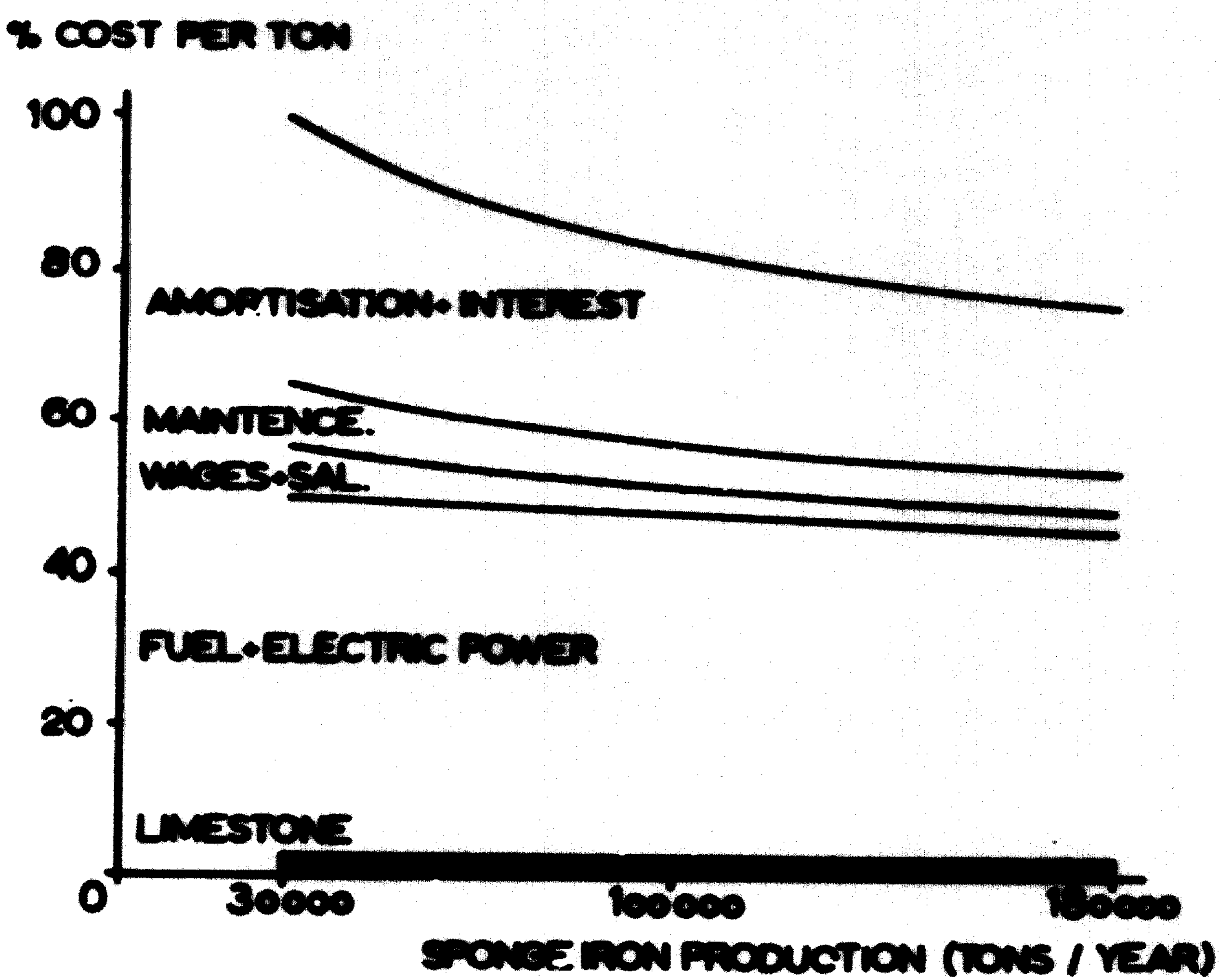




TEMPERATURE PROFILE (TEST 1-140 HR. APRIL 30/62)

FIG.2





OPERATING COSTS FOR SL-SPONGE IRON PRODUCTION

FIG. 3

4. 4.74