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Report from Pig Iron Smelting Tests at S. Norway for Canadian Javelin Ltd. Javelin Iron Prospect, Wabush Lake, Labrador

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REPORT

from

PIG IRON SMELTING TESTS

at

FISKAA VERK - KRISTIANSAND S., NORWAY

for

CANADIAN JAVELIN LIMITED

JULIAN IRON PROJECT

WABUSH LAKE - LABRADOR - NEWFOUNDLAND

by

ELEKTROKEMISK A/S, OSLO, NORWAY

February 1962.

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Elektrokemisk As

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I. INTRODUCTION

At the request of Canadian Javelin Limited, in connection with the development of their Julian ore body, Elektrokemisk A/S have run smelting tests at their Research Station at Fiskaa Verk, Kristiansand S., between February 12th and 24th, 1962.

Present during the tests was the following group of visitors:

Mr. W.H. Roxburgh, Vice President Engineering, Canadian Javelin Limited

Mr. Fred Gover, Deputy Minister of Mines, Province of Newfoundland

Mr. William Dailey, Pickands Mather & Co.

Dr. R. R. Rogers, Department of Mines and Technical Surveys, Ottawa

Mr. D.A. Sutch, President, Ramseyer & Miller, New York

Mr. Gregg M. Moga, Consulting Engineer, New York

The purpose of the tests has been to ascertain the behaviour and suitability of the Julian-Wabush concentrate and coking coal for pig iron production with pelletized charge prereduced in shaft, and to provide the basis for estimating power and raw material consumptions.

II. THE PROCESS

The conventional way of pig iron production is agglomeration of a concentrate by sintering followed by reduction and smelting in blast furnace or electric furnace. In the separate sintering plant the ore is heated to incipient fusion and thereafter discharged cold for screening and transportation.

In the new ELKEM process used for the present Javelin tests, the pelletized charge is baked and prereduced simultaneously in a simple shaft directly above the electric furnace which receives the hot, partly reduced pellets. This new technique simplifies the agglomeration plant by removal of complicated heat treating equipment. The charge is conditioned for the electric furnace smelting resulting in considerably reduced power requirement and higher pig iron production.

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Pelletization of iron ore concentrate with coal and Portland cement as binders, prereduction in shaft and electric smelting, has been developed in the ELKEM Research Station at Fiskaa during the last five years. The raw pellets are produced on disc by the same technique as used in ore pelletizing. The raw, soft pellets are hardened first by three to five days' storage for development of the hydraulic binding power of the Portland cement. The air-hardened pellets are sufficiently strong for transport and handling within the plant limits.

Batches of the charge are prepared from pellets, coke and fluxes and transported to the top of a simple shaft above the electric furnace. In the shaft the charge is heated countercurrently in a stream of hot gases to between 1400 and 1650°F. Hereby the pellets are baked hard by carbonization of the coal forming a strong carbon bond in the pellets. The hydro-carbons and hydrogen in the coal are distilled and between 10 to 30% of the oxygen in the iron ore removed from the pellets in the shaft (prereduction).

The red-hot pellets are discharged continuously and fed directly to the electric furnace below.

Due to the intimate contact between ore and coke and the shape and size of the pellets, these make a porous, reactive charge with excellent smelting properties. Despite the low stock height in the electric furnace the CO_2 content in the furnace reaction gas is high. This indicates high proportion of "indirect reduction" - as in the blast furnace.

For heating the shaft light fuel oil was used in the pilot plant test, while $CO + CO_2$ gas from the electric furnace will be used for commercial installations. The gas for heating is produced in a separate combustion chamber adjacent to the shaft. The air supply is automatically controlled to maintain excess of $CO + H_2$. Part of the top gas from the shaft is recirculated to the combustion chamber to increase the volume and sensible heat in the gas stream. The CO available in the electric furnace gas is sufficient for heating the recycled shaft-furnace gas as well as the pellets in the shafts.

The heat transfer from gas to the pellet charge is fast and efficient because only about 4 to 5 ft. charge bed thickness is required in the shaft.

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III. SUMMARY

The concentrate, Nova Scotia coal and 3% and 5% cement, have given pellets with satisfactory mechanical strength in the three different states - raw, hardened and prereduced.

No special operational difficulties were encountered during the tests. Operation of shaft as well of electric furnace was continuous and smooth. The average power consumption for each smelting period varied between 1070 and 1340 kWh per ton (x) of pig iron. The Fix C consumption was from 532 to 572 lbs with hot charging. The carbon content in the pig iron was low and the sulfur content high in Periods 1 to 5, where the slag had a basicity between 1.19 to 1.27. With higher basicity in the slag (1.43 to 1.55), the carbon content was increased and the desulfurization improved to what is considered normal for pilot plant scale smelting conditions.

By using coke and coal with normal or low sulfur content (like the Pocahontas coal), pig iron with low sulfur content has been produced in previous smelting tests from sinter and from ore/coal pellets. Data from these tests are reported in Appendices 13 and 14.

IV. MODEL THEORY

The electric furnace used for these tests has been built as a model of a smelting crater in an ELKEM furnace by application of dimensional analyses and theory of models. On a small scale, smelting zones and heat balance of large commercial furnaces are reproduced. Power consumption per ton of pig iron is in conformity with average consumption figures for large furnaces operated with the same raw materials.

(x) American units are used in this report.
All tons are net tons.

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The metallurgical conditions are, however, not completely reproduced in the model furnace. Due to the short retention time for the charge in the furnace the carburization and desulfurization are less complete than in the large commercial furnaces. Reactions which are governed kinetically by diffusion, or the like, will not run to equilibrium.

Appendix 1 shows one photograph of the electric furnace seen from the charging deck, and one photograph of the shaft and electric furnace system.

V. THE FURNACE SYSTEM

The electric furnace used during the tests (F-7) is a single-phase furnace with one central electrode and hearth contact. The furnace transformer is rated 2000 kVA and has secondary voltage steps from 35 to 80 V.

Light fuel oil is burnt with air in a separate combustion chamber. The hot combustion gases are cooled to the desired temperature by re-circulation of cold and cleaned gas from the top of the shaft. The recircu-lated gas contains volatiles from the coal in the pellets, which generate heat in the combustion chamber.

The gas mixture is introduced into the charge under inverted "V" - shaped roofs. The excess gas from the top of the shaft is, after cleaning, vented from the system.

From the shaft the charge is fed continuously into the electric furnace through two steel feed pipes.

VI. RAW MATERIALS

Appendix 2 a contains a table of chemical analyses of the raw materials used in the smelting tests, and Appendix 2 b presents sieve analyses of the coke qualities used.

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A. Iron Concentrate.

On November 6th, 1961, our Research Laboratory received samples of concentrates from Wabush Lake and Julian. The two samples were examined and tested separately.

Pellets were prepared in the laboratory from concentrates, Nova Scotia coal and Portland cement as binder. The pellets were tested thoroughly for mechanical strength and heated to different temperatures for determination of oxygen removal and strength at different temperatures (Lab. Report No. 2734). According to the test results there is practically no difference in rate of reduction or mechanical strength of the pellets prepared from the Wabush and Julian concentrates. There is an essential similarity between the two concentrates for prereduction and smelting purposes.

About 145 tons of concentrate were received for the tests. This is a high-grade concentrate of specular hematite. The concentrate was dried and ground to a suitable fineness prior to pelletization together with coal and cement in a ball mill.

B. Coal.

About 47 tons of Nova Scotia coal were received for the tests. This is a strongly baking coking-type coal which is favourable for the strength of the pellets, but the sulfur content is very high. Despite its excellent coking properties, therefore, a medium or low sulfur coal would have been a more desirable type of coal for the process. All the Fix C used in the produced pellets was from Nova Scotia coal.

C. Coke and Fluxes.

As additional reductants were used the 3/8" - 1" fraction of Irish gas coke (Coke 1) and the 3/16" - 1" fraction of English coke (Coke 2). Coke, limestone, dolomite, quartz and bauxite were drawn from Fiskaa's stock. The fluxes were all screened in the fraction 3/16" - 1".

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VII. OPERATION

A. Pelletizing.

Concentrate, Nova Scotia coal and Portland cement were weighed up in batches and charged to a ball mill. After grinding this mixture averaged 73% minus 200 US mesh with a specific surface of about 17000 sq.in./cu.in.

This ground mixture was pelletized on a 5 feet diameter disc pelletizer. Two types of pellets were produced:

	Fix C lbs per ton	% Cement	Quantity tons	Used in Periods
Type I pellets	340	5	110	1 to 6
" II "	244	3	32	7 and 8

The production of these pellets presented no difficulties. The production from the disc pelletizer was 2400 lbs of green pellets per effective hour. The size of the pellets was 5/8" to 1" diameter. Laboratory results from tests with green and hardened pellets from this production are given in Laboratory Report No. 2790. (Appendix 12).

B. Smelting Tests.

The smelting tests comprised smelting of cold pellets, Type I, smelting of same type pellets preheated and prereduced, and at the end of the tests, smelting of preheated and prereduced pellets of Type II. The charge was weighed up in batches, mixed and fed periodically to the shaft furnace. From the shaft the charge was fed continuously into the electric furnace. The furnace was tapped with two hours intervals. Pig iron and slag were tapped in a ladle with slag overflow to a slag pan. Remaining slag in the ladle was skimmed off, and the metal poured in the mould bed. Pig iron from each tapping was weighed separately. All consumption figures are based on weighed pig iron.

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1. Cold charge - Periods 1 and 2.

The first 2½ days, p llets were smelted cold in closed furnace. The voltage applied was 66 - 75 V, and the furnace load averaged 347 - 357 kW.

2. Preheated charge - Periods 3 to 8.

The rest of the raw materials was used for operation with preheated charge. The pellet charge was preheated in the shaft furnace to 1420 - 1535°F. The voltage applied averaged 46 - 52 volts, and the furnace load was 307 - 389 kW.

VIII. RECORDS FROM OPERATION

The operator on the furnace platform made hourly notes of the kWh-meter reading, kW-load, voltage, electrode current and the charge fed to the furnace system, on the furnace log sheet. The shaft furnace operator made notes every half hour of temperatures, gas volume and oil consumption in the shaft furnace system. From these data and from the weighed iron, and from chemical analyses, the average results from each smelting period have been calculated and recorded in Appendix 3.

IX. RESULTS

The most important operating data and results are shown in the Summary of Log Sheets in Appendix 3.

More complete analyses of metal and slag are given in Appendix 4.

Chemical analyses and strength properties of preheated and prereduced charge are shown in Appendix 5. These include iron analyses at the different stages of oxidation together with calculated degree of oxidation, crushing strength and drop strength of the pellets. For the limestone and dolomite in the charge the degree of calcination has been determined.

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In Appendix 6 is presented data for the shaft furnace operation.

In Appendix 7 is shown gas analyses from the electric furnace and from the shaft furnace.

In Appendix 8 is presented sieve analysis, chemical analyses and approximate weight of sludge from the shaft furnace gas cleaning system.

In the following a short description of the different periods will be given:

Periods 1 and 2.

These two periods constitute the campaign with cold charge. The charge composition was as follows:

	lbs	Moisture %
Pellets	220	9
Coke 1, 3/8"-1"	17.5 - 15.5 - 13	6
Dolomite	11	
Limestone	6.5 - 4.5	
Quartz	6.5	
Bauxite	2	

The calculated slag weight for these periods was 600 lbs per ton.

Period 1 began after tapping No. 6, thus omitting the first few hours of operation in which filling up and heating up of the system was accomplished.

The furnace operation was good.

Coke addition to the charge was decreased successively. Towards the end of Period 2 some coke was added directly into the electric furnace to stabilize the operation. Limestone in the charge was decreased and some quartz was added to the furnace. The average silicon contents in the metal were 2.62 and 1.93 in Periods 1 and 2, respectively. Power consumptions were 1805 and 1820 kWh per ton.

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Adjusted to 1% Si in the metal with a correction factor of 90 kWh per 1 % increase in silicon content, the power consumptions were 1660 and 1735 kWh per ton respectively. The Fix C consumptions in these periods were 584 and 599 lbs per ton.

Periods 3 and 4.

In these two periods (the rest of the first week) the charge was preheated in the shaft furnace.

The charge composition was:

	lbs	Moisture %
Pellets	283	9
Coke 1, 3/8" - 1"	15.5 - 17.5 - 20	6
Dolomite	15.5	
Limestone	6.5 - 9	
Quartz	9	
Bauxite	2	

The size of the batches was increased, and the calculated slag weight was 610 lbs per ton, which is slightly higher than in the previous periods. Addition of limestone was adjusted to increase the basicity of the slag.

Period 3 was the starting up period on preheated charge, and the power consumption decreased towards the end of this period. The furnace operation was satisfactory. Also in Period 4 the operation was smooth and stable. In both periods some extra coke was addded to the furnace to adjust the reduction.

The preheating temperature was 1535°F, and the percent reduction of the pellets as they entered the furnace was 26.9 %. The power consumptions in Periods 3 and 4 were 1195 and 1110 kWh respectively, and the corresponding figures adjusted to 1% Si were 1155 and 1070. The Fix C consumption dropped to 572 and 557 lbs, respectively. Operation of the shaft furnace was very stable and without any difficulties.

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Period 5.

	lbs	Moisture %
Charge:		
Pellets	283	9
Coke 1, 3/8" - 1"	15.5 - 0	6
Coke 2, 3/16" - 1"	0 - 15.5	20
Dolomite	15.5	
Limestone	17.5 - 20	
Quartz	9 - 11	
Bauxite	6.5	

The charge composition in this period corresponds to a slag weight of 760 lbs per ton. The basicity is also increased compared with the previous periods. In the middle of this period Coke 1 was replaced by Coke 2.

The furnace operation was smooth and stable with shaft preheating temperature of 1435°F. Observed and adjusted power consumption was 1240 and 1210 kWh, respectively and the Fix C consumption was 532 lbs.

Period 6.

This is a short period with the remaining pellets with 340 lbs Fix C and 5% cement.

	lbs	Moisture %
Charge:		
Pellets	283	9
Coke 2, 3/16" - 1"	17.5	22
Dolomite	37.5	
Limestone	26.5	
Quartz	20	
Bauxite	11	

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Theoretical slag weight was raised to 1200 lbs and the basicity further increased to improve sulfur removal from the pig iron.

Furnace operation was satisfactory. Some extra coke was added directly to the furnace to adjust reduction.

Operation of the shaft furnace was stable. The average sample from Periods 5 and 6 shows a percent of reduction of the preheated charge of 19.1 %. Preheating temperature in Period 6 was 1490°F.

Observed and adjusted power consumption was 1320 and 1275 kWh. This period was too short to give reliable figure for Fix C consumption.

Periods 7 and 8.

In these periods the Type II pellets with 244 lbs Fix C and 3% cement as binder were smelted.

	lbs	Moisture %
Charge:		
Pellets	264	9
Coke 1, 3/8" - 1"	26.5 - 28.5 - 13	6
Coke 2, 3/16" - 1"	0 - 0 - 15.5	20
Dolomite	22	
Limestone	17.5	
Quartz	10	
Bauxite	6.5	

Calculated slag weight was 700 lbs per ton, and the basicity about the same as in the previous period. To begin with only Coke 2 was used as reductant. From the middle of Period 7, however, approximately half of the reductant was Coke 1.

Operation of the shaft as well as electric furnace was steady. The average sample from these periods shows a percent of reduction of 18.1 %, and the preheating temperatures were 1435 and 1420°F.

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Observed and adjusted power consumption was 1355 and 1315 kWh in Period 7, and 1435 and 1340 kWh in Period 8. The Fix C consumption was 559 and 572 lbs, respectively.

X. DISCUSSION OF RESULTS

A. Operation.

1. The shaft furnace.

Operation of the shaft furnace was stable and presented no difficulties. No bridging or hanging of the charge occurred. In Periods 3 and 4 the temperature of the gas going into the shaft was 1785 and 1805°F, and the charge temperature and percent reduction was 1535°F and 26.9%, respectively.

In Periods 5 - 8 the gas temperature was decreased to 1605 - 1635°F, which decreased the charge temperature to 1420 - 1490°F, while the percent reduction of the preheated charge decreased to 19.1% - 18.1%.

Exit gas temperature varied between 255 and 285°F.

The mechanical strength of the preheated pellets was satisfactory.

2. The electric furnace.

Operation of the electric furnace was smooth throughout the tests. The electrical resistance of the cold pellet charge was extraordinary high, approximately 60% higher than previously obtained on cold sinter charge. The electrical resistance of the charge in the Periods 3 - 6 was normal. In Periods 7 and 8 with less cement and less coal in the pellets, the electrical resistance of the charge. decreased somewhat.

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B. Power and Carbon Consumption.

The power consumption on cold charge based on 1% Si in the iron was 1660 and 1735 kWh per ton in Periods 1 and 2, respectively. These figures are lower than previously obtained on cold charge and indicate high reactivity of the raw materials.

The Fix C consumption for cold operation was 584 - 599 lbs per ton, which is normal for reactive raw materials.

On preheated pellets with 340 lbs Fix C per ton iron and 5% cement, the power consumption with slag weight 610 lbs and basicity 1.15 - 1.18 was decreased to 1155 and 1070 kWh. In Periods 5 and 6 the slag weight was increased to 760 and 1200 lbs, and the corresponding basicities were 1.27 and 1.51. These changes caused a rise in the power consumption to 1210 and 1275 kWh. In Periods 7 and 8 preheated pellets with 244 lbs Fix C and 3% cement were smelted. With 700 lbs of slag and basicities 1.43 and 1.55 the corresponding power consumption was 1315 and 1340 kWh.

The Fix C consumption for preheated charge varied between 532 and 572 lbs per ton, as normal for good raw materials.

Appendix 9 contains calculations of the power consumption in the electric furnace based on the actual analyses of preheated charge, furnace gas and metal and slag. The calculated power consumption in Periods 3 and 4 is 1110 kWh, which corresponds very well with the actually observed figures for these periods, which are 1195 and 1110 kWh. The lower figure for Period 4 is the most representative, as the beginning of Period 3 includes partial heating up of the whole system during the change-over from cold to preheated charge.

The theoretically calculated average power consumption in Periods 7 and 8 is 1310 kWh while the actual figures are 1355 and 1435 kWh. Thus the theoretical calculations account for 200 kWh per ton increase in power consumption from Periods 3 and 4 to Periods 7 and 8, while the actual increase is a little higher.

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The operation in Periods 7 and 8 with somewhat lower electrical resistance and CO_2-content in the gas indicates that the furnace did not operate quite as well on the pellets low in carbon. Previous experience has also proved that a high content of the Fix C in the pellets is advantageous.

C. Electrode Consumption.

The electrode consumption is normally a function of the quality of reducing agent, the power consumption and the smoothness of operation. The electrode consumption on cold charge was 12.4 and 17.6 lbs per ton, which is about the same as previously obtained on cold sinter charge. The electrode consumption on preheated charge is decreased to 6.2 - 9.4 lbs, which is normal for preheated pellet charge.

D. Metallurgical Results.

The sulfur content in the first five periods varied between 0.38 and 0.49 % and the sulfur distribution ratios defines as

$$\frac{\%\text{ sulfur in the slag}}{\%\text{ sulfur in metal}}$$

for the same periods were 1.8 - 3.6. The slag basicities were 1.12 - 1.27.

In Period 5 the slag weight was increased to 1200 lbs per ton and the basicity to 1.51. This caused an increase in the sulfur distribution ratio to 5.6 and % S in the metal was 0.23.

In Periods 7 and 8 less sulfur was introduced into the charge. The basicity was 1.43 and 1.55 and the slag weight 700 lbs per ton. Sulfur distribution ratio was 4.8 in Period 7 and 12.2 in Period 8. Sulfur content in the metal was 0.21 and 0.12, respectively.

It is known from previous experience that desulfurization is not complete in the model furnace. Based on previous results when smelting sinter, 3 - 5 times higher sulfur distribution ratio is expected in a large furnace than in our model furnace.

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The high sulfur content in pig iron from this test is inherent with the very high percentage of sulfur in the Nova Scotia coal (2.85%). As we have previously operated the pilot plant with normal sulfur level for sintered concentrates and coke, the results from test with "Mo i Rana charge" have been included in this report (Appendix 13). Results from tests with pellets produced from hematite and low sulfur Pocahontas coal have been compiled in Appendix 14.

The analytical data for pig iron produced with coke and coal with variable sulfur content in the pilot tests prove that carburization and desulfurization of the pig iron depends on the sulfur content in the charge. Previous results in the model furnace indicate that satisfactory carburization is obtained only when the sulfur content is low.

E. Recovery of Iron.

Based on the analyses of metal and slag, and on analyses and quantities of charged materials, the recovery of iron in metal and slag was 96.2 % in Periods 3 and 4, and 96.5% in Periods 7 and 8. Of the lost iron, 2.0 % is found in the sludge from the shaft furnace gas cleaning system, while the rest is losses not accounted for.

F. Heat Economy of the Preheating Process.

During the tests the consumption of light fuel oil with 18000 B.t.u. per lb was 126 lbs per ton in Period 3, which is a starting-up period.

In Period 4 this consumption fell to 96 lbs, and in Periods 5 and 6 the preheating temperature and degree of prereduction were lower. The oil consumption decreased to about 90 lbs. In Periods 7 and 8 with less coal in the pellets, the oil consumption increased to about 107 lbs. In commercial operation the heat losses will be lower and the additional fuel could conveniently be in the form of furnace gas.

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Appendix 10 shows the heat- and gas balance for commercially sized shafts, based on Pocahontas coal in the pellets. Even with these low-volatile coals, the CO gas from the electric furnace will provide sufficient additional heat of combustion for the shaft process.

XI. CONCLUSIONS AND RECOMMENDATIONS

The tests at Elektrokemisk's Research Station for Canadian Javelin Limited have demonstrated the feasibility of pelletizing the ground concentrate with coking coal and cement, hardening the pellets by storage, preheating and prereduction in shafts, followed by submerged arc smelting. The mechanical strength of the pellets was satisfactory at all process stages.

The hardened pellets were first smelted without shaft preheating in the conventional way. This gave smooth operation and lower power consumption than ever obtained previously in the Research Station on cold charge. Probably due to the inclusion of raw coal in the pellets, the electrical resistance was exceptionally high.

With preheated and prereduced charge the smelting was smooth with normal electrode penetration and electrical conditions in the furnace.

As for commercial smelting, the power consumption varied with slag basicity and quantity of slag, actually between 1070 and 1340 kWh. The Fix C consumption with hot charge varied within the range 532 to 572 lbs per net ton of pig iron.

With regard to the chemistry of the process the high CO_2-content of the electric furnace gas, approximately 40%, is remarkable. Obviously the pelletized charge when preheated, established favourable conditions for indirect reduction in the electric furnace.

Full carburization of the pig iron within the normal range 3.5 - 4 % C was not obtained during the tests except for the last smelting period. Low carbon content in pig iron has occurred also in previous smelting campaigns, particularly in connection with high sulfur content in the charge. In these tests the Nova Scotia coal

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containing 2.85 % S added a high amount of sulfur to the electric furnace charge.

The normal sulfur level in the charge for commercial operation in Europe is equivalent to 1.0% S in the coke and the coke consumption of 800 lbs dry coke. Every attempt should be made to obtain raw materials of equivalent quality for the Julian operation.

Conditions	Sources of Carbon	lbs S in electric furnace charge (1 ton pig)
Conventional	Gas Coke	8
Javelin Smelting Tests	Nova Scotia Coal + Gas Coke	Period 1-6 14.3 " 7-8 12.7
Javelin Project Proposal	Pocahontas Coal + DOSCO Coke	6.2

Previous tests with smelting of pellets prepared from hematite and Pocahontas coal have given what we consider a normal carburization and desulfurization in our pilot furnace. Specifically, we refer to Appendix 14 which gives the test results and analytical data from the previous test.

We conclude, therefore, that no problems will be encountered on large scale with C-content or S-content in the pig iron when using Pocahontas coal and DOSCO coke. A mixture of Pocahontas coal and Nova Scotia coal may be used for the pellets. However, for obtaining a specified, low sulfur content in the pig iron, more fluxes and higher pow . consumptions will be required with a higher sulfur level in the charge. The choice of type of coal, therefore, is not only a technical question, but mainly a question of economy. For the present planning and estimating of the cost of operation we recommend the following consumption figures, confer the material balance calculations, Appendix 11.

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	Per ton pig lbs
Ore concentrate (64.5% Fe)	2950
Pocahontas coal	470
DOSCO coke	270
Limestone	170
Dolomite	240
Bauxite	55
Cement	105

It is recommended adding to these calculated figures 2 % to cover unaccountable losses.

Electrode consumption 10 lbs.

Power consumption 1200 kWh.

Available furnace gas 9.600 cu.ft. at NTP containing approximately 58/42 CO/CO_2.

The CO available in the electric furnace gas is sufficient for heating the recycled shaft furnace gas and the pellets in the shaft furnaces.

Expected analyses of iron and slag, when using the charge recommended above in a commercial electric furnace smelting operation, are given below:

Iron	%	Slag	%
C	4	SiO_2	35
Si	1	Al_2O_3	13
S	0.04	CaO	41
		MgO	9
		FeO	1.0
		S	0.88

Kristiansand S./Oslo, March 22nd, 1962.

T. Båsen
Chief
Elektrokemisk's Research Station

F. C. Collin
Director of Research

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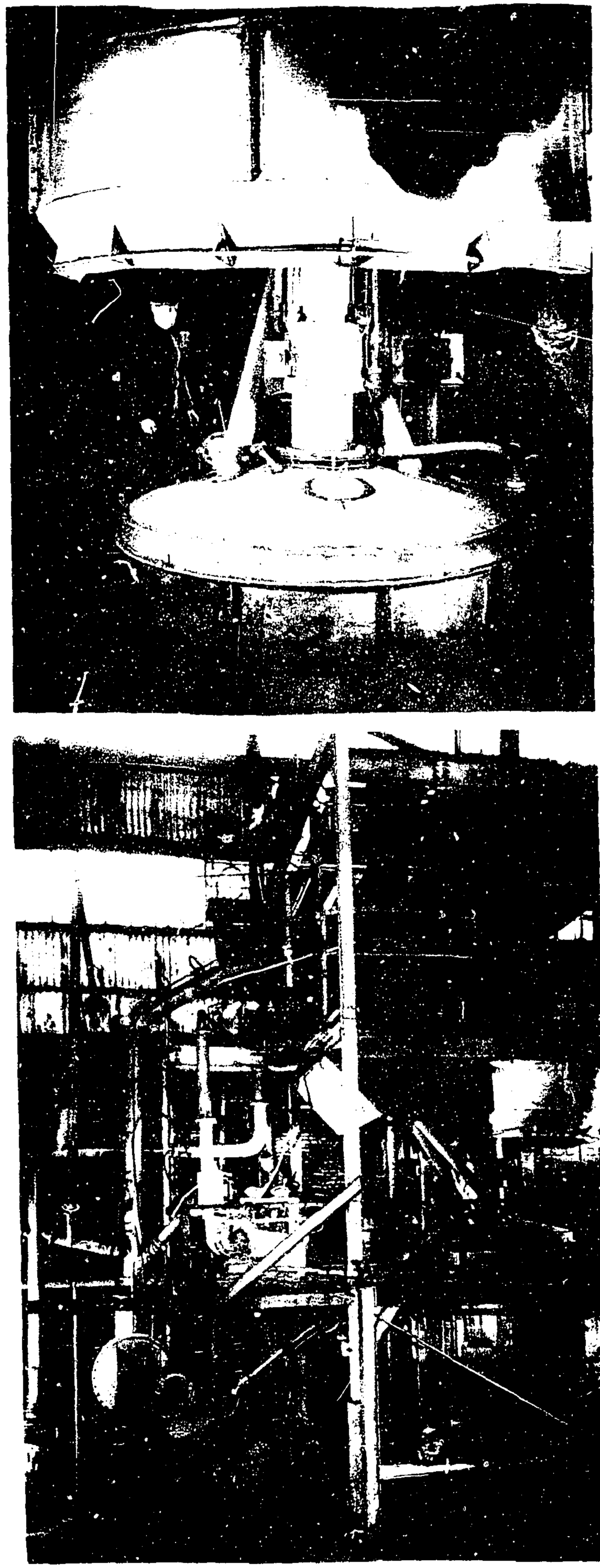
Exhibit 1

Appendix 1.



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Chemical analyses of raw materials.

Material	Analyses, dry basis.									
Ore and fluxing materials	% SiO_2	% Fe_2O_3	% $Fe_{(tot)}$	% Fe^{2+}	% Al_2O_3	% CaO	% MgO	% S	% P	Ign. loss
Canadian Javelin ore	3.10		66.3	0.2	0.73	0.17	0.57	0.02	0.024	
Limestone	5.01	1.15			1.7	48.5	1.12			40.7
Dolomite	4,46		0.24			30.6	16.7			44.5
Quartz	98.44	.			0.62					
Bauxite	1.7	23.9			60.2					
Portland cement	22				7	66				

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Chemical Analyses of Raw Materials.

Material	Analyses, dry basis.				
Reducing Agents	Volatiles %	Ash %	Fix C %	S %	Reactivity
Nova Scotia coal	31.1	8.75	60.1	2.85	0.96
Coke 1, 3/8" - 1"	3.5	13.0	83.5	1.33	1.52
Coke 2, 3/16" - 1"	3.75	11.9	84.35	1.14	1.10

Ash Analyses

	% SiO_2	% Fe_2O_3	% Al_2O_3	% CaO	% MgO
Nova Scotia coal	34.1	32.5	18.0	3.93	1.04
Coke 1, 3/8" - 1") Coke 2, 3/16" - 1")	45	15	25	3)	Approximate analyses

Comparison table for reactivity of reducing agents.

Reactivity range	Reducing power	Typical materials
0.1 - 0.3	Poor	Metallurgical coke
0.3 - 0.7	Medium	Anthracite, gas coke
0.7 - 1.0	Good	Low temperature coke
1.0 - 2.0	"	Special cokes
> 2.0	"	Chars

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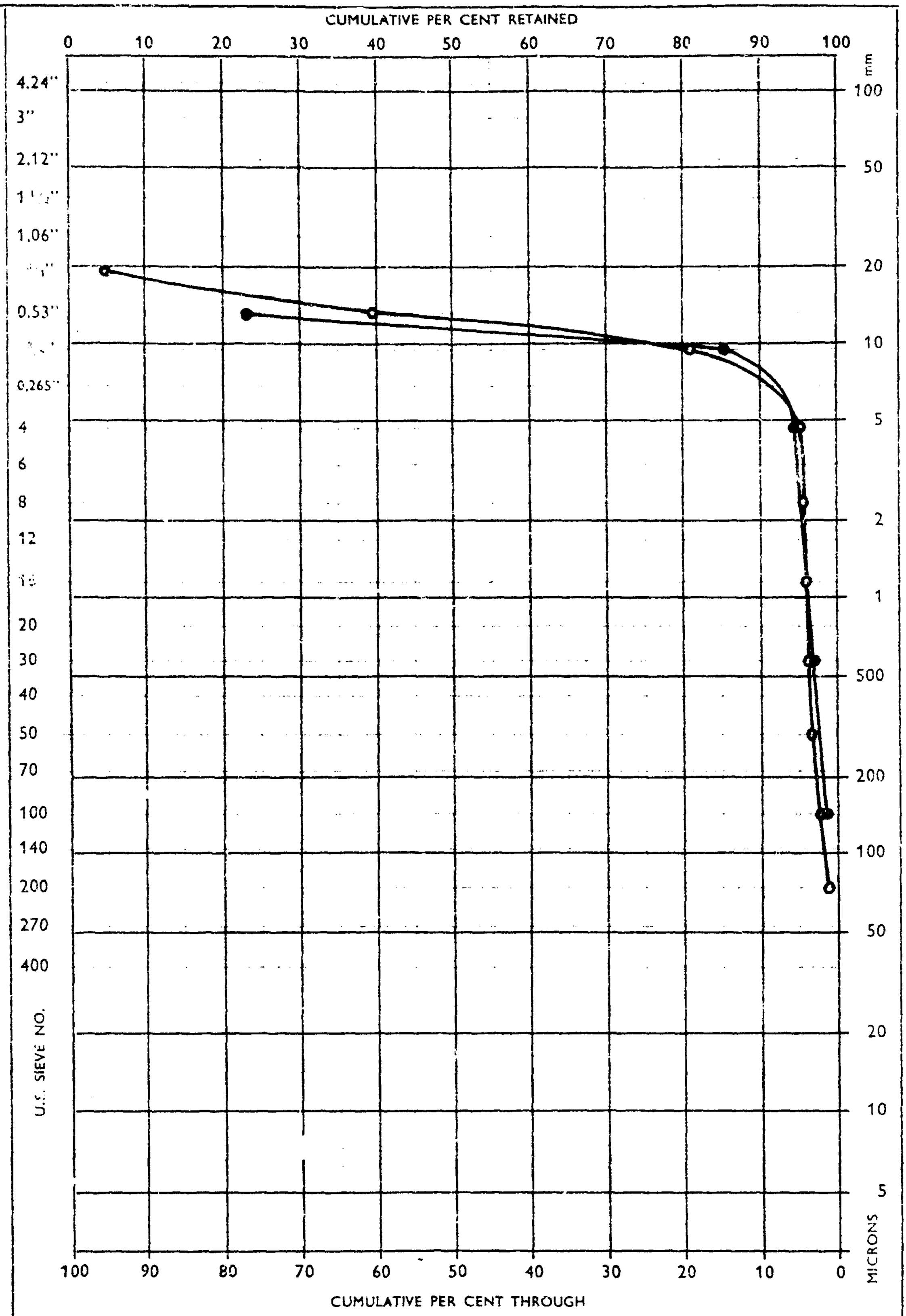

Appendix 2b. **SIEVE ANALYSIS**

SAMPLE: *Reducing agents.*

SAMPLE NO.
- ○ *Coke 1*
- ● *Coke 2*

ELEKTROKEMISK A/S
OSLO — NORWAY

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SUMMARY OF LOG SHEETS

Smelting test for Canadian Javelin Limited, 12 - 23 February 1962.

Period no.	Date	Time	Duration hrs.	Raw materials in lbs., dry basis.							Electrical data			Production			Consumption figures pr. nt. ton of pig iron					Analyses						Shaft	
																						Metal			Slag				
				Pellets	Coke 1 3/8" -1"	Coke 2 3/4" -1"	Dolomite	Limestone	Quartz	Bauxite	V	kW	kWh	Tapping no.	Metal lbs.	Slag [1] lbs/nt.ton met.	kWh uncorr.	kWh corr. to 1% Si	Electrode lbs.	Fix C lbs.	Fix C in pellets lbs/nt.ton met.	% Si	% C	% S	% FeO	$\frac{CaO+MgO}{SiO_2}$	$\frac{S_{slag}}{S_{Metal}}$	Preheating temp., °F	Degree of oxidation
1	12/2 13/2	22.30 20.25	21,9	16071	1219		883	439	737	82	75	357	7810	7-17	8664	600	1805	1660	17,6	584	340	2,62	2,09	0,38	1,15	1,19	3,6		
2	13/2 15/2	20.25 14.25	42,0	30735	2298		1689	675	1247	338	86	347	14570	18-38	16046		1820	1735	12,4	599	340	1,93	1,91	0,49	3,08	1,12	2,0		
3	15/2 16/2	14.25 13.50	23,4	26717	1623		1545	662	890	221	48	344	8050	39-50	13514	610	1195	1155	9,4	572	340	1,45	1,98	0,49	2,84	1,15	1,9	1535	73,1
4	16/2 17/2	13.50 18.50	29,0	32863	2397		1901	1066	1086	272	46	350	10140	51-65	18274		1110	1070	8,4	557	340	1,42	2,05	0,41	2,30	1,18	2,7	1535	
5	20/2 21/2	05.30 17.18	35,8	31528	567	1519	1823	2272	1316	781	48	307	10980	73-89	17733	760	1240	1210	9,4	532	340	1,32	2,10	0,48	3,28	1,27	1,8	1435	80,9
6	21/2 22/2	17.18 05.25	12,1	12826		980	1801	1272	954	530	52	357	4320	90-95	6550	1200	1320	1275			340	1,50	2,59	0,23	0,96	1,51	5,6	1490	
7	22/2 23/2	05.25 13.15	31,6	30856	1245	2161	2826	2260	1272	848	48	389	12360	96-111	18232	700	1355	1315	6,2	559	244	1,47	3,22	0,21	1,03	1,43	4,8	1435	81,9
8	23/2 24/2	13.15 09.37	20,4	17839	1157	784	1634	1307	837	490	44	358	7300	112-121	10196		1435	1340	6,4	572	244	2,05	3,46	0,12	0,67	1,55	12,2	1420	

[1] Calculated slag weight.

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Elektrokemisk A/s

Appendix 4.

Analyses of Metal and Slag.

Metal

Period	% Si	% C	% C
1	2.62	..09	0.38
2	1.93	1.91	0.49
3	1.45	1..98	0.49
4	1.42	2.05	0.41
5	1.32	2.10	0.48
6	1.50	2.59	0.23
7	1.47	3.22	0.21
8	2.05	3.46	0.12

Slag

Period	% SiO_2	% Al_2O_3 + TiO_2	% FeO	% CaO	% MgO	% S	$\frac{\text{S slag}}{\text{S metal}}$	Basicity $\frac{CaO+MgO}{SiO_2}$
1	39.54	8.61	1.15	40.3	6.72	1.38	3.6	1.19
2	38.02	12.78	3.08	35.9	6.57	0.97	2.0	1.12
3	37.80	11.71	2.84	36.4	7.22	0.95	1.9	1.15
4	37.20	11.38	2.30	37.5	6.28	1.09	2.7	1.18
5	35.66	12.73	3.28	39.6	5.86	0.88	1.8	1.27
6	33.66	12.92	0.96	41.6	9.14	1.29	5.6	1.51
7	34.20	13.28	1.03	40.2	8.80	1.01	4.8	1.43
8	32.62	13.92	0.67	41.4	9.22	1.46	12.2	1.55

SCANNED IMAGE

Elektrokemisk AS

Appendix 5.

Preheated charge from shaft.

A. Chemical analysis of preheated pellets.

Date	Period	% $Fe_{(tot)}$	% Fe^{3+}	% Fe^{2+}	% $Fe_{(met)}$	% Reduction	% S
15-17/2	3-4	53.8	10.4	43.4	0	26.9	0.49
20-22/2	5-6	46.7	20.0	26.7	0	19.1	0.42
22-24/2	7-8	45.4	20.7	24.7	0	18.1	0.37

B. Strength measurements on preheated pellets.

Period	Compression strength lbs	Drop strength inches
3-4	85.4	68.9
5-6	138.4	118.1
7-8	60.7	82.7

C. Analyses of limestone and dolomite lumps from preheated charge.

Period	$CaO_{(tot)}$	$CaO_{(burnt)}$	% Degree of calcination	% S
3-4	67.5	35.9	53.2	0.23
5-6	65.1	29.5	45.3	0.27
7-8	59.2	9.0	15.2	0.13

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Shaft furnace data.

Period	Oil lbs/ton	Gases Cu.ft./ton			Temperatures, °F			Pressure drop inches H_2O
		Air	Recycled gas	Excess gas	Gas in	Gas out	Charge	
3	126	37720	49830	41000	1785	255	1535	5.6
4	96	34330	48030	37360	1805	285	1535	5.8
5	92	35390	57530	36550	1625	255	1435	5.0
6	88	33580	49370	31470	1635	265	1490	3.4
7	106	28360	44890	28850	1605	265	1435	3.6
8	108	28570	43300	31540	1625	275	1420	3.0

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Elektrokemisk A/S

Gas Analyses.

A. Analyses of gas from Electric Furnace.

Date	Period	Time	% CO_2	% O_2	% CO	% CH_4	% H_2	Notes
13/2	1	13.10	15.0	0.8	68			
"	"	13.35	16.2	0.2	69	4.0	10.4	
"	"	13.45	17.2	0.2	69			
"	"	14.15	17.6	0.2	68			
14/2	2	12.45	22.0	0.2	63	3.8	11.0	
"	"	13.40	21.2	0.6	64			
15/2	3	15.45	42.0					
16/2	"	09.50	41.2	0.1	>55.7			
"	"	11.50	38.6					
17/2	4	10.15	44.0	0.1	>53			
20/2	5	13.30	43.4	0.2				
"	"	13.55	42.6	0.2				
21/2	"	15.35	42.7	0.2				
"	"	15.55	46.0	0.2				
22/2	7	08.35	48.6					
"	"	09.15	53.0					
"	"	15.05	49.2	2.0				
23/2	"	10.00	43.6					
"	"	10.05	42.0					
"	"	12.35	39.6					
"	8	13.15	36.6	0.4				

B. Analyses of gas from shaft furnace.

15/2		10.15	14.0	0.6	2.6	Inlet gas
"		10.55	16.2	1.4	0	"
"		11.30	17.0	0	0.8	"
"		13.00	18.0	0	0	"
"	3	15.15	16.8	0.4	3.0	"
"	"	20.55	15.0	0	6.4	"

(Cont.)

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Elektrokemisk AS

B. Analyses of gas from shaft furnace.

Date	Period	Time	% CO_2	% O_2	% CO	% CH_4	% H_2	Notes
15/2	3	21.45	17.4	0.1	0.4			Inlet gas
16/2	"	08.30	16.5	0.1	1.6			"
"	"	10.15	18.0	0.1	1.5			"
"	"	"	17.1	1.5	4.4			Outlet gas
"	"	12.5o	20.4	0.2	0.1			Inlet gas
"	"	"	19.8	0.2	7.8			Outlet gas
"	4	14.3o	18.2	0.2	1.0	0	0	Inlet gas
"	"	"	17.4	0.4	6.4	1.8	2.0	Outlet gas
17/2	"	09.40	19.8	0.2	1.0	0	1.5	Inlet gas
"	"	"	20.8	0.5	6.9	1.2	1.9	Outlet gas
19/2	"	16.25	15.1	0.3	2.6			Inlet gas
"	"	16.45	16.0	0.8	0.2			"
"	"	17.30	17.3	0.6	0.1			"
"	"	18.00	16.8	0.3	1.3			"
"	"	18.30	17.3	0.2	1.1			"
"	"	19.05	17.9	0.3	0.4			"
"	"	19.50	18.1	0.2	0.6			"
"	"	21.05	18.1	0.2	0.6			"
'	"	21.45	17.6	0.2	1.2			Inlet gas
"	"	22.30	17.8	0.3	0.5			"
20/2	5	01.00	17.0	0.3	2.7			"
"	"	01.20	17.4	0.2	1.4			"
"	"	13.10	17.6	0.2	2.2			"
"	"	13.20	20.6	0	1.0			"
"	"	13.40	19.0	0.2	0.8			"
21/2	"	01.35	16.6	0.6	0.8			"
"	"	02.30	18.6	1.0	0			"
"	"	03.00	18.4	0.6	0			"
"	"	13.25	19.0	0	0.8			"
"	"	13.40	17.6	0.6	4.0			"
22/2	7	09.05	17.2	0.2	0.4			"
"	"	09.25	17.2	0.2	1.6			"
"	"	09.50	18.1	1.5				"
"	"	13.30	15.6	0.2	1.7	0	0.6	"

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Elektrokemisk A/S.

B. Analyses of gas from shaft furnace.

Date	Period	Time	% CO_2	% O_2	% CO	% CH_4	% H_2	Notes
22/2	7	13.3o	16.6	0.3	4.1	0.8	1.6	Outlet gas
"	"	14.45	15.4	0.2	2.0			Inlet gas
"	"	"	17.8	0.2	2.2			Outlet gas
"	"	20.55	18.6	0.2	1.0			Inlet gas
23/2	"	09.30	15.5	0	3.7			"
"	"	09.50	18.3	0	0			"
"	8	14.00	17.8	0	C.8	0	0	"
"	"	"	16.9	0.3	5.1	1.5	0.5	Outlet gas

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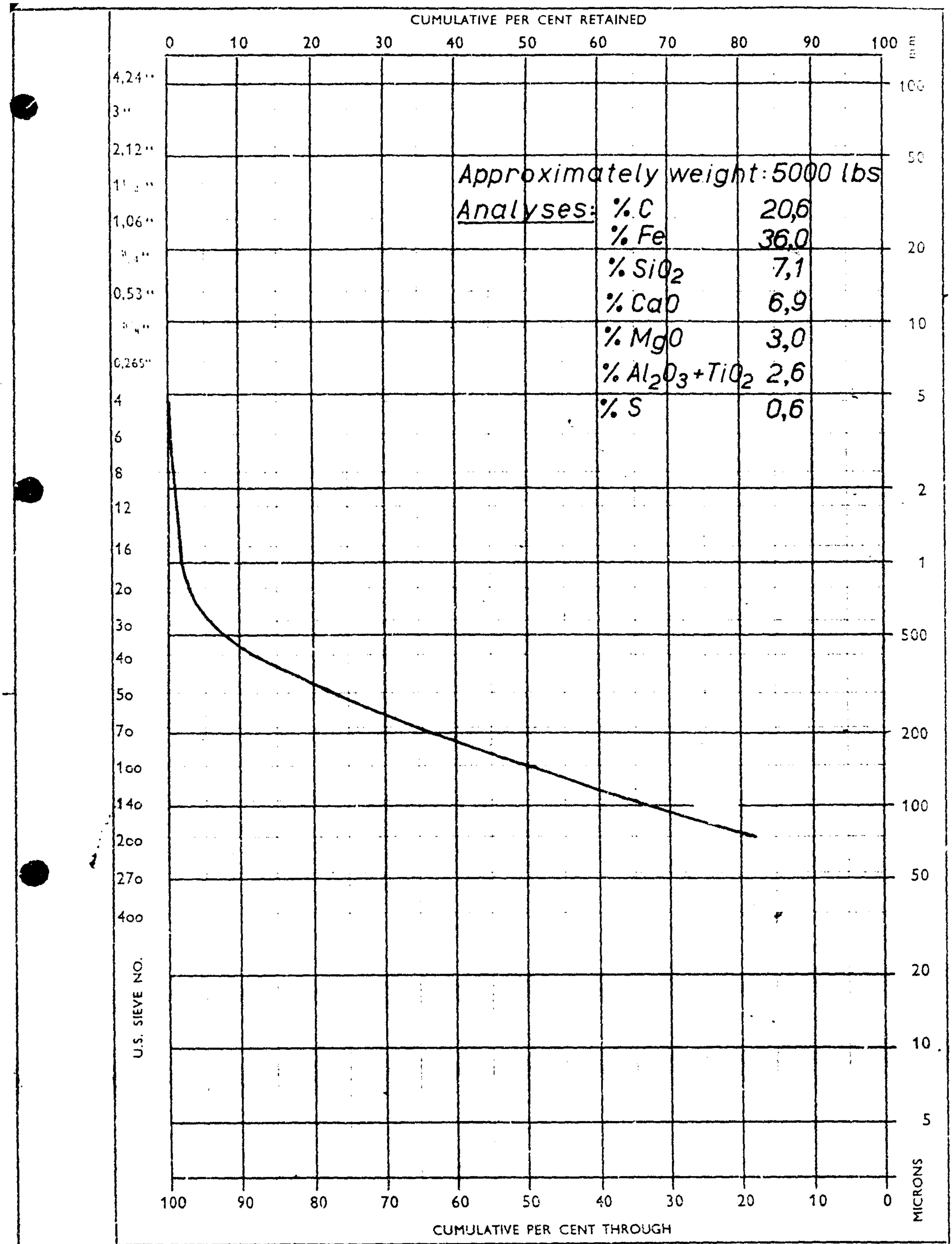

Appendix 8

SIEVE ANALYSIS

SAMPLE: Sludge from shaft furnace gas cleaning system.

SAMPLE NO.

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Appendix 9.

Theoretical Calculations of Power Consumption in Electric Furnace in Periods 3 and 4, and 7 and 8.

Assumptions:

	Per 3 and 4	Per 7 and 8
Degree of oxidation of preheated charge	73.1 %	81.9 %
Degree of calcination of limestone	53.2 %	15.2 %
Furnace gas composition, $\frac{CO_2}{CO+CO_2}$ 100%	42 %	44 %
Tapping temperature of iron, estimated	2460°F	2460°F
Tapping temperature of slag, estimated	2640°F	2640°F
Temperature of gas leaving furnace, estimated	1740°F	1650°F
Aver. silicon content in iron	1.43 %	1.68 %
" preheating temperature of charge	1535°F	1430°F
Thermal efficiency of electric furnace	78 %	78 %

Calculations:

	Per 3 and 4	Per 7 and 8
Reduction of iron oxides	1.683.000 BTU	1.984.000 BTU
" " silica	290.000 "	338.000 "
Calcination of limestone	71.000 "	245.000 "
Heat content in pig iron	1.072.000 "	1.072.000 "
" " " slag	476.000 "	540.000 "
" " " gas leaving furnace	449.000 "	522.000 "
Minus Sensible heat in preheated charge	1.092.000 "	1.217.000 "
Net heat requirement	2.949.000 BTU	3.484.000 BTU
Corrected to 78% thermal efficiency	3.781.000 BTU	4.467.000 BTU
Equivalent to	1110 kWh/t	1310 kWh/t

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Heat Balance for Shaft Furnace System.

Preheating of pellets to 1500 - 1550°F. All figures per short ton of pig iron. All volumes cubic feet NPT.

Heat requirements:

Drying of pellets and coke	480.000 BTU
Sensible heat in iron oxides	625.000 "
" " " slag	250.000 "
" " " fixed carbon	225.000 "
Calcining of dolomite and limestone	150.000 "
Reduction of Fe_2O_3 to 75% degree of oxidation	840.000 "
Sensible heat in gas formed during preheating and prereduction	45.000 "
Heat losses	75.000 "
Total heat requirements for the shaft system	2.690.000 BTU

Temperature of gas into the shafts	1800°F
" " " out of " "	400°F
Sensible heat in gas between 400 and 1800°F:	33,8 BTU per cu.ft.
Volume of gas to the shafts:	80.000 cu.ft.

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Heat Balance for Shaft Furnace System.

Volume of gas out of the shafts:

Gas to the shafts	80.000 cu.ft.
Water vapor	8.800 "
Gas from reduction	4.500 "
Volatiles distilled from coal (estimated)	1.400 "
Total	94.700 cu.ft.

Combustion chamber:

57% of the gas from the shafts is recirculated

Sensible heat in recycle gas	410.000 BTU
Combustion of volatiles and gas from reduction	1.600.000 "
" " electric furnace gas	1.290.000 * "
Total	3.300.000 BTU

* This corresponds to about 3800 cu.ft. of CO.

Gas balance:

Recycle gas	54.000 cu.ft.
Increase in volume from combustion of el. furnace gas ÷ decrease in volume - " - reduction gas	3.600 "
Air	22.400 "
Total	80.000 cu.ft.

Appendix 10
Page 2.

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Heat Balance for Shaft Furnace System.

Electric furnace gas:

Based on electric furnace gas analyses and analyses of preheated charge the production of CO and CO_2 is calculated as follows:

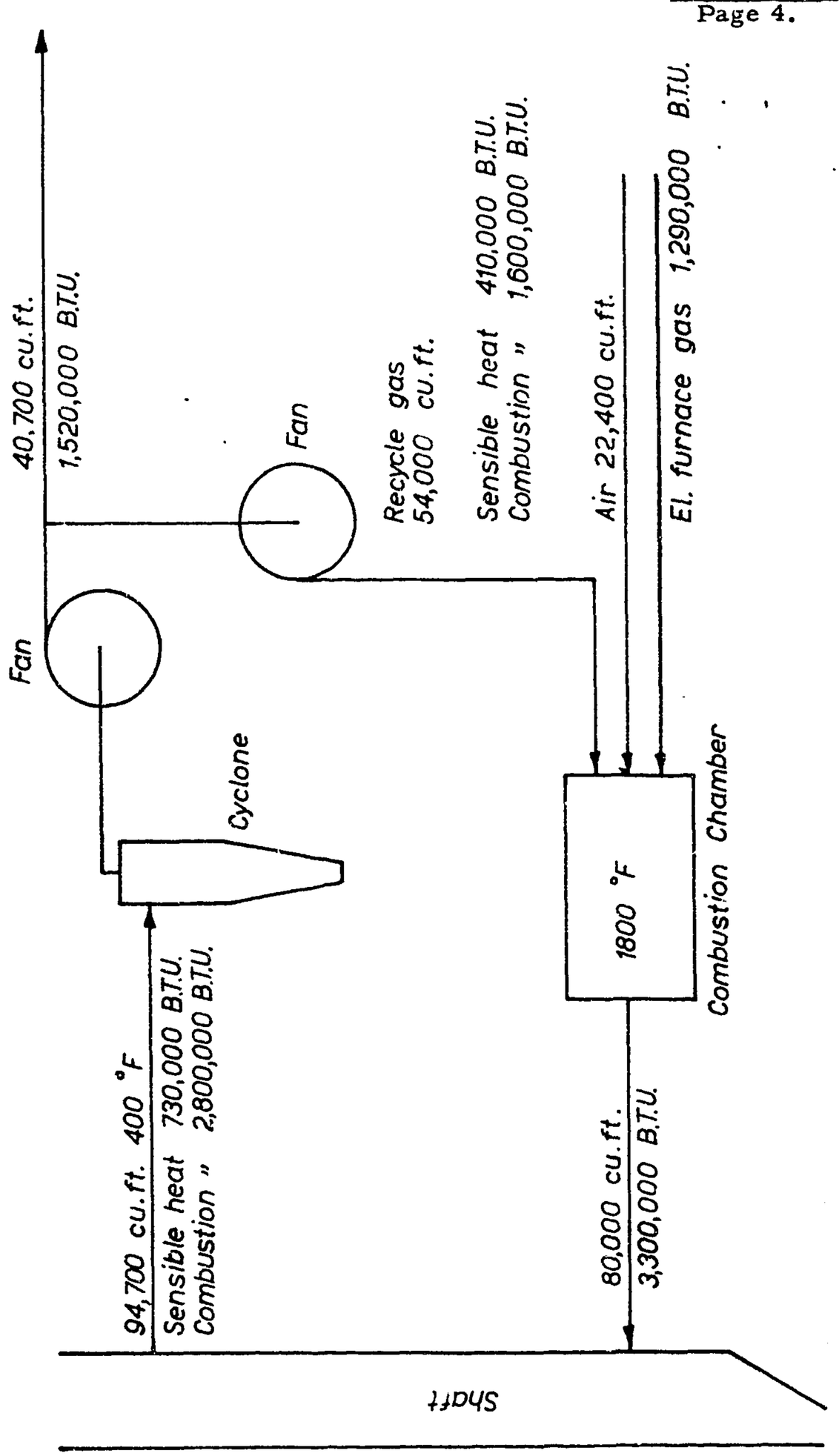
Oxygen removed from charge:

From iron oxides		611,1 lbs.
" silica		22,8 "
" limestone and dolomite		42,4 "
		676,3 lbs.
	or	7590 cu.ft.

Composition of electric furnace gas:

42% CO_2 58% CO

Volume of CO + CO_2 produced:	10.700 cu.ft.
Volume of CO produced	6.200 cu.ft.
Assuming 90% available for utilization =	
Volume of CO available	5.580 cu.ft.
Volume of CO required for preheating:	3.800 cu.ft.
Degree of utilization	61,5%



ELEKTROKEMISK A/S
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Elektrokemiske A/S

Canadian Javelin Limited

A. Basicity = 1,4

Appendix 11.

PIG IRON

MATERIAL BALANCE

Page 1.

	Marking	~~Kgs.~~ lbs.	Fe	FeO	Si	SiO_2	Al_2O_3	CaO	MgO	Mn			S	P	Fix. C
Ore sinter I	Julian	2935	1892			176	18	9	6	5			0,3		
Ore sinter II															
Ore/sinter III															
Reducing Agent I	Pocahontas coal	470											2,8		350
Reducing Agent II	DOSCO coke	270											3,0		230
Electrodes	Coal and coke ash		5			22	13	2							
Limestone		170	1			8	3	82	2						
Dolomite		240				11		73	40						
Bauxite		55	9			1	33								
Cement		105				23	7	69					0,7		
Sum			1907			241	74	235	48				6,8		580
— Fume losses +			(7)	9		5	4	9	5				1,2++		
Rest			1900			236	70	226	43				5,6		*)
— in pig iron		2000	1896		20	(43)				3			0,8		80
In slag	abt.	545	(4)	5		193	70	226	43				4,8		
SLAG %				0,9		35,7	12,9	41,6	7,9				0,88		

	Fe	Si	S	P	C	Mn
Pig iron %	94,8	1,0	0,04		4,0	0,15

*) 358 ~~kgs~~ lbs. fix. C for reduction in electric furnace

Basicity of slag = $\frac{CaO + MgO}{SiO_2}$ = 1,39

Sulphur distribution = $\frac{\%\ S \text{ in slag}}{\%\ S \text{ in pig iron}}$ = 22

+ From electric furnace only. ++ 0,6 lbs. expelled in shafts. 0,6 lbs. in fume from electric furnace

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Canadian Javelin Limited

B. Basicity = 1,6

MATERIAL BALANCE

	Marking	lbs.	Fe	FeO	Si	SiO_2	Al_2O_3	CaO	MgO	Mn			S	P	Fix. C
Ore/sinter I	Julian	2925	1887			176	18	9	6	5			0,3		
Ore/sinter II															
Ore/sinter III															
Reducing Agent I	Pocahontas coal	470											2,8		350
Reducing Agent II	DOSCO coke	270											3,0		230
Electrodes	Coal and coke ash		5			22	13	2							
Limestone		245	2			12	4	119	3						
Dolomite		250	1			11		76	42						
Bauxite		60	10			1	36								
Cement		105				23	7	69					0,7		
Sum			1905			245	78	275	51				6,8		580
— Fume losses	+		(7)	9		5	4	9	5				1,2 ++		
Rest			1898			240	74	266	46				5,6		*)
— in pig iron		2000	1896		20	(43)				3			0,4		80
In slag		590	(2)	3		197	74	266	46				5,2		
SLAG %				0,5		33,4	12,5	44,8	7,8				0,88		

	Fe	Si	S	P	C	Mn
Pig iron %	94,8	1,0	0,02		4,0	0,15

*) 358 lbs. ~~kg~~ fix. C for reduction in electric furnace.

Basicity of slag $= \frac{CaO + MgO}{SiO_2} = 1,58$

Sulphur distribution $= \frac{\%\ S \text{ in slag}}{\%\ S \text{ in pig iron}} = 44$

\+ From electric furnace only. ++ 0,6 lbs. expelled in shafts, 0,6 lbs. in fume from electric furnace.

Elektrokemisk A/S

ANALYSES OF RAW MATERIALS

	Marking	Fe_2O_3 ~~FeO~~	Fe	~~MnO₂~~ MnO	Mn	SiO_2	Al_2O_3	CaO	MgO	Ign. loss	Vol.	S	P	Fix. C	Ash	H_2O
Ore I	Julian		64,5	0,2		6,0	0,6	0,3	0,2			0,01	0,01			
Ore II																
Ore III																
Reducing Agent I	Pocahontas coal										20	0,6		75	5	
Reducing Agent II	DOSCO coke											1,1		85	10*	
Reducing Agent III	Coal and coke ash+	15				45	25	4								
Electrodes																
Limestone	Fiskaa	1,2				5,0	1,7	48,5	1,1	40,7						
Dolomite	Fiskaa	0,3				4,5		30,6	16,7	44,5						
Bauxite	Fiskaa	23,9				1,7	60,2									
Portland cement	Fiskaa					22	7	66				0,7				

* Assumed

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Elektrokemisk A/S

Appendix 12.

EXAMINATION OF RAW MATERIALS FROM CANADIAN JAVELIN LIMITED FOR SMELTING TESTS

Report No. 2790.

I. Introduction.

Samples of the raw materials from Canadian Javelin Limited for laboratory testing arrived in December 1961, while ore and coal for the smelting test arrived in January 1962. Ore and coal samples were examined and analyzed to check the quality of both shipments. Pellets including various additions of cement as a binder, were prepared and stored at different temperatures. Pellets with variable contents of reducing agents were also prepared and heat treated at temperatures from 700 to 1000°C (1292 - 1832°F), to examine their strength after baking at high temperatures.

II. Procedure.

Regarding principles and procedure in the test work we refer to our Report No. 2734, dated December 1st, 1961. We shortly repeat here that we regard the strength of the pellets at the various stages of the smelting operation to be a very important quality criterion. The strength is measured as compression strength (increasing load on a pellet until rupture) and drop strength (height from which a number of pellets can be dropped to give 50% breakage). Strength tests are made on pellets with diameter between 7/8 and 15/16 inch.

III. Results.

Analyses of the raw materials are presented in Appendix 1. The composition of the smelting test raw materials are in good conformity with that of the laboratory samples received previously.

The coking properties of the present coal also agree with the first sample, while the reactivity is a little lower.

Further, Appendix 1 presents the sieve analyses of the ore as received and the grain size of the ore and coal after milling for 90 minutes in a laboratory ball mill, expressed as the percentage - 200 #/- and as the specific surface area.

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Appendix 2 demonstrates the effect on the high temperature strength of including various amounts of reducing agent in the pellets. The effect of mixing the Nova Scotia-coal with a coal with poorer coking properties, is also demonstrated.

Appendix 3 and 4 give strength figures for pellets with 3, 4 and 5% binder, hardened at 19°C (66°F) and heat treated at temperatures from 700 to 1000°C (1292 to 1832°F). Increasing amounts of cement give increasing strength figures after storage, but have no influence on the strength at high temperatures.

The appendices 5, 6, 7 and 8 present the strength figures obtained on pellets holding 3 to 5% binder after storage at various temperatures. As seen, the rate of hardening depends on temperature, though only slightly.

Appendix 9 gives, in the form of a table, the results from hardening pellets under various temperature conditions. According to these results freezing of the pellets will stop the hardening. The pellets will, however, not be damaged, and the hardening continues when the temperature is raised again. This means that accidental freezing of the storage bins will cause no serious trouble. To get a reasonable hardening rate, the temperature will, however, have to be kept above the freezing point.

Appendix 10 demonstrates the effect of limestone additions. Pellets including limestone increase in volume and swell when heated to temperatures between 900 and 1000°C (1652 - 1832°F). The reason for this swelling is the content of chlorine in the concentrate, proably added in the form of $CaCl_2$ to prevent freezing of the ore.

Appendix 11 gives some data on the pellets produced in the disc pelletizer of the Research Station. These pellets are not so equal-sized as the pellets made in the laboratory, and for comparison of the results, we refer to the curves in Appendix 12, showing the influence of the pellet size on their strength, as determined previously in a separate examination.

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The strength of the pellets from the Research Station is satisfactory for the smelting operation.

Kristiansand, February 20, 1962.

Erik Dahl
(sign.)

ED/GH/IS.

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COMPOSITION, COKING PROPERTIES AND REACTIVITY OF RAW MATERIALS FROM CANADIAN JAVELIN LTD.

Nova Scotia - coal.

	Lab. sample, our ref. no. 7348.	Raw materials for smelting test
% moisture	2.5	2.7
% ash	5.5	8.75
% volatiles	33.4	31.1
% fixed C	61.1	60.15
Swelling index	8	8 ½
Gray King Coke index	G 10	G 9
Reactivity	1.36	0.96
% S	2.27	-

Ore: Wabush concentrate.

	Lab. sample, our ref. no. 7349 b	Raw materials for smelting test
% Fe (tot.)	66.7	66.3
Cl -	-	traces

SIEVE ANALYSES AND GRINDING TIME FOR ORE AND COAL FROM CANADIAN JAVELIN LTD.

Concentrate: Sieve Analysis:

U.S. sieve no.	Lab. sample our ref. no. 7349 b % Cum.	Raw materials for smelting test % Cum.
20	0.1	0.4
50	20.1	23.1
100	69.6	63.8
200	96.0	94.0
% - 200 #	4.0	6.0

Time of grinding: 90 min., sieve analyses, 78%-200#, specific surface area: 22000 sqin./cu in. (8600 cm^2/cm^3)

Coal.

Time of grinding: 90 min., sieve analyses, 78 % - 200 #, specific surface area: 20000 sq in./cu in. (7800 cm^2/cm^3)

Appendix I.

Raw materials from Canadian Javelin Ltd.	ELEKTROKEMISK A/S OSLO — NORWAY Report no. 2790. 20. February 1962.

123 1000 3 60 - Thv. Tvedt

STRENGTH FIGURES FOR PELLETS CONTAINING 5 % RAPID HARDENING PORTLAND CEMENT AND VARIOUS AMOUNTS OF REDUCING AGENTS.

Amount and type of reducing agents.	Strength test	Storage 0 days	Storage 4 days	Heat treated at: °C (°F) 700(1292)	800(1472)	900(1652)	1000(1832)
250 lbs./short ton pig iron(125 kg fixed C/ 950 kg Fe) Nova Scotia-coal.	Compr., lbs.	10.8	98	282	70	80	240
	Drop, in.	81	120	>120	73	104	>120
300 lbs./short ton pig iron(150 kg fixed C/ 950 kg Fe)Nova Scotia-coal	Compr., lbs.	11	108	357	107	147	83
	Drop, in.	77	120	>120	190	>120	>120
350 lbs./short ton pig iron(175 kg fixed C/ 950 kg Fe)Nova Scotia-coal	Compr., lbs.	11.3	80	368	93	143	187
	Drop in.	77	79	>120	88	>120	>120
350 lbs./short ton pig iron(175 kg fixed C/ 950 kg Fe) 75 % Nova Scotia coal, 25 % Ashibetsu Tokufun-coal	Compr., lbs.	10	88	265	61	104	124
	Drop, in.	79	120	>120	94	120	>120

ELEKTROKEMISK A/S
OSLO — NORWAY

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Pellets of raw materials from Canadian Javelin Limited.

122 1000 3 60 - Tbw. Tvedt

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Appendix 3.

Pellets of raw materials from Canadian Javelin Limited.

HARDENING RATE FOR PELLETS CONTAINING 3, 4 AND 5 % RAPID HARDENING PORTLAND CEMENT AS A BINDER. HARDENING TEMPERATURE 19°C (66°F).

Heat treated after 5 days storage. The pellets includes 350 lbs. fixed C/short ton of pig iron (175 kg fixed C/950 kg Fe).

Raw materials mixed before being ground in the ball mill

% binder	Strength test	Storage time for raw pellets						Heat treated at , °C (°F)			
		0	1	2	3	5	7	700(1292)	800(1472)	900(1652)	1000(1832)
3	Compr., lbs.	12.9	-	30	-	56	62	>400	308	140	229
	Drop, in.	79	-	79	-	94	106	>120	>120	>120	>120
4	Compr., lbs.	13.3	-	36	-	72	77	>400	304	72	190
	Drop, in.	84	-	82	-	90	120	>120	>120	>120	>120
5.	Compr., lbs.	12.8	30	-	74	93	113	>400	273	115	242
	Drop, in.	79	73	-	>120	>120	>120	>120	>120	>120	>120

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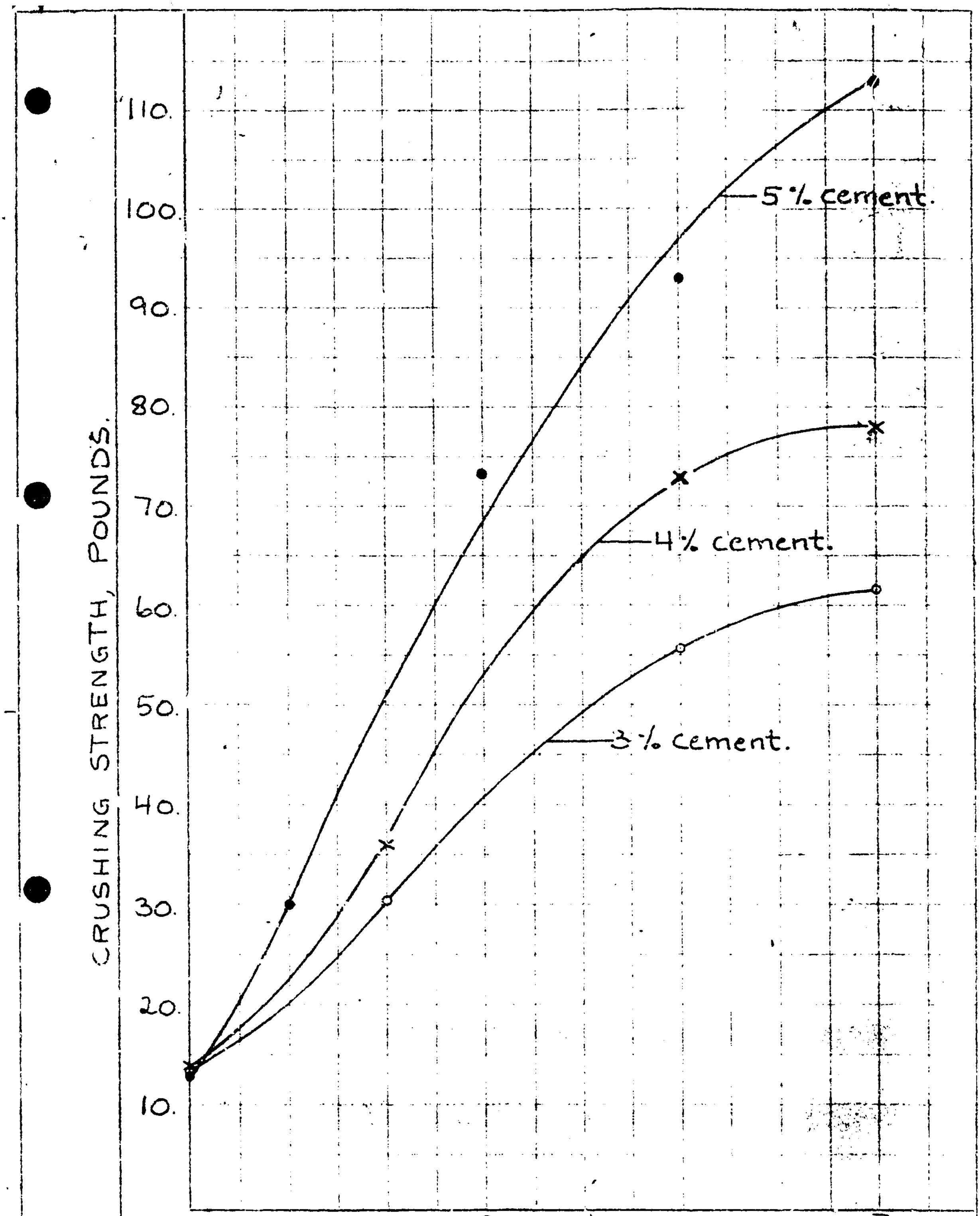

Appendix 4.

Hardening rate of pellets including various amounts of rapid hardening Portlandcement as a binder stored at 19°C (66°F).

ELEKTROKEMISK A/S
OSLO – NORWAY
Report no. 2790.
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HARDENING RATE FOR CANADIAN JAVELIN-PELLETS STORED AT VARIOUS TEMPERATURES.

Binder: 3, 4 and 5 % rapid hardening Portland cement.

Reducing agent: Nova Scotia Coal, 350 lbs. fixed C/short ton of pig iron.

	Strength test	Time of storage (days)			
		0	2	5	7
3 % cement stored at 2 - 5°C (36 - 41°F)	Compr. lbs.	12.9	21	45	51
	Drop, in.	79	79	79	83
3 % cement stored at 16°C (61°F)	Compr., lbs.	12.9	28	52	62
	Drop, in.	79	79	89	102
3 % cement stored at 19°C (66°F)	Compr., lbs.	12.9	30	56	63
	Drop, in.	79	79	94	102
4 % cement stored at 2-5°C (36-41°F)	Compr., lbs.	13.3	24	52	61
	Drop, in.	85	81	83	106
4 % cement stored at 16°C (61°F)	Compr., lbs.	13.3	32	64	74
	Drop, in.	85	91	94	110
4 % cement stored at 19°C (66°F)	Compr., lbs.	13.3	36	72	78
	Drop, in.	85	83	91	120
5 % cement stored at 3 - 5°C (38.5°F)	Compr., lbs.	12.8	8.8	33	60 78
	Drop, in.	79	75	83	>120 >120
5 % cement stored at 19°C (66°F)	Compr., lbs.	12.8	30	74	93 113
	Drop, in.	79	73	>120	>120 >120

ED/GH

Appendix 5.

Pellets of raw materials from Canadian Javelin Limited.

ELEKTROKEMISK A/S
OSLO — NORWAY

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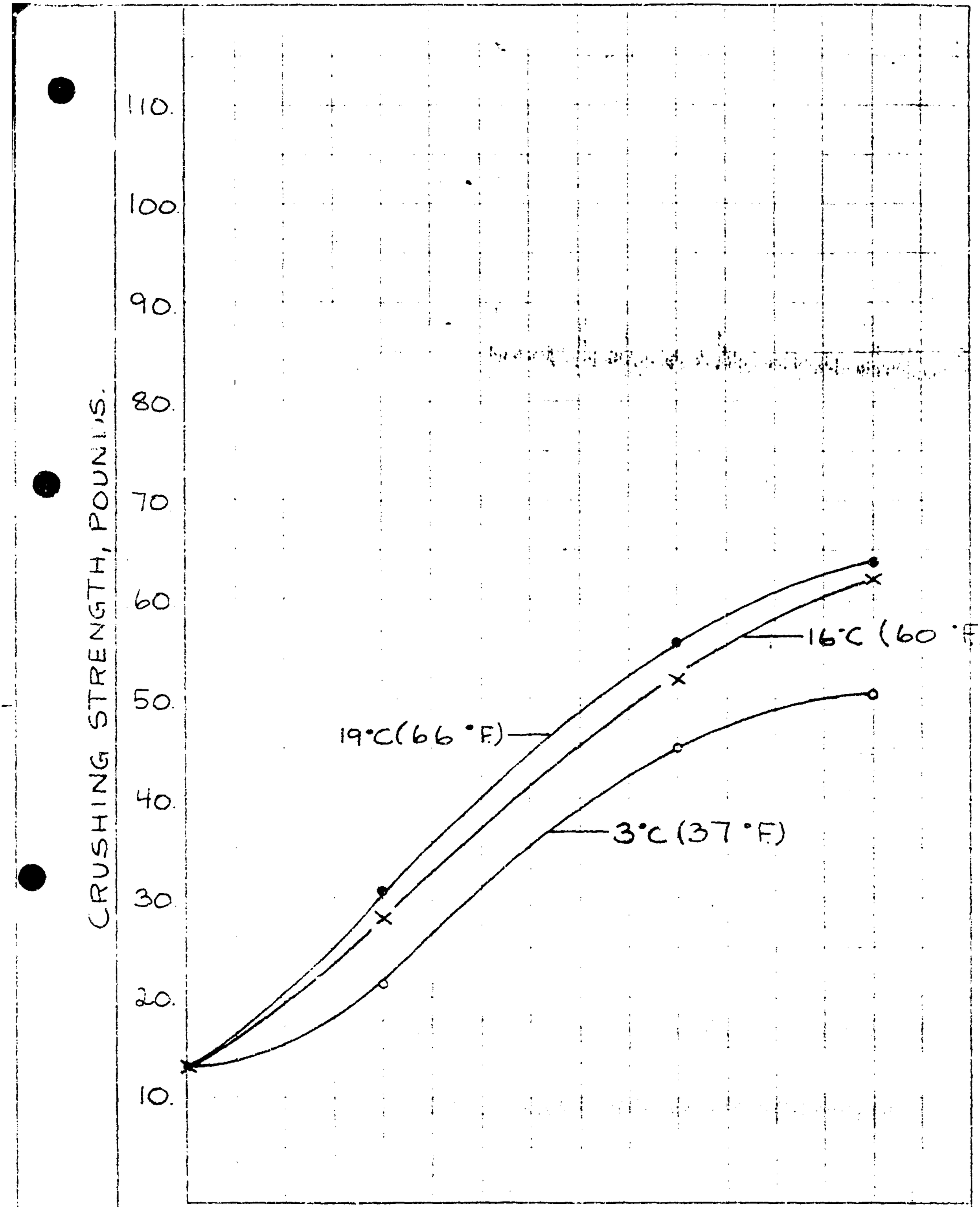

Appendix 6.

Hardening rate at various temperatures of pellets including 3 % rapid hardening Portland cement as a binder.

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OSLO – NORWAY

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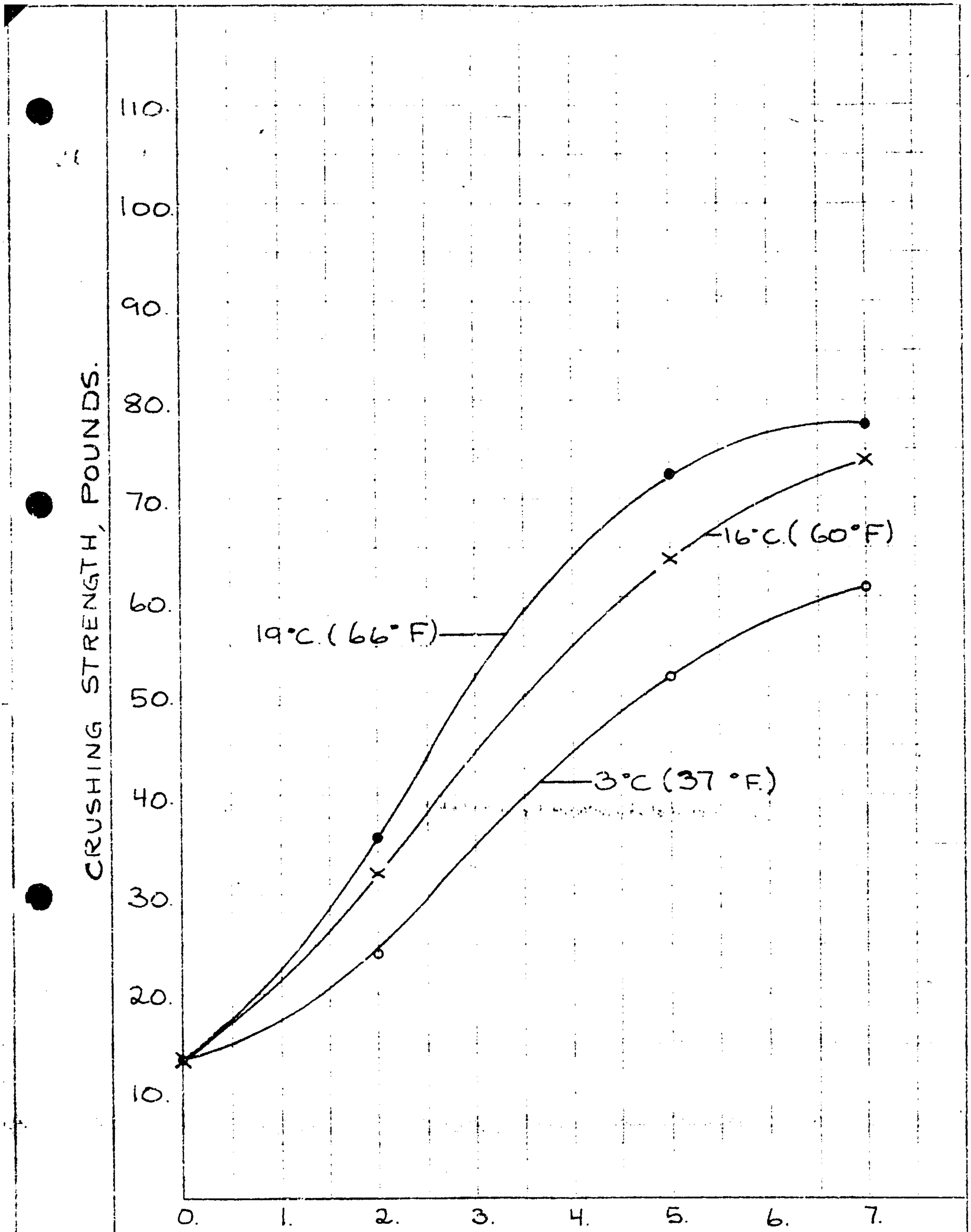

Appendix 7.

Hardening rate at various temperatures of pellets including 4 % rapid hardening Portland cement as a binder.

ELEKTROKEMISK A s
OSLO – NORWAY

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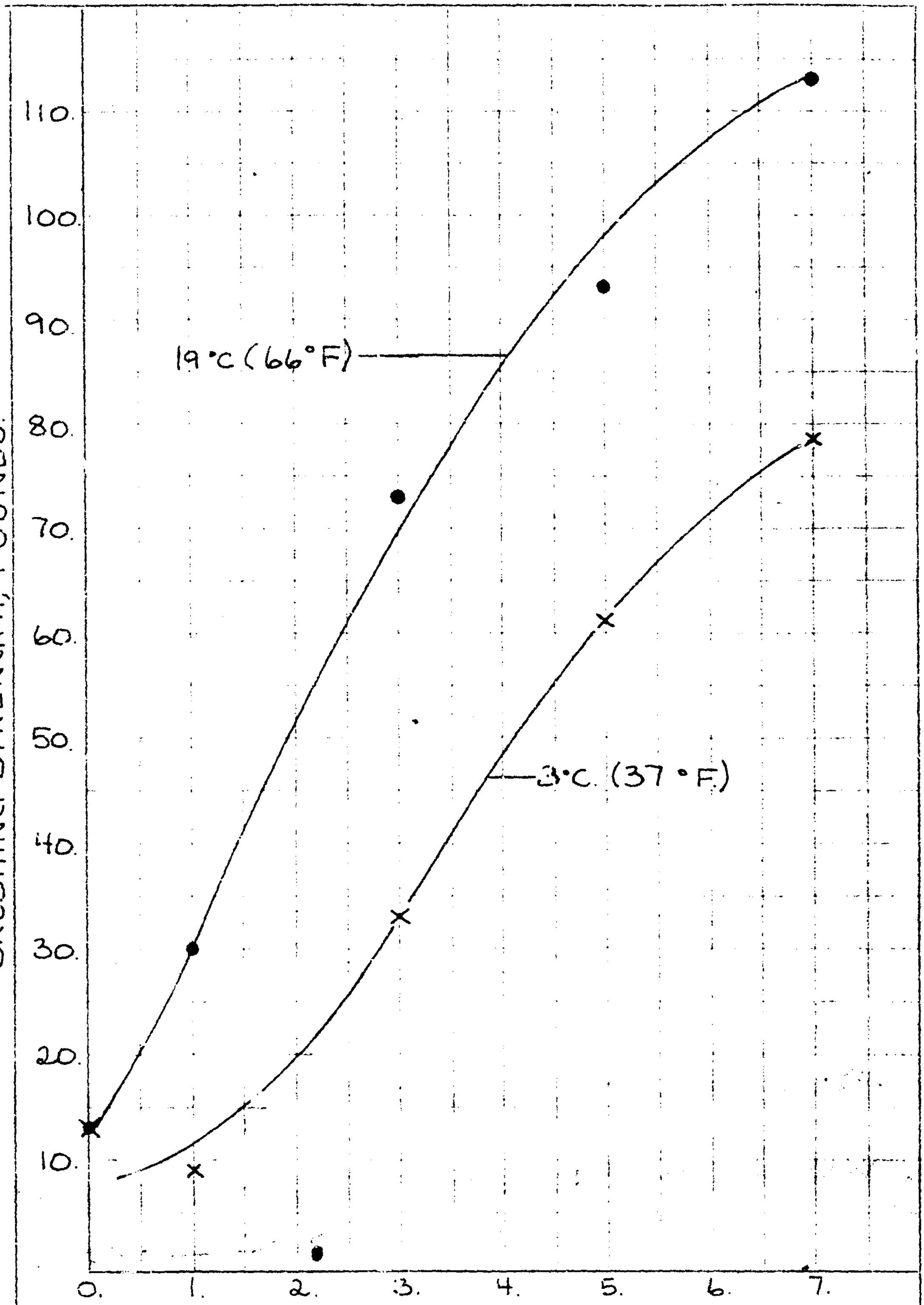

Appendix 8.

Hardening rate at various temperatures of pellets including 5 % rapid hardening Portland cement as a binder.

ELEKTROKEMISK A/S
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20. February 1962.

Appendix 1

Pellets of raw materials from Canadian Javelin Limited.

HARDENING RATE OF PELLETS STORED UNDER VARIOUS CONDITIONS.

Binder: 5 % rapid hardening Portland cement.

Reducing agent: Nova Scotia-coal, 350 lbs./ short ton of pig iron.

Storage conditions	Strength test	Storage time, days.				
		0	1	3	5	7
Stored at 19°C (66°F)	Compr., lbs.	12.8	30	74	93	113
	Drop, in.	79	73	>120	>120	>120
Stored at 3.5°C (38°F)	Compr., lbs.	12.8	8.8	33	60	78
	Drop, in.	79	75	83	>120	>120
Stored out door at temp. from -3 to +6°C(27-43°F)	Compr., lbs.	12.8	10.1	35	62	81
	Drop, in.	79	81	86	>120	>120
Stored 1 day at 19°C(64°F) 2 days at -15°C(-13°F)and further at +19°C(66°F)	Compr., lbs.	12.8	30	34	83	108
	Drop, in.	79	73	85	>120	>120
Stored 3 days at -15°C (-13°F), and thereafter at + 19°C (66°F)	Compr., lbs.	12.8	-	10.4	67	108
	Drop, in.	79	-	79	>120	>120

A/S FISKAA VERK
KRISTIANSAND S.

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Appendix 1C

Pellets of raw materials from Canadian Javelin Limited.

EFFECT OF ADDITION OF LIMESTONE TO THE PELLETS.

The raw materials mixed and ground in the laboratory ball mill.

Binder: 5 % rapid hardening Portland cement.

Reducing agent: Nova Scotia-coal, 350 lbs. /short ton of pig iron (175 kg/950 kg Fe).

Charge composition	Strength test	Storage time, days		Heat treated at: °C (°F)				Remarks
		0	3	6	700 (1292)	800 (1472)	900 (1652)	1000 (1832)	
Ore as received containing traces of Cl^- 8 % limestone added.	Compr. lbs.	7.9	-	97	>400	255	90	Not determinable.	Pellets slightly swollen at 900°C (1652°F), very swollen at 1000°C (1832°F).
	Drop in.	67	-	120	>120	>120	>120		
Washed ore, no detectable amounts of Cl^-. 8 % limestone added.	Compr. lbs.	10.4	33	-	222	106	77	76	Pellets very slightly swollen at 900°C (1652°F). No swelling at 1000°C (1832°F).
	Drop, in.	67	81	-	>120	>120	110	>120	
Ore as received. No addition of limestone.	Compr. lbs.	11.4	-	129	>400	277	115	242	No swelling.
	Drop, in.	81	-	120	>120	>120	>120	>120	

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SAMPLES OF PELLETS FROM THE DISC PELLETIZER OF THE RESEARCH STATION.

Date	30/1	31/1	1/2	2/2	2/2
Hour	10.30AM	7.30AM	10.00AM	9.00AM	2.50PM
Compr., lbs.	5.8	8.5	8.0	6.8	7.5
Drop, in.	94	69	85	55	65
Size, in.	9/16	15/16	7/8	15/16	3/4
Moisture, %	9.5	9.8	9.3	7.8	8.7
Cement, %	5	5	5	3	3

Hardening rate for pellets containing 5 % std. Portland cement (size of pellets: 9/16 in.)

Stored in the Research Station on jam jars fitted with tight lids.

Days storage	0	1	2	3	6	7	8
Compr., lbs.	5.8	6.9	12.8	20	26	34	38
Drop, in.	94	98	98	120	120	>120	>120

Hardening rate of pellets containing 3 % std. Portland cement (size of pellets 15/16 in.)

Stored in the Research Station on jam jars fitted with tight lids.

Days storage	0	3	4	6	8
Compr., lbs.	6.8	15.6	21	26	35
Drop, in.	55	51	59	65	67

Appendix 11.

Pellets of raw materials from Canadian Javelin Limited produced in the Research Station.

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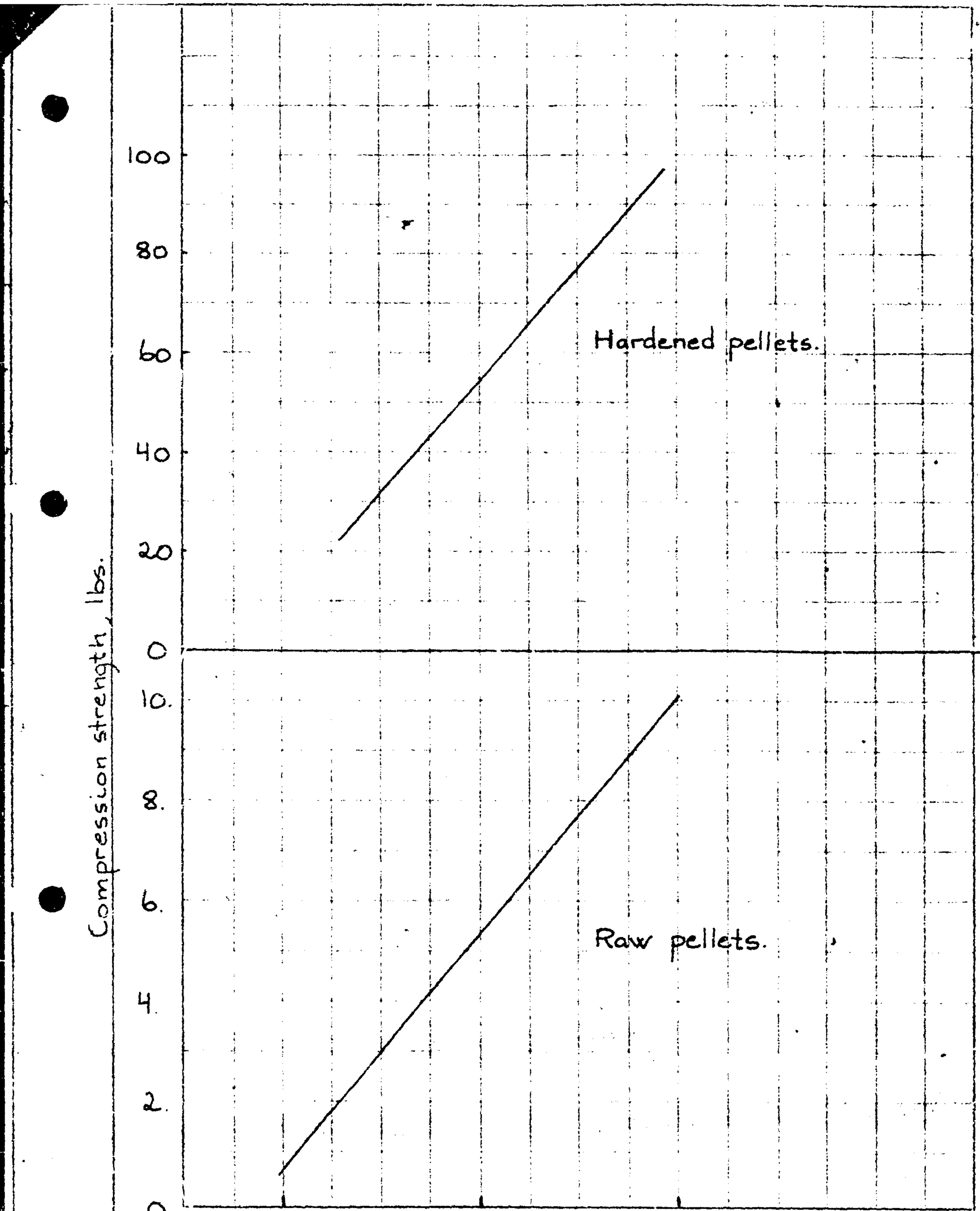

Appendix 12. Variation of the compression strength of pellets with the diameter. Normal values for raw and hardened cement bounded pellets.

ELEKTROKEMISK A/S
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Elektrokemisk A/S

Appendix 13.

PIG IRON SMELTING TEST

with

SELF-FLUXING SINTER FROM A/S NORSK JERNVERK'S

MO I RANA PLANT

at

Research Station, Fiskaa Verk

Kristiansand S., Norway

March/April 1960

by

ELEKTROKEMISK A/S, OSLO, NORWAY.

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Elektrokemisk As

I. INTRODUCTION

The smelting tests with sinter from Mo i Rana were organized for calibration of our pilot plant furnace with well-known raw materials for conventional electric smelting as well as the new process of shaft preheating, followed by electric furnace smelting. The furnace was charged with cold sinter for the first week of the tests and with sinter preheated to about 1300°F in the shaft furnace for the second week.

II. CONCLUSION

The sinter from Norsk Jernverk established very good smelting conditions throughout the tests. The furnace operation was smooth and more even silicon analyses of metal were obtained than normally in F-7. Using cold charge the power consumption was 1860 kWh per ton. With charge preheated to about 1400°F the power consumption was 1450 kWh per ton of pig iron.

The carbon content in the metal was the same in smelting of cold and preheated charge. The desulphurization was somewhat better with preheated charge, possibly due to higher slag temperature. The CO_2 - content in the gas from the electric furnace was 14% with cold charge and 41% with preheated charge. These figures demonstrate considerable increase in indirect reduction with hot charge in the electric furnace.

The carbon consumption was 616 and 568 lbs per ton of metal for cold and preheated charge, respectively.

The fuel consumption in the shaft is calculated from the measured air and gas volumes, and the average figures for the last three periods correspond to 5765 cu.ft. of CO per ton of metal. The gas production calculated from the electric furnace gas analyses is about 6550 cu.ft. of CO. Accordingly the gas production is sufficient for preheating.

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III. RAW MATERIALS

Chemical and sieve analyses are given in Appendices 3 and 4.

Sinter.

Coarse, self-fluxing sinter purchased from Norsk Jernverk was crushed and screened. During the smelting tests the fraction 1/4" to 1. 3/8" was used.

Coke.

The fractions 1/8" to 3/8" and 3/8" to 3/4" of Scotch gas coke breeze were used. The coke was not dried prior to screening.

IV. OPERATION

During the starting-up period the furnace was heated for two hours on a coke bed prior to charging.

For cold as well as hot charging conditions the charge was weighed in batches each corresponding to 157 lbs of pig iron. The charge was filled to the top of the shaft. From the shaft the charge was fed continuously into the smelting furnace by a simple table feeder.

To establish correctly the fuel gas consumption for the preheating shaft, propane was used. The gas from the electric furnace was not used.

V. RESULTS

The most important operating data and analyses of metal and slag are given in Appendices 1 and 2.

Periods 1 - 4 - Smelting of cold charge.

Charge:

Sinter	302 lbs
Coke, 3/8" - 3/4"	46 - 49 - 47 lbs
Coke, 1/8" - 3/8"	35 "

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Throughout these periods the furnace operation was good with stable reduction conditions.

The sinking of the charge was even, no poking in the electric furnace was required. Tapping conditions stable and only small fluctuations in the analyses of pig iron and slag.

Power consumption was 1860 kWh per ton of pig iron.

Periods 5 to 9 - Smelting of preheated charge.

Charge:

Sinter	302 lbs
Coke 3/8" - 3/4"	42 - 40 - 37 lbs
Coke, 1/8" - 3/8"	35 - 37 "

In Period 9 the following charge was used:

Sinter	302 lbs
Coke 3/8" - 3/4"	18 "
Coke, 1/8" - 3/8"	60 "

Also during these periods with preheated charge the furnace operation was excellent with stable reduction conditions.

The power consumption was about 1450 kWh per ton with about 1% Si in the metal, the starting-up period not included.

VI. DISCUSSION OF RESULTS

A. Smelting conditions.

In using cold as well as preheated charge the smelting conditions were very good. It was possible to maintain somewhat lower Si-content in the iron in the smelting of preheated charge than by cold charge smelting. This is in confirmity with previous experience.

B. Indirect reduction in the smelting furnace.

In the smelting of cold and preheated charge the gas from the smelting furnace contained about 14% CO_2 and about 41% CO_2, respectively. The gas analyses are given in Appendix 5. This

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indicates that a much higher degree of prereduction is obtained in the smelting furnace with hot charge.

C. Carbon consumption.

Due to the important increase in indirect reduction in the smelting furnace obtained with preheated charge, the carbon consumption decreased from 616 to 568 lbs of metal. The carbon content in the sludge from the gas cleaning plant corresponds to abt. 14 lbs per ton of pig iron. The true carbon consumption is thus 554 lbs fix C rather than 568 lbs. The carbon consumption calculated from the electric furnace gas analyses is still lower. This is possibly due to loss of coke in the tappings. The gas analyses are not showing any increase in the CO content of the excess gas from the shaft.

Usually the CO-content of the exit gas was lower than for the inlet gas. (Appendix 5). This indicates that the CO possibly formed by reaction between CO_2 and C has reduced the sinter. There might, therefore, have been some carbon consumption in the shaft. However, this should not increase the total carbon consumption.

D. Power consumption.

The power consumption of 1860 kWh per ton of metal with cold charge is a little higher than obtained in Mo i Rana. The power consumption 1450 kWh per ton of metal with preheated charge is higher than expected, the extensive indirect reduction in the smelting furnace taken in consideration. However, so far no comparable figures for smelting with preheated charge on commercial scale is available.

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SUMMARY OF LOG SHEETS

Period	Date	Time	Duration hours	Charge in lbs. dry basis: Sinter	Coke 3/8"-3/4"	Coke 1/8"-5/8"	Electrical data: V	kW	kWh	Production: Tap. No	Metal lbs	Slag lbs. pr. t	Consumption figures pr. short ton: kWh	kWh correct. to 1% Si	Fix C lbs	Electr. lbs.	Analyses, metal: % Si	% C	% S	Shaft furnace: Inlet gas temp. °F	Exit gas temp. °F
1	22/3	0530	23.8	16155	1992	1666	55	380	9110	2-13	9367		1945	1915		17.6	1.35	3.86	0.14		
	23/3	0520																			
2	23/3	0520	24.0	17875	2254	1719	55	405	9720	14-25	10237		1900	1855		15.6	1.50	3.94	0.10		
	24/3	0520																			
3	24/3	0520	24.0	18470	2340	1824	57	418	10020	26-37	10658		1885	1870	616	10.6	1.22	3.94	0.14		
	25/3	0520																			
4	25/3	0520	39.8	29775	3773	2891	56	417	16610	38-57	17689		1880	1855		12.8	1.23	4.06	0.11		
	26/3	2110																			
5	28/3	1045	21.1	24135	2607	2666	52	454	9580	59-72	12395	840	1540	1535		14.4	1.10	3.84	0.10	1560	300
	29/3	1350																			
6	29/3	1350	23.7	25080	2505	2587	53	445	10510	73-88	14643		1440	1445		14.0	0.92	4.08	0.07	1560	300
	30/3	1330																			
7	30/3	1330	23.5	25965	2596	2644	51	440	10310	89-104	14215		1450	1450	568	10.8	1.02	4.06	0.07	1560	250
	31/3	1300																			
8	31/3	1300	23.7	24135	2415	2446	51	440	10450	105-120	14504		1445	1445		13.2	0.96	4.02	0.08	1560	230
	1/4	1240																			
9	1/4	1240	37.5	39320	2186	6061	52	441	16540	121-145	23007		1440	1440		14.0	0.98	3.96	0.08	1560	300
	4	0210																			

Appendix 1.

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Analyses of metal and slag.

Period	Tap.No.	% Si	% C	% S	% SiO_2	% FeO	% CaO	% $Al_2O_3+TiO_2$	% MgO	% S	Basicity
1	2-13	1,35	3,86	0,14							
2	14-25	1,50	3,94	0,10							
3	26-37	1,22	3,94	0,14							
4	38-57	1,23	4,06	0,11							
5	59-72	1,10	3,84	0,10							
6	73-88	0,92	4,08	0,07							
7	89-104	1,02	4,06	0,07							
8	105-120	0,96	4,02	0,08							
9	121-145	0,98	3,96	0,08							
2-3-4	14-57				40,4	0,67	37,3	8,60	12,28	0,54	1,23
6-7-8-9	73-145				40,8	0,82	37,5	8,05	12,14	0,59	1,22

Analyses of preheated charge.

	% Fe_{tot}	% Fe^{2+}	% Fe^{3+}	Degree of oxidation
Charge preheated to 1560°F	51,9	10,2	41,7	93

Appendix 2.

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Analyses of raw materials.

	% SiO_2	% Fe_{tot}	% Fe^{2+}	% Fe^{3+}	% CaO	% Al_2O_3+TiO_2	% MgO	% S	
Sinter 0 - 3/16"	8,60	54,1			8,10	1,70	3,48	0,06	
" 3/16-1 3/8"	8,84	53,9	9,5	44,4	8,22	1,75	3,23	0,04	x)

x) Degree of oxidation 94

	% Ash	% Volatiles	% Fix C	% H_2O
Gas coke 1/8 - 3/8"	15,6	5,28	79,12	22,5
" " 3/8 - 3/4"	15,3	4,25	80,45	22,3

Appendix 3.

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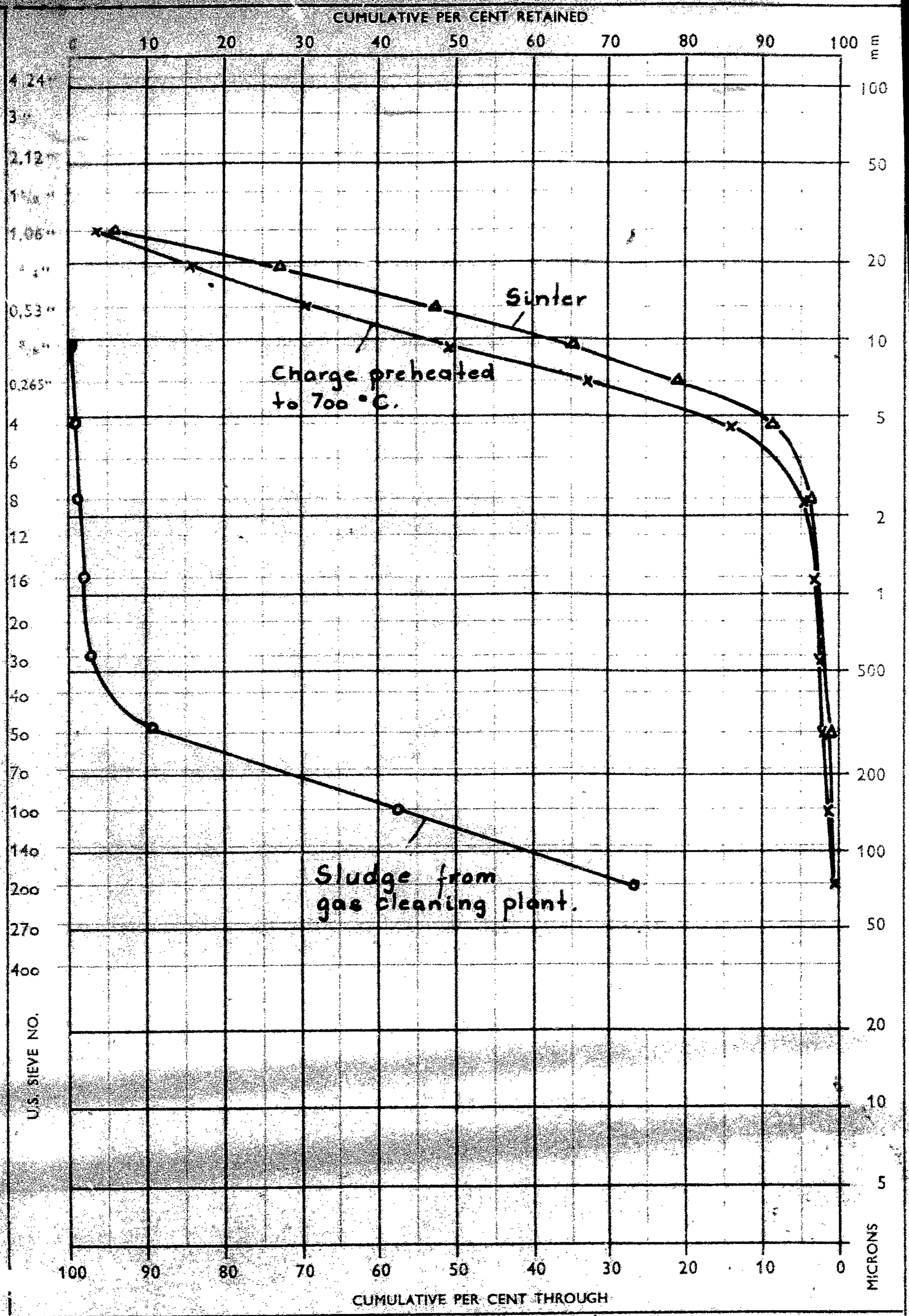

Appendix 4. SIEVE ANALYSIS

FISKAA VERK
KRISTIANSAND S.

SAMPLE: Sinter. Preheated charge.

SAMPLE NO. Sludge from gas cleaning plant.

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Elektrokemisk A/S

Appendix 5.

Measured gas volumes in the shaft furnace in preheating of sinter.

The gas volumes are converted to cu.ft. per sh.t. of produced metal.

Period	Air	Propane	Recycle gas	Excess gas
6	19860	961	37160	15375
7	18260	865	29790	15375
8	17940	753	33640	13135
9	20180	801	37480	14415

Gas analyses of inlet and outlet gas from the shaft.

Date	Sample taken	CO_2	O_2	CO
31/3	Inlet	13,2	0,2	1,2
	Outlet	13,8	0,2	0,2
1/4	Inlet	13,6	0,2	0,4
	Outlet	13,8	0,4	0,2

Average analyses of gas from the smelting furnace.

	% CO_2	% CO
Cold charge	14	
Preheated charge	41	52

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Elektrokemisk A/S

Appendix 14.

PIG IRON SMELTING TEST

ALGERIAN ORE PELLETIZED WITH POCAHONTAS COAL AND CEMENT

AT

RESEARCH STATION, FISKAA VERK

October/November 1959

BY

ELEKTROKEMISK A/S - OSLO

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Elektrokemisk A/S

I. INTRODUCTION.

Hematite ore from the Quenza Mine in Algerie was ground to powder and pelletized with ground Pocahontas coal and 5% Portland cement as a binder.

The pellets were hardened by storage in a pile on the floor and batches prepared from pellets, fluxes and coke. These batches were transported to the top of a small shaft and preheated in a stream of gas to about 1300°F.

II. CONCLUSION.

The ore was quite friable and easy to grind.

The pellets had sufficient strength and very little fines were formed in the shaft.

The carbon consumption was lower than in any previous smelting test - about 520 lbs Fix C per short ton of pig iron.

Shaft as well as electric furnace operation was smooth and stable with good tapping conditions. The power consumption was 1140 and 1170 kWh for the two smelting periods (based on 1% Si in the pig iron).

III. RAW MATERIALS.

The chemical analyses of the raw materials are tabulated in Appendix 1. The composition of the pellets (dry basis) was:

Iron ore	83 %
Pocahontas coal	12 %
Cement	5 %

IV. RESULTS.

Appendix 4 presents the main data from the tests.

SCANNED IMAGE

a. Shaft.

The inlet gas temperature in the shaft was maintained at 1700°F while the top gas temperature was 360°F. The oxidation stage of iron in the pellets from the shaft was between 82 and 83% which represents 17 to 18 % oxygen removal. The pellet temperature from the shaft is estimated to 1300°F.

The descent of the charge in the shaft was smooth and continuous.

b. Electric furnace.

Composition of each batch:

Pellets	350,3 lbs
Coke 3/8" - 3/4"	17,7 "
Quartzite	6
Bauxite	6

The electric furnace operation was steady in both periods. The charge appeared to be very porous with even distribution of the gas over the cross-section of the furnace crucible. The furnace was easy to tap. No poking was required in the charge.

V. DISCUSSION OF RESULTS.

The furnace load was 300 to 330 kW and the voltage 44 to 49 volts, which is considered normal for pig iron smelting with this load. Apparently, therefore, the electrical resistance in the charge is about the same as for conventional cold charge.

The carbon content in the pig iron produced in tests in this electric furnace has previously fluctuated from 2 to 4 %. In these tests the carbon content as average for tappings in the two periods was 3,64 and 3,40, respectively. The carbon content, therefore, is considered as normal for this furnace with cold charge.

SCANNED IMAGE

The basicity of the slag was relatively high, 1,5 to 1,6. This gave 0,04 and 0,06 % S in the pig iron.

The carbon consumption was exceptionally low - 520 lbs Fix C per ton of pig iron. This corresponds with the surprisingly high CO_2 content in the gas from the electric furnace which was some times between 40 and 50%. The high content of CO_2 is favourable both for carbon and power consumption.

Fiskaa December 21st, 1959.

T. Båsen
(Sign.)

TB/FC/IS.

SCANNED IMAGE

Elektrokemisk AS

Appendix 1.

Analyses of Raw Materials.

(Dry basis)

	Fe	SiO_2	CaO	MgO	Mn	Al_2O_3	S	Loss of Ignition	Fix C	Ash
Ore	56,3	3,36	4,5	1,45	1,96	0,14	0,06	7,3		
Pocahontas coal								19,8	74,0	6,2
Coke								2,66	82,2	15,1

SCANNED IMAGE

Elektrokemisk A/S

Appendix 2.

Analyses of Pellets from Shaft.

	% Fe (tot)	% Fe^{2+}	% Fe^{3+}	Oxidation %
Period 1	52,1	27,1	25,0	82,6
Period 2	53,2	27,5	25,7	82,9

Load Test of Pellets:

Period 1	44 lbs.
" 2	55 "

Gas from Inlet to Shaft:

Period	Date	Hour	% CO_2	% O_2	% CO
	27/10	12.00	16,3	0,1	6,3
1	"	15.40	20,2	0	4,6
	28/10	13.30	21.8	0,2	7,2
	18/11	12.55	16,2	0	4,9
2	"	14.00	20	0	5,0
	19/11	8.30	18,8	0,2	5,7

SCANNED IMAGE

Appendix 3.

Analyses of Iron and Slag.

Period	Iron				Slag							Basicity
	% Si	% S	% C	% Mn	% S	% SiO_2	% FeO	% Al_2O_3 + TiO_2	% CaO	% MgO	% MnO	
1	1,89	0,04	3,64	2,70	0,63	33.0	0,67	15,50	42,7	6,70	1,28	1,5
2	1,19	0,06	3,40	2,39	0,77	31,4	1,34	14,60	43,5	6,68	2,11	1,6

SCANNED IMAGE

SUMMARY OF RESULTS

Period	Date	Hrs.	No of hrs.	lbs charge to shaft (dry basis) Pellets	Coke	Quartz	Bauxite	Electrical data V	kW	kWh
1	27/10 28/10	21.05 21.05	24	25900	1105	604	575	44	300	7250
2	18/11 19/11	15.42 09.52	18,2	2075	955	265	397	49	330	6030

Period	Production Tap No.	Iron lbs.	Consumption per sh. ton of iron kWh	kWh correct. x)	Fix C lbs.	Electrodes lbs	Analyses Si in Iron.
1	6-17	11850	1225	1145	520	10,4	1,89
2	4-13	10140	1240	1220	516	7,2	1,19

x) Based on 1% Si in Iron
correction 90 kWh per 1%.

Appendix 4.