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The Smelting of Julian Concentrates by the Strategic-Udy Process. Report to: Canadian Javelin Ltd.

STRATEGIC-UDY PROCESSES, INC.
METALLURGICAL RESEARCH AND DEVELOPMENT
SUBSIDIARY OF STRATEGIC MATERIALS CORPORATION

DR. MURRAY C. UDY
DIRECTOR OF RESEARCH

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CABLE: SUPI

6 March 1961

Mr. William H. Roxburgh, Chief Engineer
Canadian Javelin Limited
680 Fifth Avenue
New York 19, New York

Dear Mr. Roxburgh:

It is my pleasure to send you six (6) copies of our report on the smelting of the Julian concentrates.

This project has demonstrated that premium grade iron and steel products can be easily produced from your concentrates by the Strategic-Udy Smelting Process. Power consumption will be low for both smelting and refining.

As described in the report, the iron which was produced was refined and fabricated into SAE 1010 and 1040 grades of steel. These steels exceed the specified tensile and yield strengths by at least 20% and have good ductility.

We hope the successful demonstration in our 100 KVA furnace will assist you in your decision to move ahead with the exploitation of the Julian ore deposit.

Best personal regards,

Sincerely yours

STRATEGIC-UDY PROCESSES, INC.

Murray C. Udy

Vice President-Research

Murray C. Udy:B

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PROJECT 1240-2

THE SMELTING OF JULIAN CONCENTRATES BY THE STRATEGIC-UDY PROCESS

REPORT TO
CANADIAN JAVELIN LIMITED
ST. JOHNS, NEWFOUNDLAND, CANADA
6 March 1961

By :
J. W. Donaldson, D. H. Jurden, L. E. Olds, M. C. Udy

Strategic-Udy Processes, Inc,
Niagara Falls, New York

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I. SUMMARY

The smelting of the Julian concentrate by the Strategic-Udy Smelting Process was successfully demonstrated. Over five tons of concentrate were smelted to produce the following materials:

A. Low carbon, low silicon iron with three different carbon levels: 2.0%, 0.8% and 0.4%.

B. Basic open hearth pig iron complying with the accepted specification for this product.

C. Foundry pig iron complying with the accepted specification for this product.

The metals produced were refined to SAE specification 1010 and 1040 grade steels, and rolled into flats in a merchant mill. The results of the refining, rolling and mechanical testing leave no doubt that either pig iron or low carbon iron produced from the coarse Canadian Javelin concentrates via the Strategic-Udy Process can be cheaply refined to normal carbon steel.

It is forecast that a power consumption of less than 1050 KWH per ton of metal produced would be required when smelting this concentrate on a commercial scale using the integrated Strategic-Udy Process. A further 200 KWH per ton would be required to refine the metal produced to steel in an electric refining furnace.

A separate demonstration was made on the amenability of the concentrates to prereduction in a rotary kiln. The results obtained indicate that there will be no difficulty in removing at least half of the oxygen (50% prereduction) in the kiln.

II. RECOMMENDATIONS

In view of the successful demonstration that has been made on the Canadian Javelin concentrates on the 100 KVA scale, it is recommended that a large scale prototype run be made at the Stratmet* facilities in order to obtain fully the engineering design data required for a commercial plant. The prototype plant demonstration was outlined in our proposal of 16 May 1960 and would involve the following steps:

1. The prereduction and heating of the furnace charge in a rotary kiln.

2. The charging of the hot reduced material from the kiln to the specially designed Strategic-Udy smelter where the smelting reactions would be completed and the pig iron or low carbon iron produced.

3. The refining of a portion of the pig iron or low carbon iron produced to specification grade steels in an electric refining furnace. Such refining would demonstrate both cold and/or hot metal charging.

This demonstration would provide accurate material and power requirements and also the necessary engineering data for plant design.

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*Strategic-Udy Metallurgy, Ltd., Niagara Falls, Ontario

III. INTRODUCTION

Canadian Javelin Limited owns extensive holdings of a specular hematite in the Wabush Lake areas of both Quebec and Labrador. The ore averages approximately 35% Fe as mined, and can be readily concentrated to 63-65% Fe at a coarse grind.

The concentrate produced for the SUPI* demonstration was predominantly all -16 and +100 mesh and material of this size cannot be properly pelletized without the expense of grinding to a considerably finer mesh size. It is also too fine for sintering but is most suitable for treatment by the Strategic-Udy Smelting Process.

In December 1960 arrangements were made for a preliminary demonstration of the Strategic-Udy Smelting Process on concentrates prepared from Canadian Javelin's Julian ore. The objective of this project was to demonstrate the production, on a 100 KVA furnace scale, of specification grade iron products and the refining and fabrication of this iron into finished steel.

The ore sample for the demonstration was concentrated at the Lakefield Research of Canada Limited. The concentrates were sent to SUPI and smelted in the period from 23 January to 27 January 1961 inclusive.

Mr. W. H. Roxburgh, Vice President, Canadian Javelin Limited, observed the entire demonstration. Other observers were:

Mr. K. M. Dewar, President, Kilborne Engineering
Mr. B. S. Crocker, Vice President, Kilborne Engineering
Mr. F. Schora, Arthur D. Little Company

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*Strategic-Udy Processes, Inc., Niagara Falls, New York

IV. EQUIPMENT

The equipment used in the demonstration consisted of the 100 KVA furnace used for smelting and a 3' x 5' gas fired rotary furnace used for the prereduction demonstration.

The SUPI electric furnace is shown in Figure 1. This furnace is a 100 KVA, three phase electric furnace of special design, manufactured by the Pittsburgh Lectromelt Furnace Company. The transformer delivers 60 to 360 phase volts in 4 to 6 volt steps with full power loading available for all steps. The transformer has low inherent reactance.

Interchangeable furnace shells with various types of refractory linings are available for this furnace. The inside diameter of the lined shells is approximately 30" with a depth varying from 18" to 24". A periclase (MgO) brick-lined furnace shell was used in this demonstration. The roof used on this furnace is a monolithic, dome structure, constructed from high alumina ramming mix. The furnace is fed through 4" diameter holes in the roof.

The 3' x 5' rotary furnace is used as a batch rotary kiln and is used for demonstrating the prereduction of ores and concentrates. This furnace is lined with firebrick and has an interior capacity of 28.8 cu. ft.

V. RAW MATERIALS

The concentrates were prepared at Lakefield Research and shipped to SUPI in sealed 45 gallon drums. On arrival, the concentrates were dried in the pan dryer and then a sample was riffled from the entire shipment.

Table 1A shows the detailed chemical and screen analyses of the dried concentrates.

The reductant used for this demonstration was a soft coal purchased locally. Table 1B shows the detailed analysis of the coal. This reductant is used when no reductant is definitely specified, since the composition is uniform from one shipment to another.

For an integrated Strategic-Udy smelter operation lower grades of coal, such as lignites or steam coals, are, of course, very suitable as reductants. After treatment in the kiln, the coal reaches the electric furnace as a high fixed carbon, low volatile char.

The fluxes used were also purchased locally and detailed analyses are shown in Table 1C.

TABLE 1. RAW MATERIALS

A. Julian Concentrates*

Fe	63.4
Fe^{++}	0.21
SiO_2	8.94
Al_2O_3	0.56
CaO	0.26
MgO	0.21
Mn	0.11
P	0.01
S	0.014
L.O.I.	0.22

B. Reductant

Pocahontas Coal

F.C.	78.8
V.M.	15.0
Ash	6.2
P	0.008
S	0.47

C. Fluxes

Lime -¼" +93% CaO

Silica -¼" +98% SiO_2

Spar -¼" +97% CaF_2

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*Screen Analyses of Concentrates

Mesh	%
+16	0
+30	6.5
+50	34.3
+70	21.8
+100	25.1
-100	12.2

VI. PROCEDURE

A brief description of the Strategic-Udy Smelting Process is given in the Appendix along with a list of published papers on the process. Additional copies of these papers may be obtained from SUPI if desired.

The demonstration on Canadian Javelin iron ore concentrates was divided into three separate operations as follows:

1. Smelting of the as-received concentrates into iron conforming to specifications for basic open hearth pig, foundry pig, or low carbon iron.
2. Reduction demonstration in the batch rotary kiln.
3. Refining and fabrication of the iron made in step 1.

A. Smelting the Concentrates

The integrated Strategic-Udy Smelting Process for iron involves the prereduction of ores in a rotary kiln prior to electric smelting. However, on a 100 KVA scale, charging a hot, reduced calcine is not feasible and therefore the initial, small scale campaigns are based on the use of a cold, unreduced charge. Prereduction, of course, primarily affects power consumption and does not significantly alter the grade of iron that can be produced by the specialized Strategic-Udy Smelting Process.

In the Canadian Javelin campaign the unreduced concentrates were mixed with the desired amounts of fluxes and reductants and fed manually to the furnace. The charging rate was adjusted so that the immediate area around the electrodes was kept free of unmelted material at all times. The heats were approximately 2½ hours long and were made continuously on a 24 hour-three shift per day basis.

When the charging of the furnace was completed, the reduction reactions were allowed to proceed to the desired end-point and the metal and slag were tapped through a single tap hole into a cast iron mold. Control samples were taken from the tapped metal and slag stream with a spoon and analyzed for the desired constituents.

At the conclusion of the demonstration the slags were composited into groups according to base ratio. The composited slags were crushed to -½" and all the entrapped metallic prill and shot were removed by a dry belt magnetic separator. The metal-free slags were riffled and the sample so obtained was analyzed for slag constituents in addition to the analyses that were made on the control samples.

B. Kiln Reduction Demonstration

To determine if the Canadian Javelin concentrate was amenable to reduction in the rotary kiln, one heat was made in the gas fired batch rotary kiln. The charge to the kiln was made up of concentrate, reductant and lime in approximately the same proportions as used in the smelting demonstration.

SCANNED IMAGE

The kiln was brought to temperature and samples were taken at predetermined intervals. At the conclusion of the demonstration the treated charge was dumped into a drum and sealed. When it was cool, a sample was obtained by riffling down the entire charge. All samples were analyzed for total Fe, ferrous Fe, metallic Fe and carbon, and from these analyses the amount of oxygen removed from the iron minerals was determined. This expressed as a percentage per unit of iron was the amount of reduction achieved.

VII. RESULTS OF THE SMELTING DEMONSTRATION

The demonstration was begun on the 23rd of January, 1961, when the smelting campaign was commenced and was satisfactorily concluded one month later, on the 23rd of February, when the rolling of the refined steel was completed.

A. The Smelting Operation

A summary of the materials processed and the metal and slag produced is shown in Table 2. This summary does not include the rotary batch kiln demonstration of the amenability of the ore to prereduction.

The object of the smelting demonstration was to show the various types of iron products that could be made from this ore. Table 3 shows the commonly accepted specifications for foundry pig iron and basic open hearth pig iron. Also included is a typical analysis of a low carbon, low silicon iron which can be easily produced by the Strategic-Udy Smelting Process. This iron is more easily refined than standard open hearth pig iron.

The demonstration was divided into six separate series, depending upon the metal produced, i.e. low carbon, low silicon iron, basic open hearth pig iron or foundry pig iron.

Table 4 is a summary of the metal and slag produced during each phase of the demonstration.

TABLE 2. MATERIAL SUMMARY

Materials Fed:

Series	Julian Concentrates, lbs.	Soft Coal, lbs.	Crushed Lime, lbs.	Quartz, lbs.	Spar, lbs.
1	1800	449	342	90	--
2	1200	286	228	60	--
3	1240	285	276	60	2
4	2828	770	532	168	--
5	2035	565	380	118	--
6	1004	261	150	60	--
Total	10,107	2616	1908	556	2

Material Out: (does not include metal prill and furnace clean-out.)

	Metal	Slag
Series 1	750.5 lbs.	490 lbs.
Series 2	673.0	470
Series 3	866.0	367
Series 4	1820.5	847
Series 5	1272.5	721
Series 6	654.5	348
Total	6037.0 lbs.	3243 lbs.

TABLE 3. MATERIAL SPECIFICATIONS
For Various Iron Products

	Si	S*	P**	Mn***	Total*** Carbon	Ref.
Foundry Pig Iron	1.0-4.0	.04-.10	0.10-2.00	(0.20-1.50)	(3-4.5)	1
Basic Pig Open Hearth	<1.5	<.05	.11-.90	(0.4-2.0)	(4.10-4.40)	1
Low Carbon Iron	<.2	.10-.50	<.05	--	<2.0	2

* Maximum specified; ASTM Max. = 0.05%

** Phosphorus below minimum premium grade metal

*** Carbon and manganese not generally specified

References:

1. U. S. Steel Co., "The Making and Shaping of Steel"

2. Specifications not established. Analyses typical of easily refinable low carbon, low silicon iron produced by the Strategic-Udy Process.

TABLE 4. SUMMARY OF METAL AND SLAG PRODUCED FROM JULIAN CONCENTRATES

Product Desired	Metal					Slag	
	Wt.	C	Si	S	P	Wt.	Fe*
Series 1							
Low C Iron (2%)	750.5	2.02	0.36	0.10	<.01	490	2.21
Series 2							
Low C Iron (.8%)	673.0	0.78	0.04	0.16	<.01	470	5.43
Series 3							
Low C Iron (.4%)	866.0	0.41	0.08	0.092	<.01	367	4.26
Series 4							
Basic Open Hearth Pig	1820.5	2.78	0.66	0.08	<.01	847	1.08
Series 5							
Basic Open Hearth Pig	1272.5	3.88	0.98	0.03	<.01	721	0.67
Series 6							
Foundry Pig	-	3.75	1.63	0.04	<.01	348	1.34
Clean-out	240.0	3.65	0.93	0.09	<.01	-	-
Total	6277.0	-	-	-	-	3243	-
Weighted Average	-	2.50	0.65	0.08	<.01	-	2.18

*Weighted Averages of Control Analyses.

Series 1. Low Carbon Iron (2%)
(Heats 6867-6875)

This series consisted of nine heats and included the start-up period before the furnace reached thermal equilibrium. The base ratio used in this series, and also in Series 2 was 1.34.

Table 5 shows the detailed results obtained during this series. After the first three heats the metal composition was fairly uniform; the carbon ranged from 2.05 to 2.51%, and the sulfur from 0.084 to 0.11%. The phosphorus was less than 0.01 throughout the series. This is a typical low carbon metal which can be easily refined to specification grade steel.

Series 2. Low Carbon Iron (0.8%)
(Heats 6876-6881)

Table 6 shows the detailed results obtained during this period. The carbon level was reduced to an average of 0.8%, and consequently the sulfur increased to an average of 0.16%. Sulfur at this level can be reduced by a simple injection of ladle technique, after which the composition of the metal can be easily adjusted to conform with accepted steel specifications.

Series 3. Low Carbon Iron (0.4%)
(Heats 6882-6887)

Detailed results for this series are shown in Table 7.

The carbon level in the metal was further decreased to an average of 0.4%. To control the sulfur content of the metal, the base ratio of the slag was increased to 1.42 from

TABLE 5. CONTROL ANALYSIS OF SERIES 1
CANADIAN JAVELIN CAMPAIGN

	Metal Produced					Slag Produced	
Heat No.	Wt. (lbs)	C (%)	Si (%)	S (%)	P (%)	Wt. (lbs)	Fe (%)
6867	none	-	-	-	-	27	10.63
6868	16.5	0.92	0.49	0.160	0.022	63	2.04
6869	61.5	1.23	0.50	0.096	<.01	47	1.66
6870	91.5	2.05	0.43	0.110	0.01	56	1.92
6871	114.0	2.04	0.36	0.089	<.01	47	1.06
6872	66.0	2.51	0.54	0.084	<.01	53	1.74
6873	144.0	2.01	0.65	0.084	<.01	60	0.76
6874	79.0	2.13	0.07	0.108	<.01	57	3.07
6875	178.0	2.14	0.09	0.110	<.01	80	1.49
Total	750.5	-	-	-	-	490	-
Weighted Average	-	2.02	0.36	0.099	<.01	-	2.21

TABLE 6. CONTROL ANALYSIS OF SERIES 2
CANADIAN JAVELIN CAMPAIGN

Heat No.	Metal Produced					Slag Produced	
	Wt. (lbs)	C (%)	Si (%)	S (%)	P (%)	Wt. (lbs)	Fe (%)
6876	95.0	1.15	0.120	0.110	0.015	66	2.13
6877	88.0	1.09	0.045	0.150	<.01	81	3.40
6878	102.5	0.72	0.024	0.170	<.01	65	5.70
6879	61.0	0.34	0.015	0.110	<.01	95	9.43
6880	168.5	0.72	0.028	0.250	<.01	70	5.72
6881	158.0	0.64	0.003	0.120	<.01	93	5.05
Total	673.0	-	-	-	-	470	-
Weighted Average	-	0.78	0.036	0.162	<.01	-	5.43

TABLE 7. CONTROL ANALYSIS OF SERIES 3 CANADIAN JAVELIN CAMPAIGN

Heat No.	Metal Produced					Slag Produced	
	Wt. (lbs)	C (%)	Si (%)	S (%)	P (%)	Wt. (lbs)	Fe (%)
6882	199.0	0.64	0.290	0.092	-	32	5.50
6883	124.0	0.43	0.020	0.084	<.01	46	7.40
6884	127.0	0.28	0.013	0.084	-	52	4.83
6885	135.0	0.27	0.007	0.100	<.01	80	4.30
6886	148.0	0.48	0.008	0.260*	-	96	2.81
6887	133.0	0.24	0.040	0.090	<.01	61	2.99
Total	866.0	-	-	-	-	367	-
Weighted Average	-	0.41	0.080	0.092	<.01	-	4.26

*Not included in the average

1.34, as used in the two preceding series. This reduced the sulfur content of the metal to 0.092%, which is lower than in Series 2, despite the lower carbon content.

This metal was again a good low carbon metal that could be easily refined into specification grade steel.

Series 4. Basic Open Hearth Pig Iron (Heats 6888-6901)

Detailed results for this series are shown in Table 8.

The base ratio was maintained at 1.4 and the carbon level of the metal was increased to above 3%. Only three heats were required to bring the carbon level up to 2.89%. During the remainder of heats in the series, the carbon ranged from 2.89 to 4.77%, the silica from 0.40 to 1.56%, and the sulfur from 0.025 to 0.11%. The metal produced during this series averaged 2.78% C, 0.67% Si, 0.075% S, and less than 0.01% P, and complies with the specification for basic open hearth pig iron, although the sulfur content of 0.075% is higher than the ASTM specification of 0.05%.

Series 5. Basic Open Hearth Pig Iron (Heats 6902-6911)

Table 9 shows the detailed results obtained during this series.

The base ratio of the slag wss held at 1.4 for this series, and the silicon content of the metal was increased from an average of 0.67 in Series 4 to 0.98. The metal

TABLE 8. CONTROL ANALYSIS OF SERIES 4
CANADIAN JAVELIN CAMPAIGN

Heat No.	Metal Produced Wt. (lbs)	Metal Produced C (%)	Metal Produced Si (%)	Metal Produced S (%)	Metal Produced P (%)	Slag Produced Wt. (lbs)	Slag Produced Fe (%)
6888	107.0	0.98	0.020	0.160	-	72	3.09
6889	154.0	0.93	0.058	0.092	<.01	52	3.33
6390	163.0	1.28	0.390	0.089	-	12	1.04
6891	78.0	2.89	0.160	0.100	<.01	63	1.78
6892	231.5	2.80	0.780	0.074	-	38	1.35
6893	13.5	4.77	1.590	0.030	<.01	83	0.15
6894	111.0	3.62	1.180	0.040	-	68	0.37
6895	190.5	3.58	0.860	0.050	<.01	21	1.23
6896	165.5	2.52	1.040	0.025	-	129	0.67
6897	105.5	3.78	0.400	0.068	<.01	85	0.80
6898	114.5	3.44	0.690	0.055	-	48	0.24
6899	115.5	3.28	0.570	0.070	<.01	59	0.37
6900	131.5	3.54	0.970	0.100	-	57	0.43
6901	139.5	3.72	1.000	0.089	<.01	60	1.10
Total	1820.5	-	-	-	-	847	-
Weighted Average	-	2.78	0.664	0.075	<.01	-	1.08

TABLE 9. CONTROL ANALYSIS OF SERIES 5
CANADIAN JAVELIN CAMPAIGN

Heat No.	Metal Produced					Slag Produced.	
	Wt. (lbs)	C (%)	Si (%)	S (%)	P (%)	Wt. (lbs)	Fe (%)
6902	97.0	3.94	0.88	0.060	-	104	0.45
6903	216.5	3.67	0.70	0.054	<.01	none	1.10
6904	118.0	3.88	1.49	0.020	-	76	1.02
6905	150.0	3.64	0.45	0.042	<.01	22	3.59
6906	154.0	4.02	1.61	0.014	-	21	0.83
6907	100.5	3.74	1.29	0.017	<.01	210	0.61
6908	130.5	4.26	0.76	0.025	-	116	0.67
6909	122.0	3.45	0.89	0.027	<.01	56	0.12
6910	128.5	4.38	0.64	0.030	-	62	0.18
6911	55.5	3.99	1.80	0.017	<.01	54	0.69
Total	1272.5	-	-	-	-	721	-
Weighted Average	-	3.88	0.98	0.032	<.01	-	0.67

produced during this series averaged 3.88% C, 0.98% Si, 0.032% S, and less than 0.01% P. This metal complies with both the general and ASTM specifications for basic open hearth pig iron and could be readily converted into specification grade steel by most accepted refining steel processes.

Series 6. Foundry Pig Iron
(Heats 6912-6914)

To conclude the demonstration the base ratio was decreased to 1.18 and five heats were made to demonstrate the production of foundry pig iron. Table 10 gives the detailed results for this series.

The metal produced during this series averaged 3.75% C, 1.63% Si, 0.041% S, and less than 0.01% P. This metal meets the specification for foundry pig iron and would be an excellent material for foundry purposes.

B. Metal Composition

The metals produced during this demonstration complied with the generally accepted specifications for each type of iron and would be excellent material for refining to steel by either the hot metal or cold metal route in the case of the basic open hearth pigs and low carbon-low silicon iron. It can be shown that the refining of the low carbon iron (or semi-steel) is cheaper than refining the basic open hearth pig, and that the economics of the iron smelting favor the low carbon iron. In the case of the foundry pig iron, only five heats were made because the tonnage of foundry pig iron produced is only a fraction of the basic open hearth pig iron produced.

TABLE 10. CONTROL ANALYSIS OF SERIES 6 CANADIAN JAVELIN CAMPAIGN

Heat No.	Metal Produced					Slag Produced	
	Wt. (lbs)	C (%)	Si (%)	S (%)	P (%)	Wt. (lbs)	Fe (%)
6912	170.5	3.60	1.70	0.024	-	74	0.44
6913	74.5	3.81	1.64	0.032	<.01	63	2.64
6914	166.5	3.88	1.78	0.039	-	29	1.35
6915	153.0	3.81	1.75	0.037	<.01	86	2.01
6916	90.0	3.65	0.93	0.090	-	96	0.58
Total	654.5	-	-	-	-	348	-
Weighted Average	-	3.75	1.63	0.041	<.01	-	1.34

The iron obtained met accepted specifications and would be an excellent material for foundry purposes, and could be readily produced if desired.

C. Slag Composition

Detailed analyses of the slags used in the demonstration are shown in Table 11. The base ratio varied from 1.18 to 1.42. Normal blast furnace practice requires a slag with a base ratio of at least 1.3. The slag volume requirement for the demonstration as a whole was approximately 1000 lbs. of slag per ton of metal produced. Experience at the STRATMET facilities has shown that it is possible to duplicate the results obtained at the higher base ratio and/or volumes employed at SUPI at somewhat lower base ratios and/or volumes when using the larger and more efficient furnaces. Also, feeding of the reductant to the rotary kiln, instead of to the furnace, results in a decrease in the sulfur load on the furnace since 50% of the sulfur content of the coal will be removed in the kiln. Since the sulfur in the reductant is the major source of sulfur in the charge, then this will result in a lowering in the slag volume and basicity requirements to achieve the same degree of sulfur control. Thus the excellent results achieved on the Julian concentrates, using a slag volume of 1000 lbs. per ton of metal and a base ratio of 1.2-1.4, could probably be achieved using a slag volume of 500-600 lbs. per ton of metal and a base ratio of 1.3 or less in a large commercial furnace.

D. Metal Balance

The iron balance for this demonstration is shown in Table 12. The iron accounted for exceeds that charged to the

TABLE 11. COMPOSITE SLAG ANALYSES

	Heats 6867-6881	Heats 6832-6837	Heats 6888-6911	Heats 6912-6916
Fe	3.19	4.13	1.96	2.45
SiO_2	39.77	38.00	39.26	42.92
Al_2O_3	1.89	2.13	1.81	2.16
CaO	48.90	49.87	51.14	47.89
MgO	3.09	2.95	2.82	2.04
S	.15	.10	.28	.28
Base Ratio $\frac{CaO + 1.4\ MgO}{SiO_2}$	1.34	1.42	1.40	1.18

TABLE 12. METAL BALANCE

Iron Charged

10,107 lbs. concentrates at 63.4% Fe = 6407.84 lbs. Fe

Fe Produced	Lbs. Fe Recovered			% Recovery		% Account.	% Distribution	
	Metal	Slag	Total	Metal	Slag		Metal	Slag
Heats 6867-6916	6073.66	75.07	6148.73	--	--	--	--	--
Prill*	209.00	--	209.00	--	--	--	--	--
Clean-out*	118.00	5.30	123.30	--	--	--	--	--
Total	6400.66	80.37	6481.03	99.9	1.2	101.1	98.8	1.2

*50% Fe Metal Analysis.

furnace by some 87 pounds. This may be accounted for by one or more of the following reasons:

1. Imperfect metal slag separation. Any slag adhering to the metal would be accounted for as iron.

2. Iron charged to the furnace and not accounted for, such as the iron content of the ash, of the coal or in the lime.

3. Stirring rods that melt into the furnace when the mix is stirred.

4. Possible slight inaccuracies in the weighing, sampling and analytical techniques used.

Of the iron accounted for, 98.8% is reported in the metal and 1.2% in the slag. On a large scale commercial operation an overall accountability of 99% would be anticipated with a recovery of more than 98% of the iron charged to the furnace in the metal tapped.

E. Power Consumption

Table 13 shows the observed power requirements to produce one ton of metal in the 100 KVA furnace. These figures are based on the metal tapped only and do not include metallic prill separated from the slag or iron cleaned out from the furnace at the conclusion of the demonstration, Table 14 shows the thermal balance for the smelting demonstration. The heat of formation data used in this balance were obtained from the

TABLE 13. POWER CONSUMPTION

Metal Tapped		KWH Used	Observed KWH/Ton 100 KVA Scale
lbs.	Tons		
6277	3.1385	10,160	3,237

TABLE 14. THERMAL BALANCE

		BTU/ton of metal produced
Δ H	$FeO \rightarrow Fe$	
	$Fe_2O_3 \rightarrow Fe$	
	$SiO_2 \rightarrow Si$	
	$P_2O_5 \rightarrow P$	
	$Si \rightarrow Fe_3Si$	
	$P \rightarrow Fe_3P$	
	$C \rightarrow Fe_3C$	
	$2CaO + SiO_2 \rightarrow 2CaO.SiO_2$	
		3,135,600
Hc	Metal at 1450°C	
	Slag at 1550°C	1,372,000
Total Energy Used		4,507,600
Total Energy Supplied		11,000,000
Furnace Efficiency		40.9%

literature*, and the heat contents of the products were determined in the SUPI laboratories. The overall thermal efficiency of the smelting demonstration was determined to be 40.9%. In Table 15 the observed power consumption per ton of iron produced in the 100 KVA furnace is extrapolated to the power required per ton of metal produced using the integrated Strategic-Udy Process. The efficiency in the commercial scale furnace was assumed to be 75%. Less than 1050 KWH will be required to produce one ton of iron from the Canadian Javelin concentrates by means of the Strategic-Udy Process utilizing a rotary kiln for reducing and preheating the charge to the Strategic-Udy smelter.

F. Refractories

At the conclusion of the smelting demonstration the furnace lining was examined and little or no erosion or corrosion had taken place. Magnesite or periclase refractories would probably be a satisfactory furnace lining in a commercial furnace. Numerous runs at the STRATMET facilities have been made on similar ores and in all cases magnesite or periclase linings have proven most satisfactory.

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*Elliott & Gleiser, The Thermochemistry of Steelmaking, 1960.

TABLE 15. POWER EXTRAPOLATION

To produce one ton of iron in the 100 KVA furnace with cold charging practice requires	3237 KWH
To produce one ton of iron from a cold charge in a commercial furnace with 75% efficiency would require	1770 KWH
Power savings due to 50% reduction in kiln	410 KWH
Power savings due to heat content of sinter	350 KWH
Power required to produce one ton of metal using the integrated Strategic-Udy Process is	1010 KWH

VIII. KILN REDUCTION RESULTS

A run was made to show the feasibility of reducing Canadian Javelin concentrates in the rotary kiln. The results of this demonstration are given in Table 16. These results indicate that at least a 41% reduction can be attained on Javelin concentrate with a four hour reduction treatment at 1000°C. Because of reoxidation during sampling, the above figure is believed to be very conservative and that at least a 50% reduction will be attained in the Stratmet rotary kiln.

TABLE 16. KILN REDUCTION

Kiln Charge:	100 lbs.	Julian Concentrates
	5 lbs.	Quartz
	19 lbs.	Lime
	27½ "	Coal
	151½ lbs.	Total

Kiln Loading: 13%

Retention Time	Temp. °C	Total Fe	Fe^{++}	Metal Fe	% Reduction*
0	-	63.3	0.21	-	-
1 hr.	890	47.31	31.14	1.79	25.7
2 hr.	955	47.96	39.95	nil	27.6
3 hr.	1000	50.11	41.80	4.16	35.8
4 hr.	990	53.37	39.80	8.63	40.7

* Percent removal per unit of iron of oxygen combined with the iron in the charge.

IX. REFINING OF CARBON STEEL

A. Introduction and General

After a most successful demonstration of the smelting of Canadian Javelin concentrates using the Strategic-Udy Process at SUPI in Niagara Falls, New York, some 3000 lbs. of conventional pig iron and about 3000 lbs. of low carbon iron from this operation were shipped to the plant of Strategic-Udy Metallurgy Ltd. in Niagara Falls, Ontario, for refining to carbon steel.

Two heats of steel were made and the products were specification grade SAE 1010 and 1040 steel.

Two billet sized ingots from each heat were shipped to Seaway Steel Corporation in Tonawanda, New York, for rolling. Both grades of steel were rolled to merchant flats ¼" x 1-5/8" wide. The rolled bars, together with the balance of the ingot steel, have been delivered to the Canadian Javelin authorities.

Samples of the rolled products were also sent to the Ontario Research Foundation in Toronto for determination of the tensile, yield, elongation and other physical properties.

B. Description and Results of the Refining Operation

For both heats, the pig iron and low carbon iron were charged cold to the 3-ton electric arc steelmaking furnace. The charge was roughly 3000 lbs. of metal for each heat.

Table 17A shows the charge analyses for heats 5-228 and 5-229 as well as the finished steel analyses for each.

In both heats the charge was melted down under a lime slag and blown with oxygen to a low carbon level. The oxidizing slag was then skimmed off and a reducing slag was shaped up, under which final carbon and manganese adjustments were made. A comparison of the finished steel analyses in Table 17B with the normal specifications for SAE 1010 and 1040 grades shows that the steel produced is quite acceptable in chemical analysis. It should be noted that the sulfur and phosphorus contents in the steel from heats 5-228 and 5-229 are extremely good.

The finished steel was tapped from the furnace into a 5-ton bottom-pour ladle and teemed into both 4" x 4" billet molds and 16" corrugated ingot molds.

C. Predicted Elements of Cost for Refining

Because the pig iron and low carbon iron for the refining operation were produced at SUPI, the charge to the refining furnace was necessarily cold metal. In a commercial plant, however, the pig or low carbon iron would be charged directly to the refining furnace in the molten state, and a maximum energy consumption for refining of 200 KWH per ton of steel can be forecast.

Iron recovery in the refining stage can be expected to be about 95 percent from the charge to finished steel in the ladle.

TABLE 17

A. Analyses of Charge and Refined Steel

Heat No.	Charge					Finished Steel				
	C	Si	S	P	Mn	C	Si	S	P	Mn
5-228	3.68	1.06	0.05	0.01	--	0.09	0.04	0.015	0.009	0.30
5-229	1.33	0.25	0.12	0.01	--	0.40	0.73	0.016	0.012	0.66

B. Specifications for SAE 1010 and 1040 Grades

SAE	C	S	P	Mn
1010	.08/.13	.05 max.	.04 max.	.30/.60
1040	.37/.44	.05 max.	.04 max.	.60/.90

The oxygen required per ton of steel will, of course, depend on whether pig iron or low carbon iron is to be refined. Operating data from the heats run indicate that about 1600 SCF oxygen per ton was necessary for refining the pig and about 650 SCF oxygen per ton for the low carbon iron.

The predicted elements of cost for the refining operation are given in Table 18.

D. Rolling and Mechanical Properties

As stated previously, two 4" square ingots from each heat were hot rolled by Seaway Steel Corporation in Tonawanda, New York, to ¼" x 1-5/8" flat bar.

The steel from Canadian Javelin was included in Seaway's regular rolling schedule and the operation was as routine as possible. The rolling went extremely well in the opinion of the Mill Superintendent.

The bars were cut to 10' lengths for ease of handling and were returned to Strategic-Udy Metallurgy.

One 10' length of bar from each heat was sent to Ontario Research Foundation in Toronto for mechanical testing. The results of these tests are shown in Table 19.

TABLE 18. PREDICTED ELEMENTS OF COST FOR REFINING

	Per N.T. Finished Steel	
	Pig Iron	Low Carbon Iron
Metallic Charge	1.08 N.T.	1.05 N.T.
Burnt Lime	150 lb.	200 lb.
Coke Breeze	10 lb.	10 lb.
Fluorspar	10 lb.	10 lb.
Ferrosilicon	15 lb.	15 lb.
Ferromanganese*	14 lb.	14 lb.
Oxygen	1600 SCF	650 SCF
Aluminum	2 lb.	2 lb.
Oxygen lance-pipe	10 ft.	3 ft.
Energy	200 KWH	200 KWH
Electrode	5 lb.	5 lb.
Dolomite (patch)	20 lb.	20 lb.
Roof and Ladle Brick	25 lb.	15 lb.

Other elements of cost, such as laboratory, stopper rods, labor and supervision, maintenance, continuous casting or teeming, and general works expense depend to a very large degree upon the size of the operation.

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*For normal structural grades.

TABLE 19

A. Results of Mechanical Tests (As Rolled)

Heat No.	5-228	5-229
Grade	SAE 1010	SAE 1040
Yield Strength, psi	44,800	62,400
Ultimate Tensile Strength, psi	50,300	96,300
% Elongation in 2"	43.5	24
% Reduction in Area	78	52.5
180° Bend	no cracking	no cracking

B. Normal Mechanical Properties (As Rolled)

Grade	1010	1040
Yield Strength	30,000 psi	52,000 psi
Ultimate Tensile Strength	48,000 psi	85,000 psi
% Elongation in 2"	38%	25%
% Reduction in Area	73%	40%

X. CONCLUSIONS

The smelting of Canadian Javelin's Julian concentrates by the Strategic-Udy Process was successfully made. The following metallic products were produced:

A. Three different grades of low carbon, low silicon iron (semi-steel).

B. Basic open hearth pig iron.

C. Foundry grade pig iron.

It is forecast that less than 1050 KWH would be required to produce one ton of metal by the integrated Strategic-Udy Process.

It is estimated that coal requirements (based on 79% fixed carbon) will not be over 870 lbs. per short ton of metal. This need not be a special coal. Steam coals and even lignites are usable in this process.

It is estimated that less than 1000 lbs. of limestone would be required to produce one ton of metal, depending on the sulfur content of the reductant.

A reduction demonstration in the batch rotary kiln indicates that at least 50% prereduction will be possible in a rotary kiln when using the integrated Strategic-Udy Process.

The metal produced during the smelting demonstration was refined to SAE grade 1010 and 1040 steels and then rolled in a merchant mill. The results of the refining, rolling and mechanical testing leave no doubt that either the pig iron or the low carbon iron produced from the Canadian Javelin coarse concentrate by the Strategic-Udy Process can be cheaply refined to a normal carbon steel. Both the high and low carbon structural grades produced rolled easily and presented no problems in the merchant mill. The physical properties of the as-rolled bar were better than normal.

APPENDIX

THE STRATEGIC-UDY SMELTING PROCESS

The Strategic-Udy Processes are based essentially upon the patented processes of Dr. Marvin J. Udy. The smelting process has been described in detail in the technical press*. The first technical paper on the subject was presented by Dr's. M. J. and M. C. Udy at the Electric Furnace Conference of the AIME in 1958. A paper describing the more recent developments in the process was presented by Dr. M. C. Udy at the 1959 conference of the same society. Copies of all technical papers are available upon request.

Briefly, the process in its present modification involves the use of specialized kiln and electric furnace techniques in which the chemical reactions are carefully, yet efficiently, controlled. The kiln is used to remove sulfur and volatiles from the ore and coal, and to heat and prereduce the charge with inexpensive coal and electric furnace off-gases.

The electric furnace completes the reduction and produces molten metal and slag. In this furnace special techniques allow the successful use of the hot prereduced calcine from the kiln. These techniques also result in a control of metal and slag compositions not attainable by other smelting processes.

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*See references at end of report.

The specialized smelting practice employed by Strategic-Udy is shown in Figure 2. In comparison with submerged arc electric practice, the Strategic-Udy technique positions the electrodes at the surface of the slag, thus effectively eliminating the arc. The charge rate is such that the electrodes are not covered by burden. Thus, gases are free to escape and the use of any type of hot charge in any particle size range becomes feasible.

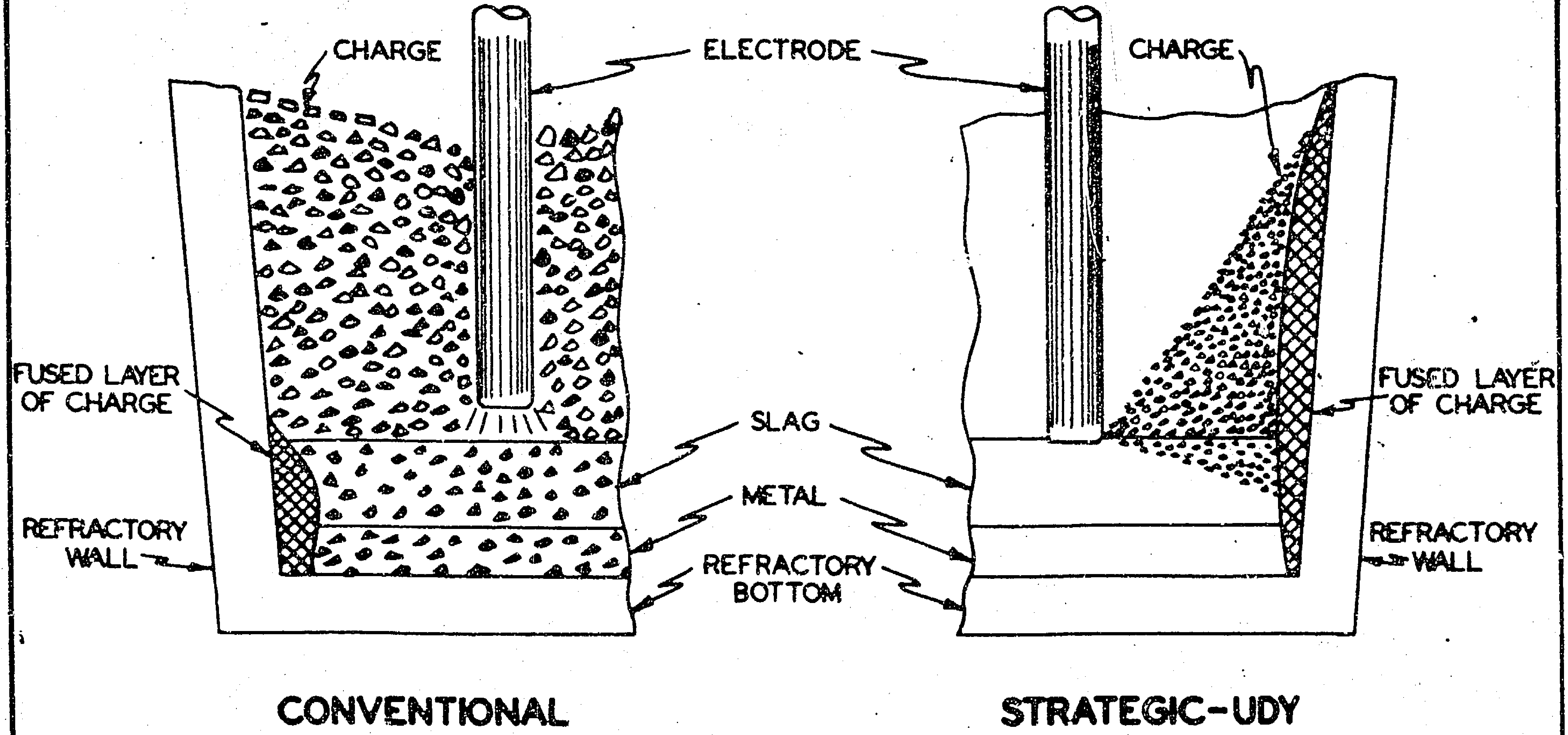
The advantages of the Strategic-Udy Process may be summed up as follows:

1. Low cost coals can be used to provide a large part of the energy required for reduction instead of high cost electrical energy. This means that in the case of an iron ore the electrical power requirements are cut in half, and in the case of ferroalloys a significant reduction in power requirements is achieved.

2. Inexpensive and often local sources of carbon can be used as reductants instead of expensive metallurgical coke. Typically, soft coals with volatile contents as high as 50% have been used. Lignite works well, so also do charcoals and other low volatile carbonaceous products. The choice is an economic rather than technical one.

3. Excellent metallurgical control is achieved and thus impurities present in the charge can be controlled without presenting undue problems. This allows commercialization of many now dormant off-grade ore bodies.

COMPARISON OF ELECTRODE ENVIRONMENT



STRATEGIC-UDY PROCESSES, INC.
DATE 3-17-60

FIGURE 2

4. The grade of the ore is not critical. Both high-grade and many low-grade ores can be treated to produce marketable products. This allows commercialization of many low-grade ore bodies without expensive concentration.

5. Size of the ore or other feed is not critical. Fines are desired. Thus, many raw materials not suitable for the blast furnace or Tysland-Hole smelting can be used without sintering or other agglomeration.

6. The process has a great degree of inherent flexibility with regard to the type of ore used and type of products produced. Changes made in operating technique or charge can be made in a minimum of time.

7. Some ores can be smelted which are not too capable of being treated to maximum economic advantage with other types of processes. Thus an iron-manganese ore which previously could only be smelted to spiegel and ferromanganese can now be smelted to a low manganese iron and ferromanganese, thus achieving the maximum recovery of manganese in the highest valued product.

8. Capital and operating costs are low; small capacity plants are often economically feasible.

TECHNICAL PUBLICATIONS ON THE STRATEGIC-UDY SMELTING PROCESS

1. M. J. Udy and M. C. Udy, "A New Direct Reduction Method", Metal Progress, Vol. 74, December, 1958.

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3. M. J. Udy, "Manganese", Mines Magazine, Vol. 49, March, 1959, pg. 26-31.

4. M. J. Udy and M. C. Udy, "Selective Smelting of Lateritic Ores", Journal of Metals (U.S.) Vol. 11, No. 5, pg. 311-314, May, 1959.

5. F. Senior, "The Strategic-Udy Process; Universal Smelting", paper presented to Metallurgical Society AIME, November 3, 1959. To be published in AIME transactions.

6. M. J. Udy and R. A. Blackburn, "The Strategic-Udy Direct Iron Reduction Process", Iron and Steel Engineer, November, 1959.

7. M. C. Udy, "Recent Developments in Strategic-Udy Smelting Processes", Electric Furnace Proceedings, AIME, Vol. 17, pg. 301-315, 1959.

8. M. C. Udy, "The Strategic-Udy Process for Smelting Iron Ores", paper presented at Electrochemical Society Spring Meeting, Chicago, May 1-5, 1960. To be published in Trans, Electrochemical Society.