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SMELTING OF TASMANIAN
SAVAGE RIVER MAGNETITE ORE

By

THE STRATEGIC-UDY PROCESS

Report To

INDUSTRIAL & MINING INVESTIGATIONS, Ltd.
Sydney, Australia

14 December 1961

OPEN FILE

By

L. E. Olds, D. Jurden and M. C. Udy

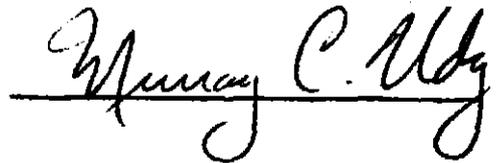
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Strategic-Udy Processes, Inc.
Niagara Falls, New York

INTER OFFICE MEMOFrom Murray C. UdyDate 15 December 1961To R. W. VollmerRe Tasmanian
Savage River Report

Here is the report of our recent 100 KVA smelting demonstration on Tasmanian Savage River magnetite ore. The ore is entirely suitable for Strategic-Udy smelting to produce a low carbon pig iron. No problems were encountered from the sulfur, titanium, or vanadium contaminants. In fact, there may be a potential vanadium by-product credit. Power requirements are nominal.

Sufficient copies are coming by separate mail for distribution by your office.

A handwritten signature in cursive script, reading "Murray C. Udy", is written over a horizontal line.

Murray C. Udy:B

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I. SUMMARY

In October 1961 some four and one-half tons of Tasmanian Savage River magnetite ore were smelted in Strategic-Udy's 100 KVA furnace. The objective of this campaign was to demonstrate that, by use of the Strategic-Udy smelting technique, a low carbon pig iron that is low in residual titanium and vanadium could be produced from the Savage River ore.

The ore for the demonstration was taken from the bulk sample of the Adit 8 underground ore (58.2% Fe). The ore was diluted before smelting so that it would represent a 55.5% Fe calcined concentrate.

The demonstration was in three parts, each part simulating a portion of the integrated Strategic-Udy Process. The first part, calcination to remove sulfur, takes place in the upper part (oxidizing zone) of a Strategic-Udy kiln, or may be done in a separate kiln if economics dictate. All the ore to be smelted received this treatment. The second part, prereduction, to remove oxygen and thereby lower furnace power requirements, is done in the lower part (reducing zone) of a Strategic-Udy kiln. Only batches of the ore were so treated in the demonstration, the bulk of the ore being smelted from the cold, unreduced condition. The actual electric furnace smelting was the third part of the demonstration. This material was calcined to an average sulfur content of 0.21%. During the calcination it was demonstrated that under optimum kiln conditions, sulfur contents as low as 0.03% could be attained at a kiln temperature of 1050°C.

A separate demonstration was made on the reducibility of the Savage River ore by the Cornwall coal in a rotary kiln. It was shown that over a 50% reduction can be expected with these materials.

The calcined ore was blended with a high titania slag and Savage River country rock (12% iron) to adjust the titania content to 2% and the iron content to represent a 55.5% iron concentrate (after calcination).

During the various stages of the campaign three general grades of pig iron were produced with the following analyses:

	C	Si	S	P	Ti	V
(1)	1.0	0.03	0.27	0.13	<0.01	0.05
(2)	1.5	0.25	0.25	0.15	<0.02	<0.1
(3)	2.5	0.45	0.20	0.20	<0.05	<0.4

*Reduced to 0.024 in steel (Pus)
0.05-0.1 analysis.*

see next page.

0.024 in final steel (Pus)

Although the higher carbon contents were not demonstrated, there should be little difficulty in producing pig irons containing up to 3.5% C. However, the titanium and vanadium contents would, of course, be higher.

In all instances the metal produced in the 100 KVA campaign was low in residual titanium and vanadium and would present no problems in refining. To demonstrate this

ease of refining, all of the metal produced in the entire campaign was refined in a three ton oxygen-electric furnace producing a 1030 grade of carbon steel with the following analysis:

C	-	0.30	P	-	.024
Si	-	0.29	Mn	-	.54
S	-	0.04	Ti	-	.002
			V	-	.005

Power and raw materials consumption will be low. Power consumption will be about 1000 to 1100 KWH per net ton of pig iron.

If desired, the slag can be made to contain up to 2% vanadium. However, the quantity of slag produced per ton of pig iron will depend on the analyses of the final concentrate selected for smelting.

II. RECOMMENDATIONS

Mr. E. R. Hudson, in his visit to SUPI-SUMAC, outlined his program for the development of the Tasmanian integrated steel facility as follows:

Stage I

Preliminary geological work to delineate the overall dimensions of the deposit followed by a demonstration to prove the technical feasibility of the Strategic-Udy Process to handle the contaminated ores. In conjunction with this program, a preliminary market study to provide order of magnitude figures.

Stage II

Detailed market study, diamond drilling campaign to prove out the minimum ore resources required for a 500,000 ton per year integrated steel facility followed by technical and economic feasibility studies including harbor development, preliminary engineering. Development of a financing procedure for the financing stage to follow.

Stage III

The financing, construction and operation of the integrated facility.

With the completion of the very successful 100 KVA demonstration described in this report, Stage I nears completion. As a result, we recommend the following:

- (1) A study be undertaken to determine the most economic grade of concentrate for use in the Strategic-Udy Process.
- (2) A large scale (500 tons of concentrate) prototype plant demonstration be made in the SUMAC* facilities. This demonstration will provide the necessary engineering data for a commercial plant and for accurate cost estimates. It would involve the following:
 - (a) The prereduction and heating of the furnace charge in a rotary kiln.
 - (b) 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.
 - (c) 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.
- (3) Start Stage II including feasibility study by Koppers.

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

III. INTRODUCTION

The Industrial & Mining Investigations Pty. Ltd. is interested in smelting the Savage River iron ores near Corinna, Tasmania. These ores are generally high sulfur magnetites contaminated with from 1 to 2% titania. While the sulfur is easily removed by magnetic concentration at about a minus 18 mesh size, the titania is so disseminated that less than half can be eliminated by magnetic concentration at a 200 mesh size. As a result, the Savage River ores have been considered to be generally unsuited for smelting by conventional processes. // *Much less*

Early in 1961 the Industrial & Mining Investigations Pty. Ltd. became interested in the Strategic-Udy Smelting Process because of its ability to selectively smelt such contaminated ores as the Savage River deposits. Arrangements were made in August 1961 for a small scale demonstration of the Strategic-Udy Process, primarily to demonstrate that low residual pig iron can be easily produced from these ores. For this demonstration some 28 tons of various grades of Savage River ore and country rock and 2 tons of Cornwall coal were sent to SUPI* and processed into pig iron in the period from October 16 to **November 3.**

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

The smelting demonstration was observed in progress by the following:

Mr. E. R. Hudson, Managing Director
Industrial & Mining Investigations Pty. Ltd.

Mr. W. St.C. Manson, Tasmanian State Government
Department of Mines

Mr. J. E. Ridgway, Senior Geologist
Industrial & Mining Investigations Pty. Ltd.

The results of this most successful demonstration are given in this report.

IV. RAW MATERIALS

Preliminary exploration and concentration studies of the Savage River deposits have been completed by the Tasmanian Department of Mines*. These studies have been based on the results of ten drill holes and a 60 foot deep adit.

The ore body consists of relatively rich lenses varying from 42% to 52% iron separated by low grade and more or less weathered amphibolites varying from barren country rock to 30% iron. Most of the surface ore in the lenses has been oxidized to give iron contents in excess of 60% and low sulfur contents.

A review and summary of the Tasmanian Bureau of Mines work on magnetic concentration of this ore has been made by Strategic's Ottawa Stratmat office**. In brief, sulfur and phosphorus are easily removed by magnetic concentration at a size of about 60 mesh. However, the titania is finely disseminated and cannot be eliminated, even at a minus 200 mesh grind.

Samples of both surface ore and underground ore, as well as barren country rock, were supplied for the SUPI demonstration. These materials were crushed to minus $\frac{1}{4}$ inch, sampled by riffing, and analyzed. Analyses of the surface ores are given in Table 1 and of the underground ores taken from the adit in Table 2. The principal difference between

* See Tasmanian Department of Mines Technical Reports.

**Letter report by J. R. Mowat, August 23, 1961

TABLE 1. ANALYSES OF SAVAGE RIVER
SURFACE ORES SENT TO SUPI

	Surface Ore Crushed Before Shipping	Uncrushed Surface Ore			
		S2U	S3U	S4U	S7U
		<u>Percent</u>			
Fe	60.5	62.5	62.5	61.2	64.2
Fe ⁺⁺	4.72	6.1	8.3	5.3	17.1
SiO ₂	3.41	-	-	2.34	-
Al ₂ O ₃	1.18	-	-	0.98	-
CaO	1.34	-	-	1.08	-
MgO	0.01	-	-	0.51	-
S	0.056	0.067	0.050	0.070	0.075
P	0.087	0.074	0.070	0.087	0.072
TiO ₂	0.38	0.18	0.18	0.30	0.27
V	0.44	0.47	0.46	0.45	0.47
H ₂ O	3.98	2.72	4.41	4.16	1.02
L.O.I.*	4.02	3.44	2.81	3.64	3.14
		<u>Pounds</u>			
Amount of Ore Received	14,364	750	753	7,673	720

*Determined on dried sample.

TABLE 2. ANALYSES OF SAVAGE RIVER
ADIT ORES SENT TO SUPI

	Blended Ore Ex D Adit Ore							
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
	<u>Percent</u>							
Fe	55.9	53.7	51.1	51.4	62.1	50.1	57.6	57.4
Fe++	11.3	11.2	10.9	10.8	13.9	11.3	12.8	10.95
SiO ₂	-	-	-	-	-	-	-	3.84
Al ₂ O ₃	-	-	-	-	-	-	-	1.55
CaO	-	-	-	-	-	-	-	0.29
MgO	-	-	-	-	-	-	-	3.08
S	4.07	4.10	3.75	4.04	4.05	4.35	3.83	4.95
P	0.17	0.22	0.21	0.27	0.075	0.23	-	0.12
TiO ₂	0.28	0.30	0.30	0.37	0.22	0.43	0.27	0.29
V	0.50	0.45	0.46	0.44	0.50	0.43	0.50	0.47
H ₂ O	3.75	4.57	5.38	4.79	3.59	4.70	4.68	3.69
L.O.I.*	4.31	6.48	6.60	5.97	2.37	6.49	4.52	3.64
	<u>Pounds</u>							
Amount of Ore Received	1,630	1,708	1,545	2,480	2,392	2,227	744	17,694

*Determined on dried sample.

these two types of materials is in the sulfur and iron contents. The surface ores were inferred to represent a typical 18 to 60 mesh magnetic concentrate except for the absence of titania contamination. The adit ores, ranging from 50 to 62% Fe and 3.8 to 4.95% sulfur, would represent approximately a 1/8 inch to 18 mesh magnetic concentrate again, except for the lack of titania contamination.

It was desired that SUPI determine a grade of concentrate suitable for the Strategic-Udy Process and blend the various ores together to simulate such a concentrate. Accordingly, it was decided to base the smelting campaign upon calcined Adit No. 8 ore diluted to a 55% Fe content after calcining by Savage River country rock. The most economical grade of concentrate to be used in the commercial plant can, of course, only be determined by a review of all economic parameters involved. It is recommended that such a study be made.

Because of the low titania content in the ores sent for the demonstration, a 39% titania slag was used to raise the titania in the furnace feed to the 2% level.

The analyses of the ores and of the final ore blend used in the SUPI demonstration are given in Table 3A.

The SUPI analyses indicate that as much as $\frac{1}{2}\%$ vanadium is present in the Savage River ore. This is sufficiently high that the vanadium could be concentrated in the slag and recovered as a by-product if desired.

TABLE 3. ANALYSES OF RAW MATERIALS USED
IN SUPI CAMPAIGN ON SAVAGE RIVER ORE

A. Ores

	Savage River Adit No. 8		Country Rock	Titania Slag from SUPI Stockpile	Calculated Analyses of Ore Blend*
	As Rec'd	Cal- cined			
				<u>Percent</u>	
Fe	57.4	64.33	12.16	8.65	55.7
Fe ⁺⁺	10.95	10.87	2.98	-	9.48
SiO ₂	3.84	3.99	46.14	17.35	9.78
Al ₂ O ₃	1.55	1.17	15.18	10.76	3.28
CaO	0.29	0.22	5.21	3.51	0.97
MgO	3.08	3.11	4.75	15.00	3.68
S	4.95	0.21	0.092	0.045	0.18
P	0.12	0.13	0.058	0.03	0.12
TiO ₂	0.29	0.36	1.69	39.60	1.99
V	0.47	0.49	0.04	0.87	0.44
Mn	-	-	-	2.28	0.07
H ₂ O	3.69	-	5.72	-	0.65
L.O.I.**	3.64	-	3.70	-	-
G.O.I.	-	1.18	-	-	-

*Charge: 100# Adit 8, 15# Country Rock, 4 $\frac{1}{2}$ # Slag

**Determined on dried sample.

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The analyses of the reductant and flux used in the demonstration are given in Tables 3B and 3C.

Screen size distribution of the Savage River ore and Cornwall coal are given in Table 4.

TABLE 3.(continued) ANALYSES OF RAW MATERIALS USED
IN SUPI CAMPAIGN ON SAVAGE RIVER ORE

B. Reductants

	Cornwall Coal
F.C.	51.84
V.M.	25.58
Ash	18.84
H ₂ O	3.74
S	0.44
P	0.007
Ash Analysis	
Fe	3.75
SiO ₂	56.60
Al ₂ O ₃	33.07
CaO	2.10
MgO	0.71

C. Fluxes

	Lime
L.O.I.	3.22
SiO ₂	0.90

TABLE 4. SCREEN SIZE OF SAVAGE RIVER ORE
AND CORNWALL COAL

(Percent Retained on Each Screen)

Tyler Screen	Ex D Adit No. 8 As Received	Country Rock	Cornwall Coal
3/4"	--	11	--
1/2"	14	35	8
3.5	29	25	44
6	10	8	19
14	15	9	24
28	8	4	3
65	13	3	1
100	8	1½	1
200	2	1½	< 1
-200	1	2	< 1
Density lbs/c.f.	157.5	94.5	51

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V. EQUIPMENT

The equipment used in the demonstration consisted of a 20" x 20' gas fired rotary kiln used for calcination, a 3' x 5' rotary batch kiln used for prereduction studies, and a 100 KVA electric smelting furnace.

The 20" x 20' rotary kiln is shown in Figure 1.

The 5' rotary batch kiln is shown in Figure 2. This kiln was used for prereduction studies. It is lined with firebrick and has an interior capacity of 28.8 cubic feet.

The SUPI 100 KVA iron smelting furnace is shown in Figure 3, and is lined with magnesia bricks. The roof is made with high alumina ramming mix. The furnace is fed manually through four inch diameter holes in the roof.

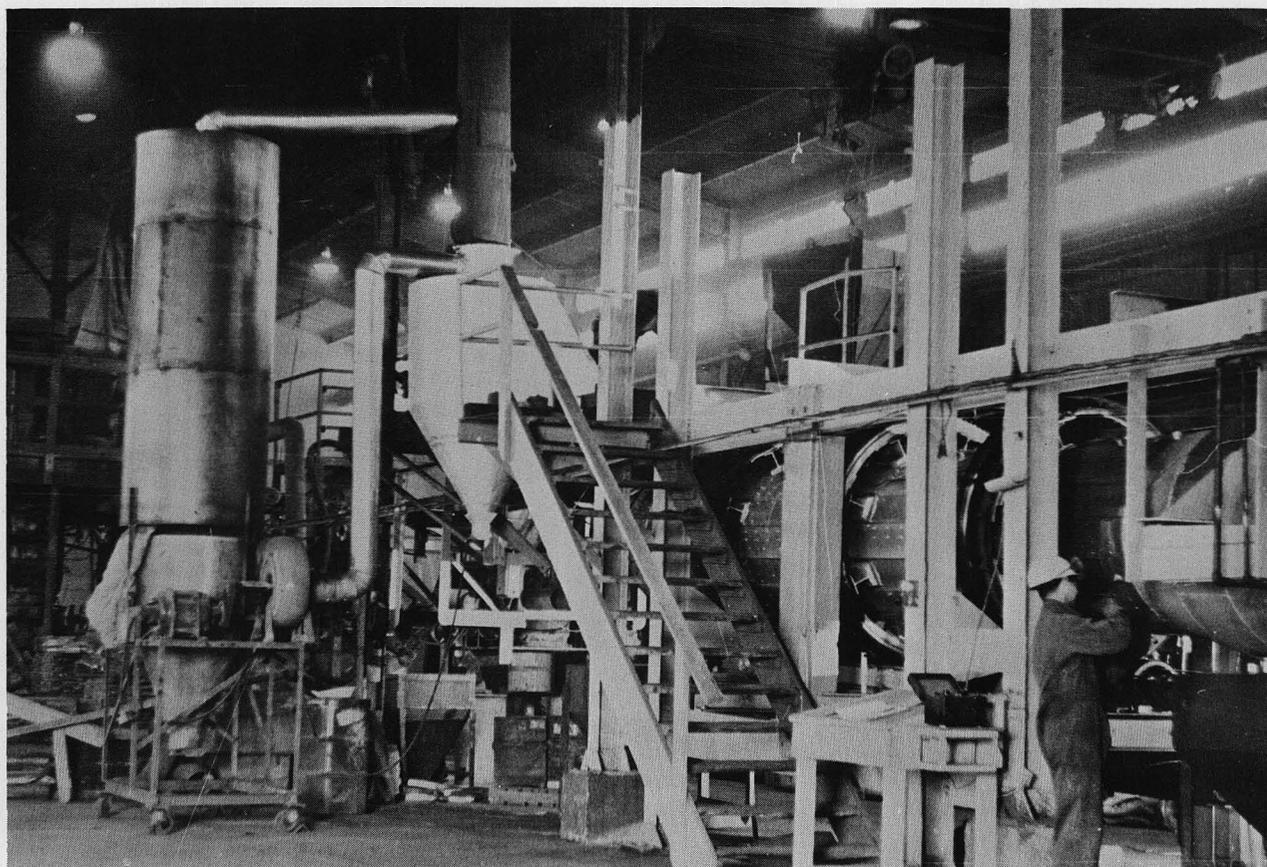


Figure 1 - 20 FOOT ROTARY KILN AT SUPI

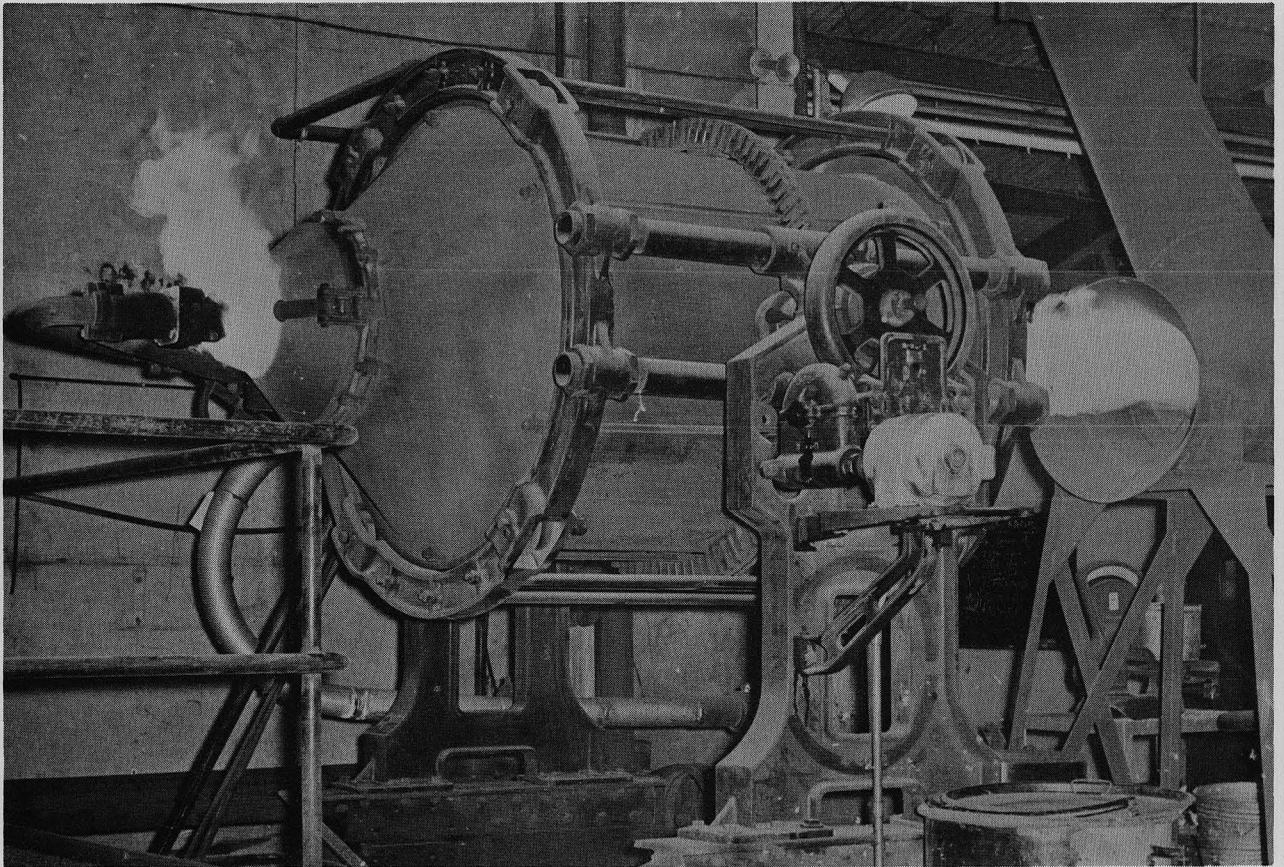


Figure 2 - 5 FOOT ROTARY BATCH KILN AT SUPI

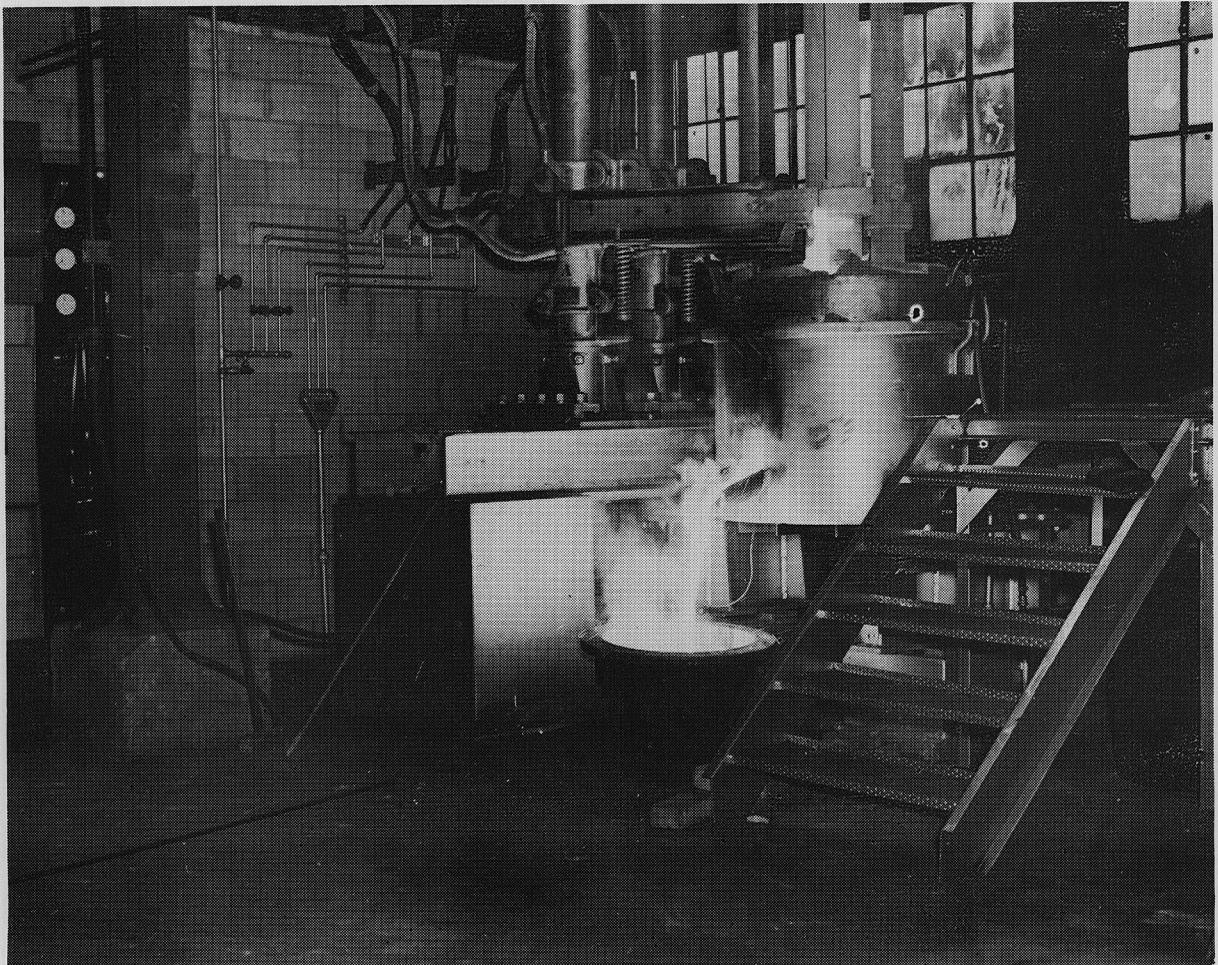


Figure 3 - 100 KVA FURNACE AT SUPI

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 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.

Accordingly, the demonstration on the Savage River iron ores was divided into three operations as follows:

- A. Calcination of each individual ore primarily to reduce the sulfur content.
- B. A separate kiln reducibility demonstration to indicate the amenability of the Savage River ore to reduction in a Strategic-Udy kiln using the Cornwall coal.
- C. Smelting of the calcined ore into low and medium carbon grades of pig iron.

A. Calcination

Calcination was performed in the SUPI 20' gas fired kiln. The conditions in this kiln approximate the oxidizing atmosphere and temperature attained in the upper half of a Strategic-Udy reduction kiln.

B. Kiln Reduction Demonstration

The SUPI rotary batch kiln approximates the atmosphere and temperature attained in the lower half of a Strategic-Udy reduction kiln.

The loaded kiln was brought to temperature, the coal was added and samples were taken at intervals and analyzed in order to determine amount of oxygen removed from the iron. This value divided by the amount of oxygen associated with the iron in the original sample is expressed as the percent reduction attained.

C. Smelting in the 100 KVA Furnace

Smelting was done on a continuous 24 hour per day basis. Each heat was approximately $2\frac{1}{2}$ hours long. To insure accuracy for the small scale demonstration the ore blend was made separately for each heat. The cold, calcined ore, flux and reductant were mixed 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.

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 according to series. The composited slags were crushed to $-\frac{1}{4}$ " and a sample was riffled out for analysis.

VII. ROTARY KILN DEMONSTRATIONS

A. Calcination in Continuous Rotary Kiln

The Adit No. 8 ore was dried in a pan drier and then processed in the 20 foot, gas fired rotary kiln to remove sulfur before furnacing. Oxidizing conditions in the kiln were kept as high as possible while maintaining a temperature of from 1050 to 1100°C. Limiting conditions were as follows:

Feed Rate lbs/hr.	Maximum Air/Gas Ratio	Maximum Temperature C	Sulfur in Calcine, %	% Removal of Sulfur
220	12.4	1090	0.03	99.4
220	12.8	1060	0.05	99.0
420	12.0	1050	0.12	97.5

Although this work demonstrates that very low sulfur values can be easily attained by roasting the $-\frac{1}{2}$ inch ore containing 4.95% sulfur in a rotary kiln, it may not be possible to realize such high desulfurization in a combination oxidation-reduction kiln. It would be more desirable to either remove the sulfur by concentration or to utilize a second kiln to roast out sulfur before the ore is charged to the reduction kiln.

C. Kiln Reduction in Batch Rotary Furnace

A run was made in the batch rotary furnace to demonstrate the feasibility of reducing the Savage River ores in a rotary kiln using Cornwall coal as the reductant. This batch rotary furnace approximates the hot reduction zone in a commercial kiln.

As shown in Figure 4, the Savage River ore can attain a high degree of prereduction, as high as 70% removal of oxygen from the iron in a four hour period. On the basis of these data the power consumption observed during the SUPI smelting campaign was projected, assuming a 50% prereduction in the rotary kiln.

✓
3 1/2 hours

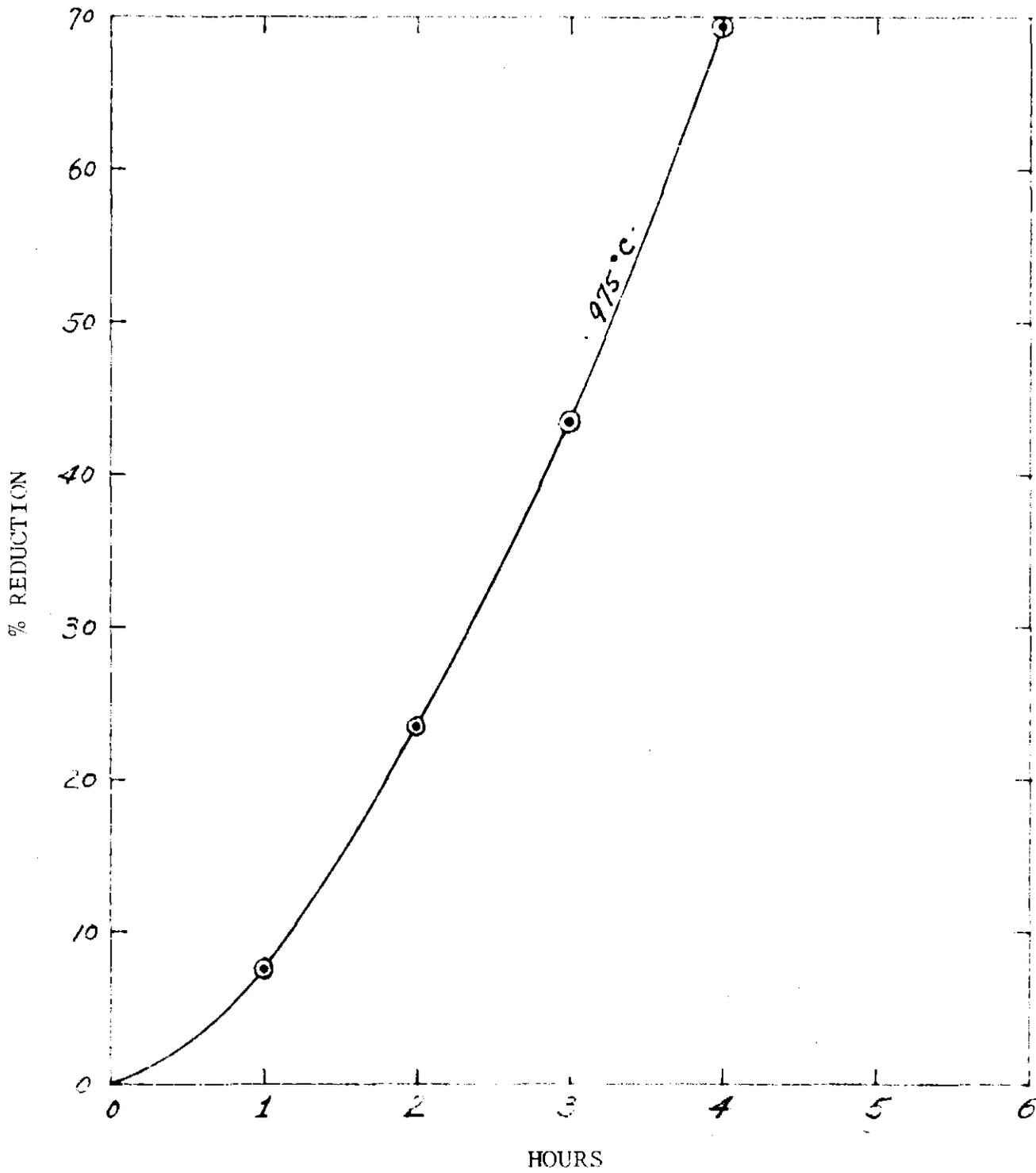


Fig. 4. KILN REDUCTION OF SAVAGE RIVER
MAGNETITE ORE, USING CORNWALL COAL

VIII. RESULTS OF SMELTING DEMONSTRATION

A. Description of Heats

The smelting campaign, consisting of some 45 heats, was made in the five day period from 23 October through 27 October 1961. The campaign was divided into four smelting series, according to metal compositions produced. A summary of the average compositions of metal and slag produced in each series is given in Table 5 and the materials summary for the campaign in Table 6. Detailed discussion of each series of heats follows:

Series 1 - Smelting of Unfluxed Ore (Heats 7761-7763)

The first three heats in the campaign were used to briefly demonstrate that the $\frac{1}{2}\%$ vanadium in the ore could be concentrated in the slag. The charge was smelted without fluxing and consisted of only Adit 8 ore, TiO_2 slag, and Cornwall coal. Under such conditions, the slag would contain over 2% vanadium if no vanadium were reduced.

The slag melted well and there was no refractory attack from the slag. A deficiency of coal was charged to hold 8% iron in the slag.

As shown in Table 7, most of the vanadium and titanium contents of the metal were very low, .06% and .002% respectively. The vanadium in the slag reached 2.04%. This

TABLE 5. SUMMARY OF COMPOSITIONS PRODUCED IN EACH SERIES

100 KVA Savage River Ore Campaign
 (Based on Arithmetic Averages of Control Analyses)

Tasmanian Ore		Metal					Slag		
Series	C	Si	S	P	Ti	V	Fe	TiO ₂	V*
1. <u>Unfluxed Ore - High Vanadium Slag</u> Avg. of 3 Heats	.75	.023	.25	.12	.002	.06	9.42	9.38	1.91
2. <u>Fluxed Ore - Low Residual Metal</u>									
A. Avg. of 2 Heats	0.91	.024	.27	.17	.01	.05	4.84		
E. Avg. of 7 Heats	1.37	.027	.28	.13	.007	.06	4.44	6.25	0.98
C. Avg. of 5 Heats	2.45	.38	.22	.17	.005	.058	3.00		
3. <u>Fluxed Ore - Vanadium in Metal</u>									
A. Avg. of 7 Heats	2.22	.33	.26	.18	.049	.44	1.88	6.05	0.64
B. Avg. of 12 Heats	1.94	.17	.23	.13	.013	.154	3.84	5.84	0.90
4. <u>Unfluxed Ore -</u>									
A. Avg. of 7 Heats	2.13	0.27	0.21	0.13	0.018	0.25	3.62	10.53	1.04
B. Avg. of 3 Heats	1.84	0.24	0.23	0.17	0.011	0.35	2.19	11.57	1.52**
Overall Campaign Weighted Average For 45 Heats	1.83	0.18	0.23	0.14	0.016	0.22	3.63	--	--

* Analyses from slag composite

** Avg. of control analyses

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TABLE 6. MATERIAL SUMMARY FOR 100 KVA FURNACE
CAMPAIGN ON SAVAGE RIVER ORE

	Weight Pounds						
	Input					Output	
	Adit No. 8 Calcine	Country Rock	TiO ₂ Slag	Lime	Cornwall Coal	Metal	Slag
Series 1	400	--	18	--	143	162	56
Series 2	3000	420	135	406	1195	1669	1049
Series 3	3800	570	171	551	1502	2496	1618
Series 4	2000	--	90	--	736	1696	356
Salamander Clean-Out	--	--	--	--	--	305	47
Total	9200	990	414	957	3576	6328	3226
						Slag to Metal ratio for entire campaign = 0.51	

TABLE 7. CONTROL ANALYSES FOR SERIES 1
TASMANIAN SAVAGE RIVER CAMPAIGN
(Unfluxed Ore - High Vanadium Slags)

Heat No.	Metal Produced							Slag Produced		
	Wt. (lbs)	% C	% Si	% S	% P	% V	% Ti	Wt. (lbs)	% Fe	% V
Series 1										
7761	-	-	-	-	-	-	-	-		
7762	162	0.76	0.026	0.29	0.13	0.06	0.003	56	7.97	2.04
7763	199	0.73	0.020	0.20	0.11	0.06	0.0015	19	10.87	
Arith. Average	-	0.75	0.023	0.25	0.12	0.06	0.002	-	9.42	2.04

is sufficiently high that the slag might be treated profitably for vanadium. A complete analysis of these slags will be given later in Table 11.

Series 2 - Smelting of Fluxed Ore Producing Low Residual Metal
(Heats 7764-7777)

At the end of Heat 7763, an additive of Savage River country rock was used to simulate the lower grade of concentrate described in Section IV. Burnt lime was added to give an intended base ratio* of 1.4 and a slag to metal weight ratio of approximately 0.7. However, the base ratio of the Series 2 composite slags was only 1.26 because of dilution by the slag remaining in the furnace from Series 1. The amount of carbon in the charge was increased slightly as Series 2 progressed in order to produce low residual metal of several carbon contents.

Detailed analyses for each heat in this series are given in Table 8.

In the first two heats of the Series (2A), a low carbon pig iron containing 0.91% carbon was produced. Silicon, vanadium, and titanium were all very low. Because of the low base ratio, there was little change in sulfur content over the metals produced from the acid slag in Series 1.

In the next seven heats (2B), a slight increase in carbon in the charge raised the carbon content of the metal to the $1\frac{1}{2}\%$ level. Residual vanadium, titanium, and silicon contents remained low (0.06%, 0.007%, and 0.27% respectively). Sulfur and phosphorus averaged 0.28% and 0.13% respectively.

* $(\text{CaO} + 1.4 \text{ MgO})/\text{SiO}_2$

TABLE 8. CONTROL ANALYSES FOR SERIES 2
TASMANIAN SAVAGE RIVER CAMPAIGN
 (Fluxed Ore - Low Residual Metal)

Heat No.	Metal Produced							Slag Produced		
	Wt. (lbs)	% C	% Si	% S	% P	% V	% Ti	Wt. (lbs)	% Fe	% V
Series 2A										
7764	51	0.93	0.025	0.27	0.16	0.05	0.01	93	6.56	-
7765	128	0.89	0.023	0.28	0.18	-	-	79	3.12	-
Arith. Average	-	0.91	0.024	0.27	0.17	0.05	0.001	-	4.84	-
Series 2B										
7766	83	1.19	0.025	0.26	0.13	0.100	0.015	63	4.60	-
7767	184	1.25	0.029	0.24	0.12	-	-	84	1.81	-
7768	77	0.91	0.014	0.32	0.13	0.030	0.007	66	6.49	-
7769	90	1.10	0.016	0.24	0.16	-	-	74	4.37	-
7770	136	1.52	0.023	0.30	0.16	0.058	0.0025	80	4.41	1.13
7771	120	1.88	0.040	0.30	0.15	-	-	79	3.03	-
7772	144	1.77	0.039	0.27	0.093	0.050	0.0025	95	6.36	-
Arith. Average	-	1.37	0.027	0.28	0.13	0.060	0.007	-	4.44	1.13
Series 2C										
7773	25	2.64	0.43	0.22	0.20	0.050	0.003	69	2.34	-
7774	192	1.99	0.28	0.23	0.11	0.050	0.004	99	2.86	-
7775	58	2.62	0.50	0.22	0.22	-	-	86	3.13	-
7776	93	2.55	0.43	0.22	0.18	0.065	0.006	81	3.31	-
7777	89	2.44	0.24	0.21	0.12	-	-	82	3.37	-
Arith. Average	-	2.45	0.38	0.22	0.17	0.058	0.005	-	3.00	-

For the next group of heats (2C), the furnace had approached thermal equilibrium and the carbon efficiency increased, raising the carbon in the metal to the $2\frac{1}{2}\%$ level. The vanadium and titanium remained low, while the silicon increased slightly to 0.38%. The effects of the residual Series 1 slag were finally eliminated by this time and the sulfur decreased slightly to an average of 0.22%. Increasing the slag volume and basicity would allow a greater elimination of sulfur.

Series 2 demonstrates effectively the selectivity in the Strategic-Udy Smelting Process. By carefully controlling the amount of carbon in the charge, very low levels of residual elements may be attained in the metal. In the case of the Savage River ore, this selectivity is attained while leaving as little as 4 to 5% iron in the slag. The irons produced in this Series could be refined into specification grade steel products following standard procedures.

Series 3

Smelting of Fluxed Ore Reducing Vanadium into the Metal

(Heats 7778-7796)

Beginning with Heat 7778, an attempt was made to further increase the carbon content of the metal by slightly increasing the reductant in the charge. This could not be done in the 100 KVA furnace using Cornwall coal because of the air leakage inherent in the furnace. When using an excess of the lighter, lower grade coals, some of the reductant is held from the slag long enough to form a nonreactive surface ash which is not fluxed by the slag. In a commercial installation the entire furnace atmosphere would be completely reducing and there would be no difficulty in producing pig iron

containing up to $3\frac{1}{2}\%$ carbon.

Detailed results of the Series 3 heats are given in Table 9.

In the Group 3A Heats, the excess carbon lowered the iron in the slag to below 2%. The average carbon content in the metal dropped slightly to 2.2% since the unfluxed surface ash on the coal made it somewhat more difficult to dissolve in the reduced iron. The excess of coal was sufficient, however, to start the vanadium reduction, and metal was produced containing 0.5% vanadium. The titanium content increased slightly to 0.05% and silicon to 0.32%. There was relatively little change in either sulfur or phosphorus.

For the Group 3B Heats, the amount of reductant was decreased but, because of better carbon efficiencies in the hotter furnace, the carbon still remained in excess. The reducing conditions were less severe, however, and the iron in the slag increased to 3.8%, while the vanadium and titanium in the metal decreased to an average of 0.15% and 0.013% respectively.

Series 4 - Unfluxed Ore

(Heats 7797-7806)

In the first series of the campaign, three heats had been made by smelting unfluxed ore. This product produced slags containing over 2% vanadium but irons containing less than 1% carbon. For the remainder of the campaign, the ore was again smelted without flux or additions of country rock to determine if the carbon content could be increased to above 1% without appreciable vanadium reduction.

TABLE 9. CONTROL ANALYSES FOR SERIES 3

TASMANIAN SAVAGE RIVER CAMPAIGN

(Fluxed Ore - Vanadium in Metal)

Heat No.	Metal Produced							Slag Produced		
	Wt. (lbs)	% C	% Si	% S	% P	% V	% Ti	Wt. (lbs)	% Fe	% V
Series 3A										
7778	122	1.78	0.39	0.25	0.17	0.35	0.066	59	1.33	-
7779	63	2.00	0.30	0.46	0.15	-	-	97	2.07	-
7780	73	2.54	0.38	0.20	0.20	0.44	0.040	86	2.27	-
7781	112	2.67	0.29	0.24	0.15	-	-	88	2.18	-
7782	113	2.64	0.41	0.19	0.15	0.44	0.060	75	1.88	-
7783	201	1.80	0.24	0.22	0.17	-	-	108	1.55	-
7784	58	2.08	0.30	0.25	0.24	0.54	0.030	77	1.87	-
Arith. Average	-	2.22	0.33	0.26	0.18	0.44	0.049	-	1.88	-
Series 3B										
7785	220	1.61	0.21	0.19	0.24	0.54	0.030	135	1.03	-
7786	218	1.66	0.17	0.23	0.16	0.220	0.005	58	2.13	-
7787	181	1.72	0.14	0.23	0.15	-	-	75	3.30	-
7788	301	2.35	0.08	0.21	0.11	0.230	0.004	74	2.83	-
7789	114	2.66	0.13	0.21	0.06	0.099	0.016	71	5.25	-
7790	83	2.57	0.29	0.26	0.085	0.170	0.037	92	4.81	-
7791	187	2.45	0.067	0.24	0.063	0.078	0.014	94	5.33	-
7792	96	1.63	0.17	0.25	0.17	0.130	0.006	88	3.54	-
7793	109	1.45	0.15	0.23	0.089	-	-	90	4.96	-
7794	130	1.68	0.11	0.21	0.13	0.150	0.006	70	2.93	-
7795	55	1.70	0.20	0.25	0.12	-	-	81	5.71	-
7796	60	1.84	0.27	0.28	0.20	-	-	100	4.20	-
Arith. Average	-	1.94	0.17	0.23	0.13	0.154	0.013	-	3.84	-

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Detailed analyses for this series are given in Table 10.

At the beginning of Series 4 the carbon content was at the 2.25% level. This was lowered to 1.55% at the end of the series by reducing the carbon in the charge. However, even for the $1\frac{1}{2}$ % carbon level, it was not possible to decrease the vanadium content of the metal below about 0.3%. As a result, the slags contained less vanadium than in Series 1. For Heat 7806 the metal contained 1.55% C and 0.33% vanadium and the slags contained 1.75% vanadium. The residual titanium content was low for the entire series, reaching 0.009% for Heat 7806.

Thus, to produce the highest vanadium slags, it would be desirable to develop the techniques required for handling metal with carbon contents of about 0.75 to 1.00%.

B. Discussion of Metal Composition

During the various stages of the campaign, three general grades of pig iron were produced with the following analyses:

	C	Si	S	P	Ti	V
(1)	1.0	0.03	0.27	0.13	<0.01	0.05
(2)	1.5	0.25	0.25	0.15	<0.02	<0.1
(3)	2.5	0.45	0.22	0.20	<0.05	<0.4

Carbon contents above $2\frac{1}{2}$ % were not demonstrated because of limitations inherent to the 100 KVA furnace. However, there should be little difficulty in a larger size furnace in producing pig irons containing up to $3\frac{1}{2}$ % carbon. The

TABLE 10. CONTROL ANALYSES FOR SERIES 4
TASMANIAN SAVAGE RIVER CAMPAIGN
(Unfluxed Ore)

Heat No.	Metal Produced							Slag Produced			
	Wt. (lbs)	% C	% Si	% S	% P	% V	% Ti	Wt. (lbs)	% Fe	% V	% Ti
Series 4A											
7797	149	2.25	0.20	0.27	0.16	0.15	0.006	23	5.51	1.72	5.54
7798	205	2.15	0.13	0.28	0.16	0.21	0.022	57	6.53	1.77	5.54
7799	164	2.07	0.19	0.26	0.12	0.29	0.028	-	2.06	-	-
7800	250	1.86	0.13	0.14	0.086	0.15	0.013	48	3.77	1.13	6.52
7801	132	2.02	0.47	0.16	0.11	0.34	0.023	17	0.90	0.31	5.87
7802	152	2.24	0.42	0.20	0.13	0.36	0.023	25	1.98	0.28	4.15
7803	69	2.37	0.33	0.20	0.15	0.33	0.014	78	4.64	1.12	6.75
Arith. Average	-	2.13	0.27	0.21	0.13	0.25	0.018	-	3.62	1.05	5.72
Series 4B											
7804	136	2.15	0.30	0.22	0.17	0.33	0.013	35	1.11	-	5.91
7805	145	1.84	0.20	0.24	0.16	0.46	0.020	36	2.82	1.28	7.06
7806	104	1.55	0.24	0.22	0.17	0.33	0.009	32	2.62	1.75	7.56
Drain	190							5			
Arith. Average	-	1.84	0.24	0.23	0.17	0.35	0.011	-	2.19	1.52	6.84
Overall Total For Entire Campaign	6328	-	-	-	-	-	-	3226	-	-	-
Overall Weighted Average, Entire Campaign	-	1.83	0.18	0.23	0.14	0.22	0.016	-	3.63	1.26	5.38

titanium and vanadium contents would, of course, be much higher than for the $2\frac{1}{2}\%$ carbon level.

In all instances the metal produced could be re-fined using standard techniques. Lower sulfur metal could be produced by increasing the lime charged during smelting. However, there would be no difficulty in removing sulfur from the pig irons produced using multiple slagging or lime injection techniques. Refining the Savage River pig iron was demonstrated using the pig iron produced in the small scale demonstration. The results of the refining demonstration are reported in Section XI.

C. Discussion of Slag Composition

At the conclusion of the campaign, the slags were crushed to $-\frac{1}{4}$ inch size, composited, sampled, and analyzed as shown in Table 11. Lots 1, 5, and 6 are the composites from the unfluxed ore and in general are lower in lime but **higher** in MgO and vanadium than the other slags. The base ratio for the slag from the unfluxed ore was from 0.781 - .875 and for the fluxed ore from 1.26 - 1.33. These slags were very easy to process and there was no difficulty in taking them from the furnace.

D. Accountabilities and Distribution of Components

An accounting of all elements analyzed for in the slag and metal is shown in Table 12. The iron accountability of 103.4% is typical of that experienced on the 100 KVA scale operations. For the volatile elements, the quantities unaccounted for were assumed to be in the fume as indicated in the

TABLE 11. COMPOSITE SLAG ANALYSES
100 KVA SAVAGE RIVER ORE CAMPAIGN

Heat No.	Lot 1 Series 1 7761-7762	Lot 2 Series 2 7763-7777	Lot 3 Series 3A 7778-7784	Lot 4 Series 3B 7785-7796	Lot 5 Series 4A 7797-7803	Lot 6 Series 4B 7804-7806	Furnace Clean-Out
Fe	9.92	5.41	4.10	5.20	7.28	6.36	10.94
SiO ₂	35.14	33.35	33.16	32.73	35.91	37.51	-
Al ₂ O ₃	16.72	14.95	14.17	14.15	19.77	21.33	-
CaO	8.73	28.60	31.07	29.80	6.03	3.88	-
MgO	15.71	9.55	9.05	9.71	15.73	17.27	-
S	0.089	0.15	0.22	0.17	0.079	0.07	0.18
P	<0.005	0.035	0.015	0.072	0.005	<0.005	0.053
TiO ₂	9.38	6.25	6.05	5.84	10.53	11.57	6.36
V	1.91	0.98	0.64	0.90	1.04	1.16	0.84
Weighted Avg. TiO ₂			5.96		10.90		
V			0.81		1.07		
$\frac{\text{CaO} + 1.4 \text{ MgO}}{\text{SiO}_2}$	0.875	1.26	1.32	1.33	0.781	0.748	-

TABLE 12. METALLURGICAL BALANCES 100 KVA SAVAGE RIVER ORE CAMPAIGN

(Continued)

Feed	Pounds	Fe	SiO ₂	Al ₂ O ₃	CaO	MgO	S	P	V	TiO ₂	C
				<u>Accountabilities (%)</u>							
METAL	--	101.0	1.9	--	--	--	40.7	69.6	28.6	.8	6.2
SLAG	--	2.9	84.2	93.7	86.3	81.8	14.4	9.9	64.2	103.2	--
TOTAL	--	103.9	86.1	93.5	86.3	81.8	55.1	79.5	92.8	104.0	6.2
				<u>Distribution (%)</u>							
METAL	--	97.2	1.9	--	--	--	40.7	69.6	28.6	.8	--
SLAG	--	2.8	84.2	93.7	86.3	81.8	14.4	9.9	64.2	99.2	--
Difference; Assumed to be fume	--	--	13.9	6.3	13.7	18.2	44.9	20.5	7.2	--	--
TOTAL	--	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	--

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distribution.

For the entire campaign, 97% of the iron reported in the metal along with 70% of the phosphorus, 41% of the sulfur, 29% of the vanadium, and 2% of the silica. Fourteen percent of the sulfur reported in the slag, while the remaining 45% was volatilized during smelting.

IX. POWER CONSUMPTION

The overall power consumption for the 100 KVA furnace campaign is given in Table 13.

Measurements of heat losses show the thermal efficiency of the furnace to be 45%. This means that of the 3265 KWH/ton of iron used in the 100 KVA furnace, 1795 KWH were heat losses and 1470 KWH were useful heat.

Extrapolating* these losses to those expected in a commercial size furnace gives 305 KWH losses/ton of iron. This, added to the 1470 KWH of useful energy, gives 1775 KWH per ton of iron for smelting in a commercial furnace from a cold, unreduced charge. By using a hot, prereduced sinter, up to 800 KWH per ton can be saved, giving a projected power consumption of about 1000 to 1100 KWH/ton in a commercial furnace using a hot, prereduced charge.

*Extrapolation on the basis of observed heat losses in furnaces of various sizes.

TABLE 13. POWER CONSUMPTION
100 KVA CAMPAIGN ON SAVAGE RIVER ORE

Total Metal Produced in Entire Campaign	6,328 pounds
Actual Power Used in Entire Campaign	10,330 KWH
Power Consumption for 100 KVA Furnace	3,265 KWH/net ton pig iron
Power Consumption for Commercial Furnace Operating on Hot, Reduced Sinter	1000-1100 KWH/net ton pig iron

X. REFRACTORIES

The smelting campaign was made in a furnace lined with periclase (MgO) brick. The roof was a monolithic structure rammed with a 70% alumina mix. At the end of the campaign there was little attack on the bottom, the sidewalls, or roof, during any of the smelting periods. The freedom from attack is the result of the charge forming a protecting crucible on the sidewalls while the metal protects the bottom. It would be expected that periclase brick will be a suitable lining for a commercial operation for slags of the compositional ranges produced in this demonstration.

XI. REFINING OF LOW CARBON PIG IRON
MADE FROM SAVAGE RIVER ORE

On October 31st, one heat (No. 5-279) of 1030 grade steel was refined in SUMAC No. 5 furnace from 4485 pounds of semi-steel produced at SUPI. No unusual electric steelmaking difficulties or problems were encountered in this steelmaking heat.

The charge was melted under a lime slag, which was flushed off after the melt was complete. A fresh lime slag was added, and the bath was blown with oxygen. Due to the extremely oxidizing conditions in SUMAC No. 5 furnace, the carbon content of the bath rapidly decreased to 0.01%. The oxidizing slag was flushed from the furnace, and a highly reducing lime, ferrosilicon, coke slag was built in order to desulphurize and recarburize the bath.

Alloying additions (ferrosilicon and high carbon ferromanganese) were made through the reducing slag, the heat was tapped into a 3 ton bottom-pour ladle and teemed into small billet molds.

The analyses throughout the heat are tabulated below:

	C	Si	Mn	S	P	Ti	V
Cold Charge	1.83	0.18	-	0.23	0.140	0.016	0.22
A (Melt)	1.26	-	-	0.090	0.050	-	-
B	0.01	-	-	-	-	-	-
C	0.07	-	-	-	-	-	-
D	0.15	-	-	-	-	-	-
E (Final)	0.30	0.29	0.54	0.040	0.024	0.002	0.005

One of the ingots was forged into 2 x 2 inch bars. The steel forged well without any difficulty.

The refined steel produced from the Savage River magnetite ore is a high quality product particularly low in titanium and vanadium. There would be little difficulty in producing any of the standard carbon steels from this ore.

XII. PROJECTED MATERIALS REQUIREMENTS

Because of the small scale, the SUPI furnace does not give a precise projection of raw materials requirements for a commercial plant. Carbon efficiencies, for example, are considerably less in the small furnace than in larger units. Also, because of the variable pool of metal and slag retained in the furnace from heat to heat, it is not possible to measure the quantities of metal and slag produced when more than one fluxing practice is used in a single campaign. The campaign does, however, establish metal and slag compositions from which the quantities of metal and slag produced in any given period can be calculated.

On the basis of the data in this report, the materials and products for both acid and basic smelting are approximated in Table 14.

TABLE 14. APPROXIMATE RAW MATERIALS REQUIRED
FOR SMELTING SAVAGE RIVER ORE BY
THE STRATEGIC-UDY PROCESS

Acid Smelting Route

Equivalent Lime-Silica Ratio = 0.7
Slag-Metal Ratio = 0.28

Feed:

3240 lbs. 62% Fe Concentrate
1050 lbs. 51.8% F.C. Cornwall Coal
Approximately 1000 - 1050 KWH

Products:

2000 lbs. Pig Iron (0.75% C, 0.03% Si, 0.29% S,
0.13% P, 0.06% V, 0.003% Ti)
580 lbs. Slag (6% Fe, > 2% V)

Basic Smelting Route

Equivalent Lime-Silica Ratio = 1.44
Slag-Metal Ratio = 0.76

Feed:

3620 lbs. 55.6% Fe Concentrate
1110 lbs. of Tasmanian Limestone (50.5% CaO, 7.5% SiO₂)
1210 lbs. 51.8% F.C. Cornwall Coal
Approximately 1050 - 1100 KWH

Products:

2000 lbs. Pig Iron (1.5% C, 0.03% Si, 0.24% S, 0.15% P
0.06% V, 0.007% Ti)
1480 lbs. Slag (4% Fe)

XIII. CONCLUSIONS

The small scale smelting of the Tasmanian Savage River ore by the Strategic-Udy Process was highly successful. The selective smelting inherent to the Strategic-Udy Process enabled the titanium and vanadium to be held in the slag and produced a low carbon pig iron (semi-refined steel) containing as low as 0.005% titanium and 0.05% vanadium. It was demonstrated that this pig iron was readily refined into specification grade carbon steel.

On the basis of this highly successful demonstration, it is now recommended that the project be carried to Strategic's larger scale facilities at SUMAC for more extensive piloting on a 1000 KVA scale.

APPENDIXTHE 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.

*See references at end of report.

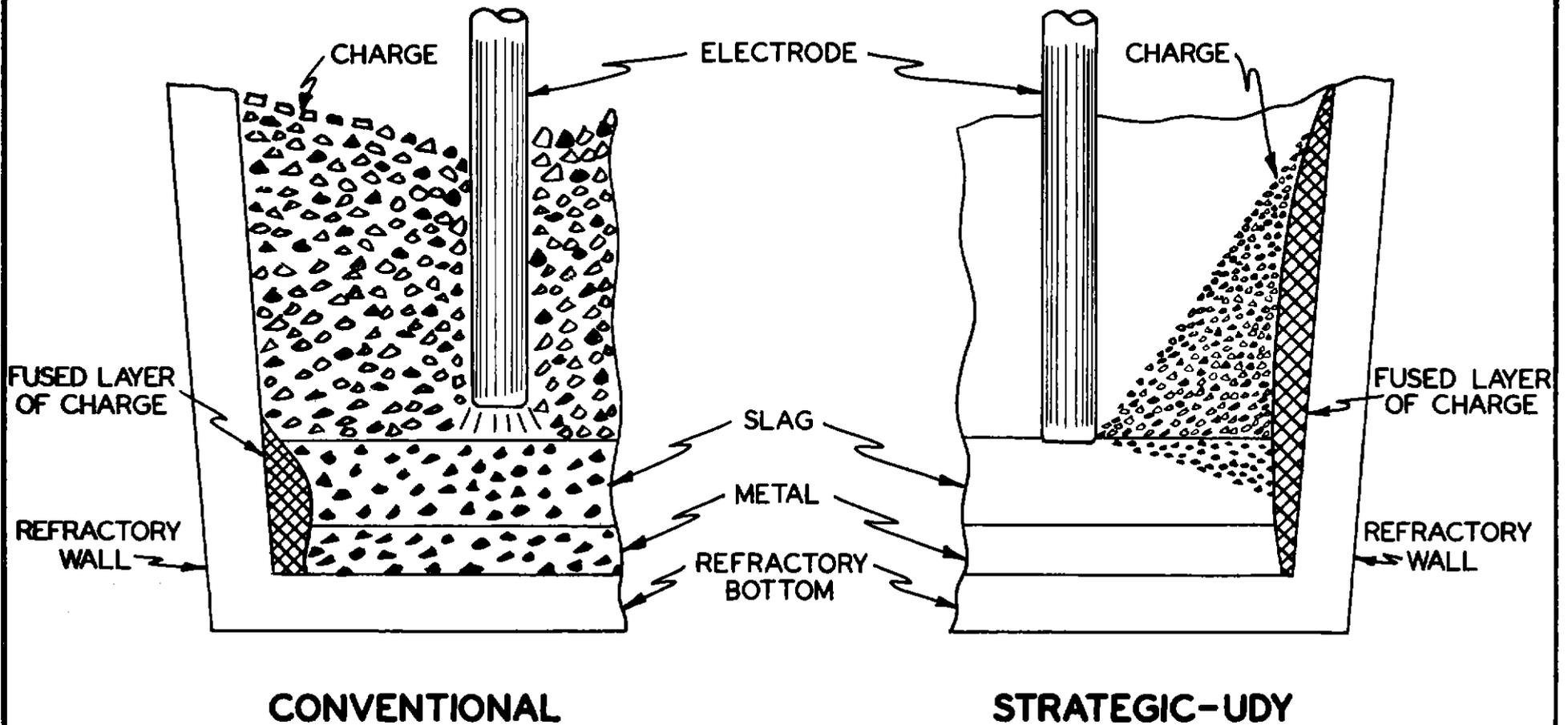
The specialized smelting practice employed by Strategic-Udy is shown in Figure 5. In comparison with submerged arc electric practice, the Strategic-Udy technique positions the electrodes at the surface of the slag, thus effectively eliminating the arc. The charge rate is such that the electrodes are 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

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FIGURE 5

- 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

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