29. ELECTRIC SMELTING OF MAGNETITE FROM SAVAGE RIVER, TASMANIA

by

Dr. Murray C. Udy,

Vice President, Research and Development, Strategic-Udy Processes Inc., Niagara Falls, New York.

and

W. St. C. Manson,

Chief Chemist and Metallurgist, Department of Mines, Tasmania.

INTRODUCTION

The exploration and development of the Savage River ore deposits have been matters of considerable interest and activity to the Department of Mines for some years. The programme has included geological surveys, including aerial and ground magnetometer surveys, diamond drilling and analyses of samples of diamond drill core for iron and other elements of importance in the production of iron and steel, mining engineering studies, and research into beneficiation of the ore to upgrade the iron content and remove impurities.

Various means of exploitation have been examined and the Director of Mines interested Mr E. R. Hudson of Industrial & Mining Investigations Pty. Ltd., holder of an Exploration licence for the Savage River area, in electric smelting techniques and processes which were reported to have advantages over blast furnace smelting in that all necessary raw materials to produce pig iron and steel were available in the State of Tasmania, which is not so in the case of blast furnace operation. Furthermore, it was claimed that selective reduction was very effective, and this could result in high proportions of impurities reporting in slags to an extent not possible in blast furnace operation.

Independent reports on the processes developed by Strategic Materials Corporation of New York and Niagara Falls were encouraging, and showed an extensive organization covering all features of treatment from raw material to smelting and feasibility studies and Mr. Hudson arranged with the corporation to undertake pre-reduction and 100 K.V.A. smelting tests at Niagara Falls in October, 1961. The raw materials used were Savage River ore and country rock, a titania slag, and coal from Tasmania donated by the Cornwall Coal Company. Smelting tests were witnessed by Messrs. Hudson and Ridgway of Industrial & Mining Investigations Pty. Ltd., and Mr. Manson of the Department of Mines.

A brief description of Strategic Materials Corporation is given and also a description of their kiln for removal of sulphur, if necessary, and pre-reduction ahead of electric smelting. Examples are shown of results of previous smelting projects.

The smelting tests using Savage River magnetite and Cornwall coal resulted in satisfactory pre-reduction and production of high quality iron and steel, with effective elimination of such elements as sulphur, titanium, phosphorus and vanadium. Pre-reduction of the ore, and feeding of the hot pre-reduced charge to the electric furnace, is claimed to result in a substantial economy in power.

STRATEGIC-UDY PROCESSES

(Extracted from publications by Dr. Murray C. Udy, Director of Research, Strategic Materials Corporation.)

Strategic Materials Corporation was formed in 1951, and in 1955 set out to develop for its own use and for licensing to others certain metallurgical processes patented by the late Dr. Marvin J. Udy on a scale that would demonstrate the commercial feasibility of the processes.

In 1956 the corporation acquired a wholly owned subsidiary by purchasing Niagara Falls, New York, facilities of Comstock and Westock Inc., and it is here that the early developmental work and smaller scale tests were undertaken. This subsidiary became Strategic-Udy Processes Inc., or S.U.P.I. for the short title. A rotary kiln, 20 feet long by 1½ feet diameter, and a 100 K.V.A. furnace were used for calcining and smelting studies.

Strategic Materials Corporation set out further to develop and demonstrate their processes on a larger scale, and under Dr. Marvin Udy's direction a two million dollar plant was designed and built, and this plant is now operated as a wholly owned subsidiary of S.M.C. under the title of SUMAC, or Strategic-Udy Metallurgical & Chemical Processes Ltd.

SUMAC has three 1000 K.V.A. electric furnaces, together with an 80 feet long by 4½ feet diameter rotary kiln and a ten ton reverberatory furnace. A 1000 K.V.A. three ton steel refining furnace has recently been installed in which finished steel ready for forming is produced.

In late 1957 S.M.C. was joined in the effort to commercialize Strategic-Udy processes by Koppers Co. Inc., a well known engineering and construction organization. It is reported that Koppers have been long established in construction in the iron and steel industry, and after extensive study of non blast furnace iron processes considered that the Strategic-Udy process was the "most likely to succeed and the one most likely to fill the long felt need for a process to handle lower tonnage requirements than a blast furnace could economically supply, and for a process to supplement the blast furnace by exploiting raw materials that are unsuitable for attractive blast furnace operation". Koppers Co. Staff are specifically interested in undertaking engineering and feasibility studies, and in the design and construction of any plants that will use the Strategic-Udy process.

In 1959 S.M.C. advised that the World's foremost designer, builder, and operator of electric smelting furnaces—Electrokemisk A/S of Oslo, Norway—had agreed with S.M.C. and Koppers to join in promoting the Strategic-Udy processes, and that they will design and supply the electric smelting furnaces for any plant to be built using the Strategic-Udy processes.

The Process

The Strategic-Udy process consists essentially of two processes.

THE KILN.

The first stage is heat treatment in a rotary kiln to oxidize and remove sulphur, followed by reduction to FeO and metallic iron. Operation of the kiln consists of mixing the ore with fluxes and the reductant in such a manner that the ore in the first section of the kiln is in an oxidizing atmosphere, and after adequate provision has been made for removal of sulphur, if that is necessary, the reductant is added and the ore is reduced to FeO and metallic iron. Fine material is stated to be advantageous for fuel economy, and, due to comparatively low gas velocities, loss of fines is not a problem. Fine material also aids the speed of reaction for pre-reduction of the ore. Another feature claimed is that the kiln becomes to some extent a sintering plant. Dust is eliminated not by blowing it out as in a blast furnace, but actually by growing the finest particles to a larger size. This occurs without any major sintering or sticking, and the discharge is still fine and free flowing and in excellent condition for charging into the electric furnace.

Much of the heat requirement to the kiln comes from the CO rich gas from the electric furnace.

ELECTRIC FURNACE.

The hot pre-reduced charge is fed to the electric furnace where the metal is separated from the reductant by a slag layer much like open hearth furnace metal is protected by slag from the atmosphere of that furnace. The composition of the metal can be controlled to almost any carbon and silicon content desired. It becomes possible to selectively control the impurities and to keep them out of the metal, and consequently the variety of ores that can be successfully smelted is greatly increased. By the combined treatments all possible energy is conserved. Control is exact in both steps. Strategic-Udy processes claim a major improvement in furnace operation by special technique concerned with the immediate environment of the electrodes. The Strategic-Udy process is not like the usual smelting furnace techniques which operate with the electrodes surrounded and submerged with respect to the solid charge. On the contrary the Strategic-Udy technique uses an open bath with the electrode spacing in respect to the molten slag controlled from ½" above the slag to a few inches submerged in the slag depending upon the needs of the particular operation.

The pre-heated and pre-reduced material can then be fed directly into a hot zone so that melting is rapid and completion of the reduction goes quickly. The conventional submerged arc furnace, when charged with cold coke and cold lump ore (50 per cent iron) without metallization, requires some 2300 kWh of power per net ton of metal produced. When hot, or more important, pre-reduced charge is introduced into this conventional type furnace, the balance of burden resistivity, main arc position, and the chemistry of the process are altered by these charge conditions. Change in charge resistivity with pre-reduction limits the extent of pre-reduction to not much over 20 per cent. It is an accepted fact in conventional furnaces that the electrodes tend to withdraw from their position of deep submergence as the degree of pre-reduction is increased. The electrodes are caused to rise higher in the burden and at the same time thermal efficiency of the process drops off because the furnace exit gases leave at higher temperatures. Thus, the conventional submerged arc process might possibly be operated at about 1600 kWh per net ton of hot metal as a practical minimum for a typical 50 per cent iron ore. This can be improved somewhat by means of a single phase rotating furnace technique. In addition to this difficulty with pre-reduction and pre-heat in the charge, control over carbon, or selective reduction and control of tramp elements such as nickel, copper, chromium, titanium, phosphorus, &c., is very difficult because the metal is almost always in contact with an excess of carbon much like in the blast furnace. The burden must be carefully maintained in order for the furnace gases to escape. As with the blast furnace, fines cannot be tolerated or disastrous blows would result. In contrast to this, the method of providing energy for smelting is completely different in the Strategic-Udy technique, and this is the fundamental reason why the process is able to achieve the results that it does. Because the energy input to the Strategic-Udy smelter is essentially from slag resistance plus a small amount from the arc buried in the molten slag, the Strategic-Udy furnace can be charged with as high percentage of metallics as is desirable from other considerations. In certain operations, as high as 95 per cent metallics have been charged with very satisfactory results. The practical limitation on pre-reduction is not determined by the furnace practice, but rather by the operation of the kiln or other pre-reduction apparatus. It appears that the most economic way is to operate with the maximum attainable pre-reduction at a good rate of throughput in the kiln. In many cases, this appears to be around 60 per cent pre-reduction.

Table 1 compares Strategic-Udy process power requirements for the production of one ton of metal from a 50 per cent iron ore at 85 per cent furnace efficiency, with two conditions in the conventional submerged arc electric furnace.

With the Strategic-Udy process, fineness of the charge is definitely desirable rather than objectionable, because with fines the operation proceeds faster giving higher metal production per square foot of hearth. Fineness of the charge has no influence on the furnace operation since the open space in the furnace allows gas to escape easily, and the burden is very light and is actually floating on the molten slag blanket. The metal is effectively insulated from contact with the excess of carbon and selective reduction is practical. Some 5000 tons of minus 100 mesh ore have been successfully smelted.

The control of the electrode environment is the main reason the Strategic-Udy smelting technique is so eminently suited for smelting fine materials. So far, no restriction has been found on the fineness of materials that can be used in the Strategic-Udy process. Successful operation has been demonstrated where the charge consisted entirely of minus 325 mesh material.

The possibility of using fine material has also relieved the operator from his dependence upon special grades of coke. The blast furnace and the conventional electric smelter are both dependent in modern practice on high strength metallurgical coke. On the other hand, with the Strategic-Udy process anthracite, low volatile bituminous coal, coke breeze, or even steam coal and some of the lignites have been used. The controlling factor in selection of the reductant will be an economic one, relating to cost per pound of carbon.

As can be seen from the foregoing discussion, the Strategic-Udy process not only can process standard high grade ores competitively, but can also very adequately and efficiently smelt ores which, while they are good sources of iron, cannot in present blast furnace, or conventional electric smelting practice, be considered as sources.

TABLE 1.

Power Requirements for Production of 1 Ton of Metal from a 50% Fe Ore, at 85% Furnace Efficiency.

	Conventional Furnace		Strategic-Udy Process
	Cold Charge	Maximum Hot Charge at 20% Pre-reduction	At 55% Pre-reduction
To Heat and Melt Charge	870 kWh	525 kWh	425 kWh
Heat for Reduction	1095 kWh	885 kWh	493 kWh
Radiation and Losses	345 kWh	250 kWh	162 kWh
Power per Ton	2310 kWh	1660 kWh	1080 kKh

A wide variety of ore types have been successfully treated. These include ores with appreciable percentages of phosphorus, sulphur, manganese, chromium, nickel, titanium, silica, alumina, lime and magnesia.

Chemistry of the Processes

There is nothing fundamentally new about the chemistry of the processes, since they involve only the well-known oxide reductions. Molten slags act as solvents for the oxides involved in the reactions. Composition of these slags helps control the activity of the various oxides with respect to the reducing agent. Control of slag composition, along with control of temperature and amount of reductant, then furnishes control for the reduction reaction. The electric furnace and the other high temperature metallurgical furnaces are instruments for carrying out chemical reactions at high temperature. Properly designed for the particular purpose for which they are to be used, and in the hands of a good chemist or metallurgist, they are capable of maintaining conditions that will produce the required results, with a high degree of accuracy. The selective reduction in separation of one metal from another involves a good knowledge of slag compositions and their effect and skill in the use of the furnace equipment.

The uniqueness of the Strategic-Udy process comes from mechanical techniques and slagging practices that allow control and exploration of the well-known chemical reactions to a degree never previously achieved. The selectivity of reduction is based on free energy differences for the reduction reactions of the various oxides involved. By carefully controlling the reductant additions, the metals will be reduced one after another, starting with copper, then in order nickel, cobalt, chromium, manganese and titanium. Another feature is: a metal on a lower curve will reduce the oxide of one on a higher curve. Equilibrium is the most important thing. At the temperatures of which we are talking, kinetics is of lesser importance. All the reactions involved are fast at these temperatures if contact is made and if energy is available for the endothermic reactions.

Several examples of the Strategic-Udy process, as applied to selective reduction are:—

1. Laterite ores contain complex mixtures of iron, nickel, cobalt and chromium, as well as MgO, SiO_2, Al_2O_3 and CaO. With these ores, the Strategic-Udy process has successfully demonstrated, on a 2000 ton scale, the economical production of three products: namely, a ferronickel containing 90% of the nickel, a low carbon pig iron containing less than 0.1% nickel and less than 0.05% chromium, and a ferrochromium product containing more than 90% of the chromium. Further, in this work, by the close control of selective reduction, the axiom that cobalt goes with the nickel has been contradicted. In the ferronickel, only 10% of the total cobalt was found with the nickel where it is undesirable, and 90% went with the iron where it was diluted to 0.05%. This distribution gave a very acceptable nickel to cobalt ratio in the ferronickel and, at the same time, cobalt was limited to less than harmful amounts in the low carbon pig iron.

2. Some of the manganese ores in which Strategic Materials Corporation is interested contain iron and phosphorus in addition to the manganese. The selective reduction techniques put the nearly 1% phosphorus contained in the ore into an iron product, eliminating both phosphorus and iron while keeping essentially all of the manganese in the slag. A premium-grade high-carbon ferromanganese, containing less than 0.1% phosphorus, was produced from the slag. The high-phosphorus iron product was refined to steel by conventional means.

3. In the field of titaniferous iron ore, iron containing less than 0.50% titanium, and only traces of vanadium and chromium has been produced. The undesirable titanium, vanadium and chromium in this instance are held back in the waste slag; these, incidently, are ores that the blast furnace cannot use unless they are greatly diluted with high quality ores. In contrast, the Strategic-Udy process used these ores as a complete furnace charge without dilution.

4. This example is in the field of chromium ore. Here ores that were poorly suited because of their low chromium to iron ratios for the production of ferrochromium were treated by the Strategic-Udy technique to produce 5% chromium irons and slags with good chromium to iron ratios from which standard grades of ferrochromium were easily produced. Likewise, from similar ores, standard grades of stainless steels were directly produced.

5: High-phosphorus iron ores containing up to 1% or more phosphorus have been readily processed into low carbon pig iron, with phosphorus content less than 0.03%. This is some distinction from the blast furnace, in which all the phosphorus charged ends up in the pig iron.

6. One final example: recently several hundred tons of a waste slag from the Western United States, containing some 33% iron, 0.6% copper, 1.5% zinc, and 1.5% sulphur, was smelted to give structural steels containing less than 0.3% copper, and less than 0.03% sulphur. Copper and zinc by-products were also produced.

That such selectivity as shown in these examples is possible is proved by the free energy of reduction curves. That such selectivity can be achieved has been shown by large scale demonstrations at SUPI and at SUMAC.

Control of Impurities

Control of reducing conditions in the furnace relates to the quantity of reductant present, and this can be precisely controlled so that selective reduction results. This can be shown by the iron content of the slags. For example a low iron content of say 0.2% Fe would result when reducing conditions are strong, and it is desired to produce a pig iron with a carbon content of 3 to 4%. A distinctive feature of the Strategic-Udy process as compared with blast furnace operation is the ability of the process to obtain any desired iron content. With high iron slags impurities such as phosphorus can be retained in the slag whilst producing a low carbon pig iron. Where it is desired to smelt selectively such metals as nickel or copper, the iron content of the slag can reach 40 to 50% depending on the iron in the original ore.

In the case of sulphur, the basicity of the slag as well as its iron content determine the sulphur distribution.

The process is directly suitable for production of low carbon pig iron from which steel can be produced. High carbon pig iron cannot be manufactured direct where undesirable impurities exist in the ore, flux or coal, and in such cases recarbonization of the low carbon pig iron is necessary.

Production Costs

SUPI state that it is difficult, of course, to give production costs as a general figure, since each plant depends upon individual factors such as cost of ore, power, coal, size of plant, &c.

In general semi-steel production costs range from 25 dollars to 45 dollars per net ton.

Recarbonization costs of low carbon iron to merchant iron grades may range from 9 to 15 dollars per net ton. This recarbonization is only necessary when impurities in the ore make it desirable to make low carbon pig iron instead of the merchant grades directly. Refining costs for producing hot cast steel for alloy steel castings range from 8 to 13 dollars per ton. For making carbon steel ingots from low carbon iron, costs would range from 9 to 14 dollars per ton.

SAVAGE RIVER DEPOSITS

The Savage River iron ore deposits are known to be very large, and although exploration has not reached the stage of proving the extent of the ore reserves, exploration by diamond drilling and magnetometer surveys indicate a potential of over 300,000,000 tons. The major iron mineral is magnetite, with minor quantities of pyrite, ilmenite, rutile, apatite, manganese and vanadium minerals, together with altered amphibolite. An analysis of this altered amphibolite forwarded to SUPI for smelting tests in 1961 was as follows:—

	%		%
Fe	12.16	S	0.09
SiO_2	46.14	P	0.06
Al_2O_3	15.18	TiO_2	1.69
CaO	5.21	V	0.04
MgO	4.75		

Some oxidized ore at or near surface assays 60-65% iron with low impurities. Other sections below 100 ft are generally of lower grade, with higher proportion of impurities, particularly sulphur.

Probable approximate value of medium grade ore would be 44% of iron, and about 5% sulphur. An open cut has been designed to extract part of the ore in the central section, between Savage River and Magnetite Creek, and it is of interest to indicate the quantities and grades of ore and waste which this section is estimated to contain:—

Eighty-two million tons of ore (23 million tons of high grade surface ore, with 60-65% Fe, and 59 million tons of medium grade ore assaying 43.8% Fe, 0.42% Ti, 0.13% P, 4.73% S and 0.31% V.); 17 million tons of low grade ore containing 17.3% of Fe; 62 million tons of waste.

The following tabulation shows the range of values in the diamond drill bores 3 to 16:

Bore No.	Footage	Fe	Ti	S	Percent SiO_2	Al_2O_3	Mn	P
3.	975	15–53	0.19–0.65	1.6 – 8.1	6–12	1–3	0.05–0.15	0.02–0.29
4.	717	8–56.7	0.11–1.06	2.0 – 8.6	4–33	1–3	0.03–0.19	0.02–0.29
5.	871	21.2–46.7	0.29–0.61	1.0 – 4.6	10–30	2–7	0.06–0.12	0.03–0.34
6.	560	10.9–56.3	0.41–0.81	1.1 – 4.8	6–37	0.5–9	0.05–0.12	0.06–0.23
7.	782	10.9–62	0.08–0.60	3.1 –11.6	2–31	0.4–12	0.02–0.13	0.02–0.44
8.	471	7.9–35.1	0.15–0.84	2.0 –11.7	13–41	2–9	0.05–0.15	0.09–0.35
9.	611	7–51.9	0.25–1.04	1.8 –7	5–40	2–13	0.07–0.16	0.07–0.14
10.	438	44.6–53	0.3 –0.41	2.3 –4.7	6–13	2–4	0.05–0.12	0.08–0.16
11.	526	4.7–59.6	0.41–1.29	0.31–5.79	2–46	2–15	0.07–0.14	0.06–0.15
12.	350	14–56.6	0.25–1.02	0.7– 3.8	3–36	2–9	0.04–0.09	0.12–0.14
13.	1,011	3.7–61	0.25–0.94	0.6 –11.9	3–16	1–12	0.05–0.15	0.05–0.27
15.	734	23.7–56.4	0.14–1.14	5.0 – 8.3	4–20	1–4	0.04–0.10	Tr.–1.23
16.	673	18.3–54.9	0.2 –1.19	2.9 –15.4	4–22	1–6	0.05–0.12	0.02–1.03

The lowest values in these bores represent waste material.

Beneficiation of Savage River Magnetite

Whilst there may be sections of the orebodies at Savage River that are of suitable quality for direct smelting there are many sections which can be upgraded with possible economic advantage.

Savings in power requirements, fluxes and possibly transport result from treatment of higher grade ore, and beneficiation tests have been undertaken to provide for costing of beneficiation and smelting cost studies.

The problem of beneficiation was examined at the Department of Mines Laboratories, Launceston, on the basis of magnetic separation of the major iron mineral, magnetite, from other minerals, and this means has proved to be very effective. The associated impurities which can be effectively separated are pyrite, apatite, silica, alumina, &c., present as weathered basic rocks, such as talc, serpentine and hornblende.

Titanium is present in the ore as ilmenite and rutile. Most of these minerals exist as extremely small plates or grains in the magnetite, and typical size range for the ilmenite is 5 by 1 micron with smaller grains which are difficult to identify. Rutile has been observed in grains up to 50 microns.

It was to be anticipated from mineralogical study that titanium minerals would not be readily separated by grinding and magnetic separation, and ore dressing investigations consisting of controlled ball mill grinding and wet magnetic separation show that the titanium content is not materially reduced.

Tests were undertaken on diamond drill samples after crushing from ½ inch down to minus 200 mesh.

Beneficiation to high grade ore was generally not effective until the ore was ground to at least minus 60 mesh.

Recovery of the magnetite in all tests was high, and mostly ranged from 90 to 98 per cent.

Composite sample from bores 7, 9 and 10 was separated in sizes from minus ⅜" ore to minus 200 mesh size, and high elimination of impurities did not result until the ore was ground to minus 100 mesh size. Rejection of sulphur was 27 per cent at ⅜ inch size, 91 per cent at 60 mesh, and 96 per cent at minus 100 mesh. Seventeen per cent of the titanium was rejected at the coarsest sizing, and was a maximum of 50 per cent at minus 200 mesh. This sample assayed 0.3 per cent of vanadium, and virtually no separation was obtained of the vanadium content at any sizing tested.

Summary of Results of Wet Magnetic Separation

Ore

Bore No.	Footage	Fe	S	P	Si	Ti	Mn	Al_2O_3	V
1. ..		40.9	0.7	0.07	8.4	0.96	0.11	2.68	..
2. ..		46.2	0.44	0.02	6.4	1.08	0.11	2.3	..
3. ..	0′–355′	49.1	4.5	0.11	3.5	0.22	0.12	1.78	..
	355′–525′	14.8	5.53	0.11	13.5	0.34	0.1	4.27	..
	785′–918′	42.1	4.37	0.21	7.4	0.83	0.05	3.54	..
4. ..	100′–839′	46.4	5.6	0.14	4.9	0.37	0.11	1.44	..
5. .. }	36′–871′ }								
6. .. }	52′–559′ }	30.4	3.6	0.15	10.5	0.47	0.09	4.6	..
7. .. }									
9. .. }		47.6	5.84	0.12	4.2	0.42	0.1	2.04	0.30
10. .. }									

Beneficiated Products by Magnetic Separation

Bore	Grind	Fe	S	P	Si	Ti	Mn	Al_2O_3	V
1. ..	66%—200 mesh	61.5	0.06	0.01	1.70	0.98	0.1	Trace	..
2. ..	—½" ,,	55.3	0.33	0.01	3.88	1.19	0.13	0.91	..
	—⅛" ,,	56.4	0.27	0.01	3.60	1.20	0.13	0.83	..
	— 60 ,,	64.9	0.06	<0.01	1.40	1.07	0.1	0.38	..
	—100 ,,	66.4	0.04	0.01	1.08	0.90	0.11	0.35	..
	—200 ,,	68.4	0.02	0.01	0.70	0.90	0.1	0.3	..
3. ..	0′–355′— 60 ,,	66.0	0.36	0.03	1.28	0.2	0.14	0.73	..
	355′–525′—100 ,,	53.9	1.5	<0.01	4.67	0.22	0.08	0.68	..
	785′–918′— 60 ,,	66.5	0.39	<0.01	1.39	0.75	0.04	1.02	..
	785′–918′—100 ,,	68.7	0.18	<0.01	0.94	0.67	0.04	0.57	..
4. ..	100′–839′— 60 ,,	64.8	0.05	0.02	1.54	0.37	0.11	0.64	..
5. and 6.	36′–871′ and 52′–559′ — 60 ,,	64.4	0.5	0.02	1.68	0.37	0.07	0.91	..
7. 9 and 10	— 60 ,,	65.1	0.75	0.02	1.22	0.40	0.1	0.91	0.38
	—200 ,,	67.9	0.33	0.02	0.80	0.31	0.09	0.88	0.37

SMELTING TESTS ON SAVAGE RIVER MAGNETITE ORE AT NIAGERA FALLS OCTOBER, 1961

By Strategic-Udy Process

Report to Industrial & Mining Investigations Ltd., Sydney, New South Wales

The following information has been obtained from project No. 1262-2 by L. E. Olds, D. Jurden, and M. C. Udy, December 1961.

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 D underground ore (58.2% Fe). The ore was diluted with associated country rock 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 sulphur, 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, pre-reduction, 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 sulphur content of 0.21%. During the calcination it was demonstrated that under optimum kiln conditions, sulphur 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 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:

	Percent					
	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

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 represent 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	0.024
Si	0.29	Mn	0.54
S	0.04	Ti	0.002
		V	0.005

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.

Raw Materials

Iron Ore

This consisted of surface ore containing 65% of iron, low in impurities, and samples of ore from D adit containing 50-62% of iron, high in sulphur and low in phosphorus and titanium.

Typical analyses of surface ore and ore ex adit:

	Surface Ore	Ex Adit
Fe	65.2	62-70
Si	1.6	....
Al_2O_3	1.2	....
S	0.06	3-5
P	0.06	0.1-0.3
Ti	0.13	0.1-0.3
V	0.44	0.4-0.5

The titania content of all samples despatched for the tests was lower than average, and SUPI decided to mix a 39% titania slag from previous smelting operations to raise the titania content in the furnace feed to about 2%.

Coal

The coal used as a reductant was supplied by the Cornwall Coal Co., Tasmania, and was analysed with the following results:—

Ash	17.7
Volatile Combustible Matter	25.6
Fixed Carbon	49.1
Water	7.6
Sulphur	0.3

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 pre-reduction studies, and a 100 KVA electric smelting furnace.

The 5' rotary batch kiln is lined with firebrick and has an interior capacity of 28.8 cubic feet.

The SUPI 100 KVA iron smelting furnace 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.

Procedure

Smelting tests were undertaken in a 100 KVA furnace, and on this scale it is not practical to operate the continuous process of calcination to remove sulphur, pre-reduction and smelting of the hot pre-reduced charge. Accordingly the demonstration was divided into three operations as follows:—

(**a**) Calcination of each individual ore primarily to reduce the sulphur 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.

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.

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 analysed 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 per cent reduction attained.

Smelting in the KVA Furnace

Smelting was done on a continuous 24 hours per day basis. Each heat was approximately 2½ 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 electrode 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 mould. Control samples were taken from the tapped metal and slag stream with a spoon and analysed for the desired constituents.

Results of Demonstrations

Calcination

Minus ½ inch ore from No. 8 Adit containing 4.95% of sulphur as pyrite was calcined at rates from 220 to 420 lbs./hour in the 20 feet rotary kiln at temperatures ranging from 1050 to 1100°C. Sulphur removal reported ranged from 97 to 90%, with calcines containing 0.03 to 0.12% of sulphur.

It is predicted that sulphur rejection would not be so high in a kiln operated for the combined purposes of a calciner and pre-reducer.

Pre-reduction of Ore

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.

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

Tests showed about 45% reduction in 3 hours and 70% in 4 hours.

Results of Smelting Demonstrations

Forty-five tests were made in a campaign divided into four smelting series as follows:—

Series 1

Three tests were used to demonstrate that the 0.5% vanadium in the ore could be concentrated in the slag. The charge was melted without fluxing and consisted of Adit D ore, slag, and Cornwall coal. The slag melted well and a deficiency of coal was charged to hold 8% iron in the slag. The vanadium and titanium in the metal amounted to 0.06 and 0.002% respectively, and the slag contained 2% of vanadium. Carbon was about 0.7%, S was 0.25% and P was 0.12%.

Series 2. Smelting of Fluxed Ore

Lime was added to give a base ratio of 1.4, and a slag to metal weight ratio of approximately 0.7. (Base ratio $\frac{CaO + 1.4\ MgO}{SiO_2}$)

The amount of carbon was increased slightly as Series 2 progressed in order to produce low impurity iron, with various carbon contents.

Typical results of this series were:—

	Metal Produced Percent						Slag Produced Percent	
	C	Si	S	P	V	Ti	Fe	V
A.	0.91	0.024	0.27	0.17	0.05	0.001	4.84	..
B.	1.37	0.027	0.28	0.13	0.06	0.007	4.4	1.1
C.	2.45	0.38	0.22	0.17	0.06	0.005	3.0	..

Series 2 demonstrates effectively the selectivity of 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 with 4 to 5% of iron in the slag.

Series 3

In this series of fluxed ore charges the object was to further increase carbon content of the metal by increasing the quantity of reductant. The results below show substantial increase in vanadium.

	Metal Produced Percent						Slag Percent
	C	Si	S	P	V	Ti	Fe
A	2.22	0.33	0.26	0.18	0.44	0.05	1.88
B	1.94	0.17	0.23	0.13	0.15	0.013	3.8

Series 4. Unfluxed Ore

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.

The following tabulation shows the summation of this series. Carbon contents ranged from 2.13 to 1.84%, but vanadium in the metal was not reduced below 0.3%. Residual titanium was low in all melts.

	Metal Produced Percent					
	C	Si	S	P	V	Ti
A Series	2.13	0.27	0.21	0.13	0.25	0.02
B Series	1.84	0.24	0.23	0.17	0.35	0.01

For the entire campaign, 97% of the iron reported in the metal. Distribution of other elements in the metal were phosphorus 70%, sulphur 41%, vanadium 29%, and comparatively minor quantities of titanium and silicon.

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	1,000-1,100 kWh/net ton pig iron.

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.

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 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 recarbonize the bath.

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

The analyses throughout the heat are tabulated below:—

	Percent						
	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.

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 per cent Fe concentrate.
1050 lbs. 51.8 per cent 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% SiO_2).
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.

CONCLUSIONS

The small scale smelting of the Tasmanian Savage River ore by 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.

The sample of non-coking coal supplied by the Cornwall Coal Company, Tasmania, was found to be a satisfactory reductant in the pre-reduction and electric smelting processes, and as suitable high grade limestone is also available from deposits in Tasmania, all the raw materials required for the production of pig iron, or low carbon steel, by the Strategic-Udy processes can be obtained from within the State.