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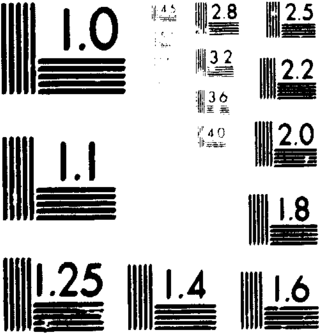

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REPORT
ON LABORATORY TESTS AND SEMICOMMERCIAL TRIALS OF INDIAN SILLIMANITE CONCENTRATE FOR PRODUCTION OF ALUMINIUM-SILICON ALLOYS.

(Contract No 77|65)

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for
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CONTENTS

I. INTRODUCTION

The present work was carried out to the UNIDO contract No. 77/65 dated June 8, 1978, concluded between the United Nations Indistrial Development Organization, hereinafter referred to as "Customer", and the All-Union Export-Import Organization Tsvetmetpromexport, hereinafter referred to as "Supplier".

The contract provided for the carrying out by the VAMI Institute of semicommercial tests of the Indian raw material - 10 t of sillimanite concentrate, 6 t of coal and 3 t of petroleum coke, supplied by the Indian Rare Metals, Ltd. for testing with the aim of setting up the production of Al-Si alloys by the electrothermal method.

It is known that in the Soviet Union the electrothermal method was developed and commercialized for production of Al-Si alloys by reducing aluminium and silicon from the natural alumosilicates and other types of silica-alumina raw material in high-power electric-arc reduction furnaces. An operational commercial unit for producing Al-Si alloys by the electrothermal method consists of raw material and charge preparation, electric-arc reduction furnaces up to 22,500 kVA, and of a metallurgical section where silicoaluminium produced in the furnaces is processed into silumin and heat-resistant aluminium casting alloys of various types and applications.

One of the major advantages of the electrothermal method over the conventional method of producing alloys from aluminium and silicon is the use of low-module type of raw material such as kaolin ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), kyanite and silimanite ($Al_2O_3 \cdot SiO_2$), low-

-iron bauxite, etc. which cannot be efficiently processed into alumina and electrolytic aluminium.

Material flows in the electrothermal method are many times less than they are in the alumina production and aluminium electrolysis. The modern electric-arc reduction furnace for production of silicoaluminium is tens of times superior of the aluminium reduction cell in power and output.

When producing the casting aluminium alloys with the use of the electrothermal silicoaluminium it is possible not to use at all the commercial grade silicon, to cut a total consumption of aluminium by 20 to 25% and to replace it by approximately 50% with secondary aluminium alloys produced by remelting the aluminium scrap.

The aim of the tests carried out according to the above mentioned UNIDO contract was to determine the technical feasibility and process parameters of the method developed in the USSR for production of Al-Si alloys from the Indian sillimanite concentrate with the use of coal and petroleum coke as reductans. At the same time the task was to optimize the process parameters for preparation of briquettes and pellets from the sillimanite concentrate feed to meet the process requirements, and to determine the data concerning the melting parameters, refining and metallurgical processing of silicoaluminium produced in the furnaces, to be further processed into casting aluminium alloys.

Prior to the semicommercial tests of the Indian raw material which were carried out at the VAMI pilot plant facilities, the laboratory tests were conducted on determining composition of the sillimanite concentrate and other physico-chemical characteristics, including its pelletizing ability together with other feed components, reducibility and electrical conductivity of the feed using as a reductant the Indian coal together with petroleum coke.

The Customer's raw material (IO t of sillimanite concentrate and 6 t of coal) were delivered for testing at the VAMI Institute in January I980. As it was agreed between the sides, the Indian petroleum coke was not supplied for testing work and was replaced by the Soviet-produced petroleum coke. The same arrangement concerns a binding materials. The Soviet-produced dry beneficiation kaolin and a water solution of sodium lignosulphonate were used in the tests.

The present report contains the results obtained during the laboratory and semicommercial tests of the Indian raw material. Taking into accoung the results obtained, a conclusion is made on a technical feasibility of the commercial production of Al-Si alloys from the Customer's raw materials by the VAMI-developed method. The report also contains recommendations concerning the selection of the main production units, the expected consumption rates and other performance figures of the electrothermal process required for technical and economic evaluation of establishing the commercial production of Al-Si alloys under the Indian conditions.

2. RESULTS OF LABORATORY TESTS

2.I. Composition of sillimanite concentrate

A trial quantity of the sillimanite concentrate is represented by a light-gray fine-grained sand stone. The concentrate grains have a glass lustre and are mainly represented by sillimanite with a minor admixture of other minerals, the most noticeable being the grains of disthen (3%), as well as of zirconium, rutile and brown hydromica. Excluding disthen and zirconium (0.5%), all other minerals are present in quantities of 0.I to 0.2% and less. A content of sillimanite (and disthen) in the sample under investigation was about 98%. The sillimanite grains are transparent, not clouded with admixtures of clay minerals and are mainly laminar in shape. A typical refractive index of sillimanite is I.660.

A chemical composition of the sample, % wt., is as follows:

Al_2O_3	- 62.3	CaO	- 0.I0
SiO_2	- 36.2	MgO	- 0.I2
$Fe_2O_3^{tot}$	- 0.3I	MnO	- 0.II
FeO	- 0.0I8	K_2O	- 0.0I2
TiO_2	- 0.II	Na_2O	- 0.I5I
ZrO_2	- 0.34	CO_2	- 0.I5
		H_2O	- 0.I7

A simiquantitative spectral analysis, besides the components mentioned above, gave the following data, % wt:

Cr	- about 0.I	Cu	- 0.00I
V	- about 0.I	Pb	- 0.0I
Be	- 0.00I	Ga	- about 0.0I.

These small and trace elements, due to a very high sillimanite content, are connected, probably, with the main mineral of the sample.

The data obtained by the complex thermal analysis (CTA)[I] of the sillimanite concentrate samples reveals a small loss of the weight (-0.23%) at I95°C and some gain (+0.I65%) at II00°C due to

[I] The CTA was conducted by "Paulik, Paulik and Erdey" thermoanalyzer: under the following conditions: sample - I g, DTA - I/I0; TG - 500, V_t - I0/min.

the sample oxidation. A total reduction in weight of the sample is, according to the CTA, - 0.065%.

The X-ray data and the infrared spectroscopy data confirm the purity of the material under investigation.

By its mineralogical and chemical composition the sillimanite concentrate meets all the requirements of the electrothermal production of Al-Si alloys.

2.2. Granulometry and other characteristics of feed materials

Prior to process testing of the sillimanite concentrate the Indian coal and the petroleum coke were ground to - 0.5 mm.

The sillimanite concentrate as well as other power materials introduced into the feed - commercial grade alumina, dry benefeciation kaolin and dust from the gas cleaning plant were tested as-received, without grinding.

The granulometry, an average size of the particles, a true density and a melting temperature were determined for all the materials under investigation.

A weight content of the major components and of specified impurities in all the feed materials used in the process tests of the raw material, is given in Table 2.I.

The data on granulometry of the materials under investigation and on their other physical characteristics is given in Table 2.2.

Table 2.I.

Average chemical composition of feed materials used in process testing of raw material

Description	Technical analysis of reducing agents, % wt			Chemical analysis of raw materials and reducing agents' ash, % wt.							
	ash A^c	volatiles yield	non-volatile carbon C_{nv}	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	ZrO_2	CaO+ MgO	R_2O	L.O.I.
I	2	3	4	5	6	7	8	9	I0	II	I2
Indian sillimanite concentrate	–	–	–	62.3	36.2	0.3I	0.II	0.34	0.2	0.07	0.065
Soviet dry benefication kaolin	–	–	–	36.2	47.4	0.69	0.56	–	0.6	–	I2.5
Commercial grade alumina, USSR	–	–	–	Main component	0.I0	0.09	0.00I	–	0.03	0.50	–
Dust of gas-cleaning plant, USSR	–	–	–	43.7	29.6	0.06	0.02	0.0I	0.6	0.2	–
Lignosulphonate (dry residue)	I4.3	–	–	In ash 0.74	0.5	0.5I	–	–	8.47	39.24	–
Coal, India	I9.76	35.5	38.8I	24.85	60.82	5.2	I.2	–	2.75	–	–
Petroleum coke, USSR	I.24	II.04	87.72	I5.9	22.4	I6.7	0.30	–	–	–	9

Table 2.2

Granulometry and other characteristics of feed materials

Description	Size distribution, % wt				Average grain size, mm	Melting temperature °C 2/	Density, g/cm²	
	+0.5 mm	0.5-0.25 mm	0.25-0.10 mm	-0.10 mm			true	apparent
Sillimanite concentrate, India	0.03	41.2	58.5	0.27	0.257	1.800	3.30	2.05
Dry benefication kaolin, USSR	-	-	-	-	0.002 1/	1.780	2.63	0.36
Commercial grade alumina, USSR	0.05	0.1	38.7	61.15	0.10	1.900	3.56	1.15
Dust of gaz-cleaning plant, USSR	-	-	-	100.0	0.005	1.750	2.3	0.2
Coal, India	2.7	7.6	64.6	25.1	0.174	-	1.48	0.78
Petroleum coke, India	5.9	11.6	47.5	35.0	0.19	-	2.06	0.7

Notes: 1) According to sedimentation analysis.

2) Determined on start of melting of Seger cones.

The data obtained on the chemical and granulometric composition on the Indian sillimanite concentrate meet the Soviet requirements to high-alumina raw materials which are used in the electrothermal production of Al-Si alloys.

Attention is drawn to an excessively high ash content of the Indian coal, which may result in some increase in consumption of the commercial grade alumina to be added into the feed to stabilize an optimum (60 to 63%) content of Al in silicoaluminium, as well as in an increase of iron content in it, which is a specified value.

2.3. Briquetting Ability of Feed and Its Strength Characteristics

All the feeds where the Indian raw materials were used were intended for production of the primary silicoaluminium containing mainly 60 to 63% of Al, the balance being silicon and impurities.

The Indian coal and the petroleum coke were used in varying ratios in all the feeds as a reducing agent. For strengthening green and dry briquettes a water solution of sodium lignosulphonate or of sulphate-cellulose lye meeting the Soviet standards, at the rate of 5% on a dry residue basis from the feed weight, was introduced, Besides, 4 to 5% of dust collected in the gas cleaning plant during the operation of the electric-arc reduction furnaces was added into the feed. For the chemical composition and other characteristics of these materials see Tables 2.I and 2.2.

The weighed out and thoroughly mixed components of the feed were pressed by a laboratory press (200 kg/cm2) into cylindrical briquettes having height and diameter of 30 mm. The briquettes were dried to constant wight at $105^{o}C$. Part of the briquettes were calcined during 2 hours without an access of air at $1000^{o}C$.

The strength characteristics for the dried and calcined briquettes were determined to evaluate the briquetting ability of the feeds and their suitability for use in the commercial process. For the main feed compositions used in the commercial production of silicoaluminium in the USSR, the strength characteristics of the briquetts produced under laboratory conditions, were as follows:

$$\sigma_{105} - 109.6 \text{ kg/cm2} \quad \text{and} \quad \sigma_{1000} - 19.3 \text{ kg/cm2}.$$

The laboratory tests for briquetting ability of the feeds were for convenience divided into several groups.

The first group of tests was designed to clarify the effect of adding alumina and dust of the gas cleaning plant into the feed on the strength characteristics of the briquettes.

A ratio of the reducing agents (coal and petroleum coke) in the briquettes, as well as of the sillimanite concentrate and kaolin in the feed of this group did not change and was 70 to 30 for coal and petroleum coke (on the non-volatile carbon content basis) and 80 to 20 for the sillimanite concentrate and kaolin (by weight of the materials).

The second group of tests was designed to study the effect of the sillimanite concentrate and kaolin content on the briquetting ability of the feed, their ratio for various feeds being 80/20; 60/40 and 35/65,

The third group of tests was designed to study the effect of the total relative content of non-volatile carbon, as well as the ratio of reducing agents in the briquettes on the strength characteristics of the briquetted feed.

The total relative content of carbon in the briquettes of this group were assumed to be I00, 80 and 50% of the stoichiometric, compensating for a deficiency in carbon in the feeds by adding ground coal. A ratio of ground coal and petroleum coke in the briquetted feed of the third group tests was assumed to be 70/30, 40/60 and 0/I00 (by content of non-volatile carbon, C_{nv} in coal and peroleum coke).

The results of the tests for determining the briquetting ability for feeds of the I-st and 2-nd groups are given in Table 2.3.

Table 2.3

Briquetting ability of sillimanite-containing feeds depending on quantities of alumina, dust and kaolin in them

Tests group and feed No.	I-st group of tests			2-nd group of tests		
	I	2	3	4	5	6
I. Briquetted feed, composition by %:						
- sillimanite concentrate	45.33	37.33	34.53	37.90	27.04	I4.86
- kaolin	II.33	9.33	8.63	9.47	I8.04	27.66
- alumina	-	I0.I0	I0.7I	6.42	9.25	I2.43
- dust of gas cleaning plant	-	-	3.78	3.84	3.80	3.74
- coal	36.4I	36.32	35.58	35.59	35.I7	34.70

Tests group and feed No.	I-st group of tests			2-nd group of tests		
	I	2	3	4	5	6
- petroleum coke	6.93	6.92	6.77	6.78	6.70	6.6I
Total	I00.00	I00.0	I00.0	I00.0	I00.0	I00.00
2. Composition of briquettes:						
- relative carbon content (C_{nv}) in briquettes, % rel.	I00	I00	I00	I00	I00	I00
- coal/petroleum coke ratio (C_{nv} basis) in briquettes	70/30	70/30	70/30	70/30	70/30	70/30
- sillimanite/ kaolin ratio	80/20	80/20	80/20	80/20	60/40	35/65
- calculated composition of feed by metals in alloy,% wt:						
- aluminium	57.88	64.8I	64.6I	6I.34	60.8I	60.06
- iron	I.39	I.2I	I.I5	I.23	I.27	I.33
- Ti and Zr	0.75	0.59	0.55	0.63	0.62	0.60
3. Strength of briquetted feed, kg/cm2 :						
- dried briquettes, @ I05^{o}	56.6	34.9	44.6	65.5	65.I	6I.3
- calcined briquettes, @ I000^{o}	6.8	2.7	4.4	7.6	8.9	9.4

Briquetting ability of sillimanite-containing feeds depending on relative content and ratios of reducing agents in briquettes

Tests group and feed No.	3-rd group of tests					
	7	8	9	I0	II	I2
I. Briquetted feed composition:						
- sillimanite concentrate	37.90	42.74	50.76	4I.I3	45.59	52.73
- kaolin	9.47	I0.68	I2.69	I6.30	II.40	I3.I8
- alumina	6.42	5.2I	3.26	7.37	6.40	4.88
- dust of gas cleaning plant	3.84	4.33	5.I5	4.I7	4.62	5.35
- coal	35.59	22.22	-	3I.II	I9.20	-
- petroleum coke	6.78	I4.82	28.I4	5.92	I2.79	23.86
T o t a l, %	I00.00	I00.00	I00.00	I00.00	I00.00	I00.00
2. Composition of briquettes:						
- relative carbon content (C_{nv}) in briquettes, % rel.	I00	I00	I00	80	80	80
- coal/petroleum coke ratio in briquettes (C_{nv} basis)	70/30	40/60	0/I00	70/30	40/60	0/I00
- sillimanite/kaolin ratio	80/20	80/20	80/20	80/20	80/20	80/20
- calculated composition of feed by metal in alloy, % wt:						
aluminium	6I.34	6I.92	62.67	6I.35	6I.72	62.28
iron	I.23	0.95	0.54	I.28	I.06	0.75
Ti and Zr	0.63	0.6I	0.57	0.64	0.62	0.59

SECTION 1

Table 2.4

Briquetting ability of sillimanite-containing feeds depending on relative content and ratios of reducing agents in briquettes

ed No.	3-rd group of tests								
	7	8	9	I0	II	I2	I3	I4	I5
mposi-									
centrate	37.90	42.74	50.76	4I.I3	45.59	52.73	47.33	50.82	56.I5
	9.47	10.68	I2.69	I6.30	II.40	I3.I8	II.83	I2.70	I4.C4
	6.42	5.2I	3.26	7.37	6.40	4.88	9.I7	8.60	7.73
ning	3.84	4.33	5.I5	4.I7	4.62	5.35	4.80	5.I5	5.70
	35.59	22.22	–	3I.II	I9.20	–	22.57	I3.64	–
	6.78	I4.82	28.I4	5.92	I2.79	23.86	4.30	9.09	I6.38
	I00.00	I00.00	I00.00	I00.00	I00.00	I00.00	I00.00	I00.00	IC0.C0
rquet-									
con- iqu-	I00	I00	I00	80	80	80	50	50	50
ke tes	70/30	40/60	0/I00	70/30	40/60	0/I00	70/30	40/60	0/I00
in	80/20	80/20	80/20	80/20	80/20	80/20	80/20	80/20	80/20
sition in									
	6I.34	6I.92	62.67	6I.35	6I.72	62.28	6I.2I	6I.44	6I.76
	I.23	0.95	0.54	I.28	I.06	0.75	I.36	I.23	I.04
	0.63	0.6I	0.57	0.64	0.62	0.59	0.65	0.63	0.62

SECTION 2

Tests group and feed No.	3-rd group of tests								
	7	8	9	I0	II	I2	I3	I4	I5
3. Strength of briquetted feed, kg/cm2 : I/									
– dried briquettes, σ I05°	75.5	III.5	I57.I	70.8	I04.2	I42.9	66.7	I02.0	I27.5
– calcined briquettes, σ I000°	I7.6	24.3	34.3	I4.2	I9.3	35.3	I2.3	20.9	35.5

I/ For the basic feed prepared from Soviet raw materials, σ I05 = I09.6 m
σ I000 = I9.3 kg/cm2.

As one can see from Table 2.3, the amount of alumina, introduced into feed No.2, calculated to produce alloys containing 63% Al, decreased considerably, as compared with feed No.I, strength of the briquetts. An introduction in feed No.3 of dust from the gas cleaning plint improved its briquetting ability and somewhat decreased the negative effect of alumina on strength of the briquettes.

Taking into account the results, obtained for the first group of tests, the following (Table 2.3) tests were carried out with feeds containing a moderate amount of alumina (calculated for an alloy, containing 60% Al) and with introduction into the feeds of dust from the gas cleaning plant (about 3.8% from weight of the feed).

The results of the second group of tests show that strength of the briquetts do not change appreciably when a kaolin content in the feed is increased two- or threefold. But this, in its turn, decreses a relative content of the sillimanite concentrate in the feed, which is the main source of production of Al-Si alloys, and results in a necessity to increase by I.5 to 2.0 times of a weight content of alumina in the feed.

The results of the third group of tests given in Table 2.4 show that strength of the briquettes increases mainly when a coal content in the briquetts is decreased and is replaced by petroleum coke. The maximum strength of the briquetts is obtained with the feeds Nos.9, I2, and I5, containing only petroleum coke as a reducing agent (without coal), Taking into account that reactivity of petroleum coke should be considerably less than for coal, these feed compositions can not be recommended for mettalurgical testing. The data of Table 2.4 show that for broquetting ability of the feeds under test the nearest to the basic compositions of the feeds used in commercial production (for which σ_{105° = I09.6 and σ_{1000° = I9.3 kg/cm2) are the feeds Nos. 8 and II. A weight ratio of coal and petroleum coke (by C_{nv}) in these feeds is 40/60, and a total relative content of non-volatile carbon in the briquettes varies within 80 to I00% as compared with a stoichiometric quantity of carbon which is required for reducing all oxides of the feed.

To check experimentally the effect of the feed materials' size on the briquetting ability of the feeds, the 4-th group of tests studied the effect of reducing the size of coal only and of coal together with sillimanite concentrate on the briquettes' strength. To carry out the test, the materials were separately ground in a ball mill down to minus 0.I mm. Then the feeds were prepared in a way it was done for the feeds studied in the 3-d group of tests, the only difference being the fact that in some feeds the additionally ground coal was introduced, and into others - the additionally ground coal and sillimanite concentrate. According to the results obtained in the tests (Table 2.5) due to additional grinding of the materials the strength of briquettes increased for both dry and calcined ones.

T a b l e 2.5

Average data on relative increase of the briquettes strength with additionally ground feed materials

Coal/petroleum coke ratio in briquettes (by C_{nv})		70/30	40/60	0/I00
Relative increase of strength, % rel :				
- additionally ground coal	$\Delta\sigma_{105^\circ}$	47.I	7.I	-
	$\Delta\sigma_{1000^\circ}$	94.3	24.4	-
- additionally ground coal and sillimanite concentrate	$\Delta\sigma_{105^\circ}$	30.9	3.9	27.0
	$\Delta\sigma_{1000^\circ}$	90.2	34.0	48.I

The data presented show that the finer ground coal is dominant in increasing the strength of briquettes.

Taking into account the results obtained and the data from Table 2.4 it is possible to recommend for further metallurgical testing No. 7 feed, along with Feeds Nos. 8 and IO.

2.4. Metallurgical evaluation of feeds

2.4.I. Reducibility of feeds

The feed reducibility tests were carried out according to the VAMI method[I/] developed to fit the production of Al-Si alloys. A laboratory electrical furnace with a tubular heater (Fig. 2.I) was used for testing. It ensures maintaining the temperature of 2.000 to 2.050°C in a reaction zone of the furnace. For testing the samples of I20 to I60 g in the form of pellets 6 to 8 mm in dia, were used. Each reducibility test consisted of two stages. During the first stage in a reaction crucible 4 and a condenser 2 (Fig. 2.I) the feed was loaded. During the second stage in the reaction crucible a content of the condenser left after the first stage of the test (calcined feed pellets covered with sublimed matter) and in the condenser - the initial feed in the same amounts as in the first stage of the test.

The content of the reaction crucible after the second stage of the tests was analyzed for metal Al and Si. Reducibility of the feed was evaluated by degree of reduction of Al and Si from the feed according to the formula:

$$B = \frac{Me_{II}}{Me_{calc}} \times 100\%$$

[I/] Tsvetnie Metalli, N 6, 1977, p. 30-32 (Non-Ferrous Metals).

where: Me_{II} - actual content of Al and Si in the crucible after the second stage, g;

Me_{calc} -calculated content of Al and Si in the feed charged into the condenser, g.

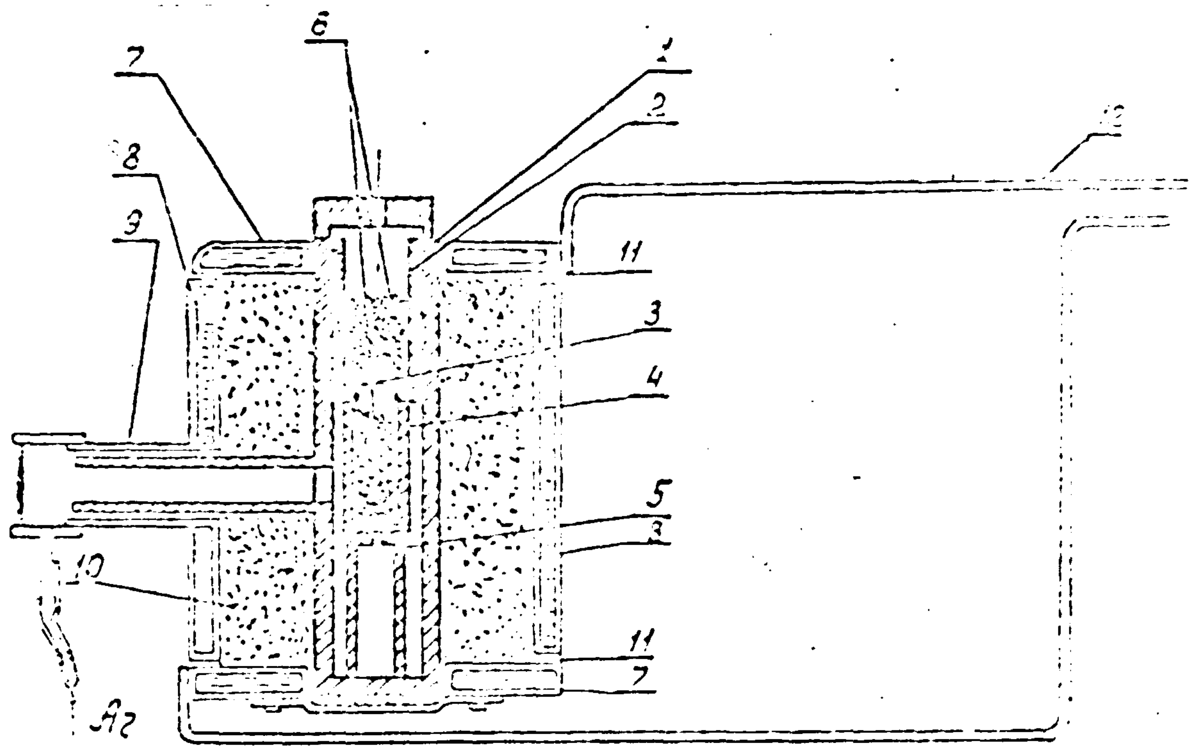

Fig. 2.I. Apparatus for studying the reducibility of feeds and feed materials

I - tubular heater, 2 - condenser ;

3 - perforated partition, 4 - reaction crucible,

5 - support; 6 - feed being studied (pellets);

7 - water-cooled cover; 8 - water-cooled case;

9 - inspection connection; I0 - graphite cuttings,

II - electrical insulation, I2 - current supply.

This investigation method permitted in the most exact manner to simulate, at the laboratory scale, the conditions of the process in electric-arc reduction furnaces. Feed charged into the condenser during the first stage of the tests, is under conditions simulating a top of the electric-arc reduction furnaces. A content of the condenser charged into the reaction crucible at the second stage of the tests, is under conditions simulating a reaction zone of the electric-arc reduction furnaces where preliminary heated and partially reduced feed of the furnace top zone comes.

The feed reducibility tests were carried out with the feed compositions given in Table 2.4. For a relative content of non-volatile carbon in the briquettes or pellets equal to 80 and 50%$_{rel}$ a feed compositional adjustment was carried out by adding to the pellets of crushed coal of 3 to 5 mm and thorough mixing of the coal with the pellets to average the composition.

The data on reducibility of the feeds are given in Table 2.6.

Table 2.6

Reducibility of the studied feeds

Feed No, (from table 2.4)	Coal/petroleum coke ratio, non-volatile carbon basis	Relative content of carbon (C_{nv}) in feed (numerator)and in briquettes (denominator) % rel.	Degree of reduction of Al and Si from feed at 2000°C, %.
7	70/30	I00/I00	60.I
8	40/60	I00/I00	53.63
9	0/I00	I00/I00	43.2
I0	70/30	I00/80	5I.88
II	40/60	I00/80	45/6I
I2	0/I00	I00/80	33.I
I3	70/30	I00/50	40.06
I4	40/60	I00/50	39.74
I5	0/I00	I00/50	34/78
Basic feed of Soviet raw materials		-	45.20

The data of Table 2.6 show that with an increase of a relative content of petroleum coke in the feed, as well as with a decrease of a carbon content in the pellets the feed reducibility becomes worse.

The highest degree of reduction of Al and Si from the feeds under investigation which is higher than the same figure for the basic feed, was obtained with the feeds Nos. 7,8, IO and II.

The reducing agents' content in these feeds is limited as follows: from 76 to 40%$_{rel}$ - for coal, and from 24 to 60%$_{rel}$ - for petroleum coke. A relative content of carbon in the briquettes or pellets should not be below 80%$_{rel}$, because an adjustment of the feed composition by crushed coal do not fully compensate for the loss of metal due to the worsening of conditions for reduction of the feed oxides.

2.4.2. Electrical resistance of feeds

It is known that a specific electrical resistance (SER) of various feeds is of the major importance in selecting design and electrical features of the electric-arc reduction furnaces crucibles. In accordance with the laboratory method adopted in VAMI an SER value was changed for feeds of various compositions.

Before testing the briquetted feeds to be investigated were calcined at I000°C in a sealed container for 2 hours and then were cooled down to the room temperature ground to minus 0.5 mm and charged into a container of the measuring apparatus.

When using the feeds lacking carbon in the briquettes, after calcining and cooling them a carbon adjustment was carried out by adding 3 to 5 mm calcined coal. The calcined briquettes were ground together with coal down to minus 0.5 mm and then charged into the container of the measuring apparatus.

A measuring method of the SER is based on determination of a voltage drop when passing direct current through the feed being tested. The feed is in the container under pressure of 40 kg/cm^2.

The measured values of the SER of the feeds are given in Table 2.7.

Table 2.7

Feed electrical resistance

Feed No. (from Table 2.4)	Coal/petroleum coke ratio, non-volatile carbon basis	Relative content of carbon in feed (numerator) and in briquettes (denominator), %C	Specific-electrical resistance of feed, ohm.cm^2
7	70/30	I00/I00	I4.30
8	40/60	-"-	I3.4I
9	0/I00	-"-	-
I0	70/30	I00/80	I5.40
II	40/60	-"-	I4.I0
I2	0/I00	-"-	-
I3	70/30	I00/50	23.79
I4	40/60	-"-	I7.70
I5	0/I00	-"-	I6.4I
	Basic feed from Soviet raw materials	-	I5.4

One can see from the table that with an increase of a petroleum coke content in the feed its electrical resistance decreases. For the feeds Nos. 7, 8, I0 and II characterized by a higher degree of reducibility of Al and Si (Table 2.6) the SER value is somewhat lower than for the basic feed prepared from the Soviet raw materials.

2.5. Conclusions for the section

Laboratory testing of the Indian sillimanite concentrate and coal was carried out to preliminary determine the process parameters and obtain the basic data for conducting the semicommercial tests.

During these tests a chemical and material composition of the sillimanite concentrate and of coal was determined. Their main process characteristics were studied including the briquetting ability, reducibility and electrical resistance. The results of the laboratory tests on the whole can be considered as positive.

The tests revealed that among the feeds tested the best process characteristics belong to the feeds Nos. 7, 8, IO and II (Table 2.4). They can be recommended for further semicommercial testing.

In these feeds the reducing agents' content should be as follows: from 76 to 40% (rel) - for coal and from 24 to 60% (rel) - for petroleum coke.

A relative content of carbon in the briquettes and pellets to be used for a semicommercial testing should be about 90 to 95% of the stoichiometric amount of carbon and should not be lower than 80% (rel), because an adjustment of the feeds during melting by crushed coal will not compensate for the loss of metal due to the worsening of conditions under which reducing reactions take place.

3. Results of semicommercial tests

The tests were carried out on the semicommercial equipment of the Leningrad Pilot Plant (LPP) of VAMI.

3.I. Schematic flowsheet and brief description of the equipment

Pelletizing the feed and its melting was carried out according to the standard procedure adopted at the LPP. Powdered components of the feed - the Indian sillimanite concentrate, kaolin and alumina were fed directrly to a weighing section.

Lumpy materials (the Indian coal and the Soviet petroleum coke) were fed into a jaw crusher for crushing down to minus 50 mm and then into a ball mill for grinding down to minus 0.5 mm. After that the materials were directed to the weighing bay. Batches of I50 kg each were prepared.

The weighed components of the feed were loaded into a receiving hopper and by a flight conveyer fed into a drum mixer for thorough blending. The blended feed then was transferred into a three-chamber drum pelletizer where it was wetted with a water solution of sulfite-cellulose lye (density I.I5 to I.I7 g/cm3) and granulated into pellets of 3 to 30 cm dia. The pelletized feed then was sent into a roll mill where at pressure of I50 kg/cm2 the ellipsoidal briquettes were formed measuring 65 x 40 x 30 mm.

The briquettes were kept for 3 to 5 days in the shop and then without special drying were sent for melting. Besides, some pellets of +I2 - 25 mm size bypassing the mill were also forwarded for melting.

Keeping a record of the quantity of feed charged into the furnace was done by a quantity of the feed containers charged and controlled by a total number of the melted batches.

The melting was performed in a two-electrode semicommercial furnace of the LPP VAMI rated at I50 kW. A basic diagram for connecting the furnace to a transformer is given in Fig. 3.1. The furnace transformer has a range of secondary voltages from 25 to 90 V (23 steps). The maximum current at the low side is 3.100 A, a working current averages 2.700 A. For the average values of working current the active power losses in the current conductors of the furnace is I9.2 kW.

The main dimensions of the crucible and shell of the furnace are given in Fig. 3.2. Sides of the crucible are lined with standard fireclay bricks and the bottom is of carbon material. The I50 mm electrodes are graphitized and current is supplied via two copper water-cooled semirings embracing an electrode from two sides.

A primary alloy produced in the furnace was refined by flux according to the standard procedure. Then it was diluted with aluminium to obtain a silicon content close to the eutectic one. After that manganese was added into the melt followed by filtration in a vacuum filter-apparatus to produce casting alloys.

3.2. Compositions of the feeds being studied and their strength

According to the results of the laboratory tests for semicommercial testing five feeds (Nos. 7, 8, I0, II and I4 (Table 3.I)) were selected having different content of a reducing agent (I00%, 80% and 50%) and different coal/petroleum coke ratio in the briquettes (70/30 and 40/60). Besides, the 7 feed was tested in a pelle-

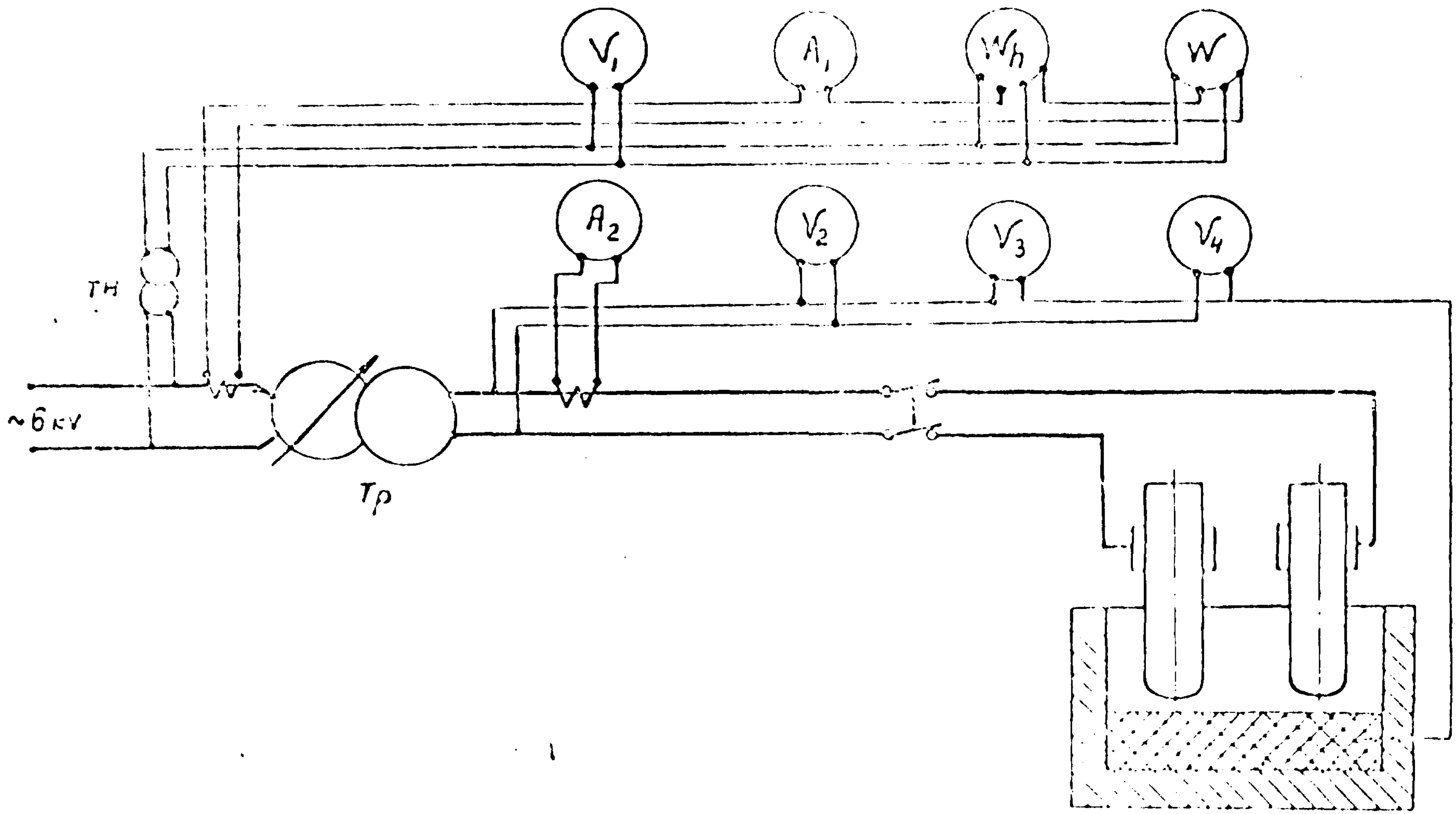

Fig. 3.I. Basic connecting diagram of the two-electrode semicommercial electric furnace.

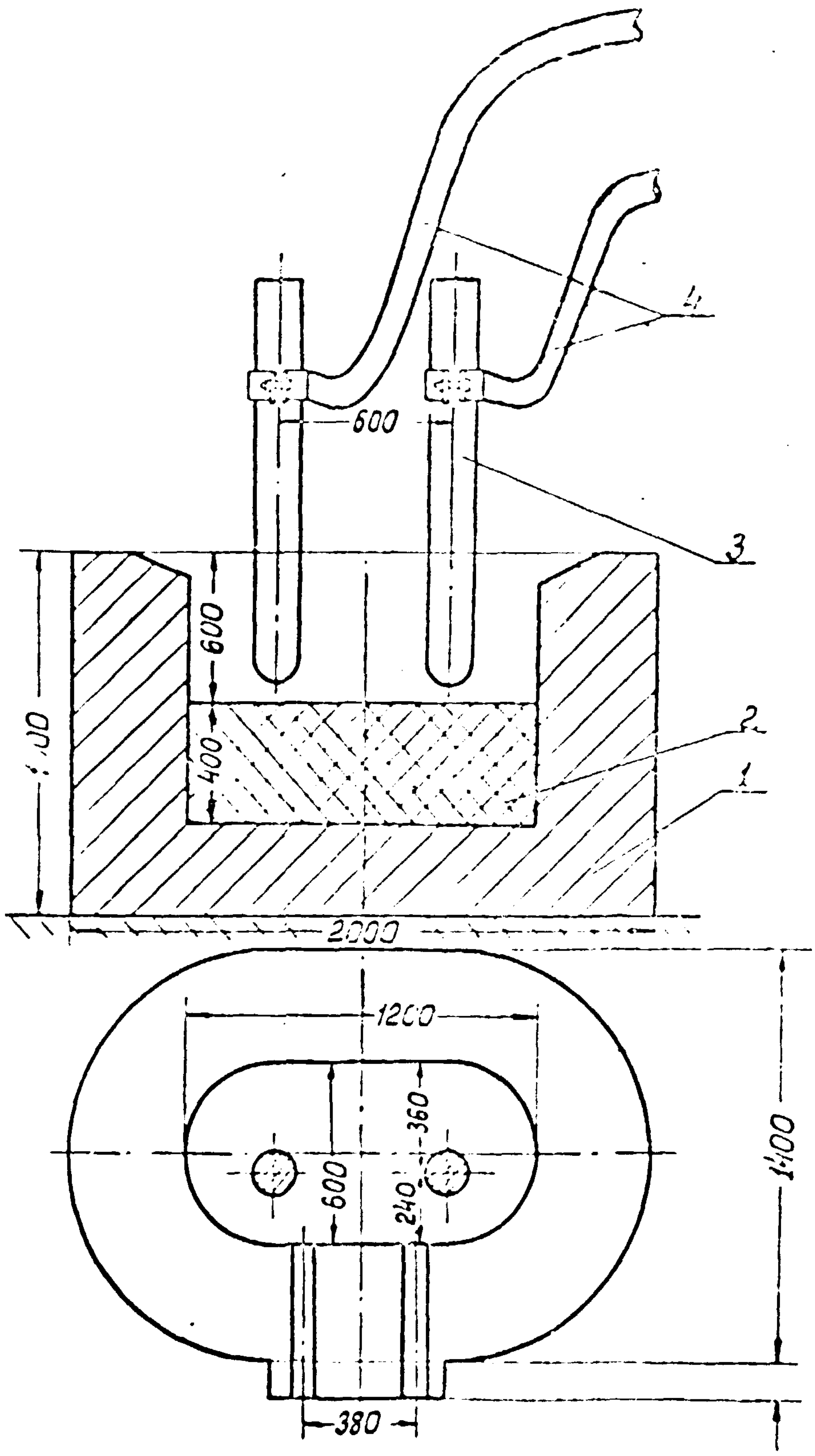

Fig. 3.2. Two-electrode semicommercial electrical furnace
I - lining; 2 - carbon bottom; 3 - graphite electrode; 4 - current conductor.

tized form and the feed I4 where the deficiency of carbon was compensated for by adding charcoal.

The basic feed A1 from the Soviet raw materials was used as a reference.

The feeds for semicommercial testing somewhat differed in their composition from the laboratory feeds. A total carbon content in them was 9I to 93% of the stoichiometric and they did not contain a recycled dust of the gas cleaning plant.

Compositions of the feeds for semicommercial tests are given in Table 3.I.

The briquetts (pellets) prepared in the plant conditions were tested for mechanical strength. Strength of the briquettes (pellets) was determined by a number of drops from 2 m height on a concrete floor to their failure, strength of dried (up to constant weight at I05°C) briquettes and pellets by a crushing pressure on a briquette (pellet).

A normalized strength was taken as a strength measure for the dry briquettes (pellets) equal to a ratio of the crushing strength to a squared normalized diameter, which is calculated according to the formula

$$d_n = \sqrt{\frac{d_I^2 + d_2^2 + d_3^2}{3}}$$

where d_I, d_2 and d_3 - the linear dimensions of the briquette along the three coordinates.

For spherical pellets a normalized diameter coincides with the geometrical one.

For the strength characteristics of the feeds see Table 3.2.

Table 3.I

COMPOSITION OF FEEDS OF INDIAN RAW MATERIALS

FOR SEMICOMMERCIAL TESTS

Item	Feeds/components	"A" (basic)	7 and 7I	8	I0	II	I4	I4 I
I	Composition of briquettes, %							
	Dry cleaned kaolin	33.68	I0.85	II.76	II.34	I2.54	I3.96	I3.96
	Commercial grade alumina	I3.75	5.38	4.50	5.63	5.62	7.72	7.72
	Disthen-sillimanite concentrate	I8.I3	–				–	–
	Indian sillimanite concentrate	–	43.42	47.02	45.33	50.I4	55.82	55.82
	Soviet coal	26.94	–				–	–
	Indian coal	–	3I.I3	22.04	30.83	I9.02	I3.48	I3.48
	Soviet petroleum coke	7.50	9.22	I4.58	5.87	I2.58	8.99	8.99
	T O T A L, %	I00.00	I00.00	I00.00	I00.00	I00.00	I00.00	I00.00
2	Reductant in feed, kg/I00 kg of briquettes:							
	Coal (India)	–	–	–	II.0I	II.89	33.72	–
	Charcoal (USSR)	–	–	–	–	–	–	I8.22
3	Percentage of reductant in briquettes, %	I00.0	I00.0	I00.00	[illegible]	80.0	50.0	50.0
4	Percentage of reductant in charge, % of Stoichiometry	95.3	9I.0	9I.0	9I.0	9I.0	9I.0	9I.0
5	Expected Al content in alloy, %	60.0	60.0	60.0	60.0	60.0	60.0	60.0
6	Coal/pet. coke ratio in briquettes	70/30	70/30	40/60	[illegible]	40/60	40/60	40/60

Table 3.2

STRENGTH OF BRIQUETTES AND PELLETS FOR SEMICOMMERCIAL TESTS

Feed No	Feed composition: percentage of C_{fixed} in briquette % of total	Feed composition: coal/pet. coke ratio	Normalised diameter d_{np}, cm	Average number of drops	Strength: measured, P, kg/briquette	Strength: normilised, G, kg/cm2
Briquettes:						
"A" basic	I00.0	70/30	5.32	I.4	I3I.5	4.65
7	I00.0	70/30	-"-	I.2	53.3	2.24
8	I00.0	40/60	-"-	I.5	I07.3	3.80
I0	80.0	70/30	-"-	I.4	I02.6	3.63
II	80.0	40/60	-"-	I.2	I22.3	4.32
I4	50.0	40/60	-"-	2.3	I42.6	5.04
Pellets:						
7Г	I00.0	70/30	2.70	2.0	23.2	3.I8
-"-	-"-	-"-	2.30	2.2	I8.2	3.44
-"-	-"-	-"-	I.90	2.3	I4.5	4.02
-"-	-"-	-"-	I.50	2.5	I0.4	4.62

Table reveals that strength of briquettes improves with lighter percentage of petroleum coke and lower percentage of reductans in briquettes, which is consistant with the results of laboratory tests. Charge No I4 (carbon in briquette = 50%, C/PC = 40/60) has a some what higher normalised strength than a the basic feed. Feed No.II (carbon in briquette = 80%, C/PC = 40/60) is similar to the basic feed with respect to strength. Feed No.7 has the lowest strength (abt. 50% of that of the basic feed), but the best reactivity. One of the ways to increase strength of briquettes is to decrease their size.the tests were also carried out with feed No.7 in a pelletised form.

Tables 3.2 and 3.3 show that normilised strength of pellets increases with smaller diameter and at a diameter of I5 mm approaches the strength of the basic feed which offers potential for successful transportation and conversion of this feed on a commercial scale.

3.3. Semicommercial Smelting Conditions

Smelting process conditions corresponded to the conditions used in similar tests. First, the furnace was heated without charge using coke filling. As soon as the furnace casing temperature was I50°C coke was removed and briquetted feed was gradually added for IO-I2 hrs, with no tapping of alloy performed. Following build-up of the ledge alloy was regularly topped every 2 hrs. As a rule, the furnace top was stoked and charge added to the furnace after each alloy tapping.

The furnace was started using the basic feed and measurements were taken, after thermal equilibrium had been established in 40-48 hrs of operation.

Alloy was tapped into molds lined with graphite. Slag boxes with sand lining were installed between the tapholes and molds. The boxes trapped unreduced oxides and carbides containing large portion of metallised phase (slags) which were then crushed down to 30-

-50 mm in size, wighed and returned to the furnace top along with the charge.

Control assessment of the quality of alloy produced and the furnace operation was carried out on the basis of decanted alloy recovery into the mold and the weight of settled slag in the slag box.

Samples of decanted alloy were taken during tapping for chemical analysis and also for content of non-metallics.

Part of decantant was resined with a mix of sodium chloride and cryolite to ensure more thorough removal of non-metallics from the alloy.

The following major operating parameters of the furnace were registered during smelting trials: power rating, operating voltage, consumption of power, briquettes (pellets) and corrective additions of coal and quartzite. Amount of decantant and slag produced were accounted, and recovery of refined decantant determined.

Visual control of condition of briquettes on the furnace top, their agglomeration on the top, descent of the charge to the lower levels of the furnace and thermal stability of briquettes was maintained.

Quantitative assessment of the furnace operation was carried out on the basis of specific consumption of electric power and minerals of the feed per 1 t of resined alloy.

The major criteria for selection of power and process parameters of the smelting tests using various charges were:

- regular tapping of alloy from the furnace while ensuring minimal contamination with slag;

- maintenance of conditions to secure continuous operation of the submerged-arc furnace, with the top being constantly covered with

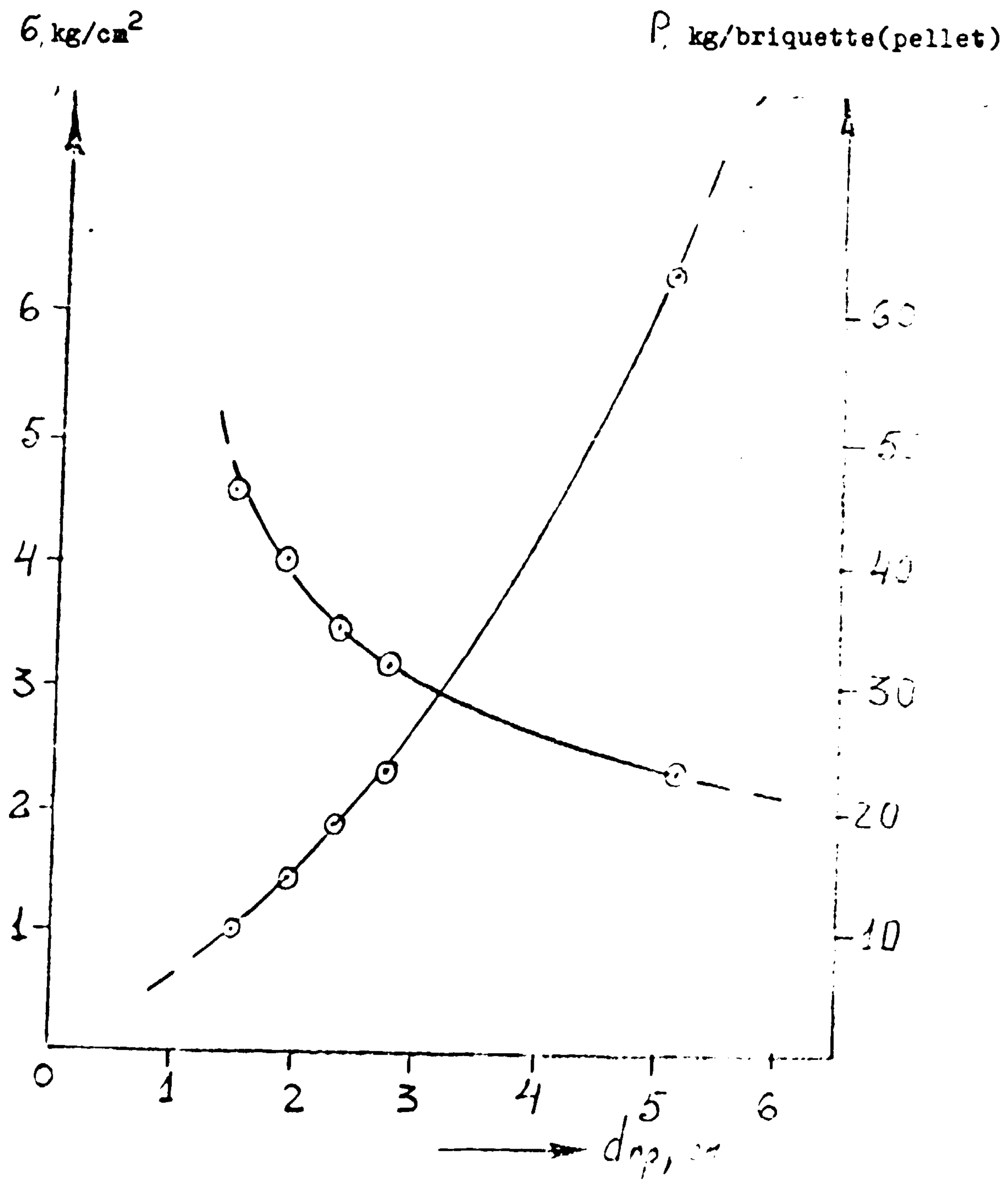

Fig. 3.3. Strength of feed No. 7 vs. normalised diameter

charge.

3.4. Crude alloy smelting and refining tests results

Table 3.3 gives the test results of crude alloy smelting and refining.

As seen from Table the smelting of feeds (Nos. 7,8,7r) with percentage of reductants in briquettes equal to 100% of the total allows the best results to be achieved (as compared with the basic feed).

For example, specific power demand for smelting feeds No. 7 and 7r decreased by II.6 and II.9%, respectively, consumption of feed minerals - by IC.5 and I2.5%. Recovery of refined alloy amounted to 91.92 and 93.6% as contrasted to 80.77% for the basic feed.

Visually smelting of feeds 7 and 7r went well. The top was stable and easily stoked, briquettes on the top satisfactorily retained their shape, though some crumbling was observed, but pellets did not breake at all. Tapholes could be readily opened, alloy tapping was unhinded Metal was hot, slag content-moderate.

Consumption of feed minerals was 2.57 t/t for feed No. 7 and 2.5I t/t for feed No. 7r , which is significantly lower than for the basic feed (2.87 t/t).

Changeover to feed No. 8 with higher content of petroleum coke resulted in somewhat higher agglomeration of the charge, however, even in this case performance data were better than the basic: specific power demand was IC.5% lower, recovery of refined alloy - - 7.03% higher, consumption of charge minerals - 2.53 t/t as against 2.87 t/t.

CRUDE ALLOY SMELTING AND REFINI…

TEST RESULTS

Feed No	Operation, hrs	Input				Output			Power rating, kW	Voltage, V	Power demand, kWh
		briquettes, kg	coal, kg	quartzite, kg	minerals, kg	decantant, kg	slag, kg	retined alloy, kg			
"A" (basic)	70	I970	-	II3.4	I4I4.2	6I0.0	244	492.7	I3I.0	70-72	9I70
7	80	2553	-	I43.3	I573.9	708.6	2I2.6	65I.3	I34.0	68÷73	I0720
7Г	26	8I3.2	-	44.5	53I.6	226.3	55.6	2II.8	I33.5	68÷73	347I
8	68	2042	-	I32.2	I39I	602.4	2I0.8	528.9	I29.5	68÷70	8806
I0	70	I858	I99.8	II4.9	I438.5	6I5.5	246.2	499.5	I35.0	70÷72	9450
II	76	2076	22I.9	I47.9	I537.4	666.2	279.8	528.3	I32.5	68÷7I	I0070
I4	70	I598	489.3	I57.I	I39I.6	620.9	322.9	448.9	I33.0	70÷74	93I0
I4"A"	40	89I.0	I45.5	86.8	776.2	344.7	I65.5	255.3	I27.5	68-70	5I00

SECTION 1

Table 3.3

...Y SMELTING AND REFINING

TEST RESULTS

...	Power rating, kW	Voltage, V	Power demand, kWh	Recovery of refined alloy, %	Consumption per 1 t of refined alloy: briquettes, t	coal, t	quartzite, t	minerals, t	power, kWh	Composition of refined alloy: Al	Si	Fe	Ti+Zr
.7	131.0	70–72	9170	80.77	4.0	–	0.23	2.87	18610	55.3	39.6	3.01	1.11
.3	134.0	68÷73	10720	91.92	3.92	–	0.22	2.57	16459	55.6	40.5	3.05	0.75
.8	133.5	68÷73	3471	93.6	3.84	–	0.21	2.51	16390	55.8	39.4	3.03	0.76
.9	129.5	68÷70	8806	87.8	3.86	–	0.25	2.63	16650	54.1	41.1	3.10	0.73
.5	135.0	70÷72	9450	81.15	3.72	0.40	0.23	2.88	18920	55.0	40.1	3.15	0.74
.3	132.5	68÷71	10070	79.3	3.93	0.42	0.28	2.91	19060	52.7	42.5	3.12	0.68
.9	133.0	70÷74	9310	72.30	3.56	1.09	0.35	3.10	20740	50.1	44.8	3.35	0.75
.3	127.5	68–70	5100	74.07	3.49	0.57	0.34	3.04	19975	50.3	44.7	3.30	0.59

SECTION 2

Visually the furnace operated well. The top was stable, agglomeration – moderate. Briquettes on the top retained their shape, did not break. No problems were encountered in tapping.

Trials of feeds with 80% content of reductant in briquettes (feeds No. 10 and 11) revealed somewhat lower fugures. Specific power demand was 18920 kWh/t of refined alloy for feed No.10 and 19060 kWh/t of refined alloy for feed No. 11, or 1.7 and 2.4% higher than the basic case. Recovery of refined alloy and consumption of feed minerals insignificantly differ from the basic feed.

Visually the furnace operated well on both feeds, though higher tendency for top agglomeration was noticeable , as well as lower performance data with increase of petroleum coke in the feed. Tapping feed No. 10 alloy caused no difficulties, though it was more complicated to open the taphole when smelting feed No. 11.

Consumption of quartzite was higher with this feed resulting in a little lower aluminum content in the alloy.

Performance data of feed No. 14 containing 50% of carbon in the feed were significantly lower. Power demand rose 11.4% as compared with the basic feed, recovery of refined alloy dropped 8.47%, consumption of feed minerals increased 8%.

Visually the furnace operation was unstable. At operating voltage 70 V side ledges formed in the upper levels of the cavity, which were hard to reduce and their melting required build-up of voltage to 74-75 V which, in turn, led to collapse of the top and more problems in opening the taphole. Quartzite had to be added not only to secure elimination of bottom ledges, but also to keep the top from falling, which resulted in 35% consumption higher than that of the basic feed an drop of aluminum content in alloy down to 50.1%.

To check whether it is possible to improve performance data of feed No. 14 lumpy coal added to briquettes was replaced by charcoal (feed 14 Д). Table 3.3 shows that such change positively improved operation of the furnace: specific power demand dropped 3.7% as compared with feed No. 14, recovery of refined alloy rose 1.77%, consumption of feed minerals were somewhat lower,-the figures were still much worse than those of the basic case.

Visually operation of the furnace with feed No. 14 Д was better than with feed No. 14. The top drops were less frequent and ledging less severe.

Summing up the semicommercial trial results one may come to a general conclusion that it is technically feasible to process all feeds under test using the proposed technology.

Lower percentage of reductants in briquettes worsens operation of the furnace, which is still rather good at 80% of the total.

Substitution of charcoal for Indian lumpy coal added to briquettes a little improves the furnace performance.

3.5. Conversion of electrothermal Crude Alloy into АЛ-2 and АКI2М2МгН AlSi-Alloys

The АЛ-2 alloy is used in manufacture of machinery, electronic and electrical industries, manufacture of consumer goods.

The АКI2М2МгН alloy is used for d.c. casting pistons for tractor engines.

These alloys were prepared from crude alloy (feed No. 7).

Chemical analysis of crude alloy, %:

Si	Fe	Ti	Zr	Al
40.5	3.05	0.45	0.40	55.6

Theoretically removal of iron, titanium and zirconium from the AlSi-alloys consists in use of difference in solidification points of various melt components by the filtering, centrifuging and other methods to separate solid phase from liquid phase and to obtain silumin at the temperature of entectics. And manganese is added to secure higher degree of iron removal from the alloy.

Production of alumin and alloy was carried out according to the flowsheet which includes melting of charged materials proportioned as to produce AlSi-alloy containing I2–I3% Si, refining with a universal four-component flux of the following composition, %: NaCl – – 56.5, NaF – 25, KCl – II.5 and Na_3AlF_6 – 7, removal of slag, cooling alloy to abt 620°C, pouring onto the filter (quartzite grit) heated to abt 600°C, cooling of alloy and filter to abt 600°C, filtering of alloy in vacuum (residual pressure abt I mm Hg).
In case of the AKI2M2MrH alloy the filtrate was alloyed with copper, nickel and magnesium.

Chemical composition and mechanical properties of the alloys produced correspond to the Soviet standards.

Consumption factors for production of alloys, kg/t:

Item	Charge components	Alloy grade	
		АЛ 2	AKI2M2MrH
I	Electrolytic aluminum	765.8	723.0
2	Crude alloy	323.I	324.0
3	Manganese metal	II.6	II.7
4	Copper	–	22.0
5	Nickel	–	II.0
6	Magnesium	–	II.0

3.5. Conclusions for the Section

The results of trials of test lots of sillimanite concentrate and coal supplied by Indian Rare Metals Co. prove a principal suitability of the materials under study for the electrothermal production of AlSi-alloys.

The tests involved the study and establishing the conditions of charge lumping by briquetting and pelletising methods using the drum pelletiser and roll press at the VAMI pilot plant, process and electrical parameters of the direct reduction process for smelting various charges to obtain the crude AlSi-alloy containing 59-61% Al and the balance of silicon and impurities: determining regime parameters of flux refining of crude alloy from non-metallics, as well as metallurgical conversion of refined alloy into AЛ 2 alloy and heat-resistant AKI2M2MrH alloy corresponding to the USSR standards (GOST 2685-75 and GOST I583-73).

The results of semicommercial trials are consistent with the preliminary laboratory results. In particular, they reveal dependence of basic process parameters of various charges preparation and direct reduction smelting on content of coal and petroleum coke, which are added in different weight ratios by fixed carbon.

With respect to unit power demand and recovery of refined alloy the best results were obtained using feed No. 7 (Table 3.3) with overall percentage of fixed carbon in briquettes 9I-93% of stoichiometry and ratio of carbon in coal to that in petroleum coke in briquettes equal to 70/30,

However, during direct reduction smelting of briquetted charge with this composition briquettes would partially break on the furnace top, which resulted in somewhat higher consumption per I t of alloy produced. Comparison of operation of the two-electrode furnace on feeds Nos 7 and 7Г using briquettes and pellets showed that specific power demand and recovery of refined alloy practically did not depend of the charge lumping method. Smelting pelletised charge 7Г resulted in lower consumption of charge which is accounted for higher thermal stability of pellets as contrasted to briquettes and, correspondingly, lower breaking and crumbling at the furnace top. Data in Table 3.2 reveals that strength (G, kg/cm2) of small pellets in higher than that of large pellets or briquettes.

Smelting of briquetted feed No 8 with carbon of coal to carbon of petroleum coke ratio of 40/60 showed that strength of briquettes was quite satisfactory and performance no worse that for standard briquettes used in the Soviet industry. This data show that feeds of this of similar composition can be smelted using the industrial technology of briquetted charge preparation and direct reduction proven in the USSR on the large commercial scale in the electrothermal industry.

The results of trial smelting of feeds Nos IO, II and I4 given in Table 3.3 show that decrease in percentage of carbon in briquetted charge to 80 and 50% (rel.) with the appropriate make-up of carbon defficiency by additions of crushed coal to the feed brings about disruption of normal ore reduction process conditions. Strength of briquettes increases but other smelting figures as recovery of refined alloy, unit power demand, etc. significantly decrease.

Replacement of crushed coal in feed No. I4 by Soviet crushed charcoal (feed I4Д, Table 3.3) secured somewhat better performance data of direct reduction process, however, the earlier results obtained using feeds Nos 7 and 8 when all carbon was introduced into briquettes were not achieved.

Part of refined AlSi-alloy produced from feeds Nos. 7 and 8 was converted to commercial grade casting alloys - A 2 alloy and heatresistant AKI2M2MrH according to the process flowsheet used in the Dnieper Aluminum Smelter. Trial lots of commercial grade casting aluminum alloys weighing I50 kg are being prepared for delivery to Indian Rare Metals Company.

4. Expected performance data of electrothermal process using raw materials under study

On the basis of results of semicommercial tests the calculated composition of refined alloy and consumption factors of electrothermal process were established under the following conditions:

- sillimanite concentrate to kaolin ratio in feed - 80/20;

- coal to petroleum coke ratio in feed (by C_{nv}) - 70/30 and 40/60;

- content of iron and silicon in crude aluminum used for dilution of crude AlSi-alloy - 0.30 and 0.I5, respectively;

- amount of recycled waste: 80% of slag and 95% of dust (of total);

- refined alloy contains 59.6% Al and 36.67% Si.

Expected composition of refined alloys is shown in Table 4.I.

Table 4.I.

Expected Composition of Refined Alloys, %

	C/PC ratio in feed	Al	Si	Fe	Ti	Zr	Ca	Other
I	70/30	59.6	36.67	2.I62	0.364	0.232	0.858	0.II4
2	40/60	59.6	36.67	I.8I7	0.3I3	0.278	0.827	0.495

Consumption factors per I t of refined alloy are given in Table 4.2.

Table 4.2

Consumption Factors per I t of Refined Alloy, kg

Item		C/PC ratio in feed	
		70/30	40/60
I	Sillimanite concentrate	960.2	III5.0
2	Dry kaolin	240.0	280.0
3	Commercial grade alumina	432.3	350.7
4	Crushed quartzite	I80.0	I80.0
5	Metallised slag	280.0	280.0
6	Dust from dust filters	256.0	256.0
7	Coal	I602.0	980.0
8	Petroleum coke	353.0	630.0
9	Electrode paste	80.0	80.0
I0	Solution of sulfite-cellulose lye I.I6 in wight	689.3	689.3

Unit process power demand per I t of refined alloy (60% Al) will be abt I3000 kWh/t: throughput of a 22500 kVA furnace - 28 - -29 tpd with an average yearly coefficient of furnace utilisation of 0.93-0.95.

Table 4.3 shows consumption factors for production of I t of some common casting alloys.

Table 4.3

Consumption Factors per I t of Casting Alloys, kg

		Grade					
		АКI2М3МгН		АКI2М2		СИЛ-2, Ал2	
		Coal to petroleum coke ratio in feed					
		70/30	40/60	70/30	40/60	70/30	40/60
I	Aluminum	706.23	695.37	701.95	701.95	731.64	720.04
2	Refined alloy	330.96	325.35	324.68	324.68	356.20	349.97
3	Manganese	9.30	8.02	–	–	9.926	8.545
4	Copper	22.0	22.0	22.0	22.0	–	–
5	Nickel	II.0	II.0	–	–	–	–
6	Magnesium	II.0	II.0	–	–	–	–

The above expected figures can serve as a basis for preparation of preliminary economic calculations to prove economic viability of the electrothermal industry estabilishment in India.

5. Conclusions

I. In accordance with the contract No. 77/55 dated June 8, 1978 signed between the UN Industrial Development Organisation (UNIDO) and Export-Import Objedinenije "Tsvetmetpromexport" a series of laboratory and semicommercial metallurgical tests were carried out during January-June 1980 of a trial lot of sillimanite concentrate IO t in weight and trial lot of coal 6 t in weight furnished by the Indian Rare Metals Co. at the laboratory installations of the VAMI Institute and pilot installations of the VAMI pilot plant with the view to establish their suitability as basic materials for electrothermal production of aluminum-silicon alloys.

2. The study and process tests conducted in accordance with all steps of the process flowsheet used in the USSR proved a principal feasibility to use the raw materials under study for electrothermal production of aluminum-silicon alloys. Aluminium-silicon alloy produced in the course of tests was converted into casting aluminium alloys: AЛ 2 and AK12M2MrH grades used in the automotive applications. Mechanical properties of the alloys meet the specifications of the current Soviet standards. Two trial lots of alloy weighing I50 kg have been prepared for delivery to the Indian Rare Metals Co.

3. Laboratory investigations and semicommercial trials established that trial lots of raw materials supplied by the Indian company differed from raw materials used in a commercial unit of the Dnieper Aluminium Smelter.

Basic differences are as follows:

- higher quality of sillimanite concentrate with respect to content of major components and specified impurities;

- higher ash content (up to 20%) of hard coal with relatively low content of specified impurities in coal ash;

- lower briquetting ability of feed made of sillimanite concentrate and coal resulting in lower strength and thermal stability of briquettes.

4. Owing to problems of briquetting feeds containing sillimani-

te concentrate and coal, kaolin was added to all the feeds during the trials, as well as petroleum coke and commercial alumina. The latter was added to maintain aluminum content in the crude aluminum-silicon alloy at 59-5I%. Aqueous solution of sodium lignosulfonate in quantity of 5% on dry basis was used as a binder preparation of feeds.

5. Optimum composition of briquetted feed basing on desired strength of briquettes and reduction process parameters is as follows, wt. %:

sillimanite concentrate	- 47.02
kaolin	- II.76
alumina	- 4.50
coal	- 22.04
petroleum coke	- I4.68
sulfite-cellulose lye (binder) above I00% on dry basis	- 5.0.

Coal to petroleum coke ratio in briquettes in terms of fixed (non-volatile) carbon was 40:60.

Smelting charge of the above composition in the furnace produced the crude aluminum-silicon alloys as follows, wt. %: aluminum - - 54.I, silicon - 4I.I, iron - 3.I0, titanium + zirconium - 0.73.

The furnace performance (throughput, power demand and recovery of refined alloy)were similar to the figures obtained when using the charge smelted in the commercial plant.

6. High performance figures of the direct reduction process were also attained using the similar feed with coal to petroleum coke ratio in briquettes equal to 70:30 (by carbon). However, this charge would require additional steps to be taken in order to secure higher strength and thermal stability of lumped charge.

7. The performed trials of raw materials were used as a basis for tentative evaluation of expected performance data of electrothermal process in the 22500 kVA furnace:

- daily throughput of furnace - 28 to 29 t of refined alloy with average furnace utilisation factor of 0.93-0.95. Expected process power demand per I t of refined alloy - I3000 kWh;

- composition of refined alloy, wt. % aluminium - 60.0, silicon - 36.7, iron - I.85, titanium - 0.32, zirconium - 0.28, calcium - 0.83;

- expected specific consumption of raw materials and carbon reductants per 1 t of refined alloy, kg/t:

sillimanite concentrate	- III5.0
dry-cleaned kaolin	- 280.0
commercial alumina	- 350.0
crushed quartzite	- I80.0
coal	- 980.0
petroleum coke	- 630.0
electrode paste	- 80.0
solution of sodium lignosulfonate I.I6 in weight	- 690.0.

Besides, recycle products - dust from gas filters (260 kg/t) and metallised waste, slags (280 kg/t) - are used in smelting:

- consumption factors of refined alloy conversion into commercial casting alloys СИЛ-2, AKI2M2 and AKI2M2MrH in accordance with the current Soviet standards are expected to be, kg/t:

materials	СИЛ 2	AKI2M2	AKI2M2MrH
refined alloy	350.0	325.0	325.5
aluminum	720.0	702.0	695.4

manganese metal	8.5	-	8.0
copper	-	II.0	I2.0
nickel	-	-	II.0
magnesium	-	-	II.0

8. The results of the performed trials and expected performance figures can be used as a basis for preliminary economic evaluation with respect to feasibility of establishing the electrothermal industry for production of aluminium-silicon alloys in India.

Appendix

SPECIFICATIONS FOR THE MAIN RAW MATERIALS AND MATERIALS USED IN THE USSR FOR PRODUCTION OF ALUMINIUM-SILICON ALLOYS BY VAMI METHOD

I. Gas coal concentrate, produced by mechanical beneficiation of young gas coals characterized by a volatives content of 32.0 to 37.0%, low ash content and by a low iron oxide content in the ash.

2. Petroleum coke, produced by coking at 580 to 700°C of residual products obtained when processing oil.

In the production of electrothermal silumin and aluminium casting alloys for engineering applications, the fine petroleum coke is used (6.0 mm and less) which is produced in delayed coking units at 580°C and has a high reactivity.

3. Electrode paste.

Composition, %

Thermoanthracite	- 50.0
Blend of cokes	- 25.0 to 50.0
Binder - coal tar pitch	- 23.0 to 30.0.

For production of Al-Si alloys a special "ЭМУГ" paste to "TY-48-I2-8-72" is used produced by the Dnieper electrode plant. The paste has in its composition a tar coke and artificial graphite.

For the physical and chemical properties of the gas coal concentrate, petroleum coke and electrode paste see Table I.

Table I

Physico-chemical properties of gas coal concentrate, petroleum coke and electrode paste

Description	Unit of measure	Gas coal concentrate: requirements to "TY I2YCCP I-I8-2-76"	Gas coal concentrate: actual properties	Petroleum coke: requirements to ГОСТ I5833-70	Petroleum coke: actual properties	Electrode paste: requirements to TY [illegible]-48-I2-8-72	Electrode paste: actual properties
Ash content, not more	%	5.0	2.5–4.5	0.8	0.30–0.[illegible]	7.0	3.2–3.9
Water content, not more	%	6.0	2.2–5.0	3.0	I.0–8.[illegible]	–	–
Volatiles yield	%	33.0–38.0	32.0–37.0	I0.0	7.0–I3.5	I2.0–20.0	I5.4–I6.0
Iron oxides content, not more:							
– limiting	%	0.8	0.8–I.I	–	–	–	–
– monthly average	%	0.55	0.35–0.60	–	0.07–0.I5	–	–
Total carbon content	%	–	78.5–79.5	–	89.0–9I.[illegible]	–	–
Specific electrical resistance, not more	ohm·mm2/m	–	–	–	–	87	–
Tensile strength, not less	kg/cm2	–	–	–	–	I5.0	–
Compressive strength, not less	–"–	–	–	–	–	–	I30–I80
Sulphur content, not more	%	–	–	I.5	0.4–I.[illegible]	–	–

4. Binder - concentrates of sulphate-cellylose lye and sulphate-yeast liquor.

These two products are processing wastes of timber into sulphate cellylose and are calcium, sodium, ammoni etc. salts of lignosulphonic acids or their mixtures freed as a result of biochemical processing from organics (sugar, organic acids).

A concentrate to OST 8I-79-74 of "[illegible]" brand is used delivered in tailway tank-cars.

Physico-chemical properties of the concentrate are given in Table 2.

Table 2

Physico-chemical properties of concentrates

Description	Requirements for "[illegible]" product to OST 8I-79-74	Actual properties
Appearance and colour	Thick, dark-brown liquid	
Dry matter content, % not less	50.0	48.0-5I.0
Content of matter non-soluable in water to weight of dry matter, %, not more	0.8	-
Density, g/cm3	-	I.25-I.26
Water content, %	-	45.4 -48.6
Composition of dry matter, %:		
carbon	-	46.0 -50.0
ash	-	II.7 -I4.6

5. Metallic manganese, brands Mp I, Mp2 to GOST 538I-70.

Supplied in a crushed form. Weight of individual lumps should not be over I5 kg.

Cathode copper, brand MC to GOST 859-66 is supplied in sheet form.

Nickel, brand H-I to GOST 849-70 is supplied in complete or cut into pieces cathode sheets and plates.

For chemical composition of manganese, copper and nickel see Tables 3 and 4.

Table 3

Chemical composition of metallic manganese

Brand	Requirements to GOST 538I-70							Actual		
	Mn not less	Si	P	Fe	Cu	C	Total admixtures	Fe	Si	Mn
MpI	96.5	0.8	0.05	2.3	0.03	0.10	3.3			
Mp2	95.0	I.8	0.07	2.8	0.03	0.20	5.0	I.2-I.7	0.7-I.0	95.5-97.0

Chemical composition of copper and nickel, %

	Main components			Impurities, not more										
	Cu, not less	Ni+Co not less	including Co, not less	Bi	Sb	As	Fe	Ni	Pb	Sn	S	O	[illegible]
Copper	99.05	–	–	0.001	0.002	0.002	0.004	0.002	0.004	0.002	0.004	0.02	0.
Nickel		99.93	0.10	0.001	–	0.001	0.01	–	0.001	–	0.001	–	0.

SECTION 1

Table 4

...cal composition of copper and nickel, %

Impurities, not more													
Sb	As	Fe	Ni	Pb	Sn	S	O	Zn	P	Ag	C	Mg	Si
.002	0.002	0.004	0.002	0.004	0.002	0.004	0.02	0.004	0.002	0.003	–	–	–
–	0.00I	0.0I	–	0.00I	–	0.00I	–	0.00I	0.00I	–	0.0I	0.00I	0.002

SECTION 2

6. Commercial purity primary aluminium, to the works standard, an iron content - not more than 0.2%.

7. Secondary aluminium and aluminium alloys produced when remelting an aluminium scrap.

An iron content - not more than I.0%, and mixed with the primary aluminium to be used - not more than 0.6%.

8. Primary magnesium, "Mr90" brand to GOST 804-72 is supplied in ingots of 8.0 ± I0 kg.

A chemical composition of the magnesium in ingots, %:

Mg, not less than 99.9

Impurities, not more:

Fe	- 0.04	Al	- 0.002
Si	- 0.0I	Mn	- 0.04
Ni	- 0.00I	Cl	- 0.005
Cu	- 0.005	Total impurities	- 0.I.

km.