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Aluminium Electrolysis Process

Evaluation and Control

Technical Report

on the expert mission carried out in India from
27th March to 26th May 1994

DP / IND/ 88/ O15 / 11-O5

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Backstopping officer : Dr. T. Grof DIO/ T/ MET/

United Nations Industrial Development Organisation

Executive Summary

The present report on " Aluminium Electrolysis Process Evaluation and Control" is a result of the expert mission DP/IND/ 88 /O15 / 11-O5 carried out in India from 27th March to 26th May (with briefing and debriefing). This expert mission is the first part of third phase of the total period 12 months.

According to the terms of reference during the expert mission the following activities were undertaken:

A.) Training the counterpart staff / scientists of the Centre relating to physico-chemical and electrochemical measurements in cryolite-alumina melts.

B.) Assisting in the installation of electrolysis laboratory

C.) Preparation of technical proposal for second phase of Bharat Aluminium Company (BALCO) modernisation. Effect of properties of alumina used on cell operation.

D.) Assisting in repairing the radiometric density gauge.

E.) Offering assistance in preparation of individual work-plan for Experts of Aluminium Electrolysis Department. Work plan of second phase of this extended expert mission.

F.) Preparation of Plant measurements at INDAL Company

All these activities have been carried out and details are provided in the report, followed by conclusions, proposals and recommendations

During this expert mission the above mentioned tasks were fulfilled:

- training provided on using of properties and process study in the R&D activities(the course material can be in the archive of Centre)
- finalisation of the procedures,equipment and consumables for the measuring methods
- individual program of the Scientists of Aluminium Electrolysis Department to realise the earlier decided tasks
- calculation for the effect of alumina quality on cell operation relating to BALCO modernisation, it is proposed to use this calculation in preparation of feasibility study
- measuring program was finalised at Indian Aluminium Company with using of mobile measuring van

The summary of present status of the Electrolysis Laboratory is followings:

- the main equipment and description of measuring procedures are available
- procurements of accessories and consumables are in going on
- Scientists of the Electrolysis Laboratory are trained in the physico-chemical and electrochemical measurements of cryolite-alumina melts

The activities are to be made for completion of Aluminium Electrolysis Laboratory

- completion of procurements and putting into operation of all measuring technique
- procurements of one sophisticated import furnace and boron nitride materials (tube and crucible) are to be initiated

CONTENTS

LIST OF ANNEXURES

INTRODUCTION

This report has been prepared by Dr. J. Horvath based on this expert mission carried out in India under UNDP/UNIDO Project DP/IND/ 88/O15- Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC). This 2 months mission is a part of the third part of 12 months expert assignment.

According to the job description DP/ IND / 88 / O15 / 11- O5 with post title " Expert in Aluminium Electrolysis Process Evaluation and Control",
as per Annexe-I, the expert was required :

- to provide training for the staff / scientists of Centre relating to physico-chemical and electrochemical measurements
- to assist in installation of Electrolysis Laboratory
- to prepare a proposal for second step of BALCO modernisation taking into account modification of alumina properties on cell parameters
- to assist in preparation individual work-plan of the Scientists in Electrolysis Laboratory
- to prepare the plant measurements at INDAL

In addition to the job description some constructive suggestions have been given at debriefing in UNIDO Vienna by Dr. T. Grof. BSO and at JNARDDC, Nagpur by Dr. J. Zambo, Chief Technical Adviser and Dr. T.R. Ramachandran, National Project Director and Mr. N. G. Sharma. Deputy Director of JNARDDC.

Job description and suggestions formed the basis for the schedule programme. prepared at the beginning of this mission (Annexe- II)

It can be noticed in the scheduled programme, that the activities and duties as per the job description were extended by preparation of plant measurements at Indal Smelter, Alupuram.

ACTIVITIES

Itinerary and list of main activities following the job description, as per Annexe I and the programme on mission as per Annexe II are described below:

1.) Training programme for the counterpart staff / scientists

The focus of the training programme was to demonstrate the capability of electrolysis laboratory for studies of properties and process in cryolite-alumina melts. During the training programme we have followed the structure of electrolysis laboratory, which is shown in Chapter "Installation of Electrolysis Laboratory.

The main elements of the training programme are demonstrated on the basis of structure of Electrolysis Laboratory, as shown below;

Structure of Electrolysis Laboratory

A1	Properties	A2	Processes
A11	Liquidus temperature	A21	Dissolution Processes Alumina Aluminium
A12	Density	A22	Electrode Reaction Anode reaction Cathode reaction
A13	Electrical conductivity	A23	Interaction with carbon
A14	Thermodynamic properties Galvanic cells Concentration elements		

A11 Liquids temperature:

Application area:
- recording phase diagram
- superheat determination
- electrolyte structure by cryoscopic method

A12 Density measurement:

Application area:
- molten electrolyte and metal
- effect of electrolyte additives
- detection of phase transition process

A13 Electrical conductivity:

Application area:
- bath chemistry modification
- structure analysis by determination of degree of dissociation
- detection of phase transformation processes

A14 Thermodynamic properties:

Application area:
- structure analysis by determination of activity (alumina, NaF, AlF3)
- equilibrium potential determination

A 2 Processes

A 21 Dissolution Processes:

Alumina dissolution:

Application area:
- effect of alumina properties on dissolution (from settled sample)
- effect of electrolyte composition on dissolution (from dispersed sample)
- crust generation properties (limited way)

Aluminium dissolution:

Application area: bath chemistry modification
prediction in current efficiency

A22 Electrode reaction:

Application area: determination of decomposition voltage
determination of anode and cathode potential
determination of anode and cathode over voltage
recording of polarisation curves
by potentiostatic method
by potentiodynamic method
at low sweep rate
at high sweep rate (impulse method)
by galvanostatic method
chronopotentiometry

A23 Interaction with Carbon

Application area: determination of anode consumption during electrolysis
determination of cathode swelling during electrolysis

2.) Installation of Electrolysis Laboratory

There are two documents, viz Project Documentation and Measuring Procedure prepared by International Subcontractor- to put into operation the Electrolysis Laboratory as a part of the Aluminium Electrolysis Department.

As per the Project Document the list of equipment was made relating to the Electrolysis Laboratory:

		Ref.No.in Proj.Doc.
1.)	Real- time signal analyser	O2
2.)	Digital voltmeter	O3
3.)	Temperature measuring system	O4
4.)	Multichannel digitising oscilloscope	O8
5.)	Oscilloscope Measurement System	O9
6.)	Plotter Multicolour Pen Plotter	11
7.)	Digital Programming Power Supplier	13
8.)	Programming Signal Source	14
9.)	Impulse Generator	2O
10.)	Impedance Meter	21
11.)	Potentiostat	22
12.)	Density Measuring Equipment	24
13.)	Cathode Swelling Determining Equipment	35
14.)	Anode Consumption Determining Equipment	36
15.)	Low Frequency Signal Source	41

List of General Purpose Equipment

16.) Real-Time Signal Analyser	O2
17.) Cassette Data Recorder	O5
18.) Tape Data Recorder	O6
19.) Multichannel Oscilloscope for Industrial Application	O7
20.) R-L-C Set and Standard	42

Structure of Electrolysis Laboratory

The main target of setting-up of Electrolysis Laboratory is:

- to understand the process taking place in Hall-Heroult Cell
- to give more accurate data for the modelling of process

In order to reach the above mentioned target the following scheme is proposed for the setting-up of Electrolysis Laboratory:

Properties	**Processes**
Liquidus temperature	Solution processes
equipment:	Alumina dissolution
Temperature measuring system	equipment: it is done
description of procedure available	description of procedure available
Density	Aluminium dissolution
equipment: Density measuring	equipment:
	it is to be done
description of procedure available	description of procedure available
Electrical conductivity	Electrochemical processes
equipment:	Anode reaction

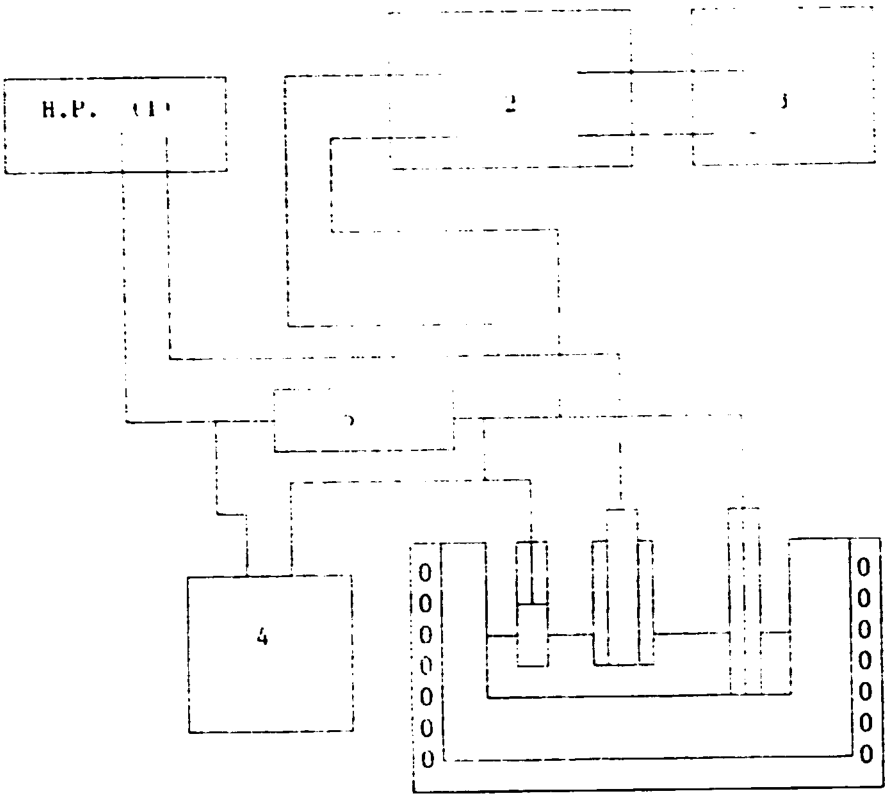
Impedance analyser
description of procedure is to be modified
Thermodynamic data
galvanic cell
concentration cell
equipment
Real-signal analyser
Digital multimeter

Cathode reaction
equipment:
Potentiostat, Pulse generator
Multichannel oscilloscope
Measurement plotting system
Programming signal source
Oscilloscope measuring device
Description of procedure is available
Interaction with carbon
Anode consumption:
equipment: it is to be done
procedure is to be elaborated
Cathode swelling test:
equipment: it is available
Description of procedure is available

On the basis of measuring procedure description the measuring scheme were made and the equipment were installed for the following experimental technique.(Annexure-III)

Determination of carbon anode potential in cryolite-alumina melts	Fig. 1.
Determination of alumina decomposition voltage in cryolite-alumina melts	Fig. 2
Alumina dissolution process	Fig. 3
Liquidus temperature	Fig. 4

MEASURING SCHEME FOR THE DETERMINATION OF
CARBON ANODE POTENTIAL IN CRYOLITE-ALUMINA MELTS



(Fig 1)

1 - H.P. CURRENT SUPPLY (Ref.No.13 Proj.D.)

2 - OSCILLOSCOPE (Ref.No.7 Proj.D.)

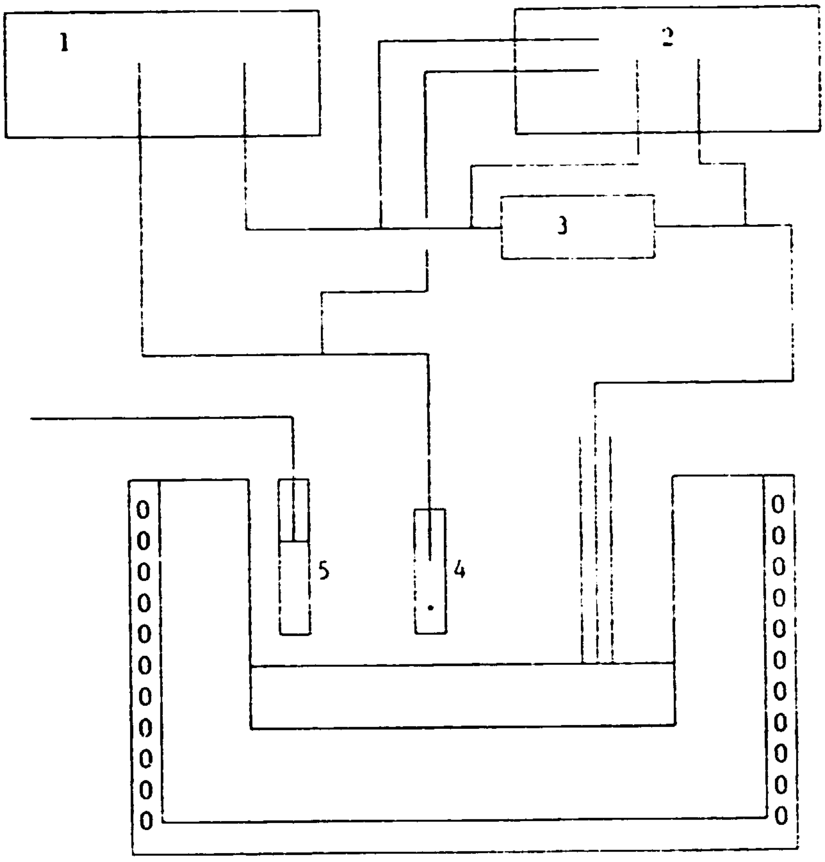
3 - PEN PLOTTER (Ref.No.11 Proj.D.)

4 - IMPULSE GENERATOR (Ref.No.20 Proj.D.)

5 - CURRENT INTRUPTION UNIT (Eq.No.54 Proj.D.Indian Inputs)

6 - ELECTROLYTIC CELL

MEASURING SCHEME FOR THE DETERMINATION OF ALUMINA DECOMPOSITION VOLTAGE IN CRYOLITE-ALUMINA MELTS



(Fig.2)

1 - H.P. CURRENT SUPPLY (Ref. No.13 Proj D.)

2 - PEN PLOTTER (Ref.No.11 Proj.D.)

3 - SHUNT FOR CURRENT MEASURING

4 - ELECTROLYSIS CELL

LIQUIDUS TEMPERATURE MEASUREMENT PROCESS

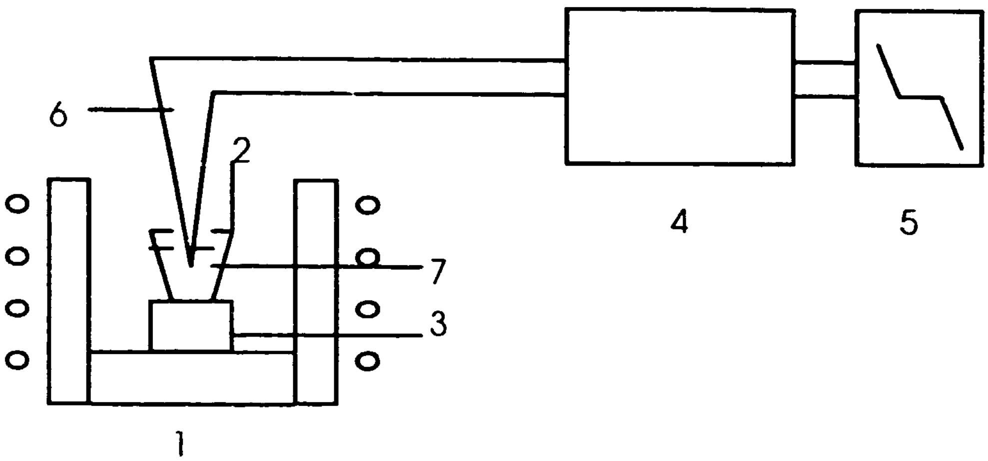


Fig 3

1. Furnace With Heating elements

2. Pt. Crucible

3. Refractory Brick Stand

4. Temperature Recorder (Keithly)

5. Plotter

6. Pt- Pt-Rh Thermocouple

7. Cryolite-alumina melt

ALUMINA DISSOLUTION PROCESS STUDY

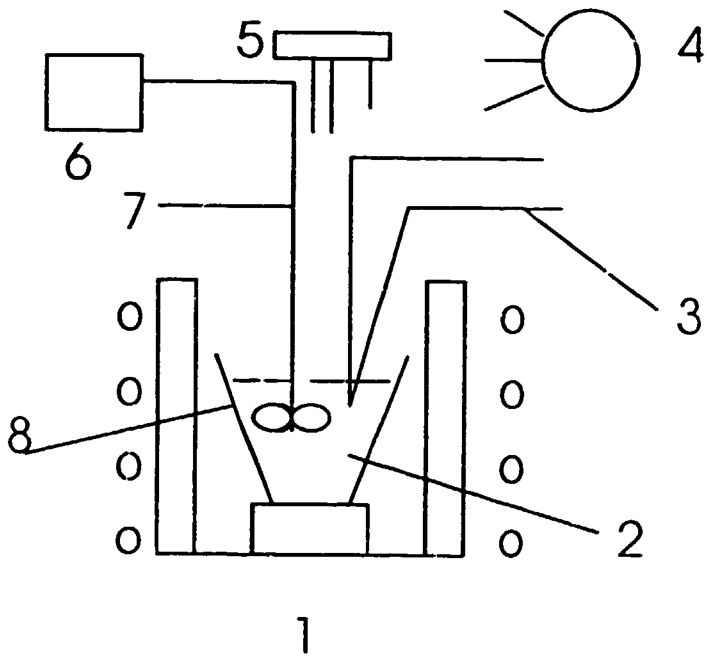


Fig 4

1.- FURNACE WITH HEATING ELEMENTS

2.- CRYOLITE -ALUMINA MELT

3.- THERMOCOUPLE

4.- SPOT LIGHT

5.- MIRROR

6.- MOTOR

7.- Pt.- MIXER

8.- Pt.- CRUCIBLE

The installation of the Electrolysis Laboratory is considered only partly completed. To achieve the full operation are requested the followings items:

	Ref. No. Gov.Inp.
Electrical furnace, 2 Nos. with power supply and temperature controller. inlet of inert atmosphere	24.25
High purity graphite crucibles.	47.
Quartz tubes	47.
Corundum crucibles	47.
Platinum crucibles	47.
Ceramic tubes	49.
Thermoelements (Pt-PtRh, Ni-NiCr)	49.
Laboratory mixer with platinum	52.
Current interruption unit	54.

The accessories and chemicals are also required for the installation of the Electrolysis Laboratory. The list of these items is shown. below:

	Nos
Inconel crucibles	5
Quartz funnel	5
Mirrors	5
Spotlight	3
Platinum mixer shaft	2
Platinum mixer propeller	2
Pincer with Pt-slipper	2

Test tube holder	5
Holder for mirror, mixer	2
Crucible tongs to Pt. crucible	5
Rotameter for argon gas	3
Nitrogen gas	3

Chemicals mainly required in the Electrolysis Laboratory are the following:

Argon / Nitrogen gas

Liquid nitrogen

Industrial electrolyte

Alumina (high purity)

Aluminium (high purity)

Cryolite (natural)

Aluminium fluoride

Lithium fluoride

Calcium fluoride

Sodium chloride

Sodium bisulphate

Copper granules

Hydrochloric- Acid

Ethyl- Alcohol

CO_2 gas

The following materials are considered as consumable :

Thermocouples, Pt-PtRh, Ni-NiCr,

Graphite electrodes (rods)

Graphite crucibles

Boron nitride crucible

Boron nitride tube, one side closed tube.

Tungsten or molybdenum wires

Ceramic tube

Heat elements and refractories for furnace lining

3.) Second Step of Balco Modernisation Taking into Account the Alumina Quality the Cell Parameters.

General and Background

The alumina feeding to the bath has two ways:

Batch feeding

Point feeding

Batch Feed Method

Advantages

- Simple Process
- Easy to Operate
- Reliable

Disadvantages:

- Large Fluctuations in Alumina Concentrations
- Large Variations in Bath Temperature

Point Feed Method

Advantages:

- More Constant Alumina Concentration
- Small Variation in Bath Temperature
- Low Tendency to Muck Formation
- Fewer and More Easily Controllable AE's
- Better Bath Level Control

Disadvantages:

- Alumina is Not Preheated

- Alumina is Not Preheated
- Can Cause Excessive Heat Losses
- Fluoride Emissions Increase

Analysis of the required alumina properties in relationship with cell construction and the alumina feeding method:

The main requirements of the alumina should :

- be easily soluble in the bath
- form a crust and cover the top of the cell
- provide heat insulation
- protect anodes against air burning
- be suitable for the dry scrubber process

Some important properties of alumina are the following:

Alfa- content, BET specific area, angle of repose, LOI, -42 micron, bulk density, and other properties of intere: t are: flow ability, dustiness, attrition index, moisture uptake, heat conductivity.

Batch Feeding

Soderberg Cells	Prebaked Cells
Wheel breaker or bar-breaker	Side or Central breaking

Alumina specifications for side-break pots :

- can use floury as well as sandy alumina
- the alumina should be well-calcined, No hydrate
- BET specific surface 35-50m2/g(higher BET area increases tendency to chemisorbe water)
- less fines, low attrition < 10%- 30 micron

Major concern : dusting

The future trends are: wheel breaker the cell construction is converted to knife-type breaker and introduced a modified crust breaking and feeding system by the cell automation.

open side breaking cell construction is converted to hooded point feeding technology and similarly to this central knife-type breaker is changed to point feeders. This trend indicates a significant modifications in requirements of used alumina quality.

Point Feeding Method

Soderberg	Prebaked

Alumina specifications :

- only sandy-type alumina is used
- BET surface area 45-80 m2/g
- LOI (300-1000 C) 0.6- 0.9 %
- Hydrate < 0.5%
- Sieve analysis -45micron < 20+100micron,<15%
- Good flow ability

The Soderberg cells are operating with point feeding system only in experimental conditions, their use is not wide spread.

In the newly installed smelters point feeders are applied.

When alumina gets into contact with the bath three possibilities can be visualised :

- crust formation
- agglomeration (partly freezing)

- dispersion of single grains followed by rapid dissolution

Initially the alumina dissolution process is determined by heat transport process. When cold alumina is added, bath freezes around the grains. The bath temperature drops abruptly by addition of alumina due to

- heating of the alumina
- endothermic dissolution process

The heating and dissolution process of alumina can be divided in consecutive steps, which are the following:

- cold alumina hits the bath surface, shell of frozen bath forms
- heating, $\gamma \rightarrow \alpha$ conversion
- sintering, agglomeration due to the conversion
- frozen shell melts, dissolution begins

The temperature drop relating to dissolution of 1% Al2O3 can be calculated assuming that all the heat is from the bath without effecting any freezing.

Heating Alumina 200- 977° C	94 200 J/mol
Average Heat of Dissolution	125 000 J/mol
Specific heat of bath	= 331.5 J/mol
Heating 200-970 °C	= 5.4 °C
Dissolution	= 8.0 °C
Total temperature drop	= 13.4 °C

In the light of above it will be analysed the changing of alumina properties on cell parameters, in connection with the BALCO modernisation. The expected parameters after finishing of first stage of modernisation are the followings; (Variant I)

Energy consumption:	16.500 kwh/ t
Current efficiency:	85%
Cell voltage:	4.70V
Molar ratio:	2.80
Average alumina content:	4.0%
Calcium fluoride content:	4.0%
Line current:	100 kA
Cell voltage:	4.70V
Current efficiency:	85%
Anode voltage drop:	450mV
Cathode voltage drop:	400mV
Bus bar voltage drop:	300mV
Anode effect voltage drop:	100mV
EMF(Electromotive Force):	1650mV
Liquid temperature:	965°C
Used alumina type:	floury
Scheduled crust breaking	
Interval:	2.0 h
Alumina consumption:	1.0%/h
Superheat should be:	min 20 C

By introducing sandy-type alumina without any changing in cell operation practice the parameter should be the followings; (Variant II)

Liquid temperature:	965°C
Used alumina:	sandy
Scheduled crust breaking	
Interval:	2,O h
Alumina consumption	1.0 %/h
Superheat should be :	13°C

The second phase of BALCO modernisation includes the introducing of knife- type crust breaking with modification of alumina feeding technology. The pot controller also will be applied during this cell operation.
(Variant III)

Superheat should be: 13°C

The calculated results are summarised in following Table

	Varaint I	Variant II	Variant III
Molar ratio	2.80	2.80	2.65
Average alumina content	4.0%	4.0%	3.0%
Average line current	100 KA	100 KA	100 KA
Electrolyte temperature	985°C	978°C	965°C
Anode voltage drop	0.45V	0.45V	0.45V
Cathode voltage drop	0.40V	0.40V	0.40V
Busbar voltage drop	0.30V	0.30V	0.30V
Voltage demand for Aluminium production	1.89V	1.91V	1.93V
Voltage drop on ACD gap	2.0V	1.95V	1.72V
Electromotive force	1.65V	1.65V	1.70V
Cell Voltage	4.70V	4.65V	4.57V
Current efficiency	85%	86.5%	88.4%
Heat losses	280.4 KW	280.1 KW	254.9 KW
Daily production	685.o kg	697.2 kg	708.6 kg
Energy consumption	16.48 kWh/kg	16.26 kWh/kg	15.40 kWh/kg

4.) Assisting in repairing of radiometric density gauge.

The repairing procedure is not completed.

5.) Offering assistance in preparation of individual work-plan for Scientists of Aluminium Electrolysis Department. Work-plan of second phase of this extended expert mission. Other activities.

As requested, the prepared Work-plan for the Scientists is shown below:

U.B. Agrawal **Scientist**

- Data collecting for feasibility report for INDAL, as requested by COMFAR program
- Assistance in preparation of BALCO R&D report
- Assistance in measurements at INDAL & NALCO
- Assistance in the activities of Electrolysis Laboratory
- Responsible for procurement of GOI input

S. Dasgupta **Scientist**

- Organisation of the installation of Electrolysis Laboratory
- Installation of equipment as per operational manuals,
- Temperature measuring unit, potentiostat interface, impulse generator
- Carrying out of electrochemical measurements by using artificial cell arrangement for getting practice,
- Current interruption method, electrical conductivity measurements, decomposition voltage measurements, potential sweep methods,
- Alumina dissolution measurements in cryolite without mixing
- Sandy and floury alumina comparison

K. G. Despande **Scientist**

- Assistance in installation of Electrolysis Laboratory
- Finalisation of use of spent pot line report
- Assistance in preparation of the plant measurements
- Assistance in Carbon Laboratory activities

G. S. Sengar **Scientist**

- Preparation of BALCO R&D Report, taking into account the following materials:
- Mobile van equipment description, Balco measurements of the first and second phase, results of cell status and revitalisation programme
- Preparation for INDAL measurements checking of equipment and spare
- Preparation for the NALCO measurements, magnetic field induction and heat-flux measurements

Work-plan for the second phase of the expert mission:

- Carrying out of the measuring program, evaluation of the measured data, as per Annexe IV
- Preparation of the Final Report for INDAL plant
- Preparation of the Technical part of Feasibility Study for INDAL Plant. (point feeding and cell automation)
- Assistance in NALCO measurements and preparation of the Process study measuring program
- Assistance in installation of Electrolysis Laboratory

Other activities:

- Participate on seminar "Status of Electrolysis Laboratory" and "Specifications of Smelter- Grade Alumina" was organised in Centre

- Preparation of two materials relating to HSS anode paste specifications and cell automation as per requested by INDAL

Annexure -I Job description

UNIDO

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

REQUEST FROM THE GOVERNMENT OF INDIA

JOB DESCRIPTION

DP/IND/88/015/11-05

POST TITLE: Expert in aluminium electrolysis process evaluation and control

DATE REQUIRED: As soon as possible

DURATION: Two months

DUTY STATION: Nagpur, India, with travel within the country

PURPOSE OF THE PROJECT: The immediate objective of the project is to assist the Government of India in setting up a functioning Aluminium Research, Development and Design Centre consisting of:

a) Alumina Production Research Department
b) Aluminium Electrolysis Department
c) Analytical Research Department
d) General Services, instrumentation and Control Department (incl. Workshop and Maintenance)
e) General Administration and Finance Department

The Centre will develop capability of carrying out the following main functions on behalf of and in co-operation with the bauxite processing/alumina production and aluminium smelter industries in the country:

a) Assimilation and adaptation of available technologies
b) Providing recommendations and ad hoc or applied and analytical research to local industries in process improvement, transfer of technology, etc.
c) Setting up and operating a data bank
d) Providing training of Indian engineers

..../..

DUTIES: The expert will be required to assist in the setting up of the Aluminium Electrolysis Research Department of the Centre, and in particiculer of process evaluetion and control leboratory. The expert will undertake and/or assist in research and investigations on aluminium electrolysis process evaluation, monitoring and control.

His main duties will be to:

a) provide training for the counterpart staff/scientists of the Centre in the measurement and monitoring of electrical parameters of the electrolysis cells, (voltage, fluctuations, noise, anodic/cathodic current distribution) as well as thermal state, magnetic field, anode gas composition and gas collection efficiency.

b) assist and train in measurement and evaluation of process data for aluminium electrolysis cells through a special mobile van.

c) assist and train in preparation of detailed energy and material balance of aluminium electrolysis cells.

d) prepare technical proposals for improvement of cells operation based on experimental measurements and process data collected.

The expert is expected to submit progress report after completion of every split mission assignment and a final report.

QUALIFICATION: University degree (preferably Ph.D.) in Chemical, Metallurgical or Electrochemical Engineering. Extensive experience in the experimental/measurement techniques for characterization of aluminium electrolysis cells parameters, evaluation of process data, preparation of energy and material balance of cells.

LANGUAGE: English

BACKGROUND INFORMATION: The Indian aluminium industry looks back to a history of 44 years. The first aluminium smelter (in Alumpars, Kerala) was put into operation in 1943. At present there are five alumina plants in operation and six aluminium smelters with an overall capacity of about 587,000 and 580,000 tonnes per year, respectively. These facilities belong to five aluminium companies, namely Bharat Aluminium Company Ltd. (Balco), Hindustan Aluminium Corporation Ltd. (HINDALCO), the Indian Aluminium Company Ltd. (INDAL), the Madras Aluminium Company Ltd. (MALCO) and the National Aluminium Company Ltd. (NALCO).

With the commissioning of NALCO the share of the public sector in aluminium smelting is more than half of the total installed capacity of India. This indicates the decisive influence of the public sector on the future of the industry. The sustained growth and development of the aluminium industry in India, apart from requiring the adoption of suitable long term policies in relation to production management, output, pricing, and fiscal levies, is also in need for technology and market development, which will gradually be handled by the proposed Centre.

During the past years, India became one of the leading countries in the world having substantial bauxite resources, after the discovery of large deposits in the Eastern Coast in the nearly 1970ies. The total bauxite reserves of India are estimated to be of the order of 2,650 million tonnes, which places India on the fifth place in the world list.

With the vast reserves of bauxite and coal in India, the aluminium industry has ambitious plans for a faster growth rate keeping in view the future demand in the foundry and export potentials.

The existing alumina/aluminium plants in India are based almost entirely on technology imported from various sources. Both in the areas of production of alumina and aluminium, a number of technological improvements have taken place in advanced aluminium producing countries. Import of improved technology is not always possible, also its introduction is not feasible in the existing plants. Import of technology necessitates proper assessments to determine its suitability under Indian conditions, the available raw materials, product demands, state of engineering developments, etc. Though research and development work is being carried out by the major aluminium producers in the country, these are mainly directed towards solving their day to day process problems in the plants. No work is done for the development of process know-how and basic engineering. The technologies followed in the existing plants are from various countries/suppliers - KAISER, ALUTERV-FKI, VAMI, ALCAN, MONTECATINI and ALUMINIUM PECHINEY. Apart from the strategic importance of having an indigenous Research, Development and Design Centre for Aluminium, the Centre is expected to save substantial hard currency payments to the foreign partners.

For meeting the estimated demand of aluminium by the turn of the century, substantial additional capacities for alumina and aluminium will have to be set up in the 1990ies. Additional demand for aluminium by the turn of the century, which is in excess of the currently available capacity would be of the order of 440,000 tonnes per annum which at the current selling price of aluminium amounts to Rs. 1180 crores. Considering the payment for know-how, basic engineering and royalties for this additional follow-up stage this would mean an expenditure of at least another Rs. 1.2 billion equivalent to US$ 95 million.

It is to be pointed out that the cost for Establishment of the Aluminium Centre in Nagpur (both Indian Government and UNDP contribution) is of the order of US$ 12.5 million. The financing of operations and further development of the Centre is envisaged by the Government to be secured through a collection of Rs. 100 per tonne of aluminium for aluminium research and development, added to the price of aluminium (established now by the State in India). The funds so generated would serve as financial basis for operation and further extension of the Centre.

When the new aluminium capacity will be established the Centre will be fully functioning and if it contributes to savings of only ten per cent of the expected expenditure for project engineering and royalties, apart from rendering other useful services, its establishment would be fully justified.

It is to be noted that all the leading aluminium producing countries have their own R and D centres. Close interactions among these Centres' Research and educational institutions and industry has enabled numerous technological advances - this example is needed to be followed in India.

In the light of the above, a co-ordinated effort in R and D will be essential for the development of know-how and basic engineering to self-reliance in alumina and aluminium technology needed for the establishment of future plants without need to go for foreign consultancy. Future development of aluminium industry in the country based on indigenous expertise demands the immediate establishment of a self-reliance full-fledged and independent research, development and design centre for aluminium at the national level.

The development objective of the project is to aim at self-reliance in alumina and aluminium production technology and to achieve faster growth of the Indian aluminium industry to meet the domestic demand for aluminium products. This goal will be achieved by setting up of an Aluminium Research, Development and Design Centre at the national level which will be in a position to carry out research and development in the field of bauxite processing, alumina and aluminium production leading to improvement in the existing plants and creating new production facilities. Thus, the output of the project will be physical facilities of an Aluminium Research Development and Design Centre, adequately equipped with specialized research and testing equipment and trained professional staff to render research and development technology in the existing plants and for setting up of new alumina/aluminium production facilities based on indigenous raw materials and natural resources.

In addition, the Centre will handle related projects such as dealing with the use of by-products, design improvements for saving of energy and materials, development of new products and alloys. Another particular problem that the Centre is expected to address is emanating from the lack of adequate and uninterrupted power supplies which has led to poor utilization of capacities in the recent past. Investigations into energy saving technologies of alumina and aluminium production will be one of the important tasks that the Centre will have to tackle.

It is expected that once the Centre is established it will meet the fast growing technological service needs of the aluminium industry in India. The Centre will consist of the following departments:

- Alumina production research department with four laboratories and one pilot plant;
- Aluminium electrolysis research department with four laboratories;
- Analytical research department with three laboratories;
- General services, instrumentations and control department with four sections;
- General administration and finance department with three units.

The civil construction works for the Centre started in Nagpur in 1990 and will be finished by 1992-1993. The centre is planned to fully operate/function by 1994-1995.

The assignment of the national staff and procurement of equipment started in 1989-1990. The first R/D works are expected to start in 1991-1992. Training of the staff will be carried out in India and abroad.

For a more detailed information reference could be made to the Project Document and the Detailed Centre Design.

Annexure II Schedule Programme

1.) Training for the Scientists in connection with the installation of the Electrolysis Laboratory
Function of the Electrolysis Laboratory in the R&D activities of Aluminium Electrolysis
Structure of the laboratory, methods for the determination of properties and processes taking place in cryolite- alumina melts
Theoretical background of the applied experimental technique the main difficulties during measurements

2.) Installation of Electrolysis Laboratory.
The following measuring methods must be demonstrated: Alumina dissolution
Electrochemical reaction, specially relating to the anode reaction
Determination of the alumina decomposition voltage
Determination of the anode potential by interruption method
Liquids temperature measurements
Installation of the potentiostat

3.) Alumina Specification and its Effect on Cell Parameters during the Second-half of the BALCO modernisation.
Alumina properties and feeding technology
Relationship between the proposed alumina specification and cell parameters (energy consumption, current efficiency)

4.) Preparation of the measurements in INDAL plant by using the mobile van, as requested.

5.) Assistance in the repair of the radiometric density measuring gauge.

6.) Preparation of individual work-plan for the Scientists in the Aluminium Electrolysis Department

7.) Programme and work-plan the second phase of the expert mission.

Annexure III

REAL TIME SIGNAL ANALYSER

Dynamic signal analyser is both a one channel & two channel FFT signal analyser. As a one channel analyser its frequency measurement range is from 488 micro Hz. to 102.4 MHz., as a two channel analyser its frequency measurement range is from 244 micro Hz. to 51.2 MHz. The analyser also contains a built in signal source & disc drive.

Input Range	: +27dBv (31.7 Vpk) . › 51dBv (39.9 mVpk) Range is adjustable in dB increments.	
Dynamic Range	: 70 dB	
Noise	: (-51 dBv range - Rs = 50 Ω. 16 r m s averages)	
Common Mode Rejection	: Frequency </= 1khz	
Residual DC Response	: Input Range (dBv)	DC Level
	27 to -35	< -30 dB relative to full scale
	-37 to -51	< -20 dB relative to full scale
Absolute Amplitude Accuracy	: +/- 0.5 dB = +/- 0.03% of input range (488 μ Hz to 102.4 KHz DC coupled)	

TEMPERATURE MEASURING SYSTEM

Keithly - 500 series measurement & control system is a system capable of acquisition of various signals connected through the interface cards for storage & analysis with the help of IBM or compatible PC. It can directly accept up to 16 differential input channels. All types of thermocouple inputs e.g. B ,E, J, R, K, S, T can be connected directly to the interface module card, with automatic cold junction reference adjustment.

Temperature Range : -200°C to 1700°C Depending on the type of thermocouple used.

OSCILLOSCOPE MEASURING EQUIPMENT
(Model HP -54503 A From Hewlett Packard U.S.A.)

An anolog scope has two major signal paths. The first is vertical signal path, which ultimately is responsible for deflecting the CRT beam vertically in response to the input signal. The second path is the horizontai. It triggers the scope & moves the beam from left to right across the screen. In a typical display , time is represented horizontally & voltage is represented by the vertical axis. Digitising scope capture the data by sampling it , storing it in memory & processing of the data to automatically measured parameters such as frequency, time interval , rise time etc.

It is a general purpose 500 M Hz band width. It has four channels & instant hard copy can be made when connected to a plotter.

Repetitive Band width	: dc to 500 MHz.
Single shot band width	: dc to 2 MHz
Maximum Vertical Sensitivity	: 1mV /div.
Maximum Sample rate	: 20 Msa / S
Number of channels	: 4
Memory Depth	: 1 k/channel

PULSE GENERATOR (PROGRAMMING SIGNAL SOURCE)
(PM 5705 FROM -PHILIPS, HOLLAND)

PM 5705 generates pulses between 0.1 Hz to 10 MHz. with a fixed transition time less than 10 nanoseconds at 5 Volts amplitude . Pulse duration, amplitude & base line offset are continuously variable . The main pulse output provides a 1 to 15 volts normal or complementary pulse train across 50 Ω or 330 Ω source impedance.

Pulse Duration	: Range 50 m seconds to 500 m seconds, Variable in 7 ranges with continuous control within the ranges.
Main Pulse output	: Amplitude Continuously variable from +1 V to + 15 V in to 50 Ω with current limited to 300 mA.
Mains supply	: 200 -260 V Switch selectable 100 - 130 V ------do-------
Mains Frequency	: 50 - 400 Hz

Power Consumption	: 40 VA
Temperature Range	: 0 - 40°C

MULTICHANNEL OSCILLOSCOPE
(PM - 3335 - 60 MHz. PHILIPS)

Digital storage oscilloscope is a 2 channel oscilloscope, which can be used both as an anolog oscilloscope & as a digital memory oscilloscope .

Total Acceleration Voltage	: 16 KV
Deflection Coefficient	: 2 mv/div. --- 10 v /div.
Error limit	: +/- 3% (only in calibrated position)
Maximum input voltage	: 400 V (dc + ac peak)
Maximum test voltage	: 500V
Rise time	: 7 nano seconds or less.
Noise (20 mv10v)	: < 0.5 sd .
Dynamic Range	: At MHz. --- +/- 12V
	At 50 MHz. -- > 8 div.

POTENTIOSTAT

The fast response PRT-20/25 Potentiostat is entirely transistorised & equipped with a direct coupled DC amplifier . The basic usage of the potentiostat is to maintain the potential of a working electrode at a determined value fixed or adjustable, independently of the other factors, likely to vary within the electrochemical system in which it is placed. This potentiostat can also be used as source of stabilised voltages (fixed, adjustable or programmable) & with an appropriate resistor, inserted in the external circuit, as current generator (Galvanostat). The potentiostat is equipped with built in centre/zero meter for output voltage monitoring & built in centre/zero meter for output current monitoring. This instrument is particularly useful for the manual or automatic plotting of electrochemical systems, for potentiokinetic studies as well as for three electrode programmed voltammetry.

Maximum output voltage	: +/- 20 V.
Maximum output current	: +/- 25A.
Minimum response time	: 7-10 μ seconds.

DENSITY MEASURING EQUIPMENT

(FROM ALUTERV F.K.I.)

The radiometric density gauge determines the density of the cryolite-alumina melt sample on the basis of attenuation of radioactive gamma radiation by means of computerised data acquisition & processing. The test sample is placed in the furnace with inert gas atmosphere & a radiation source (CS-137) generates gamma ray which is detected by a radiation detector placed at a opposite side of the source.

CATHODE SWELLING DETERMINING EQUIPMENT

Strength of lining materials for Aluminium cells can be determined by the elongation of the specimen under test during electrolysis of cryolite-alumina melts. The equipment consist of a furnace with temperature regulator. D.C. power source for supply to electrolytic cells & a dilatometer for precisely measuring the elongation of sample under test during electrolysis. The graphite crucible in which cryolite-alumina melt is kept, acts as anode, where as the cathode sample is placed from the top inside the melt. The elongation is measured through a transducer & recorded on a strip- chart recorder.

Nominal Operating Temperature	: 970°C
Power Supply	: 5 KW maximum
D.C. Supply for electrolytic cell	: Current -- 25 Amp. Voltage -- 4 Volts.
Dilatometer Measuring Range	: 0 -- 2 mm
Scale Factor	: 0.02 mm
Measurement Error	: +/- 1%
Reproducibility	: +/- 0.4%

MEASUREMENT PLOTTING SYSTEM
(PLOTTER MULTICOLOUR PEN -- 7090 A)

Measurement plotting system combines the capabilities of several measurement graphics devices as a stand/alone equipment . It can function as an X-Y Recorder , a wave form recorder or a digital voltmeter, when used with a computer H.P. 7090 A , may serve as the front end of a data acquisition system or as a graphic plotter.

No. of Input channels	: 3
Type of input	: Floating Guarded

Time base range	: a) Buffer mode -- 30 mili second in 24 Hrs.
	b) Direct record mode -- 1 second to 24 Hrs.
Accuracy	: +/- 1%

PROGRAMMING SIGNAL SOURCE
(H.P.MODEL -8165 -B)

This programme provides sine, triangle, square wave forms in the frequency range 1mHz. to 50 MHz. The mode selection & parameter setting can be done either manually or in programmed mode.

1) Wave forms	: Sine, Square, Pulse, Triangle, Ramp
2) Duty Cycle	: 20%, 50%, 80%.
3) Range	: 0.001 Hz. to 50 MHz.
4) Accuracy	: 0.001 %
5) Power	: 200 VA max.

IMPEDANCE ANALYSER

4192 A L. F. impedance analyser is fully automatic , high performance test instrument designed to measure a wide range of impedance parameters as well as gain, phase & group delay. The two measurement display sections provide direct read out of the selected measurement parameters with appropriate units.

Frequency Range	: 5 Hz to 13 MHz.
Frequency Accuracy	: +/- 50 ppm
Impedance measuring range	: 0.0001 Ω to 1.2999 M Ω
Maximum resolution	: 100 μΩ

ANODE CONSUMPTION FURNACE

In this furnace electrolyte can be kept in a graphite crucible. The consumption of anode can be determined by loss of weight during electrolysis for a specified period of time. Samples can be taken through a copper rod . The electrolysis power is supplied through a D.C. power supply.

Crucible size	: 150 mm dia. X 175 mm Ht.
	Wall thickness : 1"
Rating	: 9 KVA
Thermocouples used	: 2 Nos.

SCHLUMBERGER DIGITAL VOLTMETER

It combines high speed digital electronics with microprocessor control to provide fast & accurate system measurement.

It provides voltage, current & resistance measurement. Scanning timing & processing facilities are controllable from front pannel. It can measure up to 16 channels.

Range of Measurements	Range
DC Voltage	200 mV to 1000 V
DC Current	2000 mA
AC Voltage	200 mV to 1000 V
AC Current	2000 mA
Temperature Measurement (Using Pt. Resistance Thermometer)	-200°C to 600°C
Resistance	0.2 KΩ to 1000 MΩ

Annexure - IV

[illegible] COMPANY, LIMITED
ALUPURAM

MINUTES OF DISCUSSIONS WITH Dr. J. HORVATH & Mr. U.B. AGARWAL OF JNARDDC

1. Comparing the status of Cell Operation in Canadian and NKK designs.

   - Magnetohydrodynamic curves ie. % C.E. Vs. ACD for these pots on the basis of electrical, thermal and magnetic measurements.

   - Energy and voltage balance for these Cells.

   - Decomposition voltage and bath voltage will be measured with actual ACD measurement.

   - Technical material presentation during the measurement period for educating shop floor employees. Technical material will be prepared by JNARDDC.

2. - Comparison of bath temperature measurements with Alupuram's measurements.

   - Determination of bath liquidus and hence super heat of our operation during the measurement period.

3. - Discussion on feasibility of providing point feeders and pot controllers. Function and description of pot controllers will be sent immediately by JNARDDC. Final report will be prepared by end of October 94.

4. Dr. Horvath proposed that we send a 25 Kg CP Coke and 15 Kg pitch sample of our normal granulometry for them to suggest the optimum binder percentage.

5. The above experiments are scheduled for the month of September 1994.

6. Short Report on specification of alumina and anode paste specifications, which was requested, will be sent by JNARDDC in next week.

7. The cathode heat distribution calculations programme will be presented during the measuring period.

8. Matter was discussed regarding the location of mobile van. Dimension of mobile van will be sent.

Dr. Horvath and Mr. U.B. Agarwal would like to take this opportunity to express their gratitudes for the excellent hospitality extended during their visit.

Date 11/5/94

NB:EAJ