CATHODE VOLTAGE LOSS IN ALUMINUM SMELTING CELLS

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Components of cathode voltage loss and cathode temperatures in aluminum smelting cells were measured using electrically insulated internal probes and thermocouples. In normal operations, the voltage drop between aluminum and lining was insignificant. Lining voltage loss decreased from 0.35 ±.05 v initially to 0.09 ±.02 v with age as the lining graphitized. The collector bar voltage loss ranged from 0.08 to 0.13 v and changed only slightly with cell age. Collector bar to lining contact voltage was as low as 0.06 v shortly after startup but deteriorated with time to 0.35 ±.05 v, becoming the major factor in cathode voltage loss. It is postulated that this deterioration is caused by precipitation of very alkaline bath and β-Al_2O_3 at the collector bar interface.

Introduction

In the continuing quest to identify and reduce power losses in aluminum smelting, the cathode voltage loss in an aluminum smelting cell was measured. The cathode was considered to be the assembly of aluminum covered carbon lining and collector bars. This loss, which consumes 10-15% of the electrical power to the cell occurs in five locations: collector bar, collector bar to lining contact, lining, aluminum to lining contact, and the aluminum metal pad. Each was examined.

Experimental

The aluminum metal pad and aluminum to lining voltages were measured with tungsten probes having electrically insulated sides. Either boron nitride or much cheaper quartz was found satisfactory as the insulator. The metal pad voltage and aluminum to lining voltage were found immeasurably small except in badly mucked cells (an abnormal condition) and therefore were omitted from further consideration.

Before discussing the other components of cathode voltage, it is necessary to define them. Different values for each can be measured depending upon the particular current flow path followed. Of course, the total remains the same. The most meaningful voltages are those so selected that their product with the total current represents the electrical power loss in that component. This was accomplished by determining the point on the collector bar where half the total current carried by that bar had entered it. The collector bar voltage then is defined as the voltage drop from the external or outer end of the bar to that point; the lining to collector contact voltage is the contact voltage drop at that same point; and the lining voltage is the voltage drop from the top of the lining to a point in the lining adjacent to the described point on the collector bar.

Measurements were made of voltage and temperature gradients in collector bars using insulated iron wires and thermocouples attached at several places along the bar (Fig. 1). Adjacent to these points, steel voltage probes, insulated with refractory except at the tip, were installed in the lining. A hole was drilled in block lining to insert the probe with a press fit. Green lining was tamped around the probe in cells with monolithic linings. Voltage leads and thermocouples attached to collector bars in this manner had short lives. This was improved in later tests by a modification of the technique. A 3/8-in. diameter hole was drilled down the centerline of a collector bar, stopping 2-in. from the inner end. A voltage probe designed as shown in Figure 2 was inserted a measured distance. Pressure applied to the insulated sleeve forced the contact point of the probe against the collector bar and a potential measurement was made. The pressure was released and the probe repositioned for another reading. Following the potential versus distance scan, a type K thermocouple was inserted and a temperature versus distance scan made. Between sets of measurements, the probe was removed and the hole purged with inert gas (Ar or N_2) by inserting a stainless steel tube the length of the hole.

To analyze the data, it was necessary to know the electrical resistivity of collector bars as a function of temperature and age. Measurements on collector bars removed from cells at 465, 577, 992, and 1263 days showed a rather uniform small increase in resistivity with age at operating temperatures (Fig. 3). Chemical analysis of the bars indicated this was caused primarily by pickup of C and Al. Carbon diffused throughout the cross section but Al concentrated near the surface.

Electrical resistivity of cast iron changed even less with age. Over the range 700° to 900° C, the resistivity of this cast iron could be represented by the equation:

$$\rho = 62 + 0.11T + 0.008A \qquad \text{(Eq. 1)}$$

where: ρ = resistivity in microhm-cm
T = temperature in °C
A = age in days

Analysis of Data

Data analysis was aided by use of a computer. Temperature and electrical potential distribution within the bar were fitted with a third degree polynomial. Electrical resistivity distribution in the collector bar was determined from its temperature and age. Resistivity and potential gradient gave the current flow distribution. The change of current with distance along the collector bar gave the current pickup distribution. The difference between the electrical potential in the bar and in the lining adjacent to it gave the contact voltage drop. Contact voltage at finite points divided by the current density entering the bar at these points gave the contact resistivity distribution. The voltage drop through the lining and its geometry allowed calculation of average electrical conductivity of the lining. Conversely, knowing lining conductivity permitted calculation of collector bar to lining contact voltage in cells having potential and temperature probes in the collector bars but none in the lining, or having lining probes that failed.

Figure 4 shows the change with cell age in the current pickup pattern of a typical collector bar. Although these data were from a block bottom cell, monolithic linings produce similar results.

The shift in pickup toward the sides of the cell with age resulted to a great extent from changes in contact resistance. Bath ledging tends to shift the current pickup toward the center and causes small day-to-day changes. Ledging also increases the lining voltage by reducing the lining cross section.

Carbon block bottom cells initially showed a fairly uniform collector bar contact resistivity of 0.16 ±.03 ohm cm^2. Contact resistivity increased during the first month to 7 ±6 ohm cm^2 over the inner third and dropped to 0.081 ±.016 ohm cm^2 along the outer third of the area contacting the lining. No positive explanation has been found for this phenomenon. Expansion of the steel should improve the contact. Perhaps creep reduces contact pressure where the collector bar is hottest.

With increasing age, the contact resistance over the outer third again increases, reaching a 2 to 3-fold increase before most cells are removed from service.

Monolithic pot linings followed the same pattern except the initial collector bar contact resistivity was much higher (3.5 ±.4 ohm cm^2 versus 0.16 ±.03 ohm cm^2), and the initial lining resistivity was as much as twice that of a block lining. Within a few days, contact resistance became as good as in block bottom cells; and within a few months the lining resistance equaled block bottom cells.

Figure 5 shows a typical plot of the various components of cathode voltage as a function of cell age. These measurements were from a block bottom cell, but monolithic-lined cells were similar. Collector bar voltage drop first decreased slightly due to the shift of current pickup toward its outer end, then increased slightly as its resistance increased with age, and the current pickup shifted a little inward.

Voltage drop through the lining showed a constant decrease with cell age as the lining graphitized, lowering its electrical resistivity. This is consistent with data on lining graphitization reported by Waddington and Dell and also with measured resistivities of lining samples removed from pots of various ages (Fig. 6). (1,2)

The major factor in the increase of cathode voltage with cell age is deterioration of the electrical contact between the collector bar and carbon lining of the cell. Material that deposited at the interface between collector bar and lining was analyzed and found to be very alkaline bath containing over 30% β-Al_2O_3. Dell has described how these materials penetrate the lining. (3) He postulates that the collector bar acts as a cold finger which causes precipitation of electrically insulating frozen bath and β-Al_2O_3 at the interface. (4) This, moreover, separates the lining from the bar similar to frost heave. The thickest deposits were indeed found near the outer end where the bar was coolest, and where previously the greater part of the current entered the bar. To prevent this, one must either stop bath penetration, an exceedingly difficult assignment, or increase the collector bar temperature above the precipitation temperature. The latter invites creep which could in itself destroy the contact.

Acknowledgment

I wish to thank L.M. Butcher and J.W. Dyer for their assistance in obtaining data for this analysis.

References

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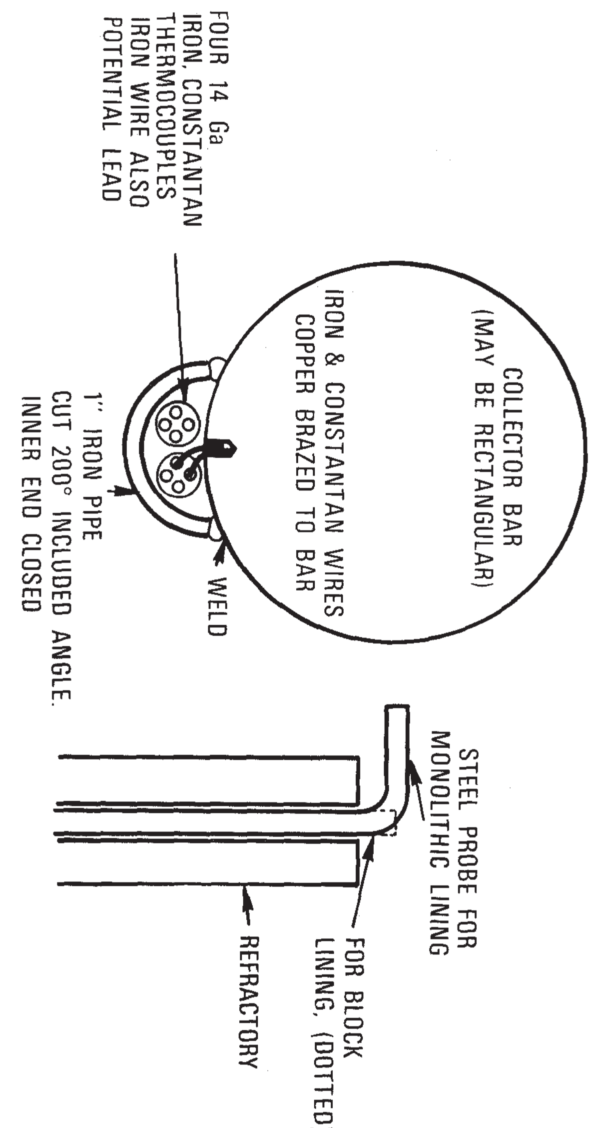
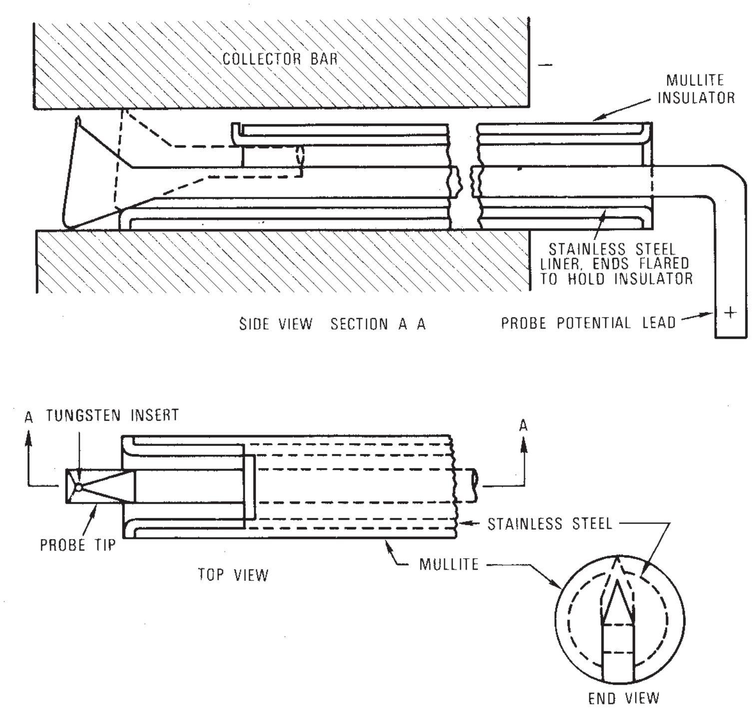
2. Dell, M.B., Extractive Metallurgy of Aluminum, V 2, p 403, Interscience Publishers, New York, 1963.

3. Dell, M.B., Light Metals 1971, p 443, AIME, New York, 1971.

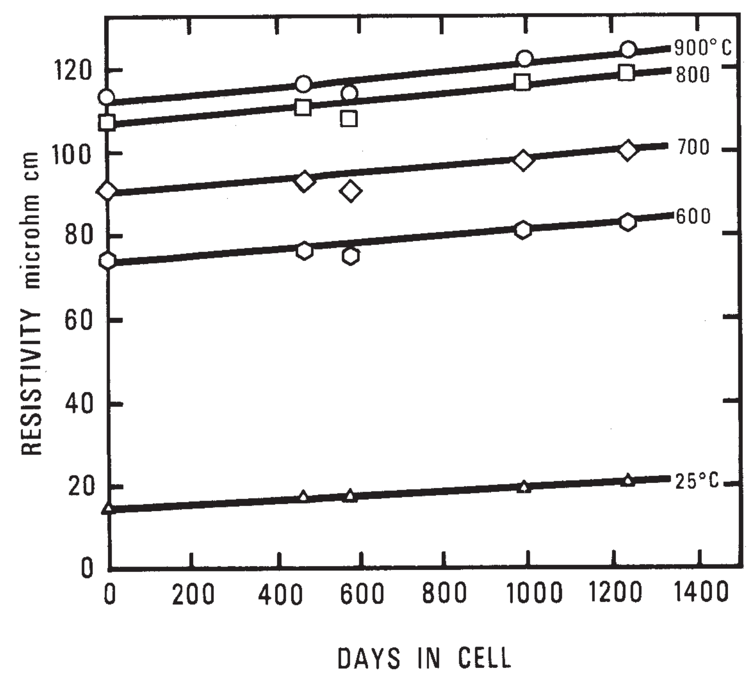
4. Dell, M.B., Personal communication.



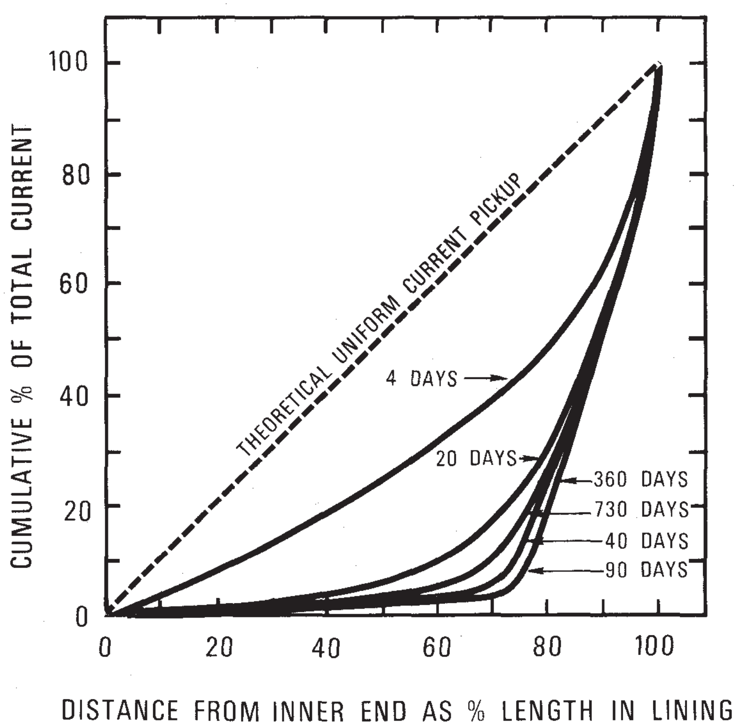
PROBE ARRANGEMENT



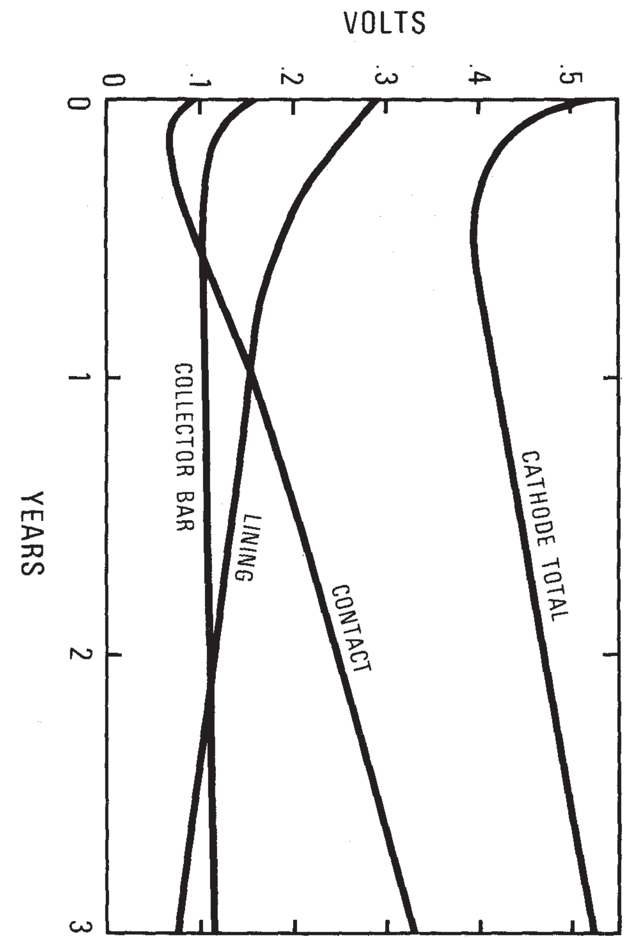
COLLECTOR BAR POTENTIAL PROBE



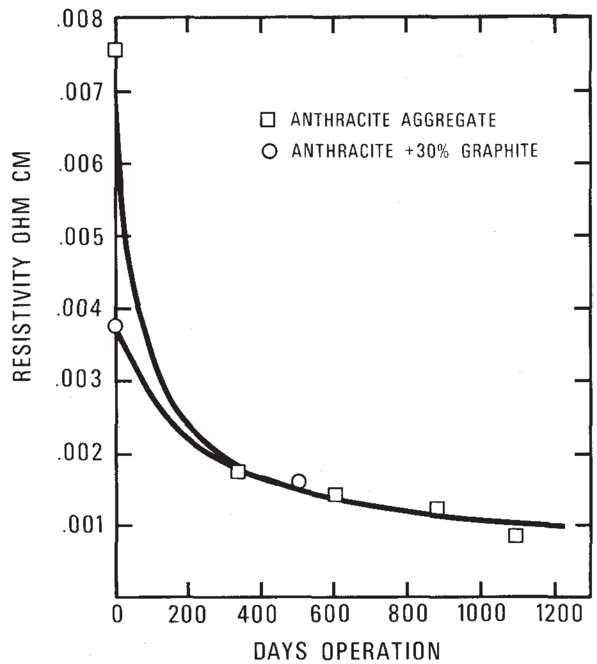
RESISTIVITY OF COLLECTOR BARS



CURRENT PICKUP BY COLLECTOR BAR



COMPONENTS OF CATHODE VOLTAGE



ELECTRICAL RESISTIVITY OF BLOCK LINING AT 800°C