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TEMPERATURE AND VOLTAGE MEASUREMENTS IN HALL CELL ANODES

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Fifty thermocouples and 30 voltage probes were placed in each of two anodes for recording data during 24 hours of operation. One of the anodes was set to the proper height in the bath and the other was set one inch lower. Current overloading was severe in the low anode, resulting in stub overheating and current imbalance. The stubs were hotter than the adjacent carbon material for the first few hours and then ran about 80°C cooler. Stub-carbon resistance decreased as stub temperature increased, leveling off at a temperature of about 600°C. Variability in stub-carbon resistance readings was appreciable. A voltage probe nine inches under a stub gave a poor indication of stub-carbon resistance. Stub-cast iron resistance was <25% of total stub-carbon resistance. Plots of isotherms showed steep thermal gradients at the corners. Low setting caused overheating in the stub hole region of the carbon, but had less effect in the lower part of the anode. Several hours were required to melt all the bath from the bottom center of the anodes. Thermal equilibrium was established by 16 hours.

Introduction

Detailed mapping of temperatures and voltages in operating anodes should be very useful in improving anode performance. Carbon cracking is thought to be related in part to thermal stresses. Calculation of this effect requires a good knowledge of the temperature patterns. Stub-carbon resistance results in considerable expense in Hall cell operation. The components of this resistance are not well known because of the difficulty in making good measurements.

With conventional means, it would be very difficult to get the extensive data needed for these investigations. However, with the advent of newer equipment such as the Digitrend 100-point temperature and voltage recorder and with computer facilities to manipulate the data, extensive testing is now feasible. This report gives results of such a test.

Procedure

Two double-stub anodes weighing more than 1,000 lbs each were sent from the smelting plant to Alcoa Laboratories for installation of thermocouples (TC) and voltage probes. Ungrounded Chromel-Alumel TC sheathed in 1/8 inch OD stainless steel were used with high temperature plugs connected to fiberglass insulated lead wires. Holes of 1/8 inch diameter were drilled for the shorter TC, but for the longer ones 3/8 inch diameter holes finished with 1/8 inch diameter were used. Union Carbide C-34 carbon cement at the bottom of each hole was used to hold the TC in place. The cement was cured to 150°C before shipping the anodes to the plant for rodding and testing.

Steel pins, 1/8 inch OD connected to iron wires, were used for voltage probes. In some cases the TC sheaths were used as voltage probes. Steel masonry nails soldered to iron wires were driven into holes drilled in the stubs and rods for these voltage measurements. Threaded bolts were placed in the molten cast iron to make binding posts for voltage readings there.

One anode at a time was tested in a center stall of an end pot. The rodded anode was brought to the potroom and the 80 lead wires were bundled together and connected to the Doric Digitrend 210 recorder, which was powered by a 120-volt isolation transformer. The recorder chassis was grounded to the upper rod voltage probe lead wire. This grounding was essential for recorder operation.

At the start of a test, the recorder was turned on and the anode was set using standard setting procedures. Two men held the lead wire bundle during setting to keep it from hanging up on obstructions. The lead wires ran up the rod and out the pot skirt so normal hooding could be used.

The recorder was set to scan all 80 points every minute during the first few minutes of operation. As the test progressed, the scan time was cut to every five minutes, and after several hours it was reduced to every 20 minutes. An operator stayed with the equipment at all times, but the test recording was essentially automatic.

After 24 hours, the carbon was consumed to the extent that some of the bottom TC were exposed to the bath. The anode was pulled and the lead wires and some TC were salvaged.

Results and Discussion

The effect of improper anode setting is shown dramatically in Figure 1. For normal setting, amperage increased gradually and leveled off to normal amperage after 16 hours operation. The anode set one inch low picked up current very rapidly and at four hours was up to double the normal amperage. Evidently this large current was concentrated at the bottom corners of the anode since temperature plots indicate a large area of frozen bath insulating the bottom center of the anode (Figures 2, 3, and 4). For the first hour of operation, little difference in temperature patterns of the two anodes was evident. After four hours, the low anode was hotter, but there was still a sizable amount of frozen bath under it. Localized overheating in the stub hole area was evident in the low anode.

This high current density in the corners might be expected to promote low current efficiency due to increased heating of the bath and turbulence so close to the metal pad.

After four hours, the low anode was raised about 3/4 inch and the current dropped to an almost normal value.

Current distribution between the two stubs in the normally set anode showed an imbalance of about 10-20% (Figure 5). For the low anode, the imbalance was as much as 90% but evened out in a few hours. This current imbalance is reflected in a large temperature difference between the two stubs in the low anode (Figure 6). At four hours, one stub was 270°C hotter than the other. This difference decreased to about 50°C after proper carbon adjustment. Average stub temperature after 16 hours for both anodes was 600-700°C (Figure 7). The temperature of the normally set anode was still increasing at the end of the test because extra alumina cover was added and, also, an anode effect occurred.

During the first few hours of the first test, the stubs were a few degrees hotter than the adjacent carbon material; however, at 16 hours the carbon was about 80°C hotter than the stubs. This pattern was exaggerated in the case of the low-set anode where the stub was 100°C hotter than the carbon material after two hours (Figure 8). This is unfavorable with respect to thermal expansion and thus could be a factor in carbon cracking.

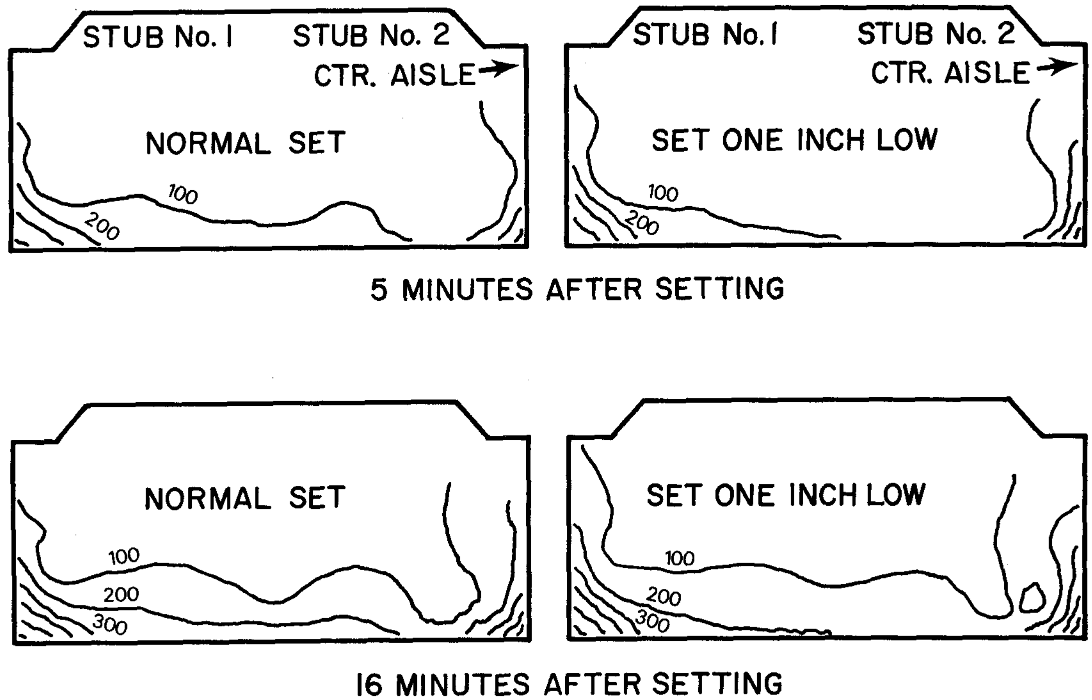
Stub-carbon resistance decreased as the stubs heated, leveling off at about 600°C (Figure 9). The shape of this curve is very similar to the graph of contact resistance versus pressure (Figure 9 insert). Data by Union Carbide have shown that above a certain contact pressure, little decrease in resistance occurs. From this standpoint, it would seem best to design for operation at a point where the curve has just become flat. Pressures above this point would cause undue risk of anode cracking without any attendant decrease in resistance.

Considerable differences in stub-carbon resistance measurements were found among the several probes used. Stub-carbon resistance for probes spaced one inch from the casting averaged about 10% lower than for probes two inches out (Figure 10). Differences in a circumferential direction were also found. In this analysis, the average resistance of the eight probes around the stub with respect to one probe in the stub was assumed to be the true stub-carbon resistance value. Readings for individual probes were compared with this average.

Further complexity is added by following the resistance of a single probe during the course of the test. In some cases a probe might give a higher-than-average value at the start and drop to a lower-than-average value later (Figure 11). Evidently, current flow is not uniform around the circumference of the stub hole and also the current flow pattern shifts with time.

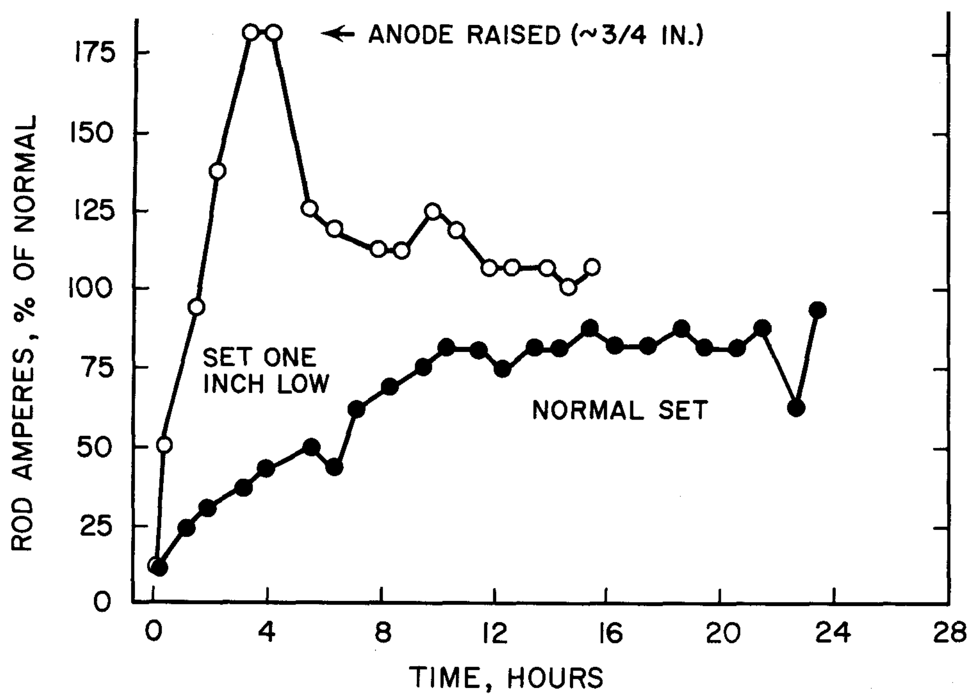
Deeper probes have been proposed to minimize these difficulties; however, this test did not indicate this would be a good method--at least in the early life of an anode. By adding an appreciable depth of carbon to the resistance path, the overall resistance is increased. This means any comparisons must be made by subtracting two relatively large numbers to obtain a small difference. Any variability in carbon quality is a part of the large number. The temperature of the carbon, thermocouple effects, and the effective cross sectional area of current flow all affect the voltage drop measured. These parameters vary during the life of an anode (Figures 12 and 13). In view of these fundamental problems, it seems extensive testing would be required to show that a deep probe (or any other novel method) is viable.

Stub-cast iron resistance was found to be only about 25% of the total stub-carbon resistance up to 550°C stub temperature (Figure 14).



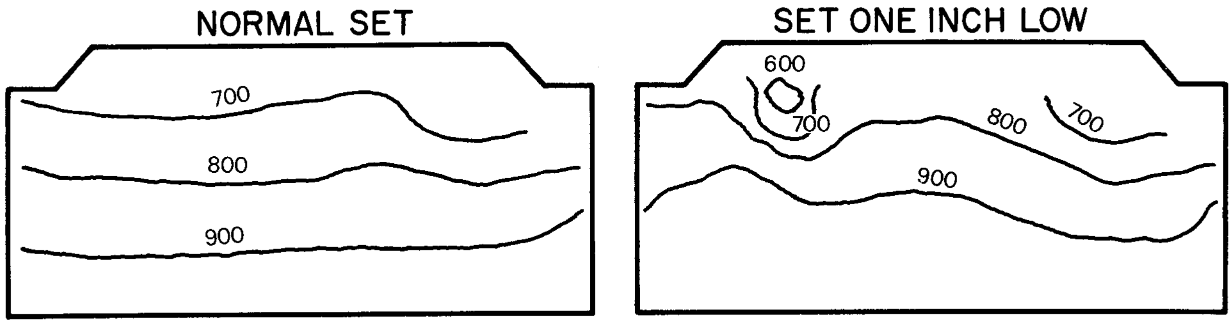
ISOTHERMS THROUGH LONGITUDINAL CENTERLINE OF ANODES, °C

FIGURE 2



CURRENT LOADING IN ANODES SET NORMALLY AND SET L

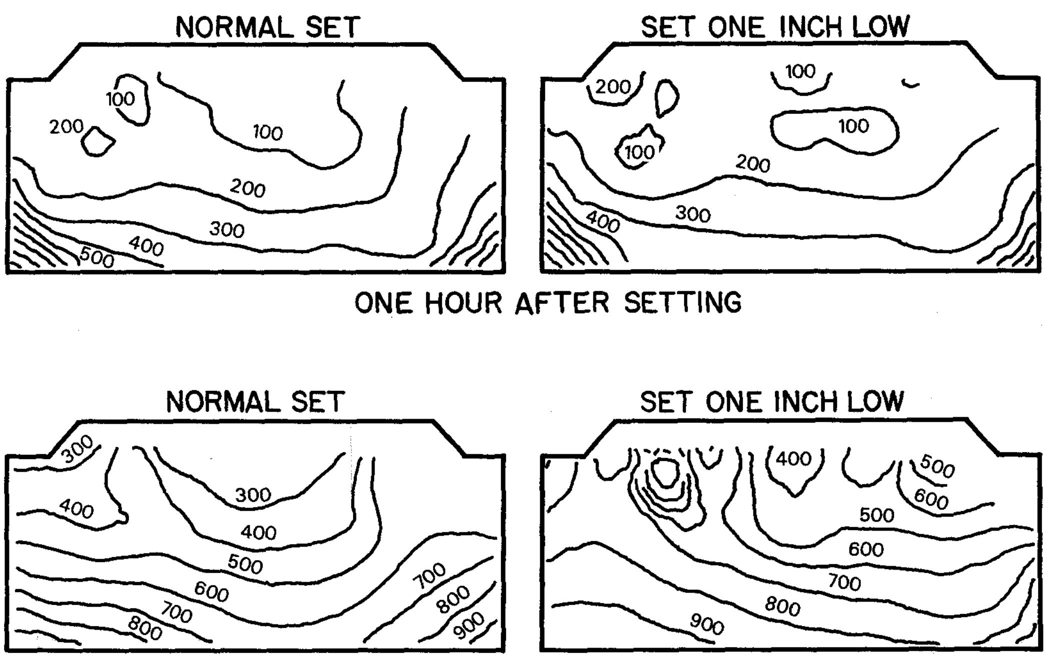
FIGURE I



16 HOURS AFTER SETTING

ISOTHERMS THROUGH LONGITUDINAL CENTERLINE OF ANODES

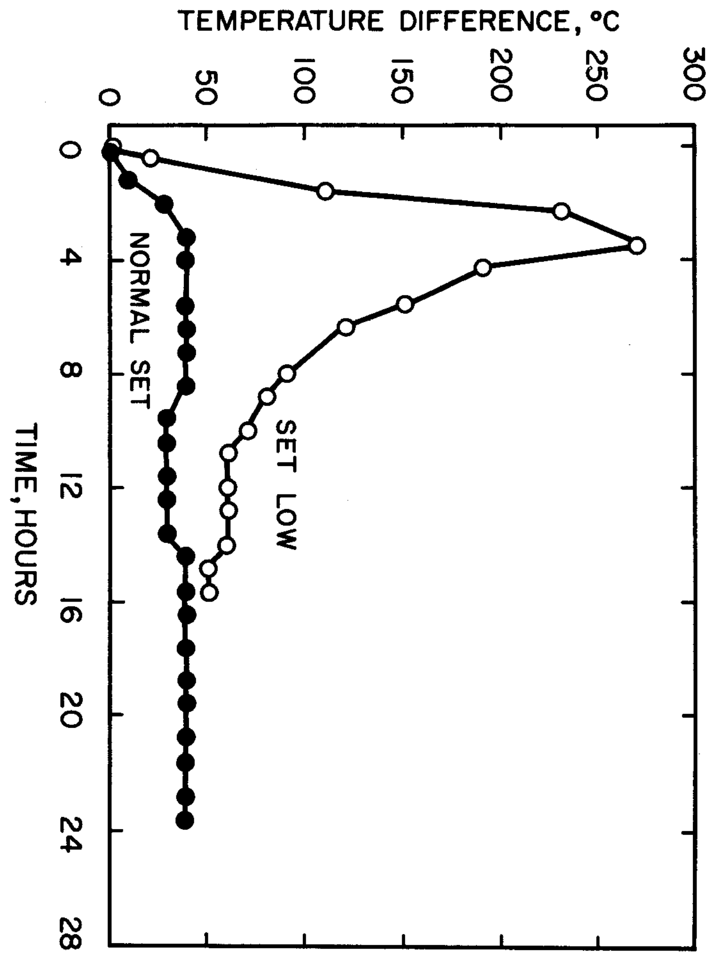
FIGURE 4



FOUR HOURS AFTER SETTING

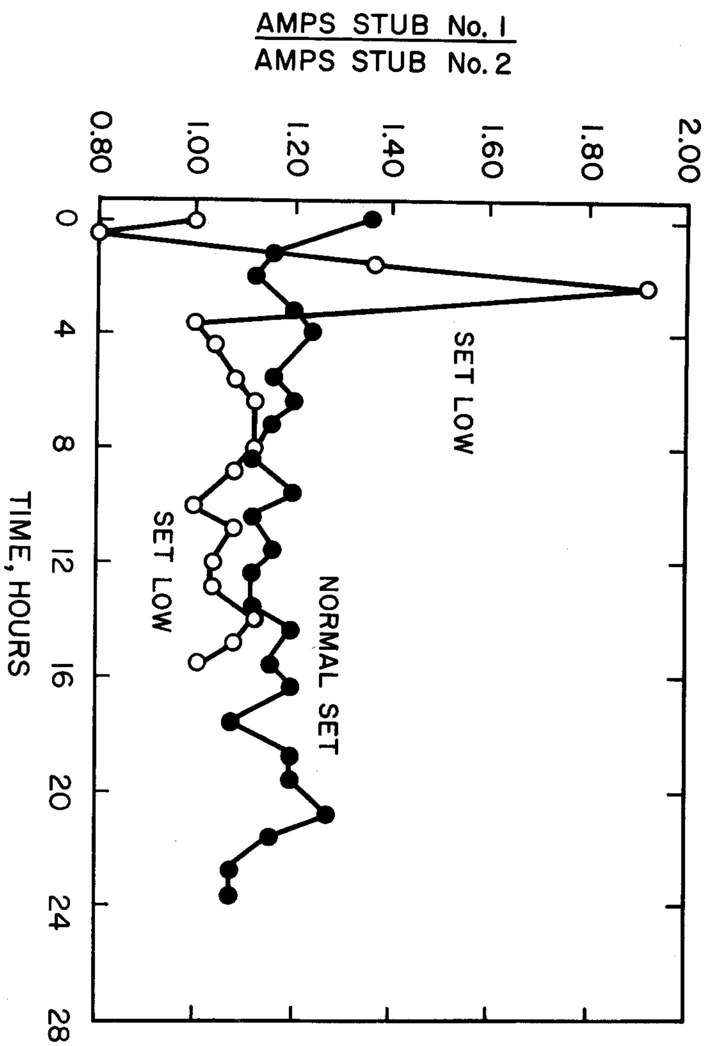
ISOTHERMS THROUGH LONGITUDINAL CENTERLINE OF ANODES

FIGURE 3



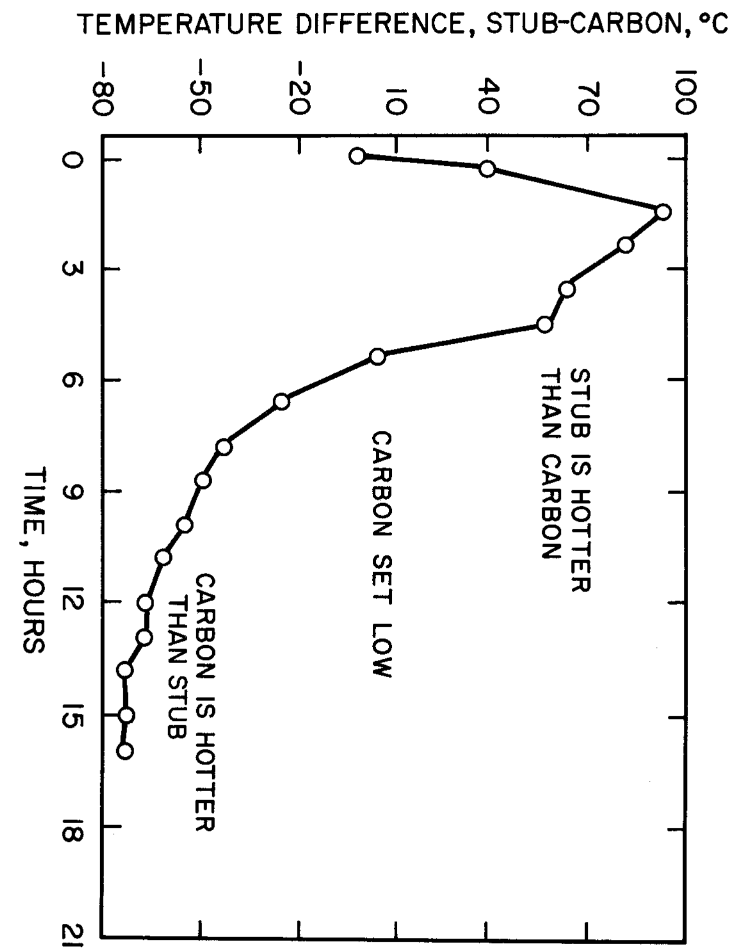
TEMPERATURE DIFFERENCE BETWEEN TWO STUBS IN ONE CARBON

FIGURE 6



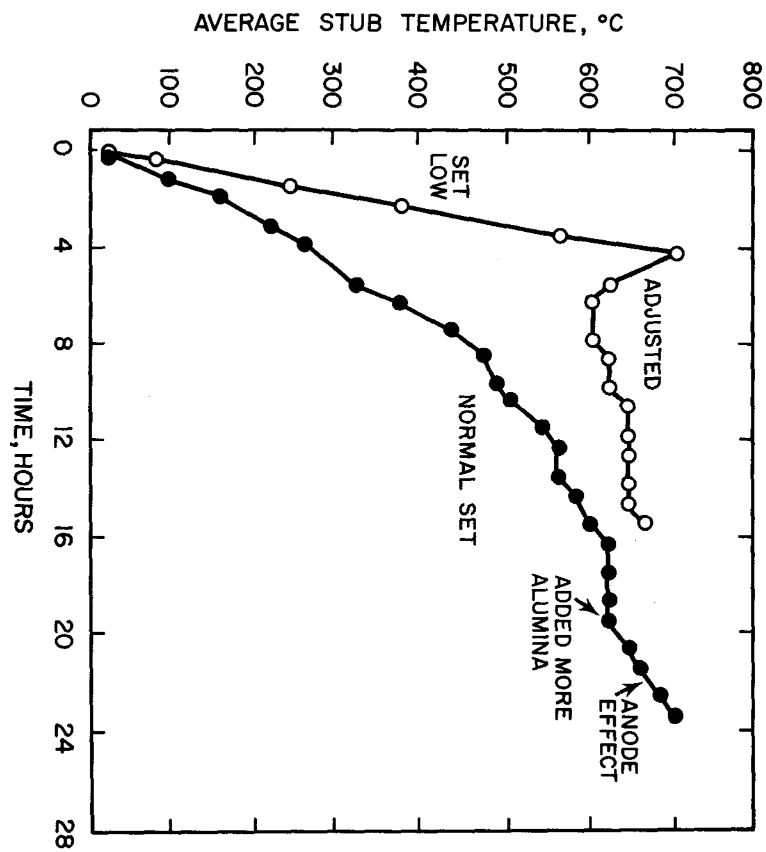
CURRENT DISTRIBUTION BETWEEN TWO STUBS IN ONE CARBON

FIGURE 5



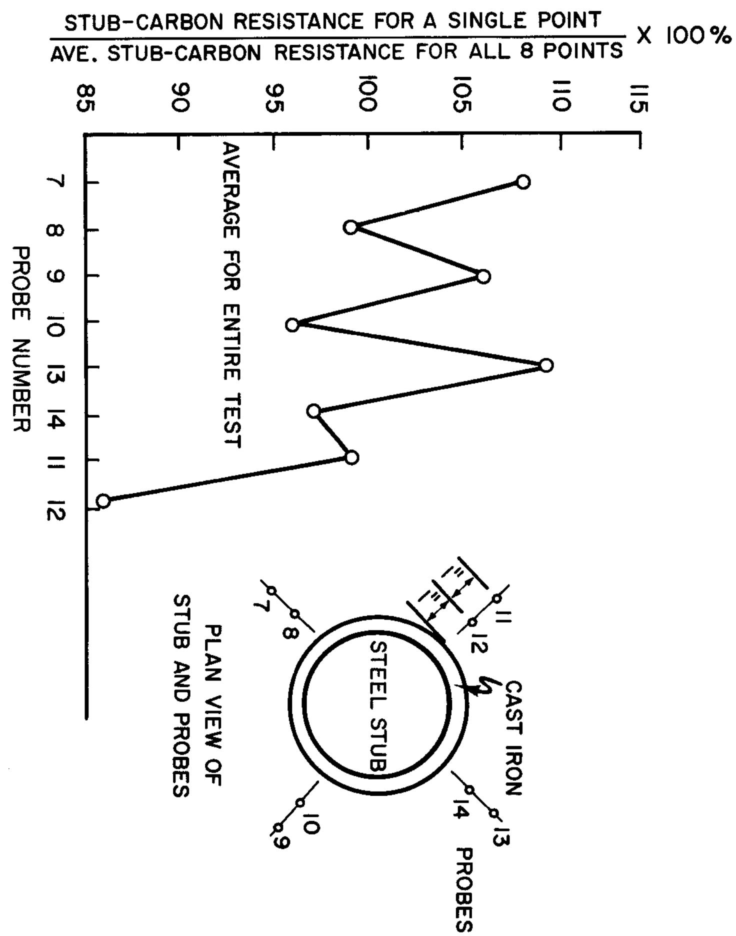
TEMPERATURE DIFFERENCE, STUB-CARBON VS TIME

FIGURE 8



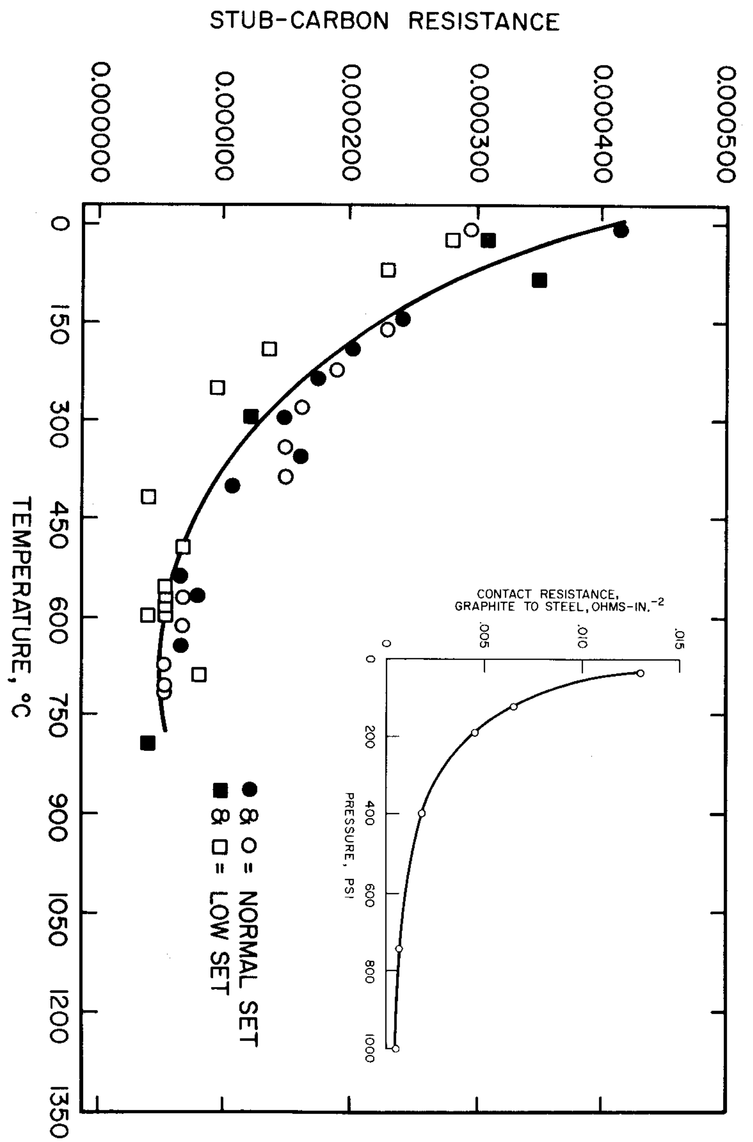
AVERAGE STUB TEMPERATURE VS TIME

FIGURE 7



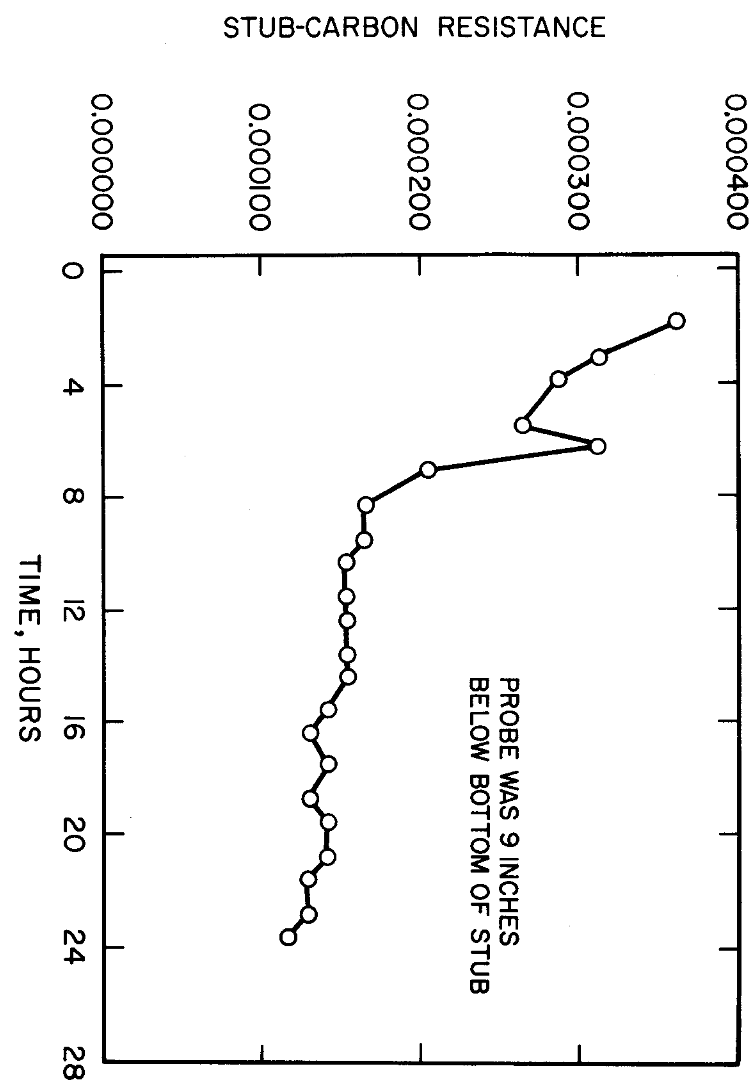
RELATIVE STUB-CARBON RESISTANCE AT VARIOUS PROBE LOCATIONS

FIGURE 10



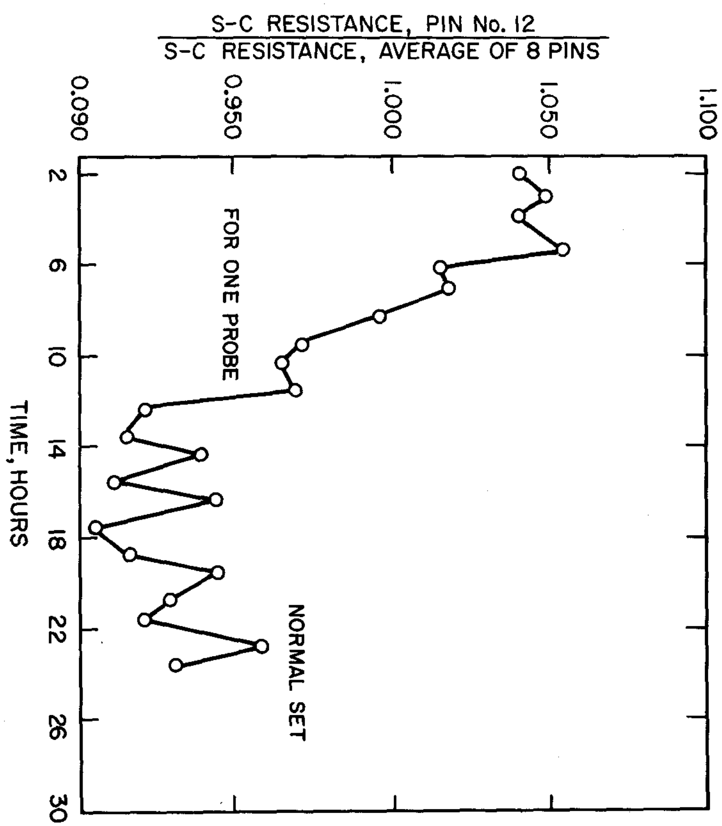
STUB-CARBON RESISTANCE VS STUB TEMPERATURE

FIGURE 9



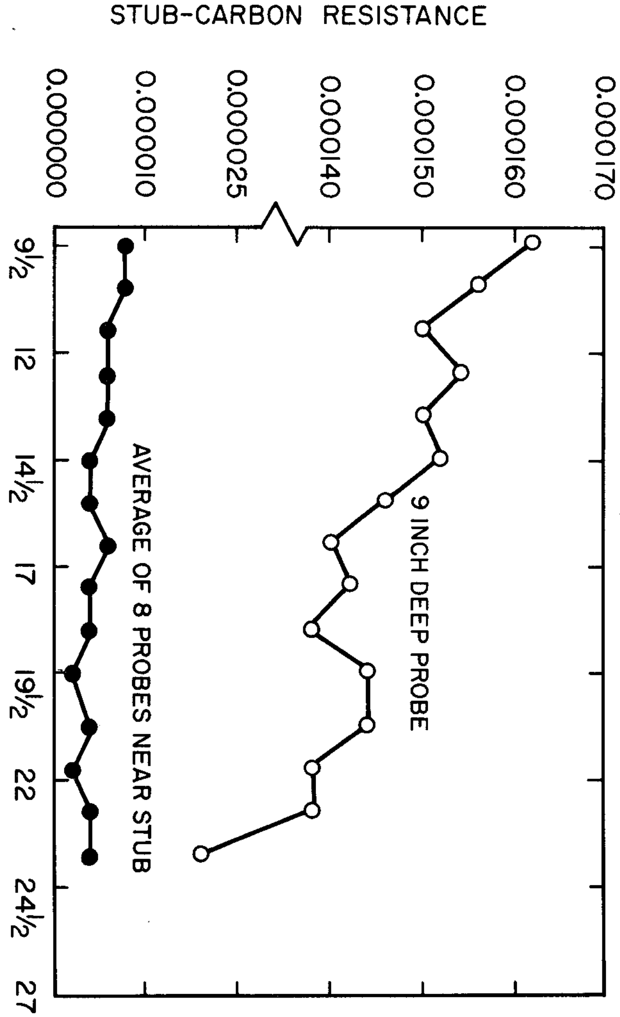
STUB-CARBON RESISTANCE VS TIME USING A DEEP PROBE

FIGURE 12



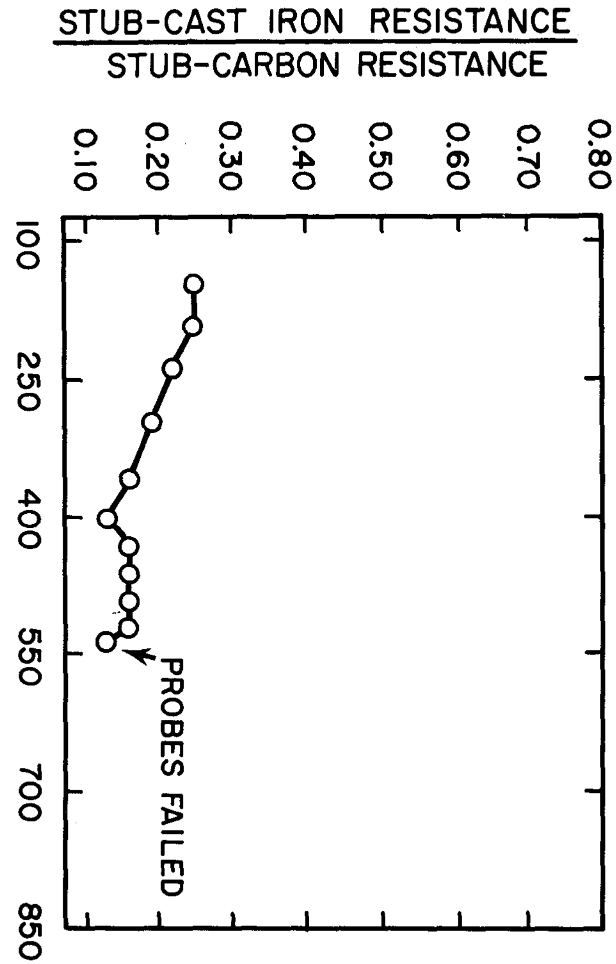
STUB-CARBON RESISTANCE FOR ONE POINT COMPARED TO AVERAGE OF 8 POINTS VS TIME

FIGURE 11



COMPARISON OF STUB-CARBON RESISTANCE MEASURING TECHNIQUES

FIGURE 13



$\frac{\text{STUB-CAST IRON RESISTANCE}}{\text{STUB CARBON RESISTANCE}}$ VS TIME

FIGURE 14