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1. INTRODUCTION and CONCLUSIONS

The purpose of this work was to test oxide cathodes with different Nickel substrates and different surface preparations. We were looking for improvements in cathode emission, life, adherence of the cathode coating and reduced droop at long pulse widths and higher duties.

All the tests were done at low duty (approximately .1%) but high loading (approximately 6amps/sq. cm). The bulk of devices built were to test in one form or another various preparations of the scandate dispersed oxide cathode. It was decided early in the program that this was the most promising avenue of inquiry. Twelve vehicles were built. Each vehicle contained 4 cathodes. Here is a list of these vehicles:

Device #	Characteristics	Purpose
1.	demountable - sprayed control device with standard sprayed oxide coating on 330 Nickel	Control device
2.	Scandate sprayed on 330 Nickel	Test device
3.	Standard sprayed on 330 Nickel	Control device
4.	Standard decals on 330 Nickel	Control device
5.	Scandate sprayed on 330 Nickel	Test device
6.	Standard sprayed on 330 Nickel	Control device
7.	Standard sprayed on 330 Nickel	Control device
8.	Scandate on A31 Nickel	Test device
9.	Standard sprayed on 330 Nickel	Control device
10.	Scandate sprayed on 330 Nickel, copper grids	Test device
11.	Scandate sprayed on 330 Nickel, copper grids	Test device
12.	Decals on chem-etched 330 Nickel, 2 with mesas, 2 without, copper grids	Test device

The scandate cathodes appear to exhibit better 0 hour performance than either decal cathodes or standard sprayed cathodes. They also appear to have longer life than either standard decals or standard sprayed cathodes. The chem-etched cathodes performed poorly, on average. Based on previous study there was reason to believe they would out perform unetched cathodes. But in this study they were

actually some what lower in performance than unetched controls, although one cathode had performance on par with the unetched cathodes.

The scandate cathodes on A31 Nickel did not perform as well as the scandate on 330 Nickel, although they did perform better than cathodes without scandate.

A life test was conducted on 3 samples of scandate cathodes, one plain decal cathode and 2 plain sprayed cathodes. Two life test stations were built. The goal was to accumulate 2000 hours or see a 20% cathode emission drop on each cathode tested. Again scandate on A31 Nickel did not live as long as scandate on 330 Nickel.

2. THE TEST VEHICLE

Figure 2.1 is a photograph of the low duty test vehicle used for this work. It is a glass device, that is bakeable to 425 degrees C. It employs 2 barium getters that are flashed (using an RF coil) onto the inside of the glass envelope. A modified pierce structure was used for the testing, since the main interest in these cathodes is in traveling wave tubes. The cathode is .250 inches in diameter and concave. A control grid was mounted about 12 mils in front of this cathode. It too is concave. The grid was made of 1.5 mil thick molybdenum. It employs a honeycomb pattern with an optical transmittance of about 90%. Later, on devices 10, 11, 12, copper grids were used. Their other properties are similar to those of the molybdenum grids except they are 2 mils thick instead of 1.5. A photo of the entire grid assembly is shown in figure 2.2. No focus electrode was used on this device and a flat anode was used. The anode is made of molybdenum. By not using a focus electrode the cathode face could be viewed throughout it's operating life. This was valuable, since temperature measurements were often more uniform from device to device on the cathode surface than they were on the Nickel shank. Also, if cathode adherence problems occured it was readily visible as a bright spot on the cathode coating while it was operating.

2.1 Cathode Loading Uniformity.

The testing was conducted at approximately 2 amps of cathode current. This calculates to an average loading of 6 amps/sq. cm. However, the peak loading in some locations may be higher and consequently the cathodes may have been given a more stringent test than was intended.

2.2 Test Vehicle Configuration.

Each test vehicle contains 4 grid assemblies. The 4 grids share a common anode. The anode is spaced 75 mils away from the grids. In devices 1 - 8 the stand-off was effected with glass beads. Later, because the glass beads were breaking down after a few hundred hours operation, we began using ceramic for the stand-off. These were used on devices 9 - 12. We had fewer problems with high voltage arcs

Figure 2.2

GRID ASSEMBLY

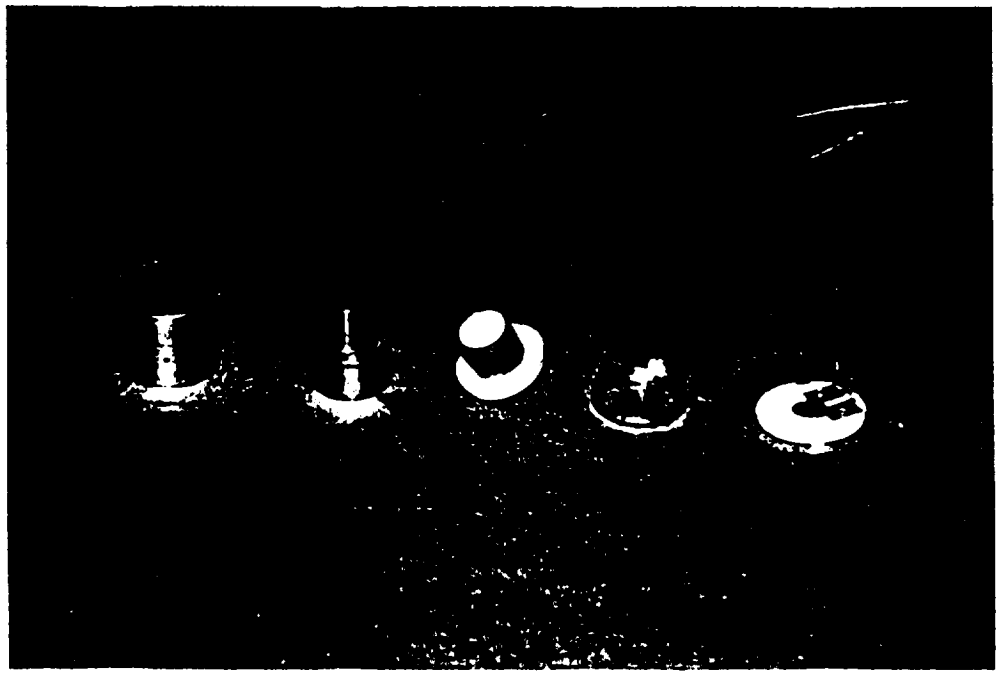


Figure 2.3

CATHODE ASSEMBLY

following this change.

The grids are all wired in common and go out to a single pin in the feed thru of the envelope. Each grid assembly has its own heater-cathode lead coming out to the feed thru and it has its own heater lead coming out. Consequently, 10 of the 14 pins of the feed thru are employed.

3. CATHODE FABRICATION AND PREPARATION

The cathode caps were in all cases fabricated from 3 mil Nickel strip. The Nickel was type 330 in all cases except test vehicle 8 which employed type A31 alloy.

Type 330 has the following chemistry: (Reference [1])

Mn (max %) .3
Mg (max %) .01 - .1
Si (max %) .1

The 330 Nickel we used was analyzed by Oremet Titanium and found to have .1% magnesium and .03% silicon.

A31 Nickel has the following chemistry:

Mn (max %) .05
Mg (%) .01 - .06
Si (%) .02 - .06
W (%) 3.75 - 4.5

A31 is a product of Superior Tube Company and is advertized as an active cathode Nickel with improved hot strength. Since our work envisions the use of large cathodes (.250 inches in diameter) in fast warm-up low cost traveling wave tubes the improved hot strength of A31 is an attractive feature.

We need to keep the cathode thin to reduce thermal mass and make it easy to form while maintaining a sharp corner at the edge. At the same time it needs to have high yield stregth so that irreversible bending does not occur particularly during a fast turn on.

The cathode strip is blanked and then formed into a cap. If the cathode is to be sprayed it will be formed into its final concave shape at this step. If it is to receive a decal it will be formed with a flat top at this stage. After the decal is applied a final forming will be done. A photo of our cathode assembly is shown in figure 2.3.

3.1 Preparation of Coating Slurry.

The standard Tektronix cathode slurry was used in this work to make the sprayed control devices. To this standard slurry was added a slurry containing scandium oxide until the scandium oxide was 4% of the triple carbonate (barium, calcium, strontium carbonate) by weight

to make test devices. Intuitively we felt that the scandium oxide particle size should be the same as that of triple carbonate. So we ball milled the scandate in the normal cathode binder solution (nitro-cellulose and amyl acetate) until the particle size was reduced to about 4 microns from 15-20 microns. However, according to reference [2] the scandate particle size should be larger than the carbonate particle size.

Actually the particle size of our triple carbonate is 5-10 microns. Consequently our scandate may have been too fine. A previous attempt to form a slurry in which the scandate particles were consideralbly larger than the carbonate produced a slurry that did not spray satisfactorily. Another reference [3] recommends that scandate be fired in hydrogen at no less than 800 degrees C for 10 minutes to partially reduce the scandate and thereby increase its reactivity. This we did not do.

The binder that the scandate was ball-milled in was quite thin-only 1% nitro-cellulose. It was mixed with the triple carbonate slurry which was separately ball-milled and mixed. The triple carbonate came from Sylvania. It is designated C-10, control lot 50105. The usual procedure is to take 601 grams of triple carbonate powder, dry at 110 degrees C, then mix into a nitro-cellulose solution containing 10 grams per liter of nitro-cellulose (approx. 1%) and amyl acetate. This gives a 750-1000 sec. viscosity solution. The 601 grams of triple carbonate is mixed with the 1000 ml. of binder solution, this mixture is then put in a 2 liter ball mill with 1 kilogram balls. Ball mill for 24 hours. The scandate slurry would be added at this point if test cathodes are to be sprayed. Next the slurry is put in a refrigerator and stored. Before use, warm it and roll for minimum of 8 hours. Dilute with amyl acetate to 32 centipoise.

Before the cathode cups are sprayed, they are cleaned in acetone and fired in hydrogen at 750 degrees C for 1/2 hour. They must be sprayed the same day. After spraying the coating thickness is checked. Ours ranged from 2.1 mils to 2.6 mils. The cathodes are stored in a dessicator until used.

In one phase of this study a coating of scandate was applied directly to a Nickel substrate. In the first case scandate powder was applied in a slurry to bare Nickel caps. The caps were then fired at 1200 degrees C in a hydrogen atmosphere in the hopes that sintering to the Nickel would occur. This test was not successful. The scandate did not adhere to the Nickel.

Another test involved purchase of a .5 inch diameter pellet of scandate. If was electron beam evaporated onto Nickel. This experiment was not wholly successful either. A layer of scandate 100 Angstroms thick did end up on the Nickel, but the pellet broke up in the process. Further work will need to be done, to improve the fixturing of the scandate pellet. According to reference [3] a layer that is 2000-4000 Angstroms thick is probably required to produce enhanced emission.

4. TUBE PROCESSING

4.1 Pumping and Bakeout

The following procedure for processing was followed on all tubes beginning with device 4. After the triodes are constructed they are sealed into a glass envelope. The tube is then pumped and baked at 400-425 degrees C for at least 24 hours. Pressure will then be below 2x10-7 torrs. The oven is turned off and raised. RF heating of the grid and anode structures is now done for approximately 2 hours. The RF level is adjusted so that the temperature of the grids is about 650-700 degrees CB.

Next comes cathode breakdown. Again base pressure should be below 2x10-7 torrs. The heater voltage is raised to 2.0 volts. Both filament voltage and current are monitored. The heater voltage is turned up in 1/2 volt increments every 2 minutes until the gas pressure begins to rise substantially. Then the voltage is raised more slowly so that pressure always remains below 9x10-6 torrs. When a cathode temperature of 800 degrees CB is reached (approx. 5.5 volts) the heater voltage is raised in whole volt increments to 7.5 volts. At 7.5 volts the cathode temperature is about 950 degrees CB. This is sufficient to complete breakdown. After 5 minutes at 7.5 volts the heater voltage is lowered in one jump to 5.5 volts (800 degrees CB). It was found that peak pressure was reached at about 4.0 volts on the heater. Breakdown is done at room temperature.

4.2 Cathode Activation on the Pumps.

All cathodes were activated on the pumps except SN10.

The anode voltage was set at 400 volts. The grid voltage was adjusted to whatever level gave 120 ma. of cathode current. The pulse width was 50 micro-seconds and repetition time was 250 micro-seconds. It was found that at duty factors much above this, grid emission occurred. This caused thermal runaway of the cathode. The electrons backstream to the cathode during pulse-off and heat it. The cathode emits more which in turn causes the grid to get still hotter thereby causing it to emit even more, etc. This was a potential problem on all devices except SN 10, 11 and 12. These devices had copper zirconium grids and did not exhibit the problem. A comparison of cathode current vs. duty and pulse width for devices with and without copper grids can be found in section 6.

Next comes cathode activation. Table 4.1 shows the procedure.

Figure 4.1 shows a plot of cathode temperature and heater power vs. heater voltage of a typical device.

The problem of cathode temperature runaway was a problem not only during activation duties, but at normal low duty operation at elevated grid drives or heater voltage. This is a problem not encountered on single grid tubes with dispenser cathodes. The cathode temperature does not rise in that case since there is no insulating layer on the cathode that can heat up. The only solution to this problem appears to be the use of a copper grid or other emission

Table 4.1 Activation Procedure

Step	Minutes	Aproximate Side Temp. (degree CB)	Heater Volts	Grid Volts	Anode Volts
1.	5	920	7.00	-15	0
2.	5	960	7.50	-15	0
3.	5	1000	8.00	-15	0
4.	5	300	2.00	0-30*	400
5.	20	920	7.00	0-30*	400
6.	3	1000	8.00	-15	0
7.	3	300	2.00	-15	0
8.	20	920	7.00	0-30*	400
9.	20	880	6.50	0-30*	400
10.	20	840	6.00	0-30*	400

*adjust grid voltage to a value that provides 120 ma of cathode current.

suppressing materials. Some help can be gotten by carefully minimizing the cutoff voltage while keeping the grid transmission high. There is a trade off between these two constraints. For most tubes almost full emission was seen within a few minutes after the voltages were applied on step 5. One exception was SN 12 which had chem-etched cathodes. These cathodes had been very quick to activate in a previous study. So it is not clear what went wrong here. Also the knee temperatures on grids 1 and 2 are quite high. The cathodes apparently were poisoned, either when the cathodes were etched or in subsequent processing. There is more information on device 12 in section 6. The other slow activator was SN 8, scandate on A31 Nickel. Again the activity knee never exhibited the quality of other scandate cathodes.

After activation the tube is sealed off. Since the tube is made of glass the pump out tube is heated until it flows and pinches in. The tubulation is then scribed and broken halfway along the seal-off constriction. The broken end is treated with Vac-Seal. Next the getters are flashed using an RF wand. Some de-activation of the cathode may occur as a result of seal-off and getter flash.

Hipot occurred at 6000 volts. First the grid, cathode and heater leads are connected together and held positive while the anode is held negative. Voltage is turned up slowly enough to keep leakage current under 100 micro-amps. Then it is held for 1 hour. Next polarity is reversed and the process repeated. Hi-potting was not instituted until device 8.

4.3 0 Hour data.

0 hour data consists mainly of an activity or roll off curve. Examples are shown in section 6.

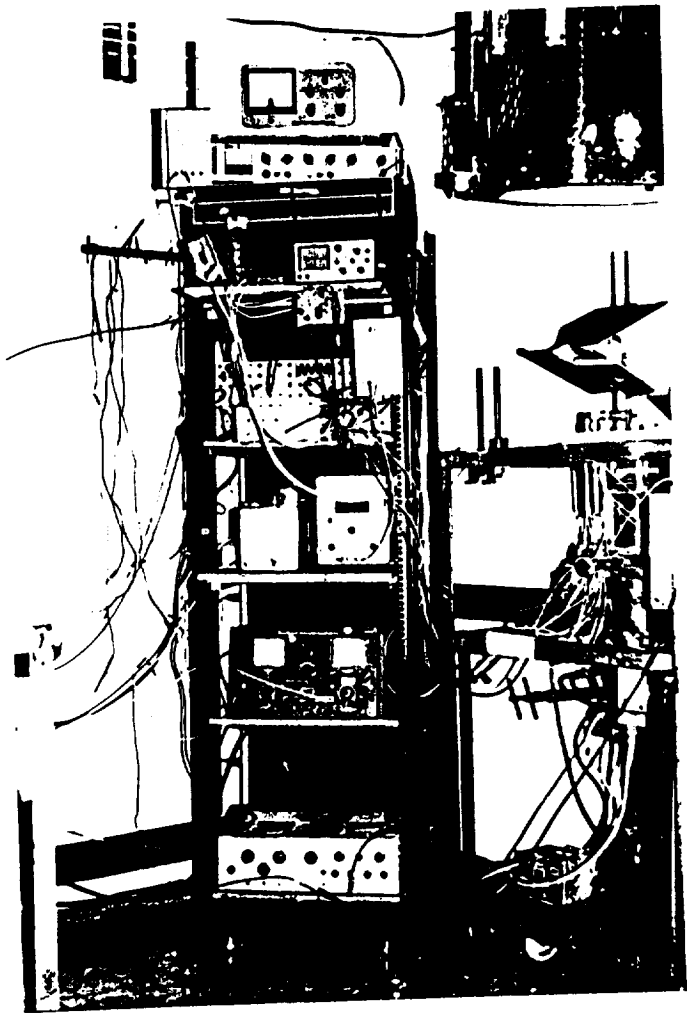
At this time the "goodness" of the cathode is judged. A duty factor of .1% with a pulse width of 10 micro-seconds is used on all devices. The high voltage was set between 2000 and 3000 volts. The grid voltage was set to allow 2 amps of cathode current at fully space charge limited flow. This translates to an average cathode loading of 6 amps/sq. cm. The "knee" was placed at the point where the temperature limited curves and space charge limited curves should have converged. The fact that they tend to "roll-off" in the transition and not form a distinct knee does not prevent us from establishing a theoretical knee and judging the cathode accordingly. Why some cathodes did not form a distinct knees is a matter of some concern. This is discussed in section 6. For example, the cathodes made of A31 Nickel did not exhibit the quality of activity knees of cathodes made of 330 Nickel. After 0 hour tube performance is characterized, at least one cathode in the device is selected for life testing.

5.0 LIFE TEST

The life test was conducted on two stations. Figures 5.1 and 5.2 show these. The duty was .1% for all devices tested. The intention was to start all vehicles out at sufficient grid drive for 2 amps (6 amps/sq. cm) of 0 hour emission. However, this wasn't always possible

Figure 5.1

LIFE TEST STATION 1



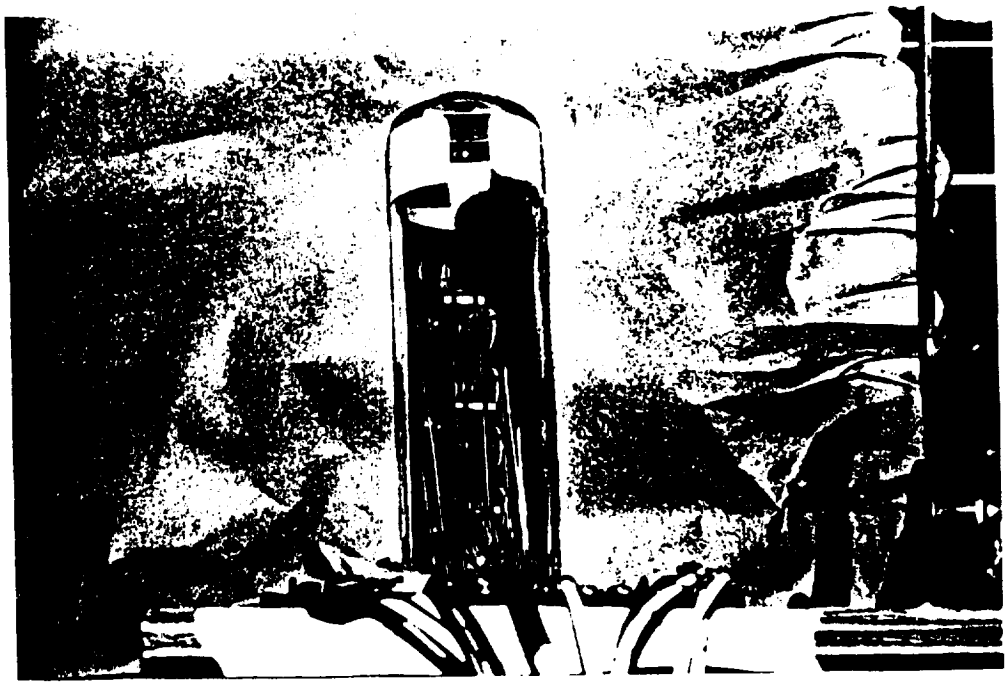
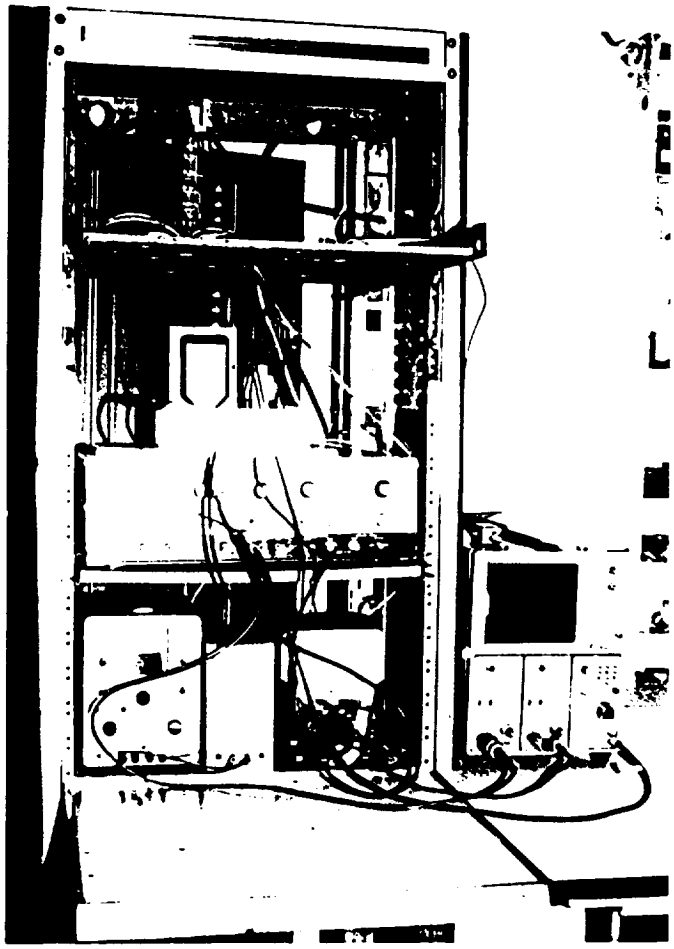


Figure 5.2

LIFE TEST STATION 2



because the grid driver on station 2 is deficient in voltage and current.

The rules for the life test are as follows: the heater voltage is fixed at .5 volts above the 0 hour activity knee. This remains fixed unless a drop in cathode temperature of at least 20 degrees occurs during life testing. Then heater voltage is renormlized to bring the cathode temperature back up to its 0 hour level. Grid drive and anode voltage are fixed throughout the test.

Figures 5.3 and 5.4 show plots of normalized cathode current vs. days of service. The cathodes with scandate in their coatings lived longer than either decals or sprayed non-scandate cathodes. However, scandate on A31 Nickel does not appear to be as good as scandate on 330 Nickel. This is true of both 0 hour performance and life test. We should say say though, that this cathode had poor adhesion as evidenced by a "mud-flatting" mottled appearance when viewing with the optical pyrometer. Also the cathode was operated at higher temperature than the other scandate cathodes.

As for the decal cathode in figure 5.3 it shows rapid deterioration, even taking account that an arc damaged the cathode on the 28th day. This cathode was operated at about 830 degrees CB (side temperature). It took just 28 days for its emission to drop 20%. However, the operating temperature was quite high. This may account for most of it's rapid deterioration relative to others. For expample SN 5 was operated at 800 degrees CB and SN 7 was operated at about 810 degrees CB.

It is claimed in reference [3] and [4] that much of the improvement derived from the sccandate is the prevention of a build-up of silicon oxide and magnesium oxide in the interface between the cathode coating and the Nickel. If this is true, the cathode current should remain roughly constant at fixed drive at the knee. This is what we see on dispenser cathodes. The activity knee constantly moves toward the operating point but current in the knee is stationary. At some point the knee crosses above the operating point and the cathode goes temperature limited. It is certainly true that device 5, for expample, remains more constant in cathode current than the other, non-scandate cathodes. We can see this from figure 5.4 and 5.5. What these plots don't show is the other factor in cathode deterioration, namely movement of the knee toward the operating point. Figure 5.6 is a plot of this for each of the life test cathodes. Of interest is that device 7 had no movement in it's knee temperature after day 24. Then all of it's deterioration was caused by a drop in cathode current, ascribable to interface buildup. The data for device 7 is incomplete since an arc occurred and damaged the cathode before final activity data was taken. All the other cathodes, both scandate and other show movement in the knee with time.

6.0 DATA AND INTERPRETATION

6.1 Cathode Activity

Cathode temperature for each grid assembly was read by viewing

through a hole in the side of the grid against the bare nickel cathode shank. There was some dispersion in these measurements, largely because of variations in the surface condition of the nickel. Even on the same cathode shank differences of 20 degrees could sometimes be seen between light and dark patches. The measurement was directed at the darker regions, as these seemed to yield the most consistent results. These patches correspond to bright, smooth nickel.

Because the triode structure was open it was also possible to measure cathode face temperature. This measurement was done against the oxide coating. It averaged 20 to 40 degrees cooler, in appearance, than the bare nickel, side reading. This is surprising but, nevertheless, was seen on all devices.

A poor coating looked like a mud flat with dark regions separated by irregular bright colored "cracks". A good coating was of uniform brightness everywhere. A lifted coating (usually the result of a high voltage arc) was invariable brighter than the region around it.

The pyrometer used in all these studies was a model 95 micro-optical pyrometer from Pyrometer Instrument Company, New Jersey. We did a check of this pyrometer on a 20 to 1 aspect ratio black body hole in a piece of 304 stainless steel. The absolute temperature was measured with a thermocouple and further checked by using a cusil braze flag, and making a measurement of temperature when it melted at 780 degree C. The optical pyrometer read 780 degree C at that point, incidentally. A plot of the pyrometer calibration is shown in figure 6.1.

A third piece of data that we collected is heater power. Correlations of heater power to cathode side and face temperature can be made and are shown in figure 6.2 - 6.5. The physical construction of the test devices remained essentially the same throughout the study. However, it still proved difficult to assign an absolute value of temperature to a given heater power. However, the relation between change in heater power and a change in cathode temperature is much more predictable.

The most important plot in comparing cathodes is the activity or roll-off curve. A representative sample for each device is shown in figures 6.6 to 6.13. An activity curve is taken at the completion of cathode activation, then at regular intervals as the device accumulates life. The test conditions are .1% duty, 2500 - 3000 anode volts, and sufficient grid voltage to achieve 2.0 amps of space charge limited cathode current at the highest heater voltages.

Table 6.1 is a list of relevant information at the cathode activity knee. It is comprehensive in that it lists all cathodes that were testable and were not pathological in one way or another. The device number, grid number, the characteristics of the cathode, the heater voltage to the activity knee, the heater power, the cathode side temperature and the cathode face temperature are all shown. The heater power is shown two ways. The first number is the raw data. The second number is corrected to account for a systematic drop in heater power, that was observed as the device builds proceeded. More on this later.

On average the scandate cathodes are superior to the others. However, device 8 (scandate on A31 Nickel) is not as good as scandate on 330 Nickel (devices 11 and 5) at least so far as direct temperature is concerned. The lowest average side temperature was device 5 (scandate on 330 Nickel) at 734 degrees brightness (Nickel). The lowest average face temperature was also device 5 at 709 degrees brightness.

A couple of cautions are in order. Device 4 (Elcon decal) appears to have a significantly lower side temperature than device 7 (standard sprayed). Unfortanately the decal cathodes in device 4 had guard rings welded to their sides.

The side temperature measurement is on this guard ring and is somewhat lower than a direct view of cathode would yield. Consequently the 766 degrees average side temperature for device 4 is too low. Device 12 which is also decal cathodes, but without the guard ring, shows a side temperature of 790 degrees on grid #4. This is probably more realistic and is close to the 782 degrees on device 9 (standard sprayed) and the 784 degrees on device 7 (also standard sprayed).

Moreover, regarding heater power, a systematic trend toward lower values was observed as the device builds proceeded. This tendency is summarized in tabel 6.2. We have no explanation for this except to suggest that our fabrication technique improved with time and so the thermal efficiency of the device improved. The temperature change for 1 watt of power increase (near the knee) in device 4 was 66 degrees. By device 11 this temperature delta had increased to 76 degrees. As a result of this power change a correction power is calculated in table 6.1 which compensates for it.

Another caution is that there appears to be a significant thermal emissivity difference between scandate sprayed, regular sprayed and decals. This difference distorts the comparisons in the cathode face temperature measurements shown in table 6.1. The Elcon decals in device 4 show, on average, only a 14 degree difference between face and side. Of course we already know that the side measurements on device 4 are too low because of the guard ring problem. However, turning to device 12, grid 4 (also a decal) we still see only 27 degrees difference. Even on grids 1 and 2 of device 12 the difference is only 29 degrees and that's at much higher temperature. Again we do not know why the decal cathode has higher emissivity. Because it is smoother, one would expect it to be lower.

On the other hand the standard sprayed cathode has much lower emissivity relative to bare Nickel. SN9 had a 43 degrees apparent drop from side to face. And SN7 has a 38 degree drop from bare Nickel to the cathode face.

The scandate sprayed cathodes show much less difference between sides and cathode faces, than standard sprayed cathodes. Device 5 has only an 18 degree drop side to face. Device 8, scandate on A31 Nickel, has only a 13 degree drop. And device 11 has a 26 degree drop. In summary the scandate oxide material appears to have a higher emissivity. The result is that the standard sprayed cathodes compare more favorably with the scandate cathodes on face measurements of

temperature than the facts warrant.

Table 6.3 is a difference chart based on table 6.1. It shows differences in heater voltages, heater powers, the corresponding temperature differences that apply to those powers, and the side and face temperature differences, for all devices. It shows that device 5 (scandate) is lower in side temperature than device 7 (plain sprayed) by 42 degrees but is lower by only 22 degrees on face temperature. Again, device 11 (scandate) is lower than device 9 (plain sprayed) in side temperature by 23 degrees, but is lower in face temperature by only 4 degrees. This discrepancy is caused by the lower emissivity of the plain cathode material over the scandate cathode material. It is important that this difference be taken into account whenever a life test is conducted where only face temperature is read. This is the case, for example, in the RADC life test vehicle.

There is still another caution when viewing the data. The activity curves are subject to some interpretation when determining the activity knee. Figures 6.6 to 6.13 are representative exhibits of these curves. In several cases the knees are not distinct, but are smeared to some extent. Most of the time a single point near the transition is sub-par. That is, cathode current s deficient near the knee. An example, is device 8, grid 1, shown in figure 6.9. In this case a theoretical knee can be constructed which leaves the deficient point out. This has been done in this study. Often the deficient point simply indicates that the cathode is not fully activated. After a period of operation, however, the point moves up and takes its correct position. In device 8, however, all cathodes had this problem to some extent and none of them recovered fully, even after hundreds of hours operation. The conclusion, is that A31 is not a good material to use as a substrate for the scandate dispersed cathode. Or the cathode was somehow poisoned, or the cathode material was too old when it was used and so it didn't adhere properly to the Nickel. Further study is required here. Also device 11, scandate on 330 Nickel, did not perform as well as the earlier scandate 330 Nickel (device 5). When viewing the cathodes with the optical pyrometer there is evidence of adherence problems. Again it's possible that the scandate-carbonate mixture was too old when spraying on for device 11 occurred. I am told that cathode slurries are not used after they are 3 months old at Tektronix. The scandate slurry was more than 6 months old when spraying for device 11 occurred.

There is a possibility that the apponent differences between side and face temperature represent an actual temperature drop through the cathode coating. This would explain alot. For example the Elcon coating is denser so it conducts heat from the substrate better than the sprayed coatings which are rather fluffy and porous. The scandate cathodes, by virtue of the sandium oxide are more conductive so they also have a smaller difference.

6.2 Grid Characteristics.

Figure 6.14 shows a plot of cathode current vs. grid drive at fixed cathode voltage and heater voltage. They are plotted on 2/3 power paper. Again data was collected at .1% duty. The plot should be a straight line in a space charge limited region. A rolling over

of the curve at high drives indicates temperature limiting is beginning to occur. A discontinuity in the curve usually means the grid has shifted its position. This occurs because the grid intercepts electrons and is heated by them. At higher drives this can cause substanial thermal expansion effects. The first thing we generally do when a cathode activity curve doesn't look right is plot grid characteristics. This sometimes locates the source of the problem as a movement of the grid.

6.3 Long Pulse Width, High Duty and Choice of Grid Materials.

One of the main limitations on high duty operation is the problem of grid emission. As soon as the grid intercepts substantial power (approx. .8 watts) from the beam it gets hot and eimits electrons back to the cathode during the pulse off mode. This is not a problem on dispenser cathodes tubes because the cathode surface is not an insulator. On an oxide cathode it can be disastrous. The electrons backstreaming to the cathode heat the surface. This has the effect of increasing emission either because the cathode moves closer or because there is a small temperature limited component to its emission. In any case, the process leads to a cyclical instability in which the cathode and/or grid eventually burn out.

To address this problem and to acquire data at higher duties, copper zirconium grids were mounted on devices 10, 11, 12. They were found to be much better than moly grids. Zirconium is a potent grid emission suppressor and the high thermal conductivity of copper lowers the operating temperature of the grid. Table 6.4 shows data for long pulse width and high duty operation for device 11, grid 2. It used a copper grid. Table 6.5 shows comparison data for device 9, grid 1, which employed a molybdenum grid. In both tables the test conditions were essentially those under which the cathodes are activated. Anode voltage is 400 volts, pulse width is 50 micro-seconds and repetition time is 250 micro-seconds, and duty factor is 25%. The grid voltage was turned up until grid emission began with consequent heating of the cathode.

iH the heater current is recorded in table 6.4 because when the cathode receives heat from an external source the heater current drops. The bias voltage was set at -200 volts. It did not need to be this high for this experiment, but in an actural TWT it could be this high. Of course, the power flux against the cathode is directly proportional to this voltage. It was found that in both devices, once the cathode began to rise in temperature, it could be cooled off again by raising the grid bias toward 0.

It's clear from the table that the threshold of cathode thermal runaway is lower for the moly gridded tube. In fact a plot of grid power consumption vs. grid pulse-off current is very revealing. It is shown in figure 6.15.

How much power can an oxide cathode intercept before runaway occurs? It is reasonalbe to assume that the grid emission current is divided equally - half goes to the anode and half to the cathode. This is true because the emission is temperature limited. Then based on table 6.4 the pulse-off grid current was 13.8 ma. One half of this

is 6.9 ma. The bias was 200 volts and the pulse-off condition occurred 75% of the time. Average power to the cathode then, was 1.03 watts. A similar number is derived from the other tube's data. Our cathode's area is .317 sq cm. Consequently maximum power flux it can tolerate is 3.25 watts/sq cm.

Table 6.6 shows tube performance on device 11, grid 2 in normal operating mode as duty was raised. It was possible to achieve in excess of .5% duty without serious backstreaming to the cathode or excessive heating of the anode. At a reasonalbe perveance the grid interception can be reduced to 10% of cathode current. That would be down by a factor of 4 from what is shown in the table. Consequently a duty factor of 2% could be achieved with an oxide cathode and a copper-zirconium grid. In addition, an increase in grid bias from -200 volts to -100 volts would allow a further doubling in duty to 4%. This is probably an upper limit on duty factors for TWT's with intercepting grids and oxide cathodes if cathode thermal runaway is to be avoided. This assumes high cathode loading - 6 amps/sq. cm. in our case.

Table 6.7 shows the effect of long pulse width on cathode performance for device 9, grid 1. It is well known that the oxide coating is a semiconductor and that it stores charge in the pulse-off condition. The layer is conductive but becomes less so as the pulse width is extended and the electrons are swept out of donor sites. However, the data in table 6.7 shows very little cathode current decay out to 100 micro-seconds. We were hampered by the large slump in cathode voltage within the pulse-on period. Also the duty factor had to be kept low to avoid the cathode runaway problem. Most of cathode slumping that was seen was caused by the cathode voltage slumping.

6.4 Chem Etched Cathodes.

Device 12 contained decal cathodes on chem etched Nickel. Grids 1 and 2 were plain etched; grids 3, 4 were mesa etched. Their performance was disappointing. Grid 3 failed to activate at all. Grids 1 and 2 activated, but at high cathode temperatures. Grid 4 with mesas performed in line with a decal cathode on an unetched surface. For example, in table 6.1 device 4, plain decal cathodes, had an average side temperature of 766 degrees. But this was a measurement to the cathode guard ring, which means that the actual side temperature was higher. The face temperature of these cathodes was 752 degrees which compares very well with the 763 degrees seen on device 12, grid 4. Also the heater power to grid 4, 4.48 watts, is lower than the 4.57 watts on the plain decal cathodes. The conclusion based on grid 4, device 12 is that mesa etched decal cathodes perform about the same as unetched decal cathodes. As for the non mesa etched cathodes more study is needed.

7. REFERENCES

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3. U.S. Patent 4,797,593, January 10, 1989.

4. "Thermonic Cathodes for CRT's," Nakanishi, OYO BUTSURI Vol. 56, No. 11, 1987, pp. 1423-1432.

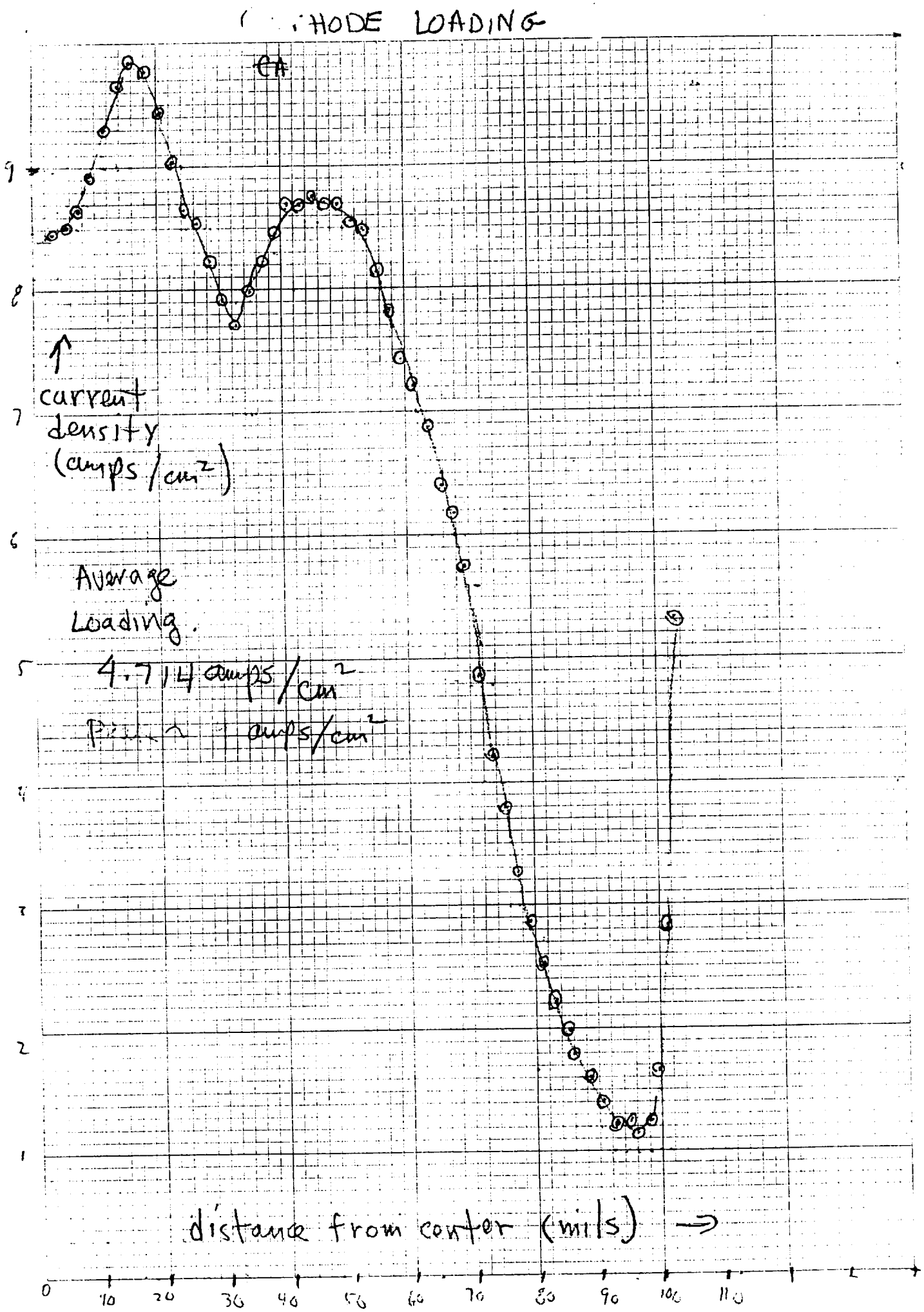

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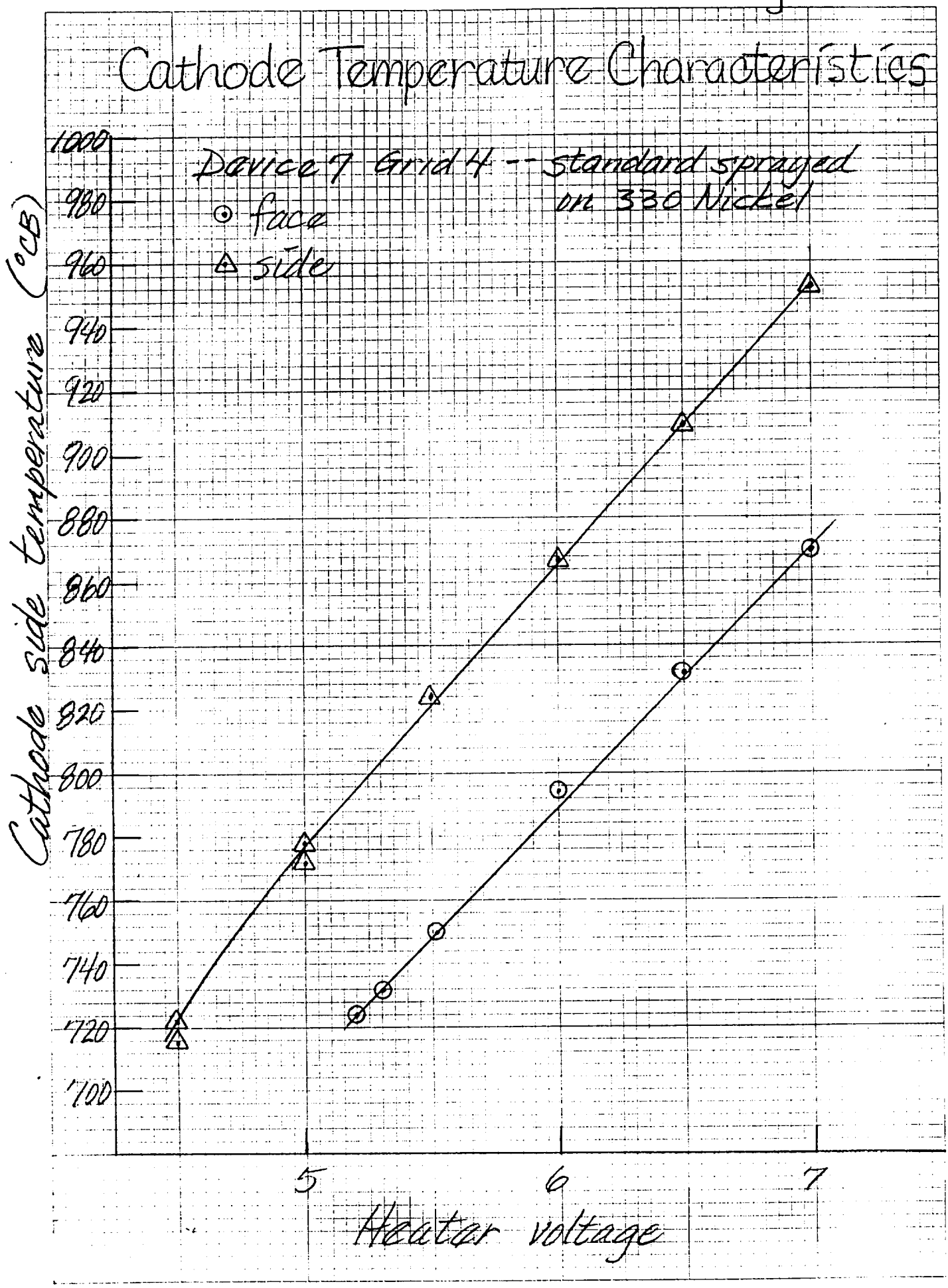
Fig 4.1



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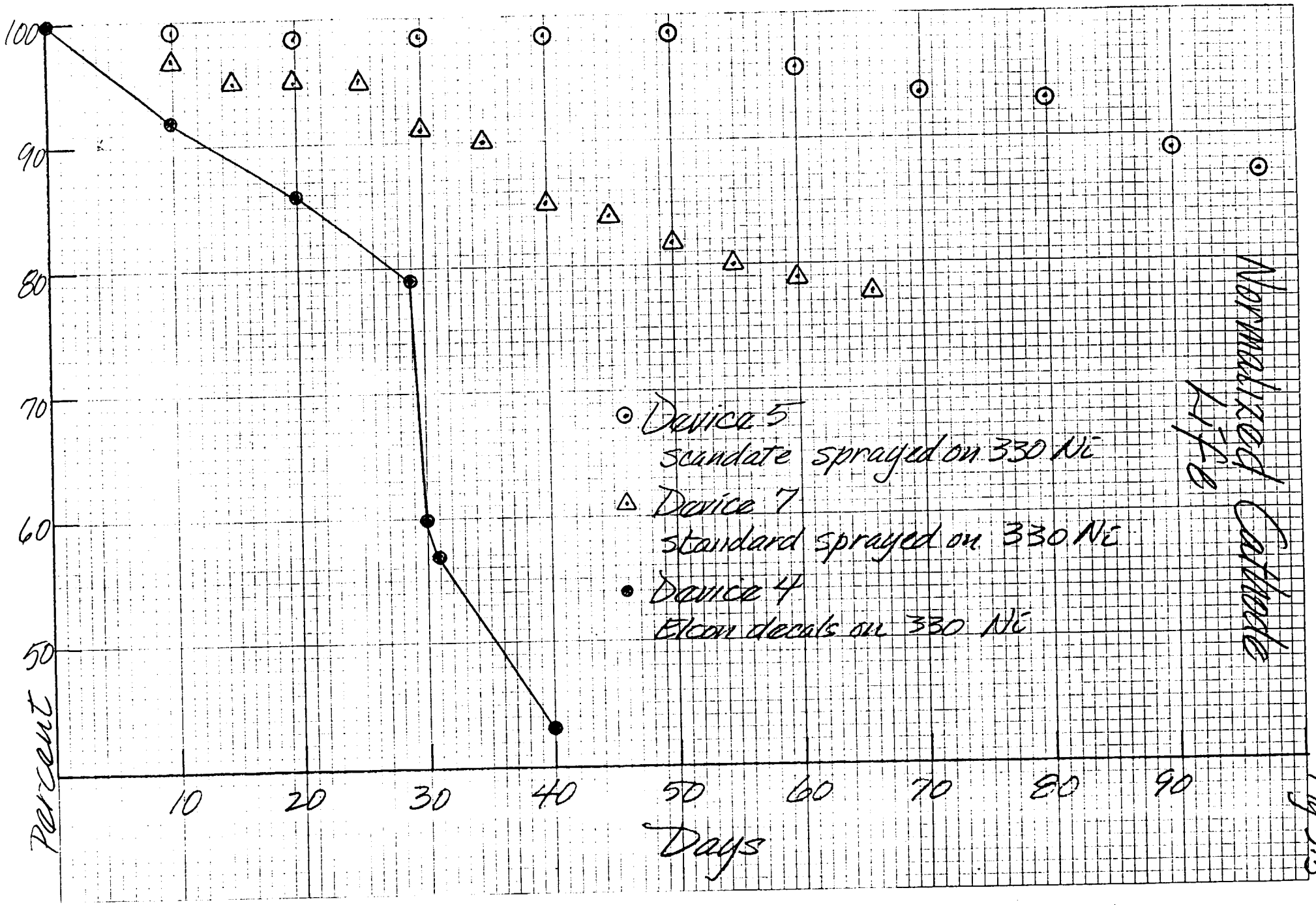

Fig. 5.3

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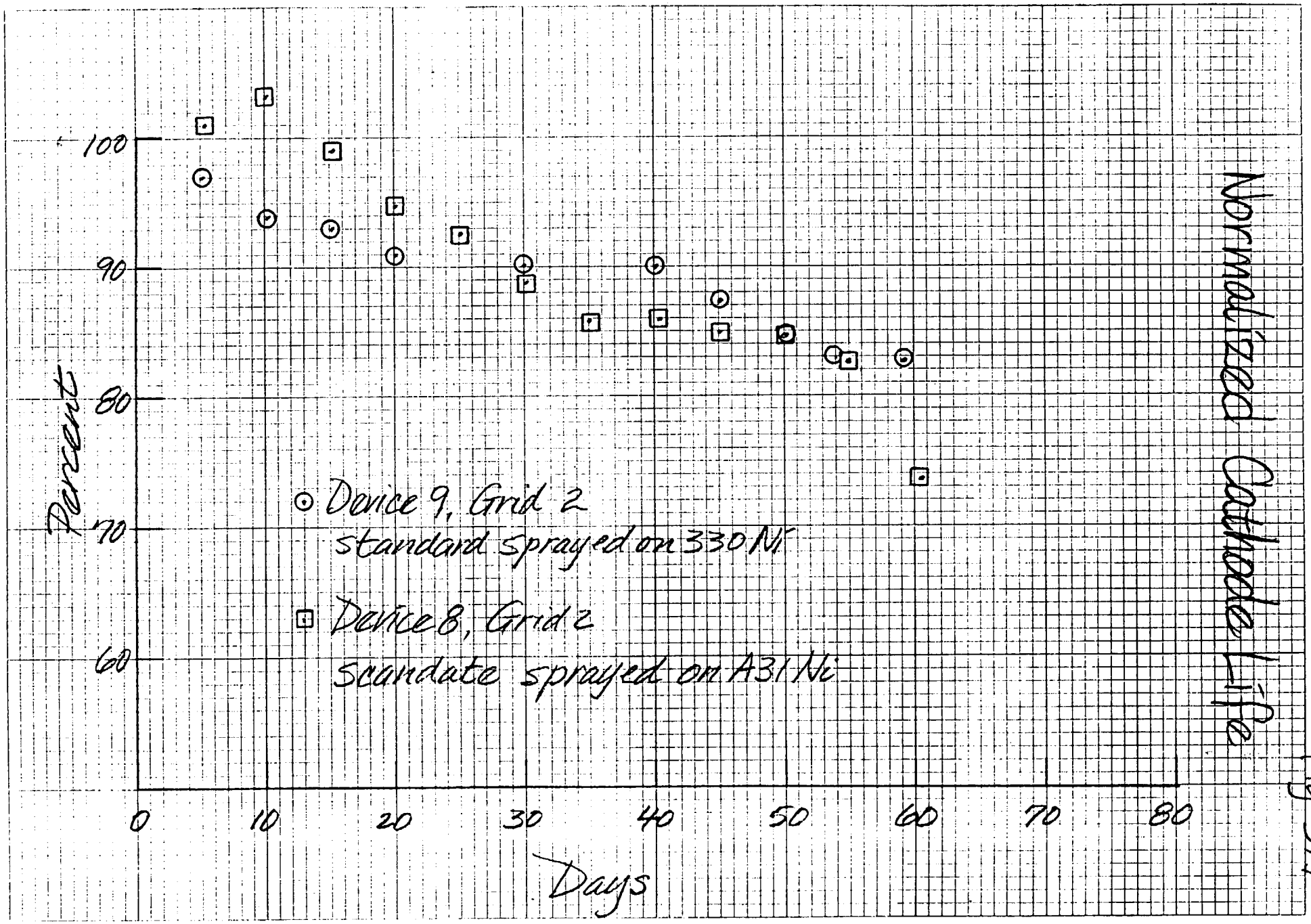

Fig 5.4

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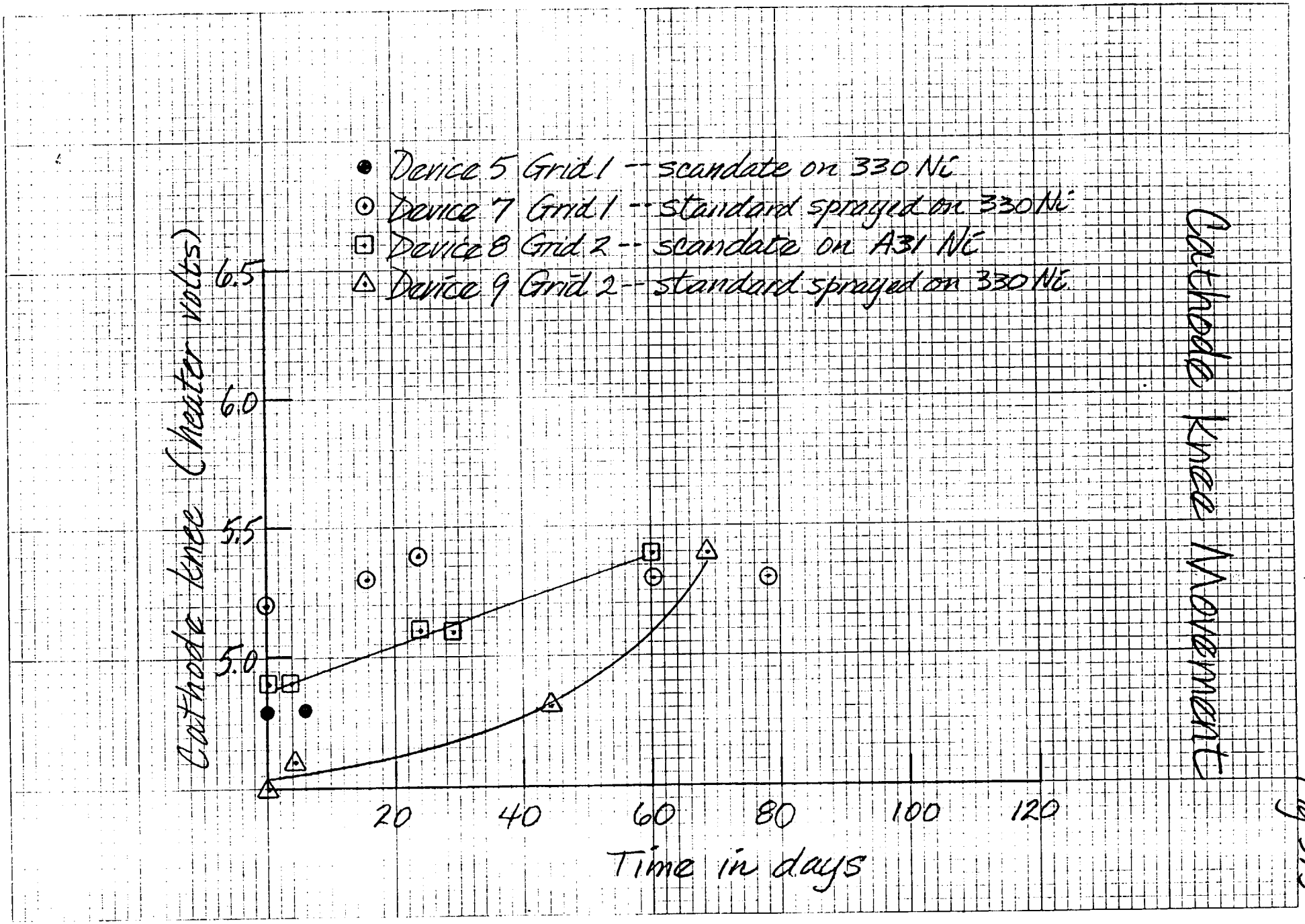

Fig 5.5

K·E 10 X 10 TO THE INCH • 7 X 10 INCHES
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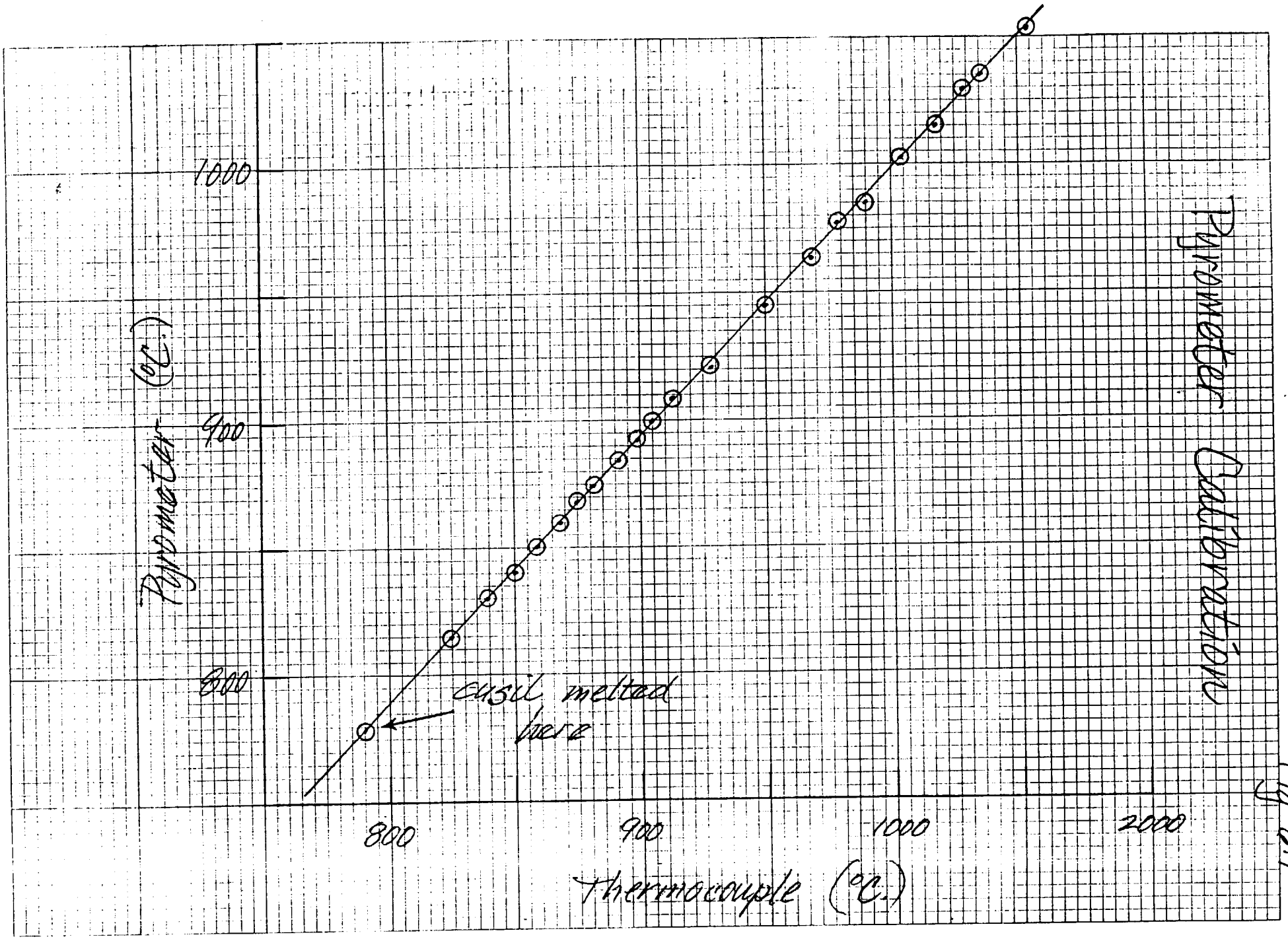
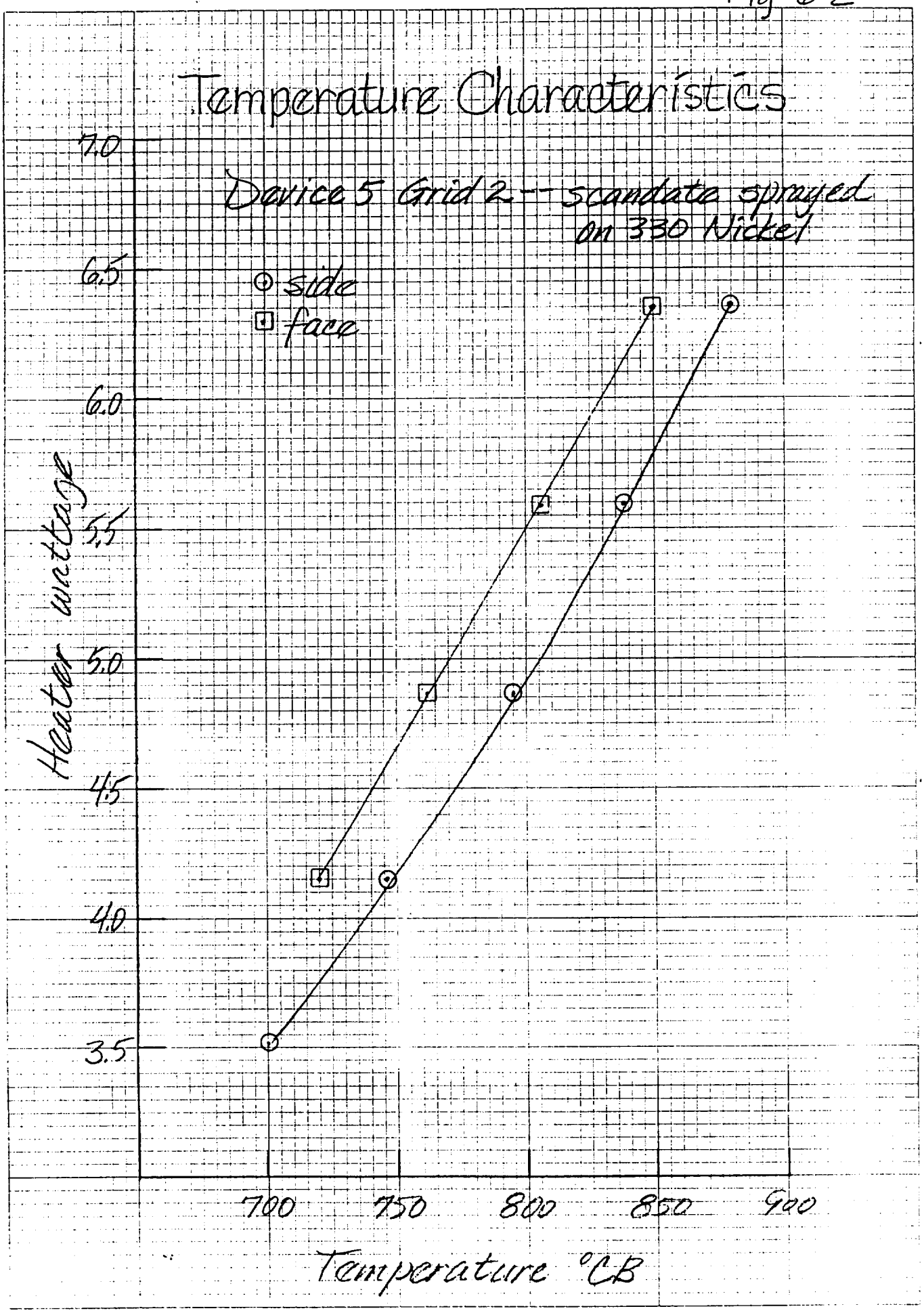


Fig. 6.1

Fig 6.2



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K&E 10 TO THE INCH 7 X 10 INCHES
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Fig 6.3

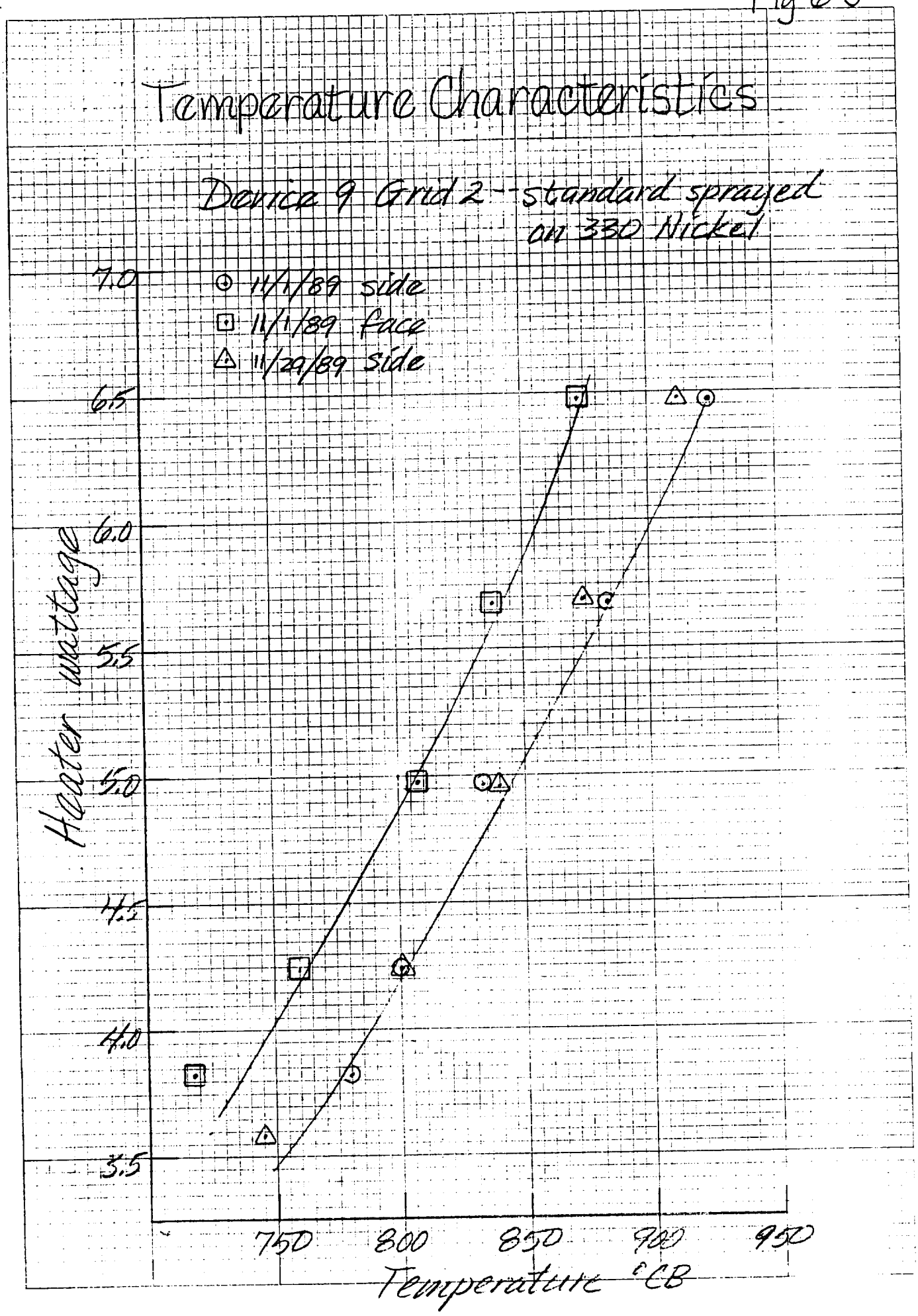

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Fig 6.4

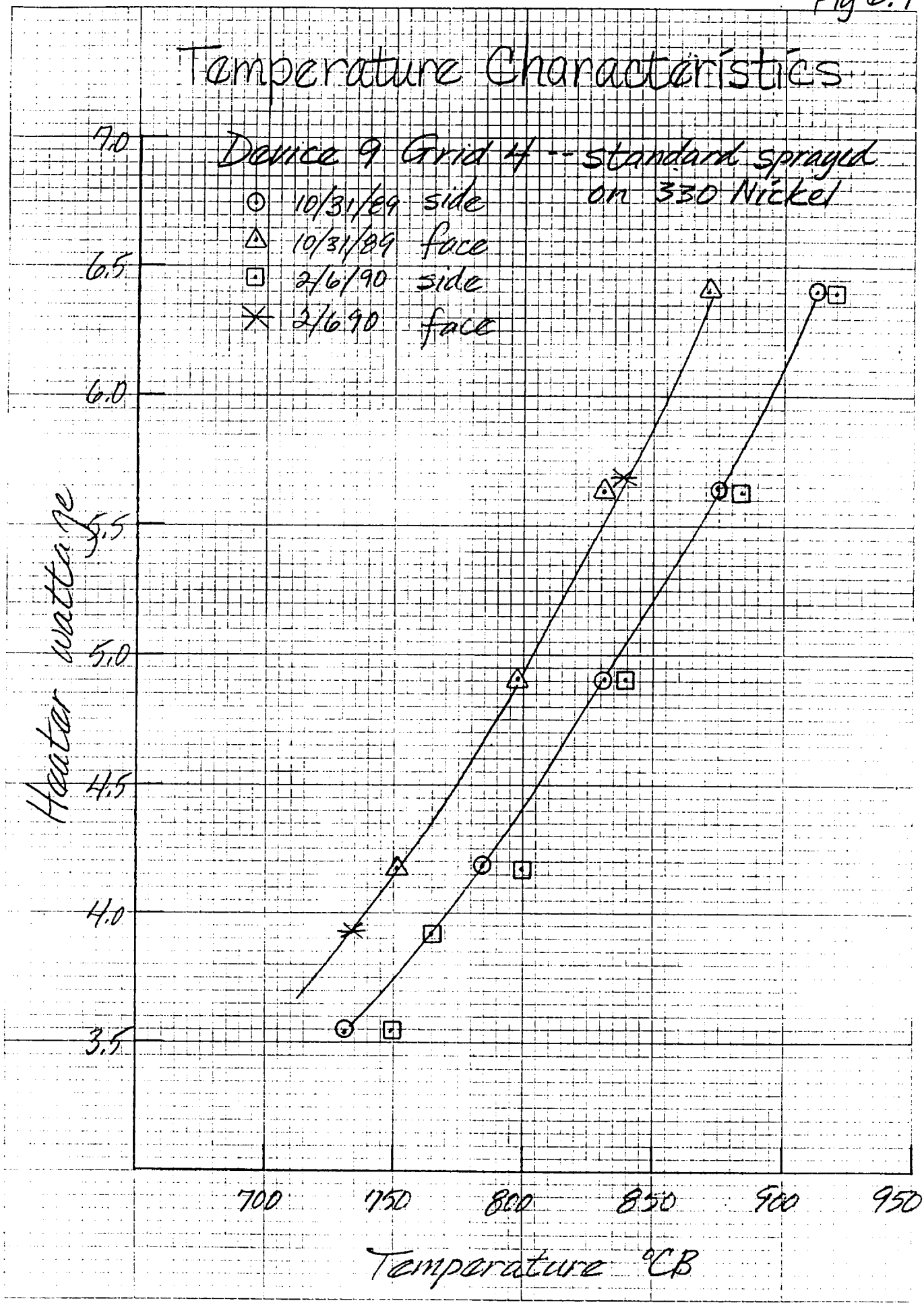

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Fig 6.5

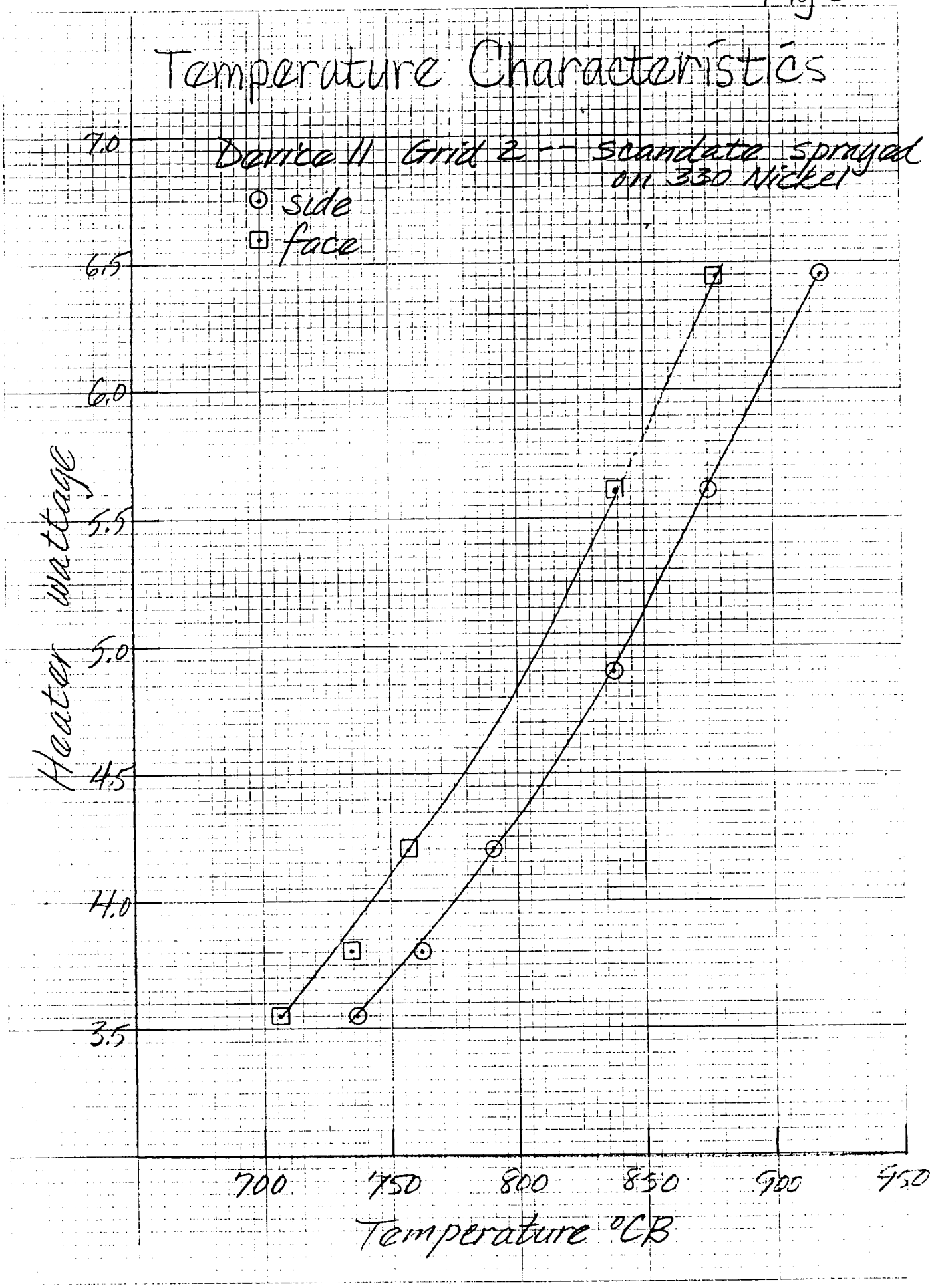

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TABLE 6.1

The table that follows shows the device, description, cathode side temp., cathode face temp., and heater power to the knee.

Device #	Heater Volts	Heater Power	Side Temp.	Face Temp.	Description
4					
Grid 1	5.3	4.41	763	739	Elcon decal, standard coating on 330 Nickel moly grid welded in new heater.
Grid 2	5.4	4.39	744	739	
Grid 4	5.7	4.91	790	779	
Average	5.47	4.57	766	752	
		4.52cor			
5					
Grid 1	4.8	3.91	734	709	Scandate sprayed on 330 Nickel,moly grid welded in.
Grid 2	5.0	4.33	746	720	
Grid 4	5.0	4.15	747	742	
Average	4.93	4.13	742	724	
		4.07cor			
7					
Grid 1	5.2	4.43	772	753	Standard sprayed on 330 Nickel, moly mesh brazed in.
Grid 2	5.1	4.33	765	734	
Grid 3	5.4	4.70	797	757	
Grid 4	5.30	4.46	800	738	
Average	5.25	4.48	784	746	
		4.48cor			
8					
Grid 1	5.0	4.26	778	755	Scandate sprayed on A31 Nickel.
Grid 2	4.90	4.06	757	749	
Grid 3	4.7	3.73	732	726	
Average	4.87	4.02	756	743	
		4.06cor			

9					
Grid 1	5.2	4.48	798	750	Sprayed standard cathode.
Grid 2	4.6	3.74	770	730	
Grid 3	4.0	4.06	795	742	
Grid 4	4.80	3.92	765	735	
Average	4.88	4.05	782	739	
		4.13cor			
11					
Grid 1	4.7	3.77	761	728	Scandate sprayed copper mesh.
Grid 2	4.7	3.82	760	727	
Grid 3	4.9	4.01	761	745	
Grid 4	4.8	3.86	755	740	
Average	4.78	3.87	759	735	
		3.96cor			
12					
Grid 1	5.9	5.21	837	810	Standard decals on chem etched 330 Nickel copper mesh.
Grid 2	5.8	5.37	860	840	
Average	5.85	5.29	850	821	
		5.50cor			
12					
Grid 4	5.2	4.48	790	763	Standard decals on mesa etched 330 Nickel.

TABLE 6.3

DIFFERENCE TABLE

	Device 4	Device 5	Device 7	Device 8	Device 9	Device 11	Device 12 Grids 1&2 plain etch	Device 12 Grid 4 mesa etch	
Device 4 Elcon Decal on 330 Ni	ΔV_H= $\Delta P_H/\Delta T_p$= ΔT_s= ΔT_f=	.54 .45/31° 24 28	.22 .04/3° -18 6	.60 .46/32° 10 9	.59 .59/41° -16 +13	.69 .56/39° 7. 17	-.38 -.98/-68° -84 -69	.27 .05/3° -24 -11	ΔV_H= heater voltage difference
Device 5 Scandate Sprayed on 330 Ni		ΔV_H= $\Delta P_H/\Delta T_p$= ΔT_s= ΔT_f=	-.32 -.41/-28° -42 -22	.06 .01/1° -14 -19	.05 -.06/-4° -40 -15	.15 .11/8° -17 -11	-.92 -1.43/-99° -108 -97	-.27 -.4/-28° -48 -39	ΔP_H= heater power difference
Device 7 Standard Sprayed on 330 Ni			ΔV_H= $\Delta P_H/\Delta T_p$= ΔT_s= ΔT_f=	.38 .42/29° 28 3	.37 .35/24° 2 9	.47 .52/36° 25 11	-.6 -1.02/-70° -66 -75	.05 .01/1° -6 -17	ΔT_p= Cathode temperature equivalent of heater power difference
Device 8 Scandate Sprayed on A31 Ni				ΔV_H= $\Delta P_H/\Delta T_p$= ΔT_s= ΔT_f=	-.01 -.07/-5° -26 4.0	.09 .1/7° -3 8	-.98 -1.44/-99° -94 -78	-.33 -.41/-28° -34 -20	ΔT_s= temperature difference on cathode side (bare Nickel)
Device 9 Standard Sprayed on 330 Ni					ΔV_H= $\Delta P_H/\Delta T_p$= ΔT_s= ΔT_f=	.10 .17/12° 23 4	-.97 -1.37/-95° -68 -82	-.32 -.34/-23° -8 -24	ΔT_f= temperature difference of cathode face measurement
Device 11 Scandate Sprayed on 330 Ni						ΔV_H= $\Delta P_H/\Delta T_p$= ΔT_s= ΔT_f=	-1.07 -1.54/-106° -91 -86	-.42 -.51/-35° -31 -28	
Device 12 Grids 1, 2 decals on etched 330 Ni							ΔV_H= $\Delta P_H/\Delta T_p$= ΔT_s= ΔT_f=	.65 1.03/71° 60 58	

TABLE 6.4 High Duty Test

Device 11, Grid 2 (copper grid)

Heater volts 5.4, cathode volts 400 grid bias -200, pulse width 50 micro-seconds, repetition 250 micro-seconds.

i_H Heater Current (amps)	i_k Cathode Current (ma)	i_g Pulse-off (ma)	i_g Pulse-on Grid Current (ma)	eg Grid Volts Pulse-on	Grid Power Interception (watts)	Tc Cathode Temperature (face)
.880	105	0	28	21.5	.151	802° CB
.882	150.5	.9	50	30	.375	803°
.882	200	3.9	82	39	.800	810°
.875	250	13.8	115	43	1.24	835°
.859	285	←	Cathode Thermal Runaway		→	930°

TABLE 6.5 High Duty Test

Device 9, Grid 1 (molybdenum grid)

Heater volts 5.4, cathode volts 400 grid bias -200, pulse width 50 micro-seconds, repetition 250 micro-seconds.

i_H Heater Current (amps)	i_k Cathode Current (ma)	i_g Pulse-off Grid Current (ma)	i_g Pulse-on Grid Current (ma)	eg Grid Volts Pulse-on	Grid Power Interception (watts) Average	Tc Cathode Temperature (face)
.879	95	.15	15	23.5	.088	764° CB
876	154	2.77	40	35	.35	768°
.873	195	12.7	70	46	.800	808°
←		Runaway at all Values Above This			→	

TABLE 6.6 High Repetition Rate Test

Device 11, Grid 2

Cathode Voltage 2950
Heater Voltage 5.4
Pulse Width 10 micro-seconds

i_H Heater Current (amps)	i_k Cathode Current (amps)	i_g Pulse-on Grid Current (amps)	Repetition Time (ms)	Duty Factor %	Cathode Face Temperature
.885	1.85	.385	15	.067	810° CB
.883	1.85	.420	10	.1	810°
.880	1.85	.430	8	.13	810°
.882	1.85	.460	5	.2	812°
.880	1.85	.480	2	.5	815°

TABLE 6.7 Long Pulse Width Performance

Device 9, Grid 1

Heater Voltage 5.4

i_k Cathode Current (Pulse Start) (amps)	i_g Grid Current (ma)	ΔE_k Cathode Voltage Slump	Pulse Width (micro-seconds)	Duty Factor % (ma)	Δi_k Intra-pulse Cathode Current Slump (ma)	Repetition Time (ms)
1.92	350	60	10	.1	0	10
1.85	400	100	20	.2	0	10
1.75	415	130	30	.3	20	10
1.85	340	140	30	.15	70	20
1.80	370	180	40	.2	60	20
1.75	400	200	50	.25	50	20
1.70	450	200	60	.3	50	20
1.68	420	250	70	.23	120	30
1.64	440	250	80	.27	140	30
1.60	495	280	100	.33	120	30

TABLE 6.6 High Repetition Rate Test

Device 11, Grid 2

Cathode Voltage 2950
Heater Voltage 5.4
Pulse Width 10 micro-seconds

i_H Heater Current (amps)	i_k Cathode Current (amps)	i_g Pulse-on Grid Current (amps)	Repetition Time (ms)	Duty Factor %	Cathode Face Temperature
.885	1.85	.385	15	.067	810° CB
.883	1.85	.420	10	.1	810°
.880	1.85	.430	8	.13	810°
.882	1.85	.460	5	.2	812°
.880	1.85	.480	2	.5	815°

TABLE 6.7 Long Pulse Width Performance

Device 9, Grid 1

Heater Voltage 5.4

i_k Cathode Current (Pulse Start) (amps)	i_g Grid Current (ma)	ΔE_k Cathode Voltage Slump	Pulse Width (micro-seconds)	Duty Factor % (ma)	Δi_k Intra-pulse Cathode Current Slump (ma)	Repetition Time (ms)
1.92	350	60	10	.1	0	10
1.85	400	100	20	.2	0	10
1.75	415	130	30	.3	20	10
1.85	340	140	30	.15	70	20
1.80	370	180	40	.2	60	20
1.75	400	200	50	.25	50	20
1.70	450	200	60	.3	50	20
1.68	420	250	70	.23	120	30
1.64	440	250	80	.27	140	30
1.60	495	280	100	.33	120	30

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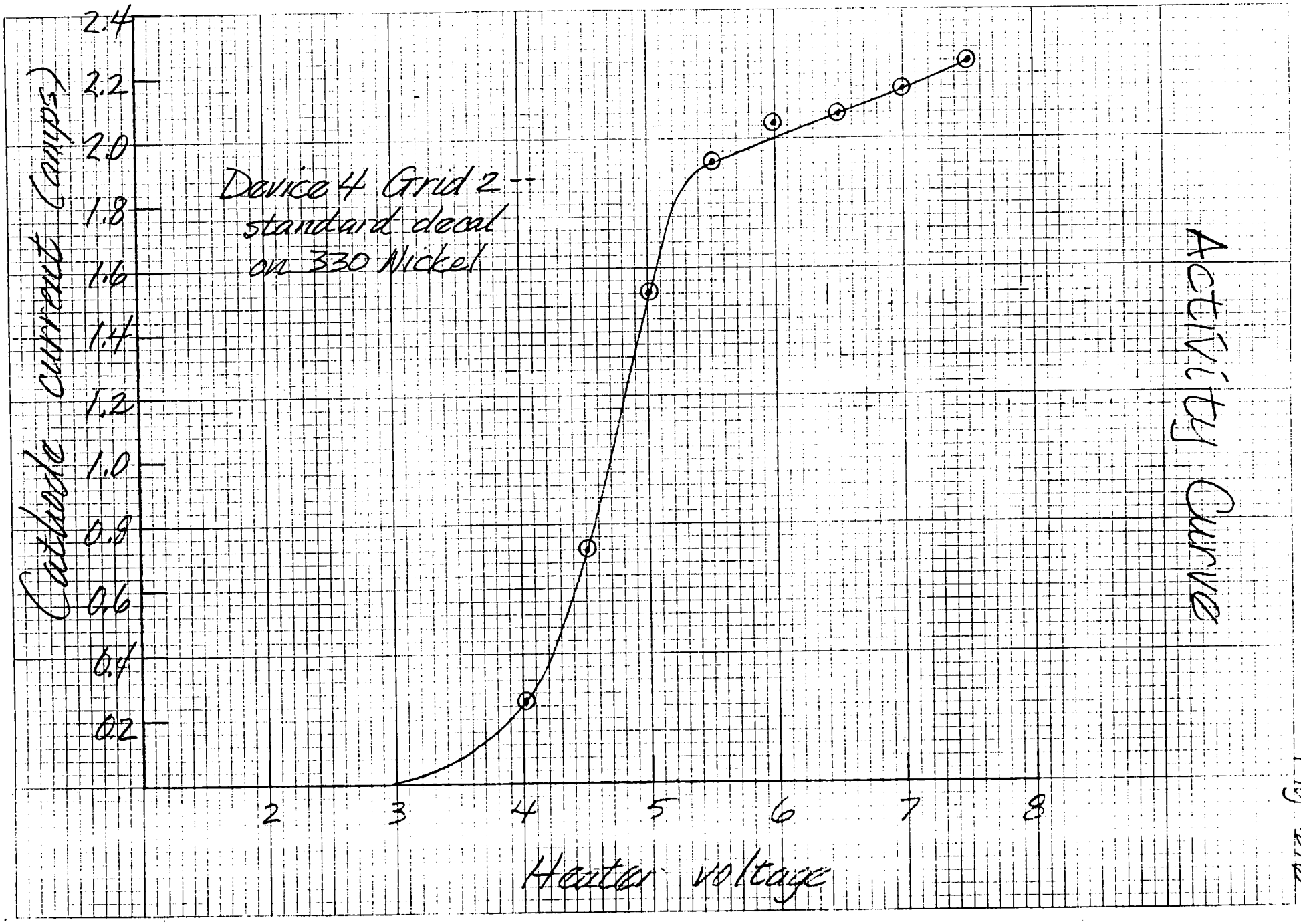

Fig 6.6

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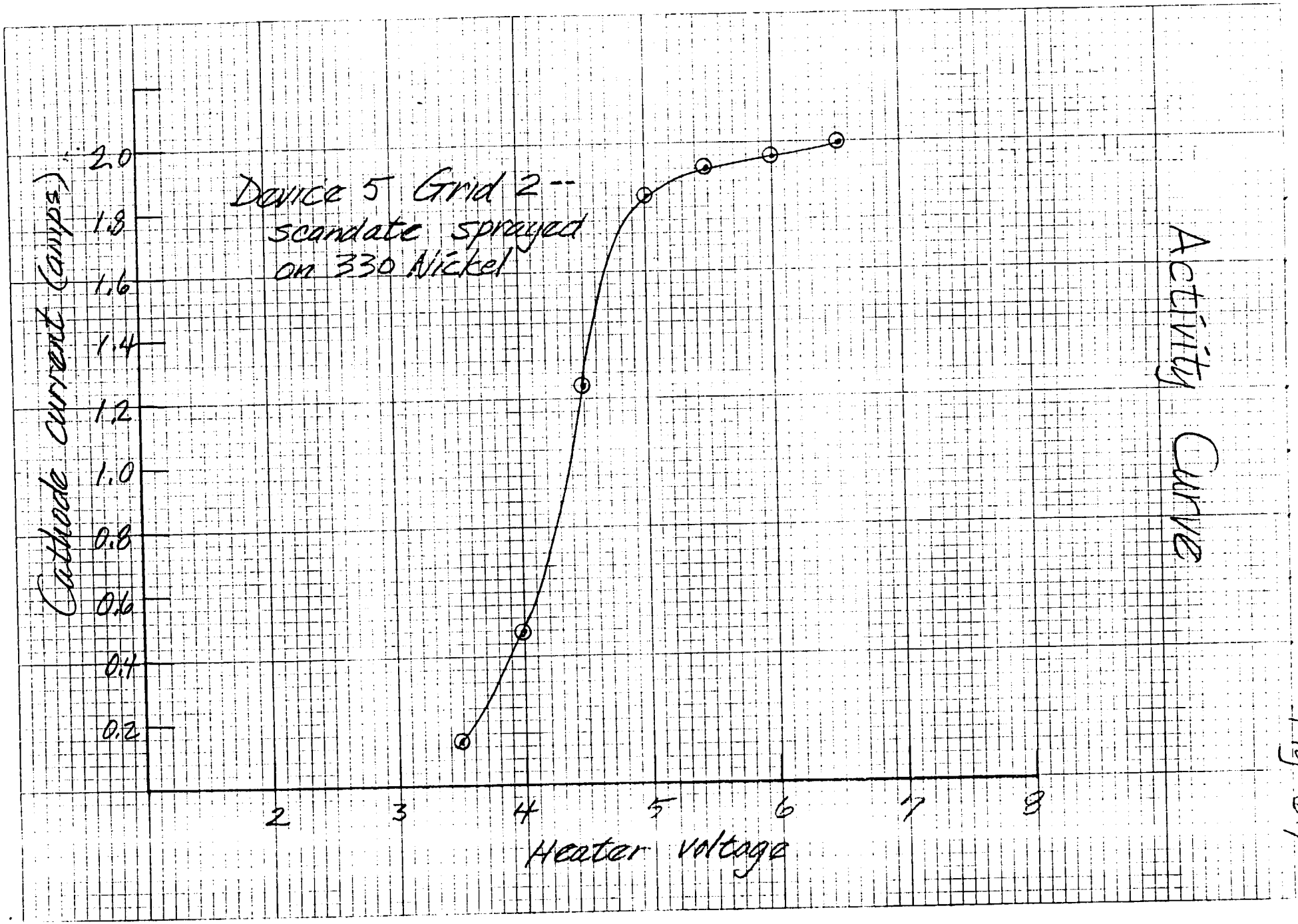

Activity Curve

Fig. 6.7

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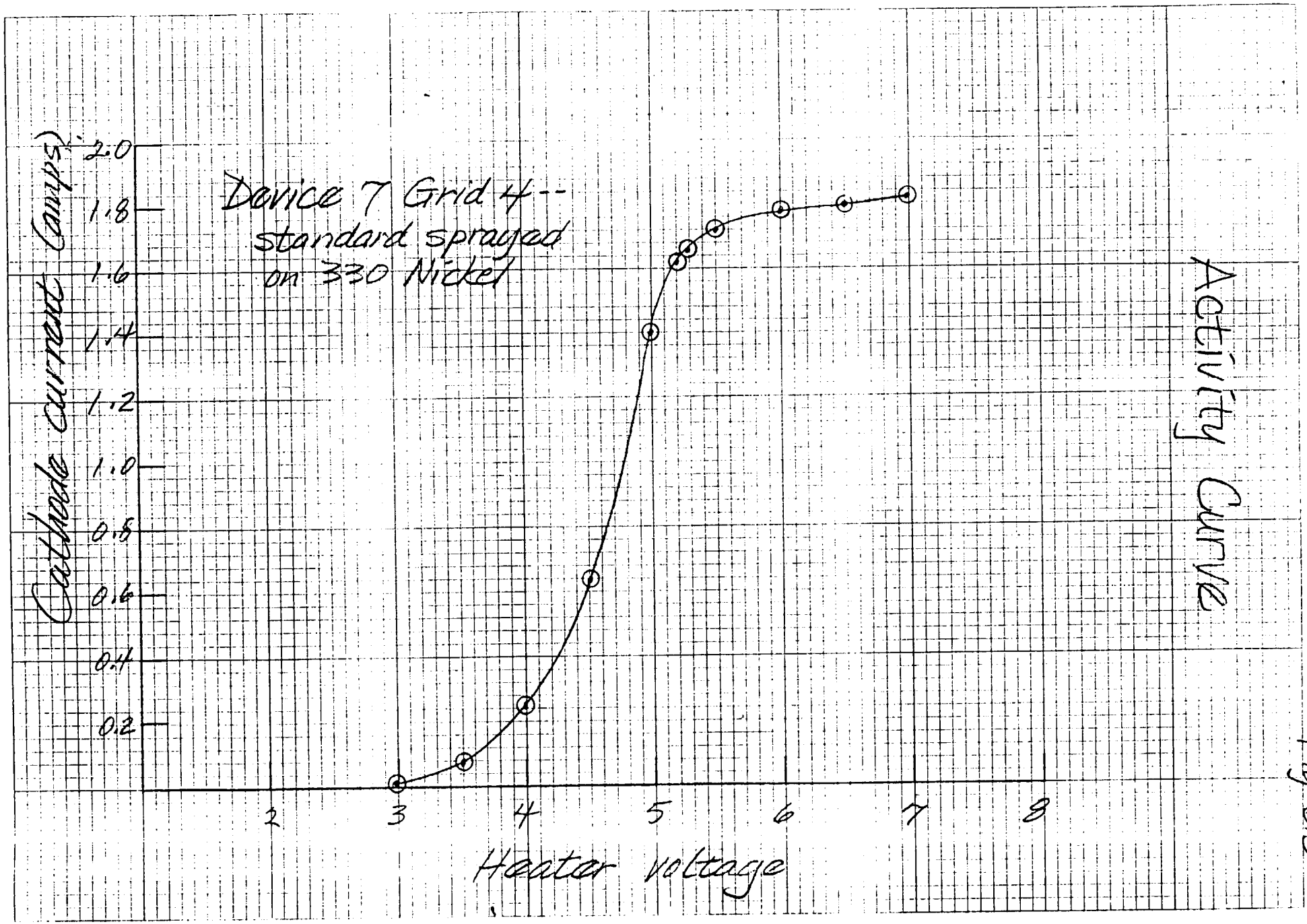

Activity Curve

Fig 6.8

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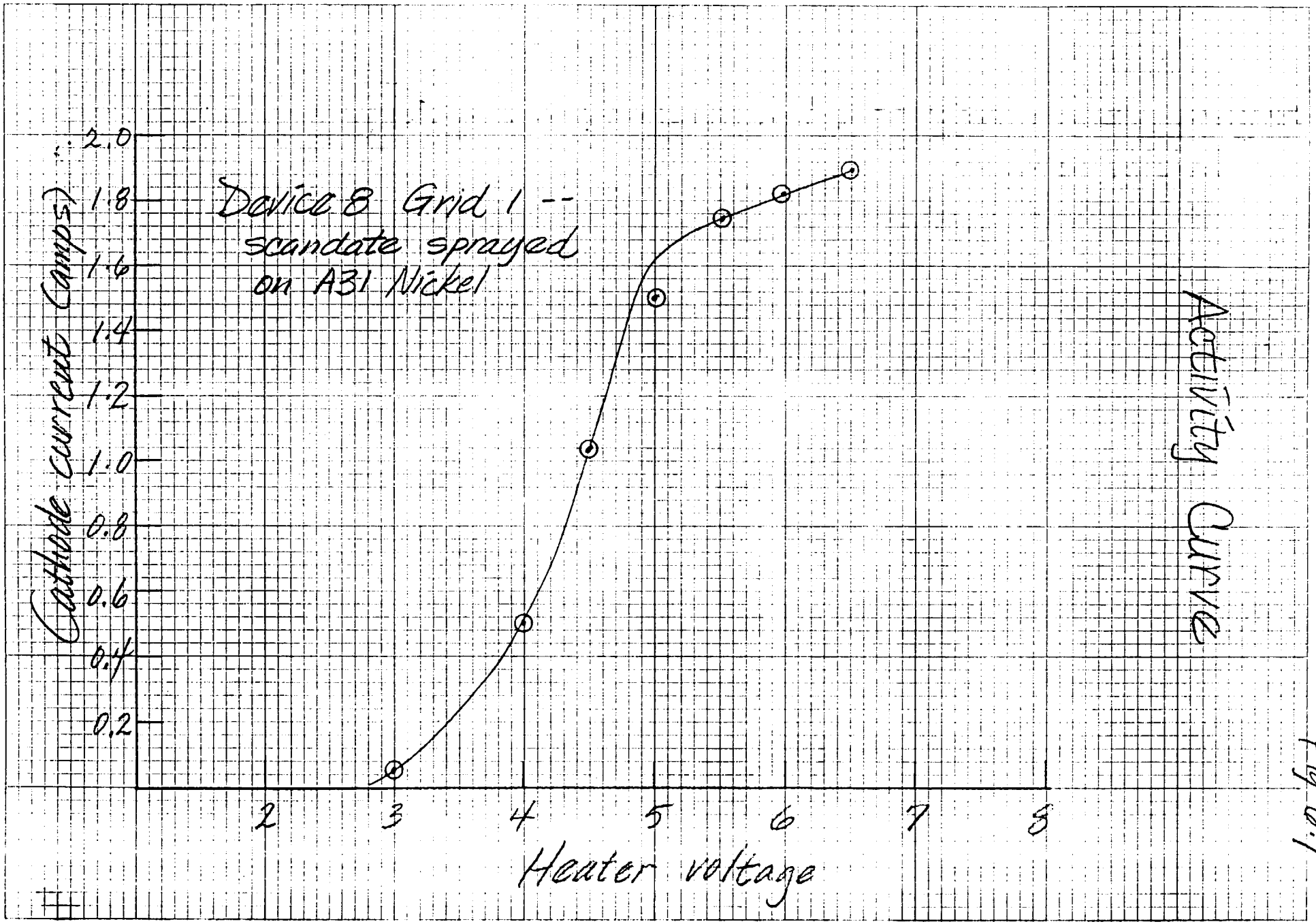

Activity Curve

Fig 6.9

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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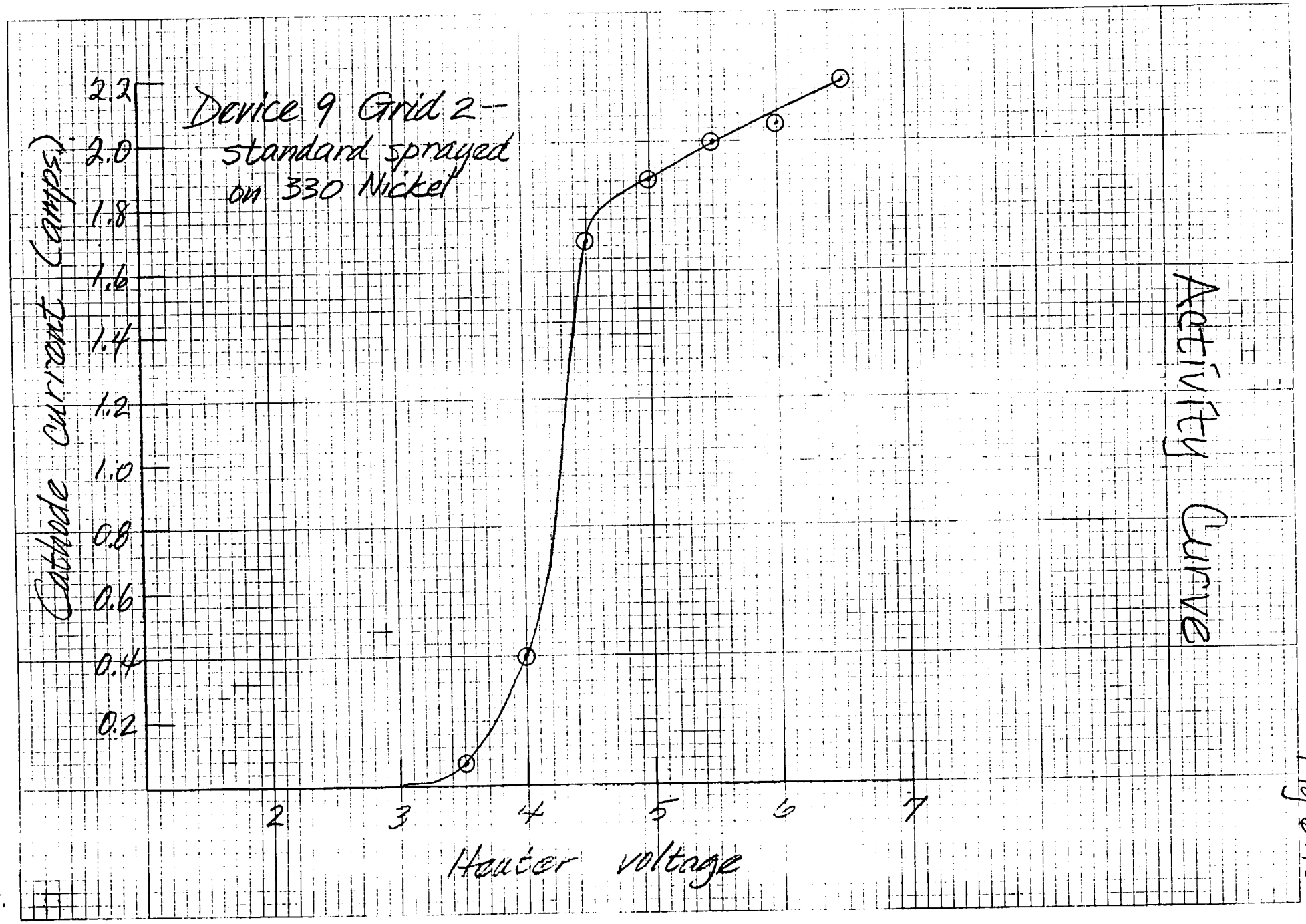

Activity Curve

Fig 6.10

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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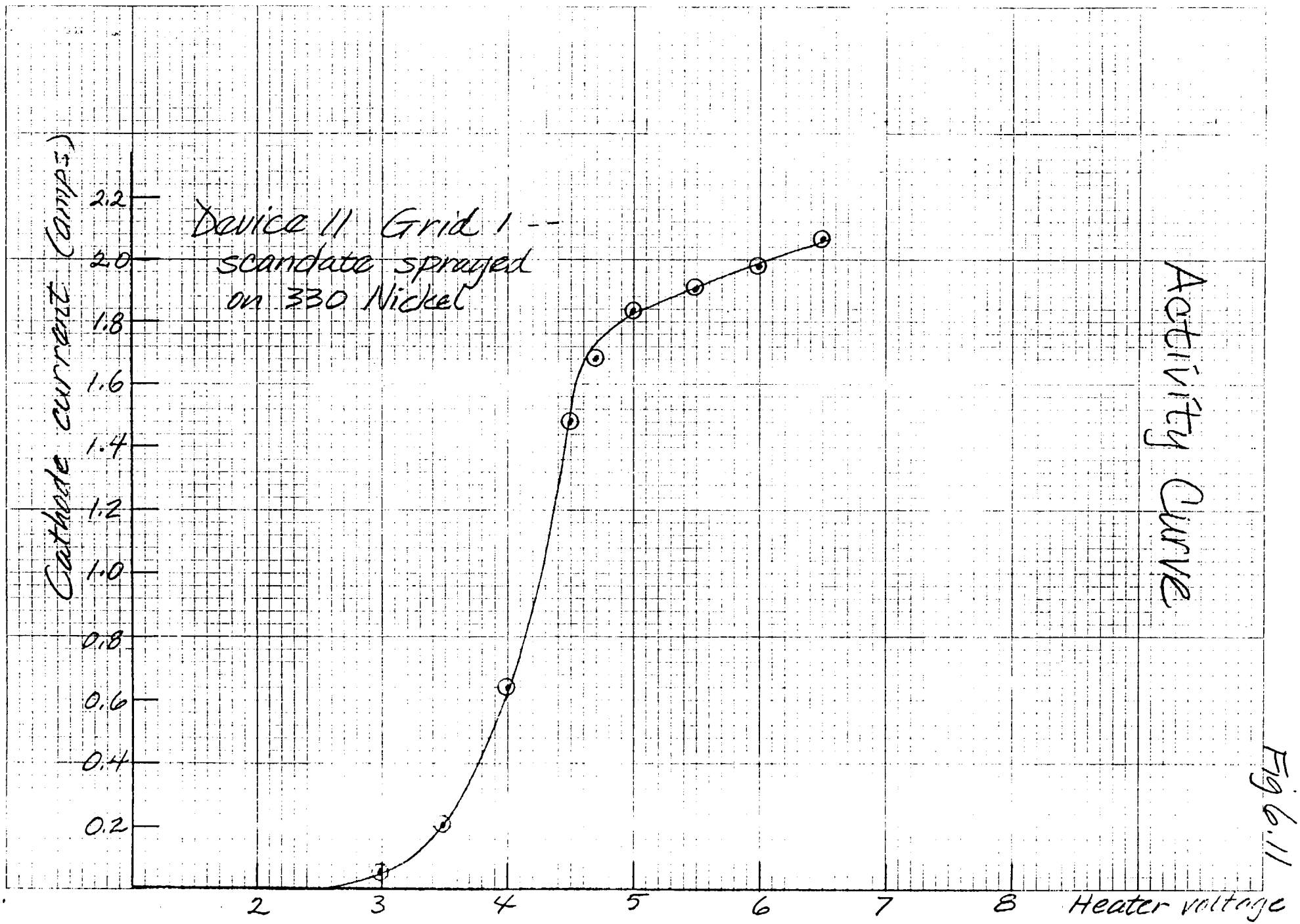

Activity Curve

Fig. 6.11

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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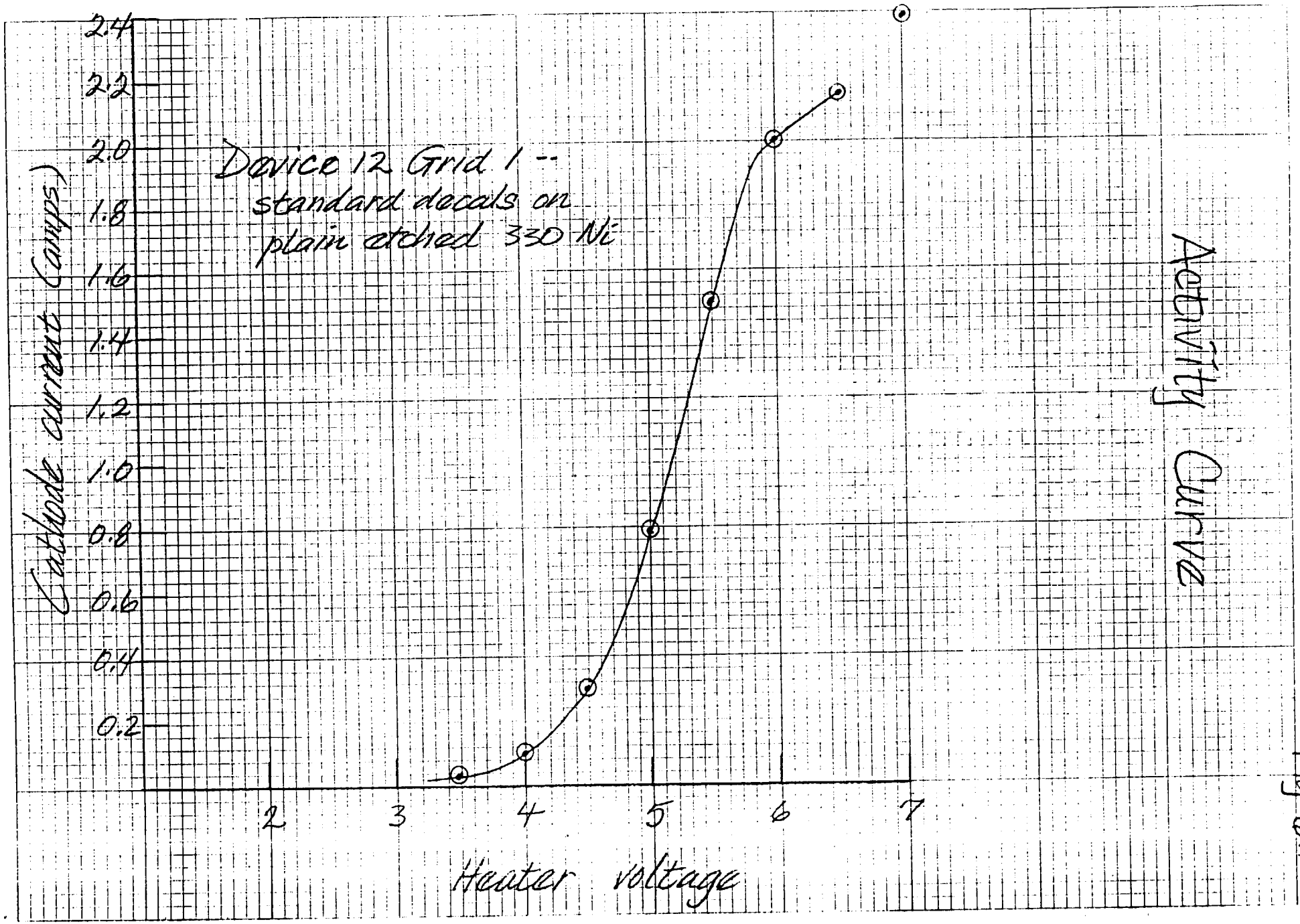

Fig 6.12

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
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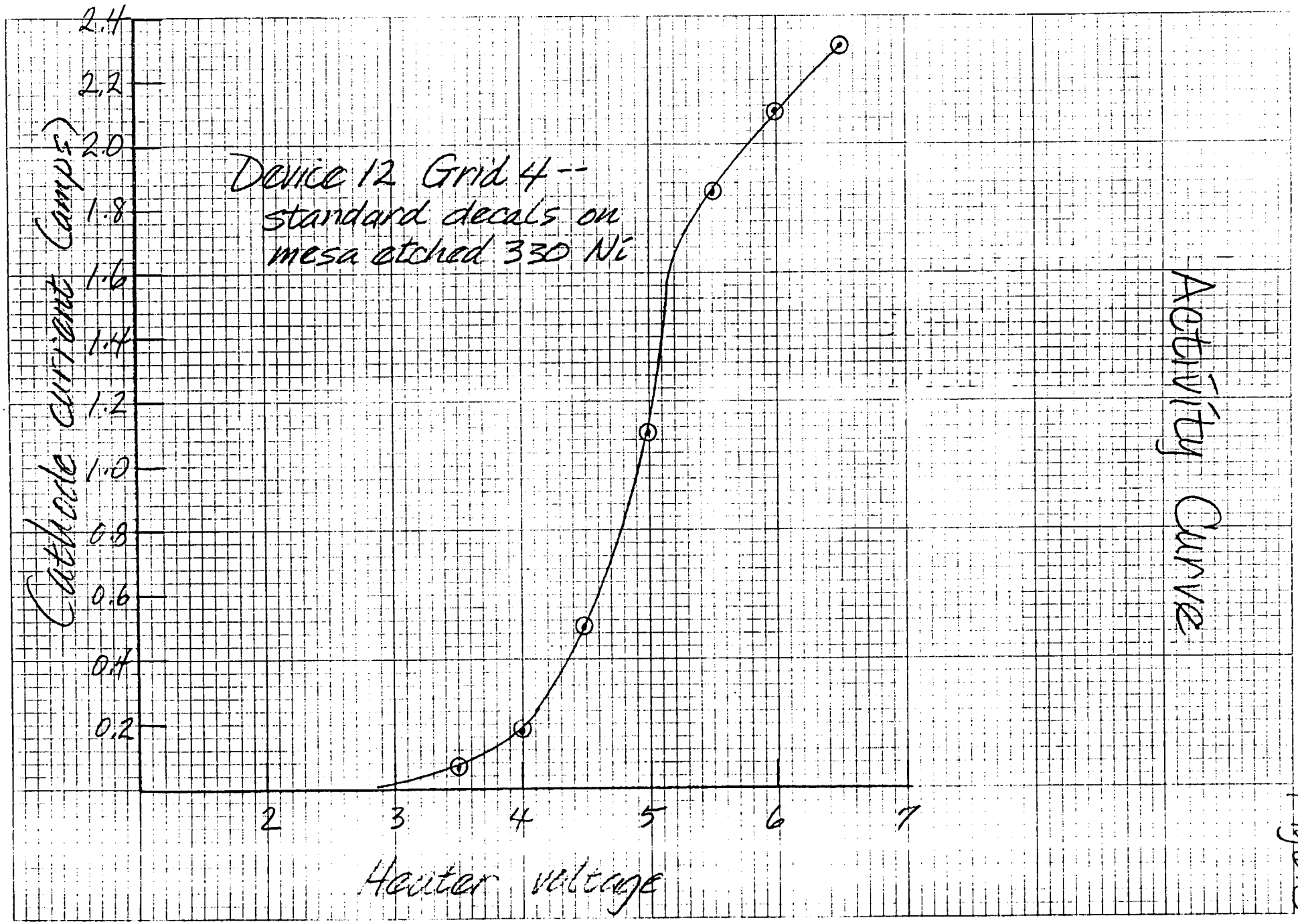

Activity Curve

Fig. 6.13

Grid Characteristics Fig 6.14

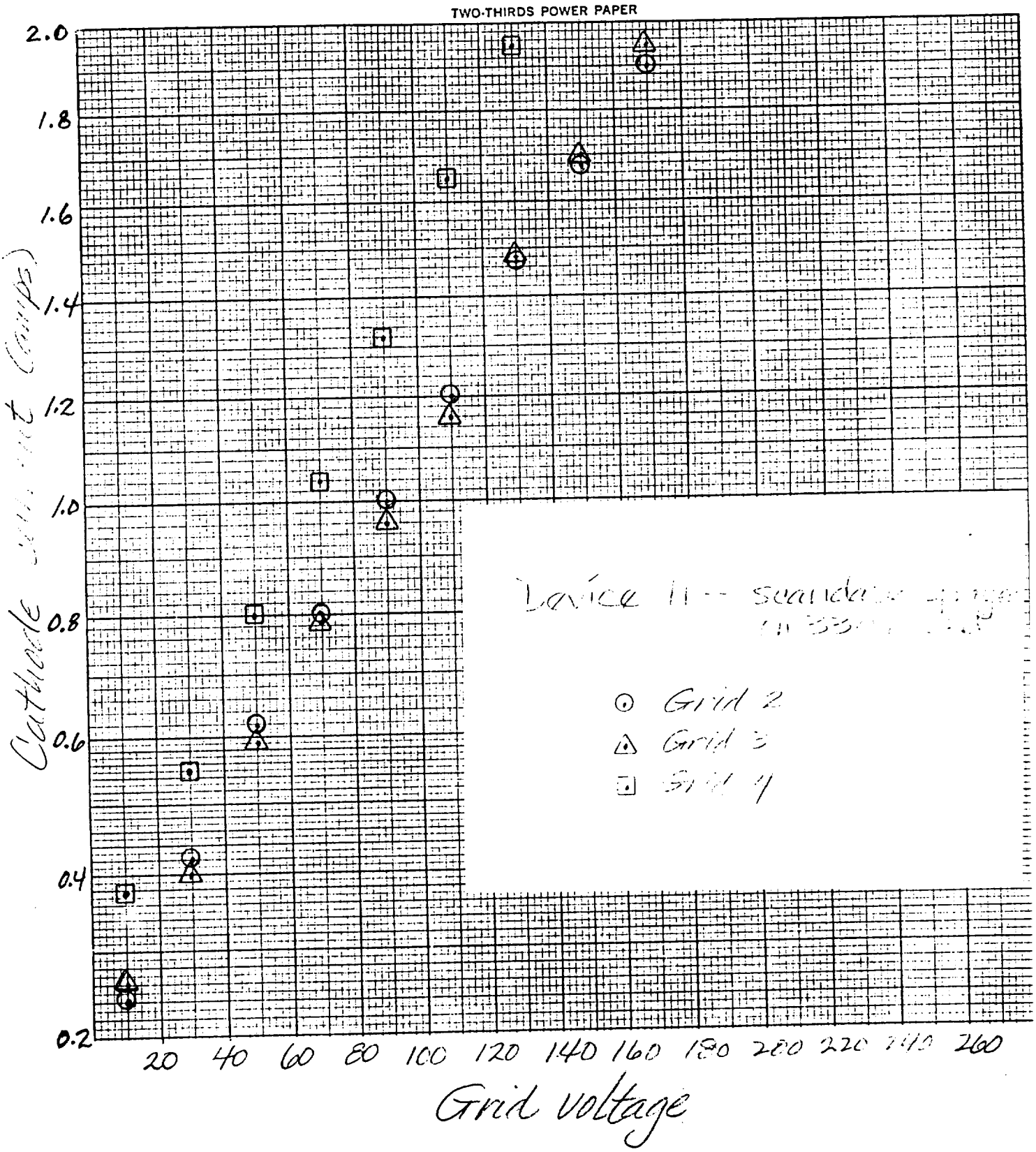

TABLE 6.2

Cathode Temperature Change/Heater Power Change.

Device No.	Temperature (degrees)/Watts
4	
Grid 1	66/watt
Grid 2	70/watt
Grid 4	62/watt
Average	66/watt
5	
Grid 1	78/watt
Grid 2	72/watt
Grid 4	46/watt
Average	65/watt
7	
Grid 1	66/watt
Grid 2	72/watt
Grid 3	66/watt
Grid 4	72/watt
Average	69/watt
8	
Grid 1	62/watt
Grid 2	80/watt
Grid 3	74/watt
Average	72/watt
9	
Grid 1	80/watt
Grid 2	68/watt
Grid 3	66/watt
Grid 4	84/watt
Average	75/watt
11	
Grid 1	82/watt
Grid 2	82/watt
Grid 3	70/watt
Grid 4	68/watt
Average	76/watt
12	
Grid 1	58/watt
Grid 2	56/watt
Average	57/watt
12	
Grid 4	70/watt

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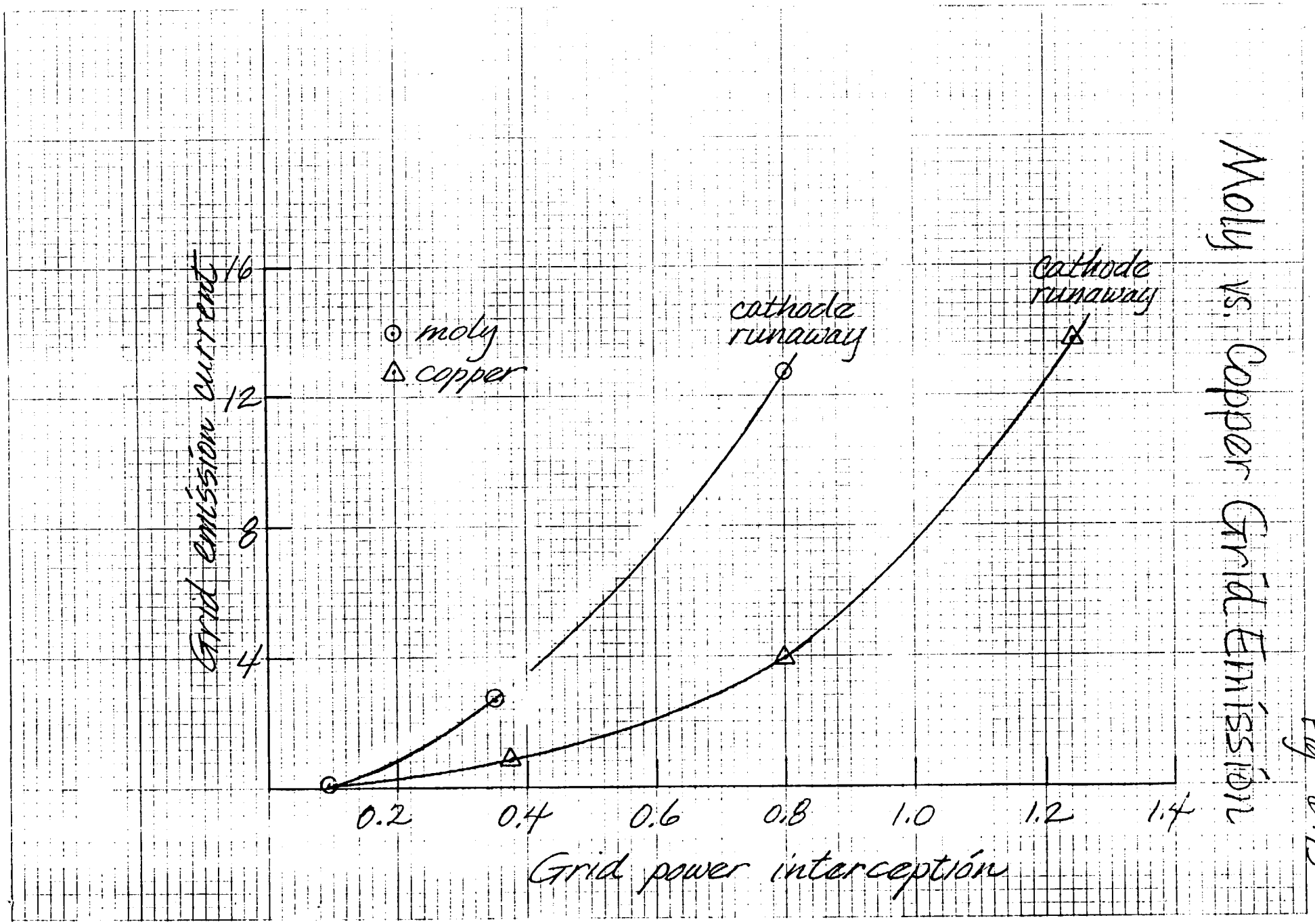

Moly vs. Copper Grid Emission

Fig. 6.15