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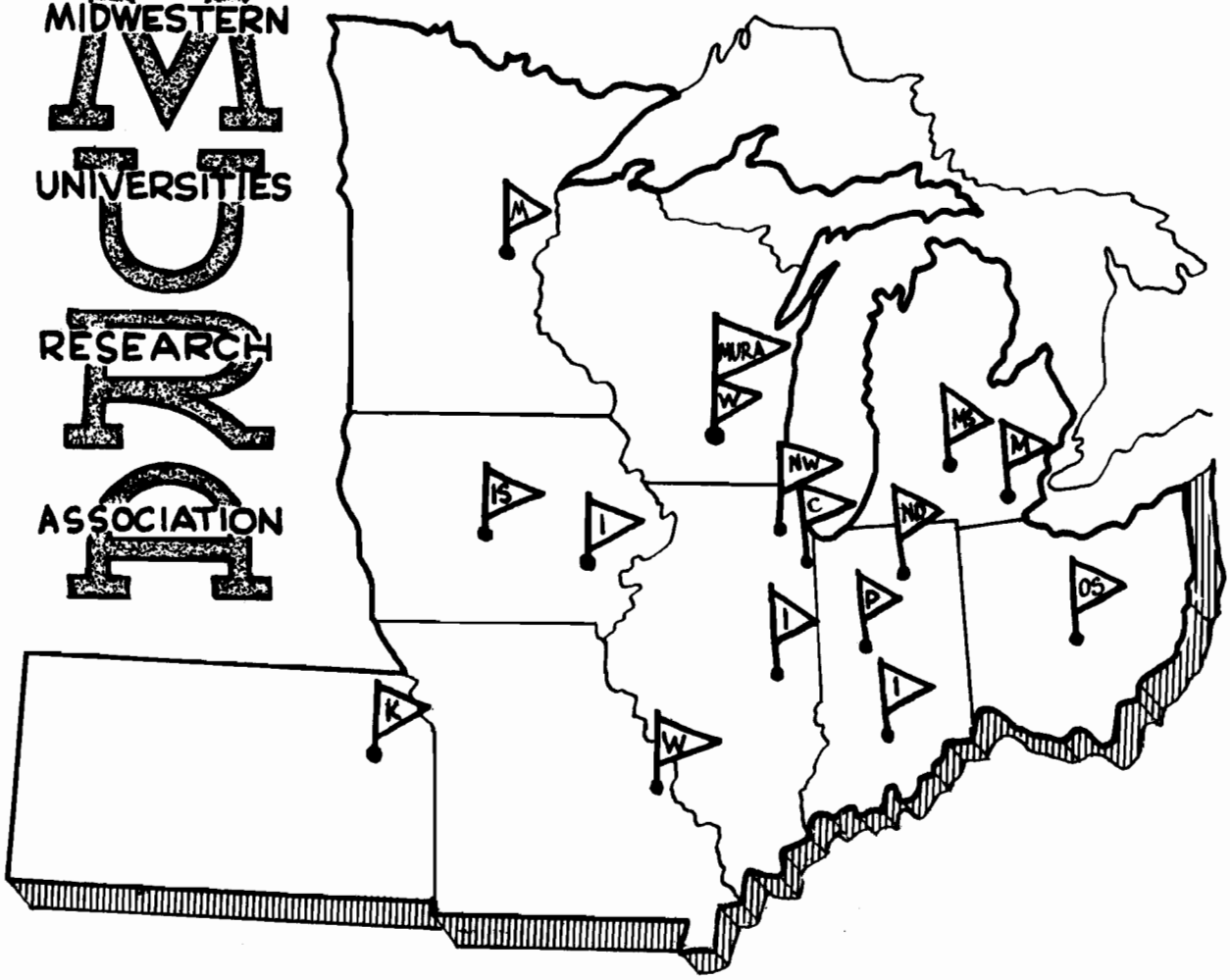

USE OF AN ELECTROLYTIC TANK

C. D. Curtis and R. E. Rothe

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A brief review of electrolytic tank principles is followed by a discussion of some specific applications. Emphasized are the techniques, sources of error, and reliability of measurements which existed in the design of electrodes for a Pierce-type electron gun.

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as those in the problem in question, there is an exact analogy between current or field lines in the tank and field lines in the problem.

Any equipotential surface, including an electrode in the problem to be solved, can be represented in the tank by a thin metal sheet electrode having the same shape. Any surface containing field lines can be represented in the tank by an insulator with a surface of the same shape. The reason for the latter is simply that current can have only a component parallel to the insulator surface. Therefore, the field perpendicular to this surface, or normal potential gradient, is zero. This fact is responsible for a great convenience in tank use. Planes of symmetry for field lines or planes perpendicular to potential surfaces can be represented by the water surface in the tank and by the plane tank bottom. A shallow layer of water in the tank and narrow strip electrodes consequently correspond to a similar slice through the problem electrode system. The complete problem is then represented if it is two-dimensional or has axial symmetry. The problem with axial symmetry uses a wedge-shape layer of water with the edge of the water (intersection of top and bottom planes) coinciding with the axis of the system. Alternatively, half the electrode system may be submerged in a layer of water with its axis and plane of symmetry lying at the water surface.

Magnetostatic problems where cuts are made to disallow multiple-valued potentials can be mocked up in a tank. For example, two magnetic poles of high μ material and with appreciable separation can be represented by constant potential electrodes of the same shape in a tank. The current lines are then magnetic field lines and equipotentials in the tank represent

magnetic equipotentials. If the gap separation of poles is made very small or if the permeability is low, the relative conductivity of electrolyte and electrode in the tank must be considered.

On the other hand, certain magnetic problems may be represented conveniently by insulator surfaces or current lines corresponding to equipotentials rather than to field lines. For example, the simple case of a long line current is given in a tank with a rod electrode perpendicular to the parallel plane surfaces of the water.

In practice, potentials are measured in a tank by use of an a.c. bridge circuit with an oscillator connected across a pair of electrodes, as shown in Fig. 1. The sliding contact Q on the precision potentiometer is

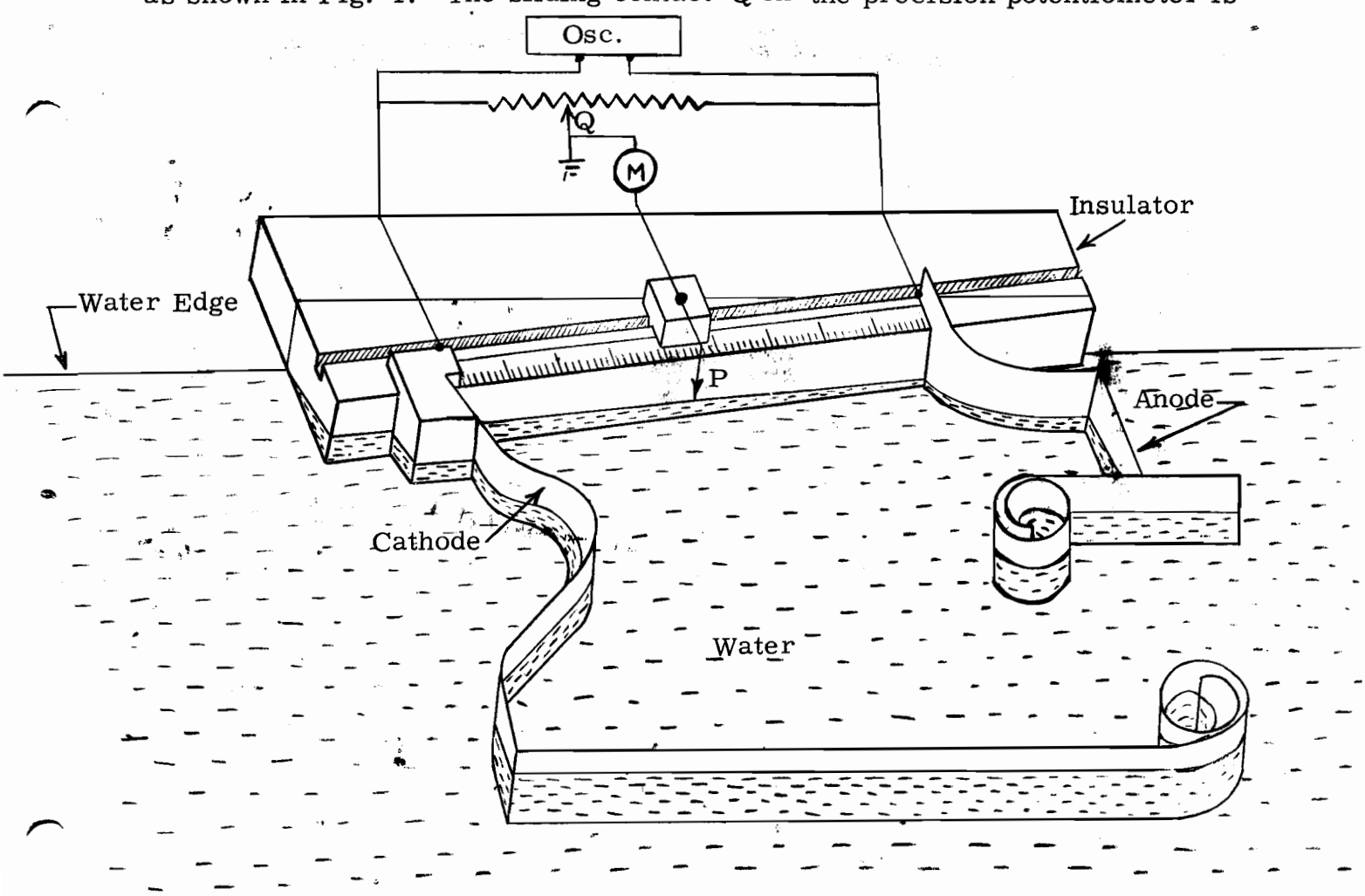

Figure 1
Tank Layout for Pierce Gun

adjusted so that the null detector M records zero voltage difference when the probe P is touching the water. Equipotential lines may be traced out by leaving Q fixed and moving P through the tank if the problem is one of mapping the equipotential and field lines. The frequency of the oscillator should be in the range of approximately 400-1000 cps to avoid polarization effects and to keep the effect on the null position due to undesirable reactances small. A variable capacitor, which can be switched from one arm of the bridge to another, may be desirable to cancel the effect of stray capacitances.

The electrolyte may be water with some convenient salt dissolved in it. Clear tap water, such as found in Madison, has enough mineral content to be suitable.

III. Specific Applications

A. Inflector Field. D. A. Swenson used the tank to determine the electric field pattern between parallel plates curved along 70° arcs of concentric circles. These plates bend 100 Kev electrons along a path with a radius of 12.5 cm. for injection into the 40 Mev two-way accelerator. In actual construction one curved plate was placed inside a metal box with a curved side acting as one plate. The shape of the interior plate was modified at the edges to reduce spreading of the field lines between the plates, as indicated in cross section in Fig. 2(a). Fig. 2(b) shows the corresponding arrangement used in a shallow tank with a glass bottom. Swenson scaled the tank electrodes up by a factor of four.

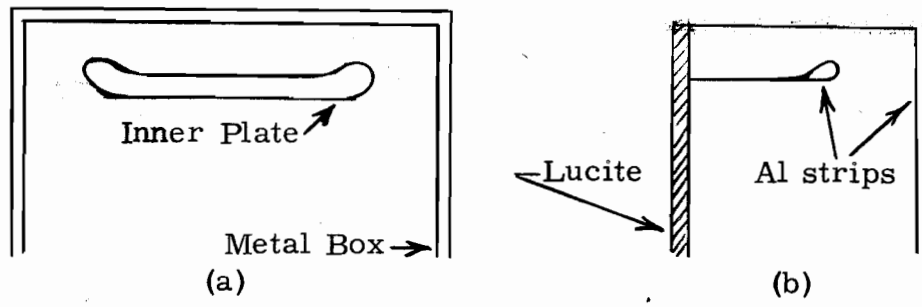

Figure 2.
Inflector Electrodes

B. Pierce Gun Electrodes. During the past summer J. N. Bradford used the tank to design a pair of electrodes for a Pierce-type[1] electron gun. While checking the potential distribution given by his design, the authors decided to alter the design as a result of certain practical considerations of overall gun construction. A discussion of techniques of measurement and of resulting experience follow.

In this gun, having a cathode with space charge limited emission, electrons follow converging radial lines in spherical geometry from cathode to an aperture in the anode. When the current flows in a beam of limited solid angle, space charge forces tend to spread the convergent beam. These forces are cancelled by giving the cathode and anode in the region outside the beam an appropriate shape, differing from spherical geometry. The solution of the potential distribution between cathode and anode which must hold within the current region was obtained accurately by Langmuir and Blodgett[2]. The potential varies radially only approximately as the four thirds power of the distance from the cathode emitter.

There are thus two boundary conditions to be satisfied along the edge of the electron beam, (a) the correct potential variation and (b) a field tangent only to the beam boundary to give radial convergent flow. The tangential field can be assured in the water tank by use of an insulator whose boundary coincides with the beam boundary as shown in Fig. 1. Because of axial symmetry, a thin wedge-shape layer of water whose edge coincides with the beam axis permits use of narrow electrode strips on only one side of the axis. With probe P at a known position, the slider Q can be adjusted to the correct potential for that position and then the electrode strips bent to give a null reading on the detector M. This process can then be repeated for several points distributed along the insulator edge until nulls are achieved at all points with the same electrode configuration. Once the electrodes reach an approximately correct shape, attachment of thin metal shims with clips serves as a convenient way to test the effect of small changes in shape.

One condition on the cathode dictated by the theory is that, adjacent to the emitter, that position of the cathode external to the beam must meet the beam surface, (or insulator strip in the tank) at an angle of 67.5°. The electrode shapes in Fig. 1 are approximately those which gave a measured potential distribution everywhere to within 5% of the required values. The somewhat peculiar configuration was the result of a restriction on the maximum diameter of the gun and of the desire to shield the beam from a ceramic wall around the gun. There are an infinite number of rather different electrode shapes which can approximately meet the required boundary conditions along the beam.

For measurements in the tank the gun system was scaled up for accuracy of measurement by a factor of four, making a nine inch separation of electrodes along the beam direction. The probe was a 7 mil tungsten wire attached to a block which slid alongside a distance scale attached to the lucite insulator and parallel to its edge (the beam edge). The a.c. source was a variable frequency Hewlett-Packard Generator Model 200CD with a 600 ohm output impedance. For a detector, vacuum tube voltmeters, Heathkit V7A and Hewlett-Packard 400D, were used with equivalent results but with much more sensitivity by the latter. The potentiometer slide wire was a 50 K, 10-turn Helipot.

Tap water was used as the electrolyte although at times various quantities of wetting agent were added. The angle of the water wedge was approximately 5°. Placed below the glass bottom tank (2.5 ft. x 2.5 ft. x 0.5 ft.) was a large graph paper sheet with mm. divisions for aid in alignment. The edge of the water wedge was aligned with the axis of the system scribed on the lucite. A sensitive technique for alignment was the observance of three flashlight filament images near the edge of the water when the flashlight was held several inches above the water edge and the images observed from that point. The three colinear images were the result of reflections from the glass surface, water edge and water surface. The water edge was aligned correctly when the interior spot was equidistant from the other two (usually a distance of $\approx$5 mm.) and immediately above a line on the graph paper colinear with the gun axis. Adjustments were made with leveling screws and change of water volume.

Straightening of the water edge was effectively accomplished by wiping the glass along the edge with a fine emery cloth.

IV. Sensitivity and Errors of the Method.

A. Variation with Generator Frequency.

Over most of the range of positions in the tank for the Pierce gun layout shown in Fig. 1, successive potential readings through repositioning of the probe differed by well under one percent when the detector nulls were sharp. This was true in general, however, only for short time lapses. At an individual position, the sharpest null could be obtained by tuning the generator, where the null-tuned frequency varied for different positions over the approximate range of 100-1400 c. p. s. for tap water and 200-2000 c. p. s. for tap water with considerable Alconox wetting agent added.

The sharpest nulls gave voltmeter readings of 1 mv when the voltage difference between the electrodes was 4 volts. For most nulls the readings were between 2 and 20 mv with a few of the order of 100 mv. Although a low null reading implies very little relative phase shift along two arms of the bridge, it does not follow that the potentiometer setting then necessarily gives the correct potential at the probe. For example, two frequency nulls at one probe position were observed for potentiometer settings which were 10-15% different. Such pairs of frequencies were 5 and 1800, 10 and 3000, 22 and 7000 c. p. s. with null readings of a few millivolts in all cases. It is observed, however, that the lowest frequencies are in a range not recommended because of polarization effects.

Another reason to question the accuracy of the potential measurement for a sharp null is a consideration of the stray impedances in the bridge circuit. The general circuit looks like Fig. 3 where all components in the four

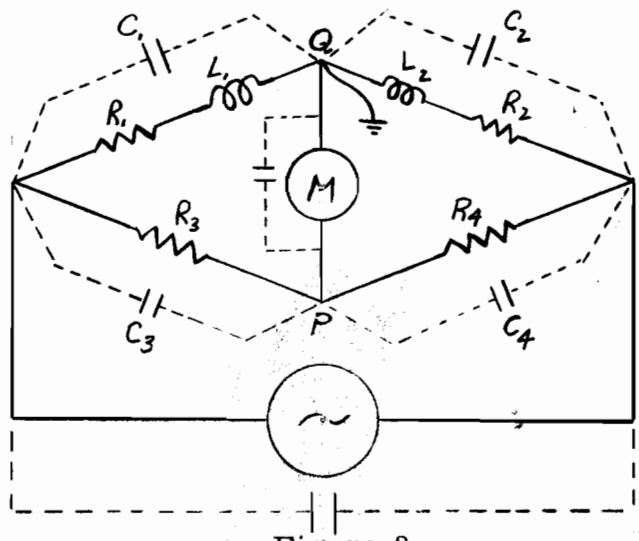

Figure 3
Bridge Schematic

bridge arms are at least partially variable with positions of P and Q. The small inductances, L_1 and L_2 are due to the winding of the helipot. From this standpoint noninductive, precision, variable resistances for R_1 and R_2 would be preferable. The balance equations for the bridge show multiple frequency solutions for the nulls. Three distinct frequencies for nulls were observed in a few instances. The balance equations also show that the potentiometer ratio R_1/R_2 will not in general equal the desired ratio R_3/R_4.

Because of the relatively small values of the reactive parts of the bridge impedances at low frequencies, the reading of the helipot is expected to be quite good as long as extremely low frequencies are avoided. The variation of the helipot setting to produce a null as a function of frequency on either side of the tuned frequency was examined. Table I gives some of these results. It can be seen that the variation between frequencies of 400 and 1000 c. p. s. is generally

TABLE 1
Helipot Reading Versus Frequency

Probe Position 1		2		3		4		5+	
f(c. p. s.)	R	f(c. p. s.)	R	f(c. p. s.)	R	f(c.p.s)	R	f(c.p.s.)	R
10	.0142	10.5	.0805	21	.124	77	.435	100	.801
50	.0103	105*	.0792	100	.131	770*	.450	500	.828
100	.0097	1050	.0785	210*	.1335	7700	.456	650*	.829
200	.0094	10500	.044	400	.134			1000	.833
400*	.0093			800	.1335			3000	.854
1000	.0090			2000	.129				
2000	.0083			4000	.115				
5000	.0060								

\+ Parallel plate geometry
* Frequency with sharpest null (tuned frequency)

less than one percent going up to 3% for the position with the lowest helipot settings. For the final series of measurements in the design of the Pierce gun electrodes it was decided to use a constant frequency of 400 c. p. s., which was a fair average of those frequencies giving sharpest nulls at all positions.

The bridge leads and electrodes were not shielded by use of coaxial cables or a shielded tank. There was some pickup at line frequency and its low harmonics which produced beats when the generator frequency was near 60, 120 or 180 c. p. s. A good ground eliminated any trouble at other frequencies.

B. Use of Wetting Agent.

Meniscus effects of the tap water were for the most part negligible in large scale layouts. Wetting agent is beneficial if added in small quantities and well mixed to give a uniform solution. Most variations between tap water and "wet" water runs could be explained by insufficient mixing or by the settling out of a deposit onto the glass bottom. The deposit from wet water occurring during periods of one hour or more would raise the potential readings by a few percent. Large quantities of wetting agent in solution with no settling out were observed to lower the potential readings by the order of 10% or more. This accompanied a marked drop in the resistance of the electrolyte between electrodes, which was for tap water $\sim$7000 ohms. Measurement of d. c. resistance with an ohmmeter was rather uncertain because of rapid polarization.

C. Parallel Plate Electrode Check.

Because of the presence of stray bridge reactances and variation of potential readings with electrolyte resistance, a test of the bridge circuit was made with the use of parallel plate electrodes, for which the potential varies linearly between the plates. Fringing fields in the tank were eliminated by use of insulators at the plate edges whose plane surfaces were perpendicular to the plates. The measured potentials agreed with the calculated values to within one percent except at points very close to the cathode plate. At a distance of 1/8 inch rapid variation of reading with frequency permitted an error of about 10%. No discrepancies resulted when small quantities of wetting agent were

present. There was the usual variation of potential reading with frequency, as indicated in Table I. The parallel plate check was not sensitive to a uniform deposit of sediment on the bottom of the tank because of the uniform potential gradient. The conclusion was that the bridge was suitable for use in other electrode systems with impedances not greatly different from those in the parallel plate system.

D. Reproducibility of Potentials.

Electrodes could be shaped for the Pierce gun so that the required potential distribution was met at all points to within an error of 5%. The reproducibility of the measured values for an electrode shape thus determined was checked under the following conditions: refillings of tank several times with tap water, removal and reinstallation of electrodes, addition of wetting agent, and recementing of insulator strip in position. Under controlled conditions of elapsed time for equilibrium, thorough mixing of solution, cleansing of tank bottom, and a constant generator frequency, the measurements repeated the required values to within an error of 5% at all points except those closer to the cathode than 0.4 in. (0.1 in in the full scale gun) where the discrepancy at times went to 20%. Table II gives an example of the range of values.

TABLE II

Dist. from Cathode in inches	0	.198	.398	.898	1.398	1.898	2.398	3.398	4.398	6.398
Calculated fractional potential	0	.0024	.0061	.0189	.0354	.0551	.0790	.1367	.2130	.436
Measured Potential		.0020	.0060	.0190	.0353	.0565	.0799	.1348	.2087	.444

Dist. from Cathode in inches	7.398	7.916	8.416	8.666	8.791	8.916	9
Calculated fractional potential	.602	.709	.831	.901	.937	.975	1
Measured Potential	.610	.715	.837	.903	.939	.981	

In general a period of several minutes following filling of the tank with water was required to reach an equilibrium value of the potential readings. The reason for this was not fully explained. The initial readings after filling were frequently high by a few percent and in the most extreme cases were high by as much as 30% at distances only of $\sim$ 0.4 in. from the cathode.

At points near the cathode accurate measurement of the potential relative to the cathode potential is difficult for two reasons. For one thing, errors in the reference scale reading corresponding to zero distance becomes relatively more important for small distances. An effort was made to keep this error less than 0.01 in. by visually observing the contact between the probe wire and the cathode and by correcting for the finite size of the wire in the water. Another factor, which in general tends to make the measured values near the cathode too low, is capillary action at the probe and the cathode surface.

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