

Searching for excess heat in Mizuno-type plasma electrolysis

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Abstract

Excess heat generated in the glow discharge plasma electrolysis, first reported by Mizuno and Ohmori (1), has been studied by several researchers, both in Japan (2, 3, 4) and in other countries (5, 6, 7, 8). Most reports, but not all, confirmed generation of excess heat. Facing this situation we decided to replicate the most recent experiment (8) in which excess heat was reported to increase with voltage. Our results do not confirm reality of excess heat.

Introduction

Suppose that a common immersion heater is inserted into a beaker with water. How should thermal energy released in the container depend on the amount of electric energy supplied? The answer is in the law of conservation energy. The amount of electric energy, E , supplied to the cell must be equal to the amount of thermal energy released, Q .

$$E = Q \tag{1}$$

But in the setup described in (8) the right side of the above equation was reported to be significantly larger than the electric energy on the left side. The authors believe that some hidden energy, presumably nuclear, is released during the plasma electrolysis. That is the essence of the excess energy claim. Another way of expressing the claim is to say that the coefficient of performance (COP), defined as Q/E , is larger than unity.

According to (8), the COP at 350 V is between 1.31 and 1.41.

In this experiment, where the electrolyte is always boiling, part of the heat energy produced goes into vaporizing water and the remainder is lost from the cell through conduction and radiation. To determine the heat output in this experiment we measure the amount of water evaporated, multiply by the heat of vaporization (2260 joules/gm) and then add on a correction to compensate for the non evaporative losses of heat. Expressing this in terms of power (i.e. the rate at which energy is delivered and released):

$$P_{\text{out}} = dm/dt * 2260 + P_{\text{loss}} \tag{2}$$

where P_{out} is the total heat power produced in the cell, dm/dt is the rate at which mass is lost by the cell due to vaporization, and P_{loss} is the heat power lost through conduction and radiation.

To determine P_{loss} , we conducted a series of tests in which the electrolyte was boiled with an ohmic heater at various power levels. Comparing the actual mass loss to the electrical energy input revealed that, as in (8), the heat loss through conduction, and radiation is reasonably constant and independent of the electrical input power P_{in} . That stands to reason because the cell is always operating at $\sim 100^\circ\text{C}$ and always has approximately the same level of electrolyte in it. As detailed below we observed a P_{loss} value of 94 ± 10 Ws from our cell.

The COP can also be expressed in terms of power as follows:

$$\text{COP} = P_{\text{out}}/P_{\text{in}} \quad (3)$$

where P_{in} is the electrical input power.

Experimental setup

As described in (9), this experiment was prompted by desire to either confirm or refute claims of excess heat reported in (8). That is why our setup was very similar to that used by Fauvarque et al. Approximately 725 cm^3 of the K_2CO_3 electrolyte (0.2 M) was placed into a polycarbonate vessel (inner diameter 32.0 cm, depth 11 cm). The initial setup, described in (9), had to be modified to match (8) as closely as possible. Instead of a spiral Pt anode, we used a cylinder made from the platinized niobium mesh.

A schematic of our setup is shown in Fig. 1. The height of that cylinder was 5 cm and its diameter was 6.3 cm. The anode was a 2.38 mm diameter tungsten welding electrode containing 2% of thorium. Both electrodes, and the steam-escape PVC pipe, were mounted on the lid of the main container. The entire setup was supported by a sensitive scale. The fresh water reservoir, also mounted on the lid, provided periodic refilling of the vessel. In our case, as described later, the refilling would not proceed as anticipated. A plastic baffle, near the steam exit, was used to shield the pipe from occasional splashes of the electrolyte foam and liquid. Some condensation is expected to occur on the inner surface of the escape pipe, mostly at the section where the temperature is the lowest. Drops of condensed water could occasionally be seen dripping into a collector.

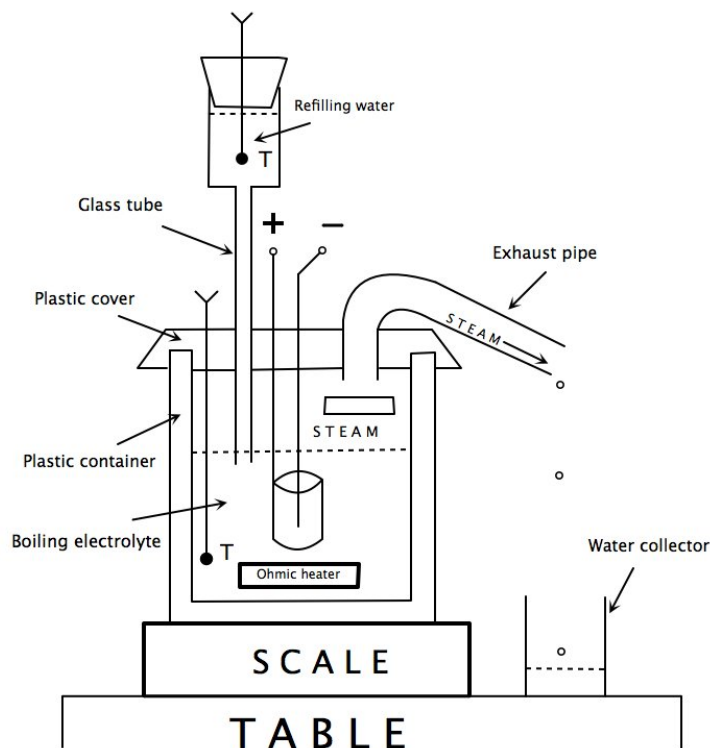


Figure 1. Schematic diagram of our setup

The intensity of splashing during the high voltage electrolysis, had a tendency to increase with the potential difference between the electrodes. Unless mechanically reduced, such splashing could possibly create an illusion of a voltage-dependent excess heat. The same kind of illusion could also occur if invisible droplets of foam, mixed with steam, were ejected. Ideally only water vapor (plus some hydrogen and oxygen) should escape from the boiling liquid. The photographs of the entire setup are shown in Figure 2 and 3. Potassium carbonate, used in common detergents, decreases the surface tension of water and causes foaming (10). Foaming interfered with constant replacements of evaporated water, used in (8). The head space in our well-closed cell contained almost nothing but hot water vapor mixed with foam. When bubbles would start up the refill tube so as to permit water from the reservoir to be displaced into the vessel, the bubbles would rapidly collapse and disappear completely upon entering the cooler water in the refill tube. However, when we turned off the power to the cell briefly cooler water vapor would successfully enter the reservoir and allow the refilling to occur. For that reason replacements of evaporated water (typically 30 grams) were performed manually before the tests. The electrolyte was then brought to the boiling point by using the ohmic heater. Masses of water evaporated in consecutive tests were electronically determined (once every second) from the readings of the scale. Flexible conductive filaments were used to connect electrical components mounted on the lid with outside circuits. This did not interfere with precise measurements of masses (better than 0.5%).

The ohmic heater was used to measure P_{loss} , and to preheat the electrolyte before plasma experiments. A computer-based data acquisition system was recording average electric currents, $i(t)$, average potential differences, $v(t)$, and the remaining mass $m(t)$ once every second. The

Clarke-Hess 2330 Power Analyzer measured power delivered to the cell by simultaneously sampling v and i at about 2000 Hz, multiplying the pairs of readings together, and averaging the results over several seconds. The data acquisition system interrogated the Clarke-Hess once per second to obtain the values for rms I , rms V , and power.

Clarke-Hess VAW meter (model 2330) is designed to measure power of arbitrary waveform from d.c to 400 kHz. Power is calculated from sampling volts and amperes about 2000 times per second (16 bit ADCs). Sampling is asynchronous (to stay away from the fundamental and harmonics of frequencies present in the waveform). The data acquisition program controls the run length and measures cell current, voltage, power, mass, temperature, and room temperature. The program also records the date and time, calculates total cell input energy, and plots all variables to a screen display. Measurements are written to a disk file unique to each run, which permits later playback and analysis. It also permits transfer of the data to a separate spreadsheet program. A Startorius model LC620S digital scale (resolution 0.01 gram) was connected to the data acquisition system. The electrical setup is shown in Appendix 1.

Ohmic heater results

The direct current power supply of our ohmic heater was similar to that used during the plasma electrolysis. Time dependencies of E and m , at constant electrical power, are shown in Figure 5.



Figure 2. The photo of the setup showing the foam above the electrolyte. The dark cushion below the vessel helped to prevent bouncing of the scale. The inner diameter of the white PVC pipe was ~2 cm

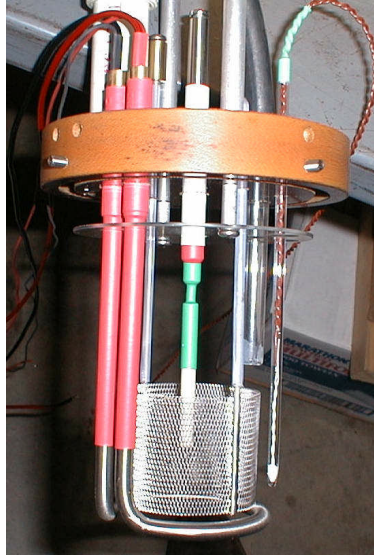


Figure 3. Electrodes and other components mounted on the lid. The ring below the anode is the ohmic heater, the vertical glass tube on the right contains the thermistor. The transparent anti-splashing baffle can be seen below the lid. The side screws were used to mount the lid rigidly on our polycarbonate cell (note the deep groove on the lower surface of the lid). The tip of the tungsten cathode is shown in Figure 4 below.

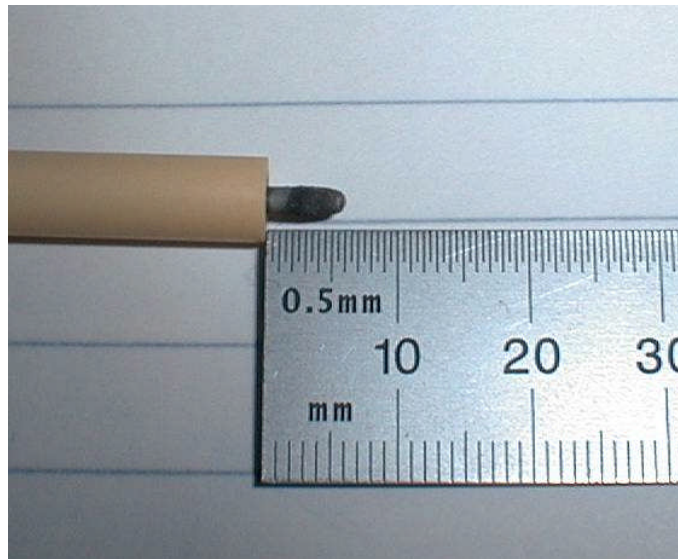


Figure 4. Appearance of the cathode, originally extending 13 mm beyond the ceramic sheath, after a 350 V plasma test (see below) lasting 3 minutes. Typical current densities were in the range from about 3 to 10 A/cm²

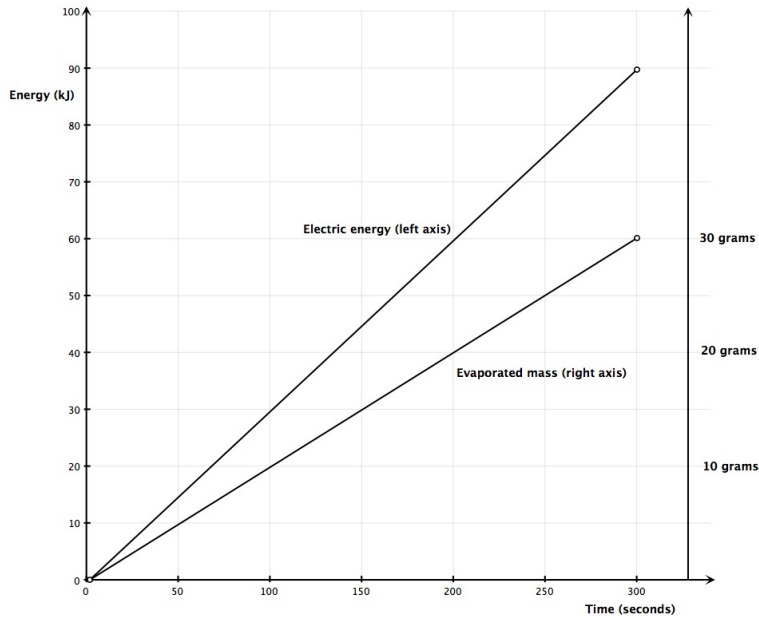


Figure 5. Time dependence of the energy received ($P_{in} \cdot t$) and of the evaporated mass, $m(t)$, at $P=300$ W using the ohmic heater.

The rate of evaporation, dm/dt , was also constant, as shown. The values of P_{in} , P_{out} and P_{loss} , extracted from this figure are shown in the line 4 of Table 1.

Table 1 (Ohmic heater results)

P_{in}	P_{out}	P_{loss}	$P_{out}+P_{loss}$	COP*
201	107.3	93.7	201.7	1.00
230	131.9	98.1	226.3	0.98
262	184.9	77.1	279.3	1.07
300	208.1	91.9	302.5	1.01
364	280.2	83.8	374.6	1.03
479	377.1	101.9	471.5	0.98
486	380.5	105.5	474.9	0.98
565	461.6	103.4	556.0	0.98

* The last column shows what the COPs would be if they were calculated by using the mean value of P_{loss} , 94.4 W, instead of numbers from column 3.

This table summarizes results of eight measurements; powers in lines 1 to 3 and 5 to 8 were calculated from the time dependencies similar to those in Figure 5. Note that the third column displays differences between the numbers in column one and two. These are values of non evaporative powers, P_{loss} . As in (8), we found that the values of P_{loss} , are essentially identical for all P_{in} . This is illustrated in Figure 6. The mean value and standard deviation of P_{loss} turned out to be 94.4 W and 9.9 W, respectively. The last column shows that the COP fluctuations match

experimental uncertainties in the third column. Note that the variations in COP using the ohmic heater are essentially the same as they are with the plasma going (last column in Table 2 below).

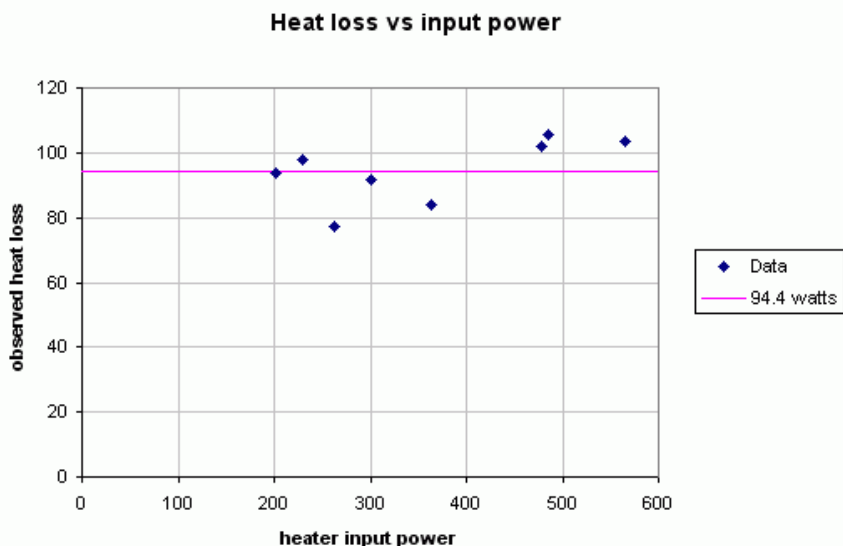


Figure 6. Dependence of P_{loss} (conduction and radiation) on the electric power, P_{in}

In performing these experiments we discovered that the potassium carbonate electrolyte tends to create foam above the boiling surface. This is illustrated in Figure 2. At first we thought that the foam was due to chemical interactions between the electrolyte and cell materials (walls, partially coated electrodes, the lid or the PVC pipe). But foaming was also observed when the electrolyte was boiled in a clean pyrex beaker. Foaming seemed to be less intense during high voltage electrolysis. Occasional accumulation of the foam resulted in its sudden ejections. Fortunately, a setup in which all measurements are recorded once a second can identify ejections as sudden mass changes. After discovering non evaporative ejections we watched the foam and stopped the runs when foaming became excessive. In that way non evaporative losses of mass were totally eliminated.

High voltage electrolysis results

Curiously, the foaming seems to be worse during ohmic heating than during plasma operation. It seems that the shocks of the plasma action are breaking the bubbles faster. Table 2 is the summary of experimental plasma electrolysis results. The most important numbers are in the last column; they are the values of COP calculated according to the formula (5). The mean COP, and the standard deviation, turned out to be 1.00 and 0.02, respectively. The table shows that the value of the electric power, P , is not predetermined exactly by the applied voltage. This is probably caused by progressive decomposition of the cathode and by chemical changes taking place during consecutive tests.

TABLE 2. Voltage, Power and COP

Volts	Power (electric)	Pv (evapor)	Pc	Pe+Pc	COP
250	249.0	155.5	94.4	249.9	1.00
250	338.0	240.8	94.4	335.2	0.99
300	626.4	512.6	94.4	607.0	0.97
300	521.0	424.4	94.4	518.8	1.00
300	563.0	466.4	94.4	560.8	1.00
325	718.8	640.3	94.4	734.7	1.02
350	998.2	934.8	94.4	1029.2	1.03
350	859.7	748.0	94.4	842.4	0.98
350	331.2	246.9	94.4	341.3	1.03
400	323.9	243.5	94.4	334.0	1.03

The last two lines in Table 2 refer to experiments in which the concentration of the electrolyte was reduced drastically (from 0.2M to 0.02M). This reduced the foaming and sloshing inside the cell significantly, most likely due to the unusually low electric current (low P). The cathode, however, still achieved a bright incandescent temperature. Thus, even at 400 V, the COP was still very close to unity. Time dependencies of P_{in} and P_{out} associated with two lines of the table are shown in Figure 7. As in Figure 5, one can see that the evaporated mass increases linearly with time, according to the value of P_{in} . The values of P_{out} , during plasma electrolysis, are not as constant, as it was when the 360 W ohmic heater was used. At point B that heater was turned off manually and the potential difference of 300 V was applied to electrodes. The power level jumped to nearly 600 W and the rate of evaporation increased accordingly. The voltage $v(t)$ remained constant but the power drifted slowly toward nearly 500 W. Rapid fluctuations of electric power (plus or minus 5%) were due to fluctuations of electric current, $i(t)$. At point C the voltage was increased to 325 V and the power level jumped to nearly 700 W. The rate of evaporation increased accordingly. The direction of the power drift changed and the intensity of rapid fluctuations increased (to about 12%).

The data collection was stopped manually at point D because of intensive foaming. The trend toward more rapid drift and stronger fluctuations of $P_{in}(t)$ continued when potential differences were increased to 350 and 400 V. This was associated with intense arc-like explosions inside the vessel. Obtaining reproducible data became more and more difficult above 350 V. Excessive arcing was unpredictable but short time intervals without excessive arcing at higher voltages -- our rare "windows of opportunity" -- were sometimes available to make measurements. No evidence of excess heat at higher voltages (up to 400 V) emerged from these quick explorations.

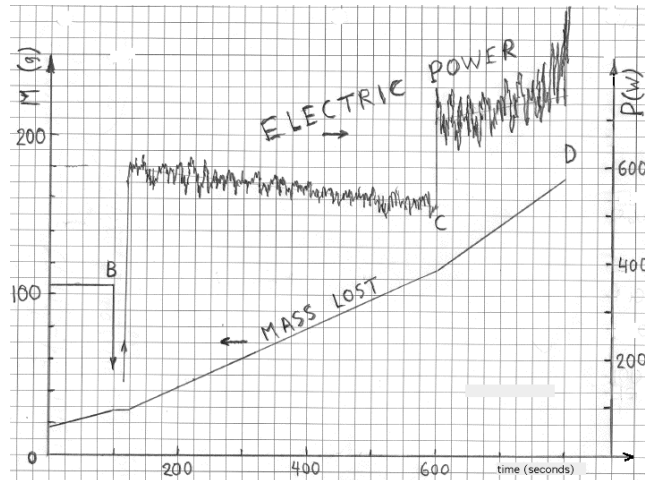


Figure 7. Time dependence of the electric energy received and of the mass of evaporated water at 300 V (between B and C) and 325 V (between C and D) during plasma electrolysis. Note that the values of $P_{in}(t)$, at constant voltages, were not as stable as when the ohmic heater was used to sustain boiling.

Discussion

Our experiments show no sign of the large excess power reported in (1,2,3,4,5,7, and 8). But they confirm findings reported in (6). It is remarkable that the COP at 200 V and 250 V, reported in (8), are very close to ours. Discrepancies, however, become progressively larger at higher voltages. Splashing of the electrolyte also becomes more significant at higher voltages. This suggests that unnoticeable losses of the electrolyte, from an open vessel used in (8), might be responsible for differences between the two set of results. Other discrepancies are worth mentioning. According to (5), the excess energy can be much larger than in (8), even below 200 V. The COP of the cold fusion reactor of Naudin (CFR1.1), for example, was reported as 1.85 at 150 V and about 2.5 A. The electrolyte used in CFR was exactly the same as in (8). Let us also mention that the COP values between 1.2 and 1.4 were recently reported in (7). The corresponding voltages, however, were not specified. The issue of foaming, most likely associated with formation of CO₂ at boiling temperature, (11) was, unfortunately, not addressed in (5), (7) and (8).

The challenge presented by ejection of liquid water is indeed very serious because the latent heat of evaporation is large. Mist ejection, at the rate of 50 milligrams per second, results in the overestimation of P_{out} by $2260 \cdot 0.05 = 113$ W. This, however, is only one possible explanation of discrepancies. Another might be associated with micro-explosions we occasionally observed during plasma electrolysis, especially at higher voltages (see Appendix 3). Such explosions are accompanied by loud popping noise and very intensive arcing. We suspect that escaping hydrogen and oxygen occasionally combine under the influence of arcing. That could be a possible non-nuclear source of excess heat reported by several researchers.

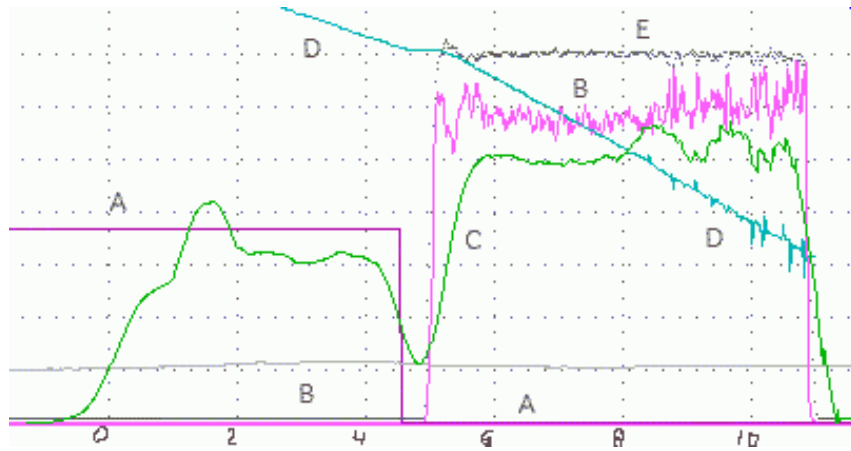


Figure 8. Time dependencies of several parameters: A. ohmic heater power; B. P_{in} ; C. P_{out} ; D. Mass of cell; E. applied voltage.

Figure 8 shows time dependencies of several parameters. Trace A is the ohmic heater power, initially 360 W and then zero. Trace B is the P_{in} , the electric power during plasma electrolysis. It was initially zero and then fluctuated near 700 W, more or less as in Figure 8. Trace C, shows the values of P_{out} . Unlike other traces on this figure, each data point along the C is the average power from many instant powers (30 seconds on the left and 30 seconds on the right). That explains why oscillations along the trace C are relatively slow. Note that the boiling temperature was reached shortly before $t = 0$. Trace D is mass of the cell measured with the weight scale. It gradually decreases as the water is boiled away. It can be used to calculate instant the rate of evaporation. Trace E shows that the applied voltage, 350 V, remained essentially constant.

Anticipating a possibility of hydrogen burning our tests were manually interrupted as soon as arcing became extensive. Fortunately, prolong arcing is accompanied by thermal instabilities (large fluctuations in P_{out}) that can be recognized when data are analyzed after experiments. This is illustrated in Figure 6. It shows that P_{out} was stable between $t=6s$ and $t=8s$. After that it became unstable, due to arcing. Micro-explosions can also be identified by oscillations along the mass trace, D. They are caused by dynamic effects on the scale during micro-explosions. In this case data at $t > 8s$ were ignored. Another description of the experimental setup can be found in (12)

APPENDIX 1: Measuring electric energy

Electric energy delivered to a cell, is the integral (over a test duration) of $i(t) \cdot v(t) \cdot dt$. The instrument we used, Clarke-Hess model 2330 power analyzer, sampled the $v(t)$ and $i(t)$ about 2000 times per second. As expected, the voltage between the cell electrodes, $v(t)$, was essentially constant but the current $i(t)$ was highly irregular. Digitized samples of $v(t)$ and $i(t)$ were recorded by the computer and the cumulative input energy was displayed during the data acquisition, as shown in Figure 2. A highly irregular nature of the $i(t)$ waveform guarantees random sampling and the average energy, over a time longer than several seconds, is highly reliable. To verify this we also used an a.c. watt meter at the input of our d.c. power supply. The a.c. energy measured with that instrument was only slightly larger than the d.c. energy. The difference, was consistent with what is necessary to operate the power supply when it is not loaded. The Clarke-Hess meter adjusts the sampling frequency to avoid beats with the current and voltage signals.

APPENDIX 2: Steam Condensation

Is it possible that condensation of steam inside the cell, for example on the inner walls and on the lid, is responsible for the underestimation of excess heat? The answer to this question seems to be negative. First, condensation is likely to take place near the outlet of the exhaust pipe where the temperature is relatively low. Water condensed near the ending of the pipe does not return to the electrolyte. Second, consequences of condensation, if it were significant, are not as serious as one might think. Heat released in condensation of one gram of steam is the same as heat used to evaporate one gram of water. Thus each gram of condensed water brings back 2260 Joules of heat. Heating of the electrolyte by condensation is not distinguishable from heating it electrically. Thus, in the first approximation, condensation has no effect on the CPU. In reality some heat released in condensation is removed by conduction and convection. But, as in (8), the non evaporative losses, P_{loss} were measured. In other words, the effect of condensation on COP is practically eliminated. Unfortunately, this cannot be said about splashing; unaccounted splashing might lead to exaggerated values of CPU, and to an illusion that the CPU increases with voltage.

APPENDIX 3: Micro-explosions

Using 0.2M K_2CO_3 electrolyte, our cell consumes nearly 1000 W at 350 V. The resulting plasma is so violent that the electrolyte sloshes all over the place and periodically exposes the cathode. When that happens an arc, possibly accompanied by a H_2+O_2 explosion occurs and a small hole is melted in our anode grid. The shock from these explosions is so violent that, even with our present shock-mounting of the cell, the Sartorius balance is unable to provide stable mass readings, thus ruining our data collection.

Despite these difficulties we have tried running at 350 V about 6 times now (our Pt-coated Nb mesh anode has about 50 small holes in it now). On most of these attempts something inside the cell broke apart or the balance was so disturbed by the shocks that its data was meaningless. But we were lucky enough to catch the cell "behaving" well enough on two of these runs and we got "reasonable measurements" from them.

Another problem is that 1000 W is out of the power range (0-550 W) that we can explore with our existing ohmic heater. Thus we are forced to extrapolate the heat losses and that could be erroneous. On the other hand, if we dilute the electrolyte to 0.02M K_2CO_3 , then the cell consumes about 300-400 W at 350 V and all of the measurement strategies we developed specifically for this experiment work satisfactorily.

To date we have made three "good measurement" runs at 350 V. The COP observed on the two runs with 0.2 M K_2CO_3 were 0.98 and 1.03. The COP observed with 0.02 M K_2CO_3 at 350 V was 1.03. As it turns out none of these COPs is significantly different from 1.00.

Acknowledgments

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