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# Production of Heat during Plasma Electrolysis in Liquid

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Plasma was formed on the surface of an electrode in a liquid solution when metal cathodes underwent high-voltage electrolysis. A real-time heat calibration system was designed for detecting the amount of heat generated during plasma electrolysis. The measured heat exceeded the input power substantially, and in some cases 200% of the input power. The heat generation process depended on the conditions for electrolysis. There was no excess heat at the beginning of plasma electrolysis. However, after plasma electrolysis for a long time, a large amount of heat was generated. The reproducibility would be 100% if all factors such as temperature, voltage and duration were optimized. Based on the heat and the products, we hypothesize that some unique reaction occurs on the cathode surface. This reaction may not occur at energy levels available during electrochemical electrolysis.

KEYWORDS: plasma electrolysis, hydrogen evolution, calorimetry, heat generation, tungsten electrode

## 1. Introduction

When certain types of metal are used as cathodes in liquid electrolysis, various reactions take place. In particular, when palladium is electrolyzed in heavy water, there are many unknown reactions occur. However, these reactions are extremely difficult to reproduce and control, and the mechanism is still unclear. Several possible causes of such difficulty have been proposed. We think that the two main causes are reproducibility and controllability, and that measurement techniques suitable for plasma electrolysis have been used, which do not work well with other method.

Replication attempts have been too closely related to the methods originally described by Fleischmann and Pons.[1)] In other words, electrode materials, the electrolyte, and the operating parameters have not been sufficiently optimized to realize an easier and more reproducible methodology. For example, it has long been the goal of this research to increase hydrogen loading in metals by employing titanium,[2)] palladium and various alloys of these metals, and by employing metals such as nickel which is known to have high surface reactivity to hydrogen,[3)] and Ti, Ni, LaNi alloys which absorb large amounts of hydrogen. Lithium was the first electrolyte to be employed as an electrolyte. Later, alkaline metals and salts were employed, and materials that were thought to increase overpotential were selected. The idea has been to achieve high fugacity by increasing electrode overpotential, and thereby increasing the concentration of hydrogen inside the metal. High current density helps achieve that goal, but high current density in the early phase of electrolysis can cause high loading of hydrogen near the metal surface, which acts as a barrier to prevent additional loading of hydrogen into the rest of the metal bulk. Therefore, low current density is used for an extended period at first, and the cathode metal is gradually loaded. Current density is held to no more than 1 A/cm$^2$, with 30–50 V as the upper limit. When the cell temperature is too high, it can break up layer of highly concentrated deuteride which have been formed, lowering the overall deuterium concentration level, so room temperature is considered most suitable for this experiment.

Previous studies have failed to reveal the cold fusion effect because most of the measurement techniques were based on the hypothesis that cold fusion is similar to conventional nuclear fusion. Instruments were designed to detect the products of high-temperature plasma fusion, such as heat, neutron, tritium and charged particles as well as $\gamma$-radiation. However, the expectation that these products would be detected was purely based upon theory, and it might not have been a good idea to pursue these studies to such an extent. If the reaction were unlike any known fusion reaction, it would be better to focus our research on transmutation products rather than conventional reaction products.

We previously reported that anomalous isotopes are created on metal surfaces and surface regions, which cannot be explained by conventional electrolysis.[4)] This extruded material consists of elements which cannot be thought of as contaminants, because the isotopic distribution of most of the elements is unnatural. This indicates that some type of reaction affecting the nucleus has occurred. We expect to clarify the reaction mechanism by analyzing these reaction products.

In this study, we dispense with weak electrolysis, and employ instead an extremely powerful method of electrolysis, i.e., plasma electrolysis, which produces heat. The plasma phenomenon has been reported in the literature for a long time.[5)] When a liquid electrolyte is polarized at a high voltage (70–3000 V), electric discharge and light emission occur. Studies of the light spectrum and of the breakdown of the insulating layer between the cathode material and the solution have been conducted.[6–9)] Hickling and Ingram[9)] and Hickling[10)] applied high voltage to a liquid electrolyte and created a layer of gas and vapor surrounding the cathode surface, and determined that a plasma was formed along with incandescent light emission. They measured a number of reaction products and determined that the reaction mechanism is different from the mechanism of normal electrochemical reactions. Sengupta, Singh and Srivastava[11, 12)] clarified experimentally that $H_2O_2$ is formed at a higher rate than that predicted by conventional theory for a given level of current flow during plasma electrolysis, and demonstrated that the phenomenon is not a form of Faradaic electrolysis. The plasma discharge reaction and the mechanism are still not understood in as much detail as a phase of conventional electrochemical reactions.

## 2. Experimental Method

### *2.1 Electrolysis system*

Heat is measured by a method that combines open cell isoparabolic calorimetry and flow calorimetry, as shown in Fig. 1. The cell is a cylindrical glass vessel 100 mm in diameter and 150 mm high. The cell is made of layers, or chambers. The anode, the cathode and the electrolyte are set in the inner chamber that is surround by the outer chamber. The chamber consists of a heat exchanger coil made of Teflon tube, through which secondary water coolant flows. The outer chamber is equipped with thermocouples at the heat exchanger inlet and outlet, and a constant volume pump (Cole Palmer PA-71B) circulates the secondary coolant water from a constant temperature bath (Advantec LF480). Cooling water is circulated through the Teflon tube by an FMI metering pump at 1% precision, for example, 4.26 ± 0.05 ml/s. This pump circulates water at any rate from 1 to 20 g/s. The flow rate is confirmed by collecting the water in a container for a fixed period of time and weighing it. Variations in the flow rate are measured and found to be less than 1%. Cooling water temperature can be set anywhere from 15°C to 60°C, and varies less than 0.1°C.

The top of the cell is covered with a Teflon cap as in figure, but it is not closed in the electrochemical sense; a hole in the cap allows decomposed hydrogen and oxygen to escape. This effluent gas carries away a portion of the energy produced; thus the heat generated in the cell is underestimated. However, in some cases so much excess heat is generated, and output exceeds input power even when energy lost to effluent gas is not accounted for. The electrolyte temperature in the cell is measured with Teflon-covered thermocouples. The mixer within the cell ensures uniform temperature distribution. The temperature of the coolant water is measured at the inlet and the outlet of the coil by thermocouple temperature probes located in Tee fittings that are buried in the thick Styrofoam insulation that surrounds the outer chamber of the cell. The heat output of the cell is obtained by multiplying the observed temperature rise of cooling water by the water flow rate and the specific heat of water. This assembly is then surrounded with thick Styrofoam insulation, which reduces heat loss to very low levels.

The entire plasma electrolysis cell is placed in a constant-temperature air incubator (Yamato 1L-6) which is held at 23 ± 0.1°C. Air inside the hood is circulated with a fan. A Takasago EX-1500H direct current power supply is used, with 0.01% load regulation. Input power is checked by a digital power meter (Advantest WT130); the ratio of the power data with the data measured by following procedure is 0.99 ± 0.07 during 60 s. The electrolysis power leads are 1-mm-diameter platinum wires. A platinum mesh was used as the anode.

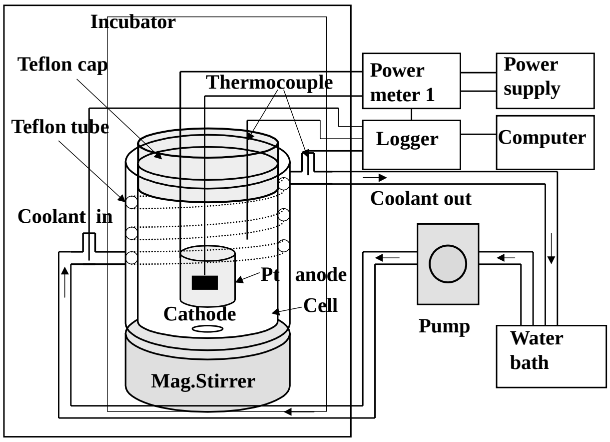

Fig. 1. Schematic of heat measurement apparatus. The method is a combination of open cell isoparabolic calorimetry and flow calorimetry.

Temperature is measured with K-type thermocouples. The thermocouples are calibrated against a standard thermometer. The precision of the thermocouples is 0.05°C. Holes are bored in the stopper to allow passage of electric power supply terminals, thermocouple sensor wires, and effluent gas. A Teflon-coated heater is installed to allow calibration in increments as low as 1°C, and calibration is performed at different phases of the experiment, whenever the need arises. The thermocouples recorded temperature within the electrolyte. The thermocouple tips are coated with 0.1-mm-thick Teflon. A Teflon-coated stirrer is placed at the bottom of the cell, and it is driven by a Yamato MA300 constant-speed magnetic stirrer located under the cell.

### *2.2 Heat calibration*

Heat balance is obtained from the following formulas:

$$\text{Input energy } = I \times V \times t$$

$$\text{Output} = H_\mathrm{e} + H_\mathrm{c} + H_\mathrm{r} + H_\mathrm{v} + H_\mathrm{g}$$

Here, $I$ is electrolysis current, $V$, electrolysis voltage, $t$, time, $H_\mathrm{e}$, the heat of electrolyte and cell, $H_\mathrm{c}$, heat carried out by the coolant, $H_\mathrm{r}$, heat losses from the cell wall during calorimetry, $H_\mathrm{v}$, heat removed from cell as water vapor, and $H_\mathrm{g}$, energy for produced by water decomposition. These can be broken down in greater detail as follows:

$$H_\mathrm{e} = \text{heat capacity of electrolyte and cell } \times \text{ change in temperature },$$

$$H_\mathrm{c} = \text{heat capacity of coolant } \times \text{ change in temperature },$$

$$H_\mathrm{r} = \text{heat capacity of electrolyte and cell } \times \text{ temperature drop },$$

$$H_\mathrm{v} = \text{mass of vapor } \times \text{ specific heat },$$

$$H_\mathrm{g} = 1.48 \times \text{ electric current }.$$

The masses of the electrolyte solution and the primary coolant are normally 1000 g and 700 g, respectively. The precise heat capacity of the solution depends upon the temperature; however, it can be taken as 4.18 J/g·°C. The heat capacity of the Pyrex glass cell (inner chamber; 364 g, outer chamber; 460 g) also varies with temperature, but on average it is 0.76 J/g·°C. $H_\mathrm{r}$ is calculated from the temperature drop, which is determined from the heat decay curve obtained after the end of the experiment. $H_v$ is based on the volume of steam times the temperature of the steam; an average value of 2,256 J/g is used. Finally, the energy used in decomposing water into hydrogen and oxygen varies with the electrode conditions and various other factors, but an average value of $1.48 \times I$ is used here.

All data, including voltage, current, temperature, and mass of secondary cooling water, are collected with a data logger (Advantest R7326-B) at 10 s intervals. Current is determined by measuring voltage through a shunt (Hioki Co., 9081; 0.01 Ω, DC 10A ±0.1%). Cell voltage is measured by attaching sensor wires directly to electrode leads on top of the cell. Data from the logger are captured by the computer, and recorded on a diskette. All electric lead junctions from the thermocouples to the logger are compensated.

The error of the input power and output heat can be estimated from the stability of the power supply, the temperature precision and the flow rate fluctuation. Here, the stability of the power supply is evaluated as 0.1% of input power due to the stability of the shunt; for example, when typical input is 100 W, the input error is 0.1 W. Temperature resolution is within 0.05. Here, the typical mass of the electrolyte is 1000 g and the heat capacity of that is 4180 J/°C. The resolution of the heat is estimated as 209 J for 10 s intervals. Therefore, the output resolution can be evaluated as 21 W. The error from flow calorimetry is estimated from the stability of the metering pump and thermocouples. Here, these are 1% and 0.05°C. We assume the typical flow rate of the secondary coolant to be 4 g/s, and the resolution of the heat is finally estimated as $4 \times 4.18 \times 0.05 = 0.84$ J/s, i.e., 0.84 W.

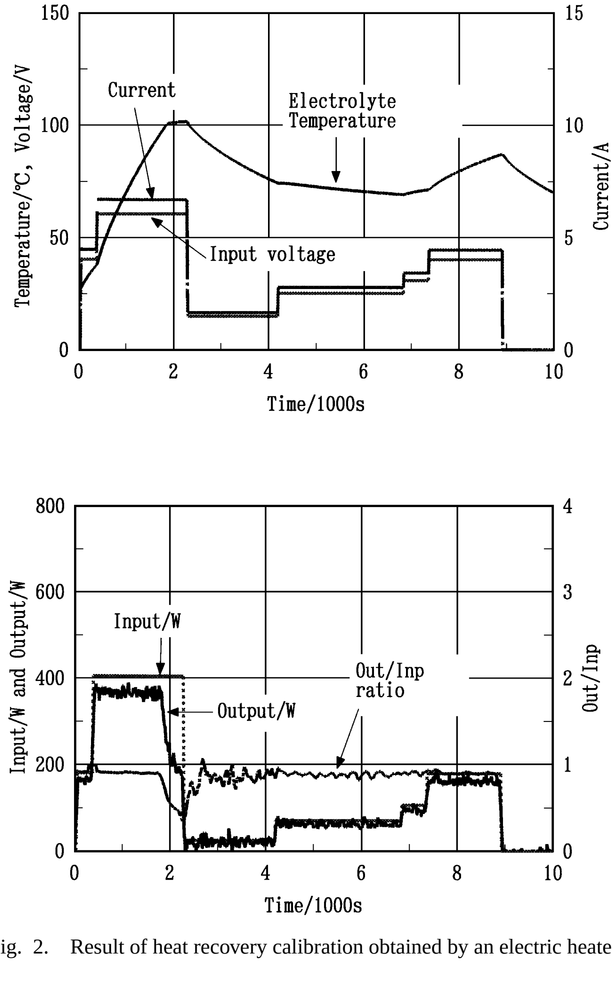

Fig. 2. Result of heat recovery calibration obtained by an electric heater.

Heat balance measurement is calibrated by changing the input power of a heater wire immersed in electrolyte. A typical relationship of input and output power is described in Fig. 2. Heater current, voltage and the electrolyte temperature changes are indicated in upper figure and input power, output power and the output/input power ratio are shown in the lower one. The input change is typical of plasma electrolysis. The temperatures of the electrolyte, the water bath and the primary coolant are kept at 26.8°C at the start of the experiment. Input power is first set at 180 W, that means 40 V and 4.5 A for 500 s, and then is increased to 400 W and kept there for 1800 s. During the high input power, the temperature exceeds boiling point at 1800 s. At that time, the output/input power ratio decreases with time because the calibration method does not taken into consideration the contribution of vapor. At 2300 s, input power is decreased to 25 W and then the electrolyte temperature decreases. The output/input power ratio again shows a high value because boiling is stopped. After that, the input power is again increased to 70, 106 and 180 W. Meanwhile, the output/input ratio remains at 0.89 during the entire duration. According to the calibration results, it can be said that the steep input change has no effect on heat recovery. In other words, we can monitor the input change using the heat measurement equipment that is composed of flow calorimetry and isoparabolic calorimetry. The only disadvantage of the method is the uncertainty over the low input power range because temperature measurement accuracy is restricted to 0.1°C. However, the precision of the measurement is sufficient up to an input power of 70 W.

### 2.3 *Electrolyte and cathode material preparation*

The electrolyte solution is prepared with filtered Milli-Q pure distilled water. It is used after being redistilled in quartz glass. Ultrahigh-purity reagents are used for the $K_2CO_3$ electrolyte. The concentration of impurities such as Cl, $SO_4$, $SiO_2$ and $PO_4$ is less than 10 ppm. Impurities in the alkaline metals include 5 ppm of Ba and 1 ppm of Ca. Other metallic impurities are Fe at 0.05 ppm at maximum.

The cathode is 5 mm × 10 mm rectangular of W plate (0.3 mm thick) with 1.5-mm-diameter W lead. We conduct tests using this type of sample. The lead rod is covered with a thin tight-fitting Teflon sleeve (3 mm in diameter). The exposed area of the W plate is therefore 1.09 $cm^2$. Nilaco tungsten is used for the cathode and lead wires, both of which are 99.98% pure. Impurities present in the sample are 20 ppm Fe, 20 ppm Mo and less that 5 ppm of other elements. The foil is cut into a rectangle and polished with #1500 emery paper. The lead wire is spot-welded perpendicular to the long side of the cathode. After welding, the cathode and the lead wire are cleaned with 1.0% HF and 3% $HNO_3$ at 25°C for 2 h, followed by a solution of HCl and $HNO_3$ 3:1 for 2 h, to wash off impurities. The sample is rinsed, the lead wire is completely covered with a Teflon shrink-wrap tube, and then the sample is electrolyzed.

Platinum wires or mesh is used as the counter electrode and electrode lead wires. Purity was 99.99%. Impurities include 18 ppm Rh, 2 ppm Si, Cr, Pd, and less than 1 ppm Au, Ag, B, Ca, Cu and Fe and no detectable levels of other elements.

The anode is a piece of Pt mesh (made of 0.2 mm wire) 5 cm × 15 cm in size. The nominal area of the mesh (both sides) is 55 cm$^2$. Thus, the anode/cathode area ratio is about 50.5. A 1.5-mm-diameter Pt lead wire is crimped to the anode mesh. This lead wire sleeved with Teflon tube is led out of the cell through a rubber seal. The two electrodes are positioned about 2 cm from the bottom of the vessel and are located about 3 cm apart.

### *2.4 Electrolysis*

Figure 3 shows a typical relationship among voltage, current density and temperature when the cathode is electrolyzed in 0.2 M potassium carbonate in light water. Each curve shows temperature dependence of the current and voltage relationship for various plasma and cathodic electrolyses. Open symbols show the current density performance as the voltage is changed. Cell performance varies with temperature, and it is summarized as follows: As the voltage is increased, the anode begins to produce copious amounts of oxygen, while the cathode produces hydrogen. At maximum current density, hydrogen production at cathode is at a maximum, and at the same time the sound of boiling is heard. After exceeding the maximum current density, when voltage is slightly raised, current density suddenly falls, and at the same time it begins fluctuating violently. Light emissions due to electrical plasma discharge at the cathode surface begin. While the temperature remains low, the current fluctuations are large and difficult to stabilize; however, when the temperature exceeds around 85°C, the fluctuations show a regular periodicity of 0.5–0.6 s duration, which is caused by bubble formation. After exceeding the maximum current density, the current does not increase any longer and decreases when voltage is increased. Current density remains at approximately 0.5 A/cm$^2$ at voltages of 200 V and above. When we compare the impedance of the solution at different stages of the electrolytic process, we find that increases by a factor of 20, from 60 Ω to 300 Ω, as a layer of gas is formed. The transition appears to increase the electrical charge of the cathode reaction by a factor of 20. This discharge phenomenon was discovered in the early 1950 s and reported by Kellogg[13)] Polakowski.[14)] Ohwaku and Kuroyanagi[15)] clarified the roles played by temperature, electrolyte type, current density, and cathode area in this form of electrolysis. Later, when voltage is reduced, the relationship between voltage and current exhibits a hysterisis. As shown by solid symbols in the figure, the discharge continued until voltage reached roughly 60 V. After that, the discharge stopped abruptly and at the same time the current increased suddenly, as ordinary electrolytic evolution of hydrogen was re-initiated.

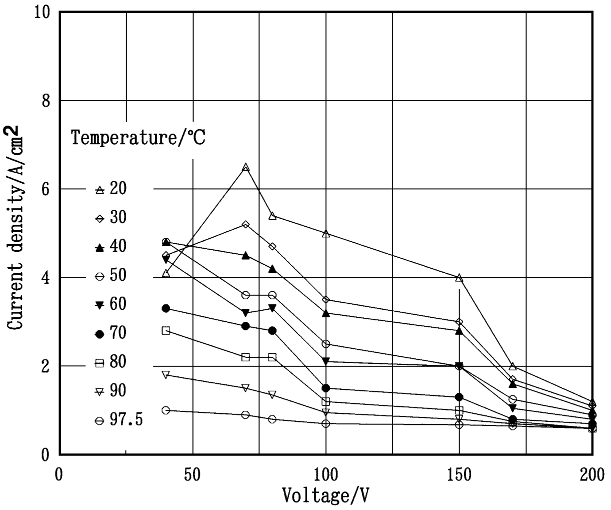

Fig. 3. Typical relationship among voltage, current density and temperature when the cathode was electrolyzed in a 0.2 M $K_2CO_3$ in light water.

## 3. Results

An example of the measurement result for ordinary hydrogen production is shown in Fig. 4. In this case, a tungsten plate was used as the cathode and electrolyzed at 40 V. When electrolysis began, the temperature rose simultaneously and stabilized at around 95°C. The current reached 5 A, or 200 W input. As the temperature rose, the current declined, and after 500 s it was down to about 1.6 A. However, in this case, excess heat production was not observed. The output heat was clearly followed by the input power fluctuation.

Starting with the normal cathodic electrolysis, voltage was increased. At 80 V, the entire cathode begins to generate plasma weakly. Current density, temperature and other factors are shown in Fig. 5. In the first stage of electrolysis, the current reached 5 A because the plasma discharge had not yet begun, and the input was the same at 400 W. Simultaneous with the commencement of light emission, the current decreased, falling to 1 A after 300 s, or about 80 W of input. Figure 5(b) shows the appearance of heat generation. In contrast to the test shown in Fig. 4(b), heat production was observed. In this case, the output heat was no longer followed by the input power fluctuation. The output heat showed a large fluctuation compared with the stable input power. The difference between output and input clearly exceeded the heat estimation resolution by 20 W. For example, the excess heat increased

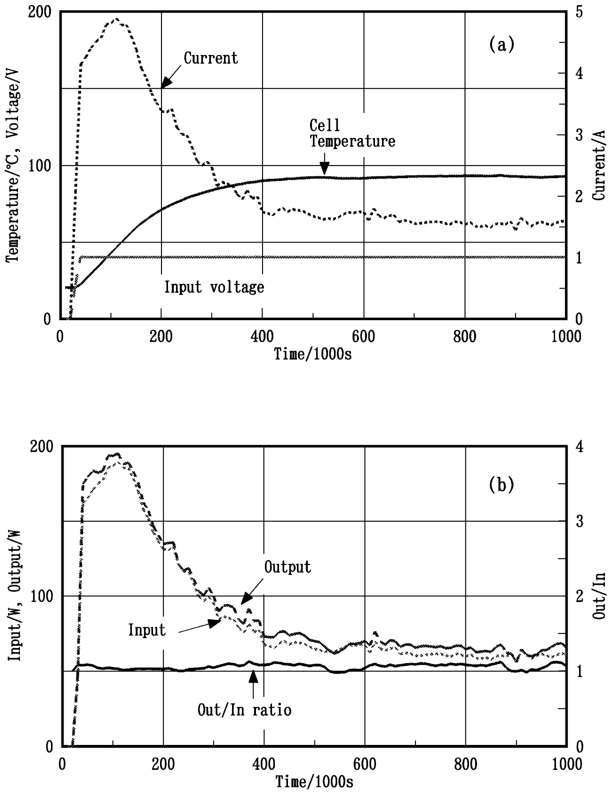

Fig. 4. Measurement of the heat balance for input and output during the ordinary hydrogen production reaction.

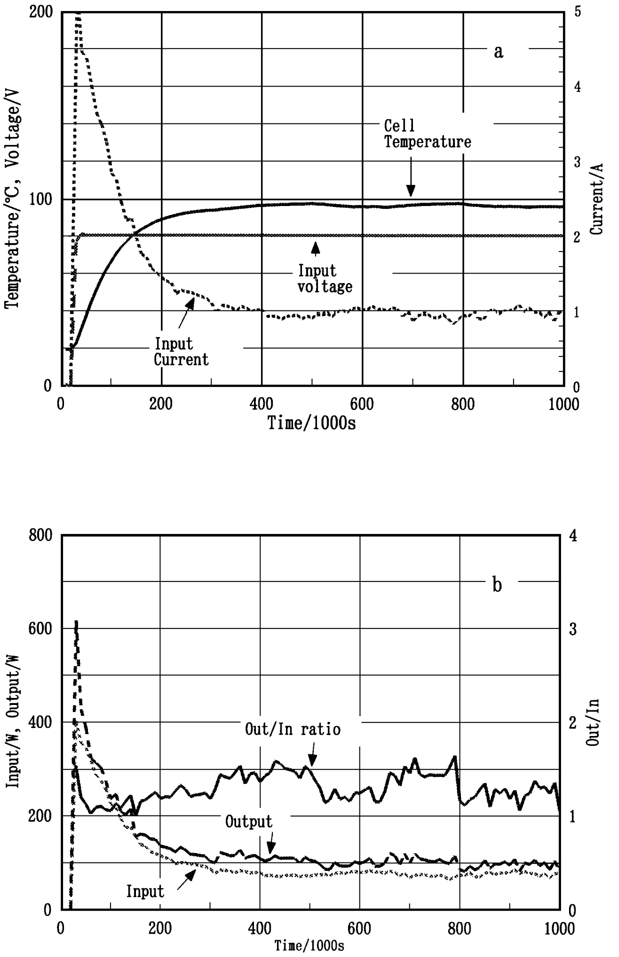

Fig. 5. Result of current density, temperature and the heat balance at 80 V of cathodic electrolysis.

to 30 W from 320 s to 480 s and from 700 s to 790 s. The amount of heat produced during electrolysis was estimated as 27.4 kJ over 1000 s, averaging 27.4 W. As in other cases, heat production expressed as percentage of input power increased with time, reaching about 40%. Evidence of heat production was also seen in the cell temperature, which continued to increase by 2°C despite the fact that input power wattage was decreasing. This clearly demonstrated that anomalous energy production occurred.

If the input voltage were increased, it would be seen as significant excess heat generation during plasma electrolysis. A typical result is shown in Fig. 6. Figure 6(a) describes the changes in input current, voltage and electrolyte temperature during electrolysis. Figure 6(b) shows input and output in watts and their ratio. Electrolysis voltage was initially set at 200 V. The input voltage, at the beginning, was increased to a certain voltage during 100 s. Current at the beginning of electrolysis increased to 4.3 A and after that it steeply decreased to 1 A when plasma production was initiated. Then, it gradually decreased with time to reach about 0.5 A after 2000 s. Even after decreasing the voltage at 3100 s to 100 V, the plasma remained. At 4800 s, input voltage was decreased further to 60 V, and plasma production ceased.

The output heat showed excess compared with the input power at 100 s after the start of plasma electrolysis. At that time, the output heat excess was considerably larger than the heat measurement error of 20 W and reached 40 W on average during initial 1500 s of plasma electrolysis; the percentage of it was 20%. After 1600 s, it increased to around 60% and showed some fluctuation. The percentage increased to 200% after 3000 s and decreased to 0% after the voltage was decreased to 100 V. The total output heat power during plasma electrolysis was estimated as 388.7 kJ while the total input electric power 334.3 kJ. Here, we can estimate that the excess output heat is 54.4 kJ, and is 16.4% of the input power.

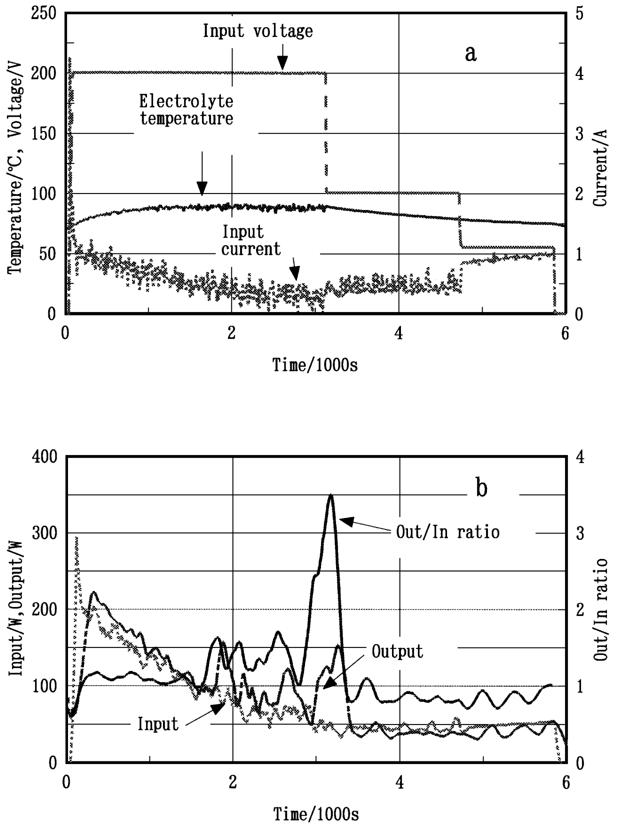

Fig. 6. Result of current density, temperature and heat balance at 200, 100 and 60 V of plasma electrolysis.

However, at 3100 s, the electrode lost 20% of it original weight, i.e., 0.1 g. Therefore, its shape changed from rectangular to disk-like. Excess heat generation immediately ceased after voltage was decreased to 100 V, even if plasma electrolysis continued. The electric current increased when the voltage was decreased at 3100 s and 4800 s. Plasma electrolysis stopped when the voltage was decreased to 60 V and changed to normal cathodic electrolysis. After the voltage was decreased to 100 V, the output to input ratio gradually changed below unity. The ratio slowly increased after the voltage was decreased to 60 V. The reason for this is considered to be as follows: when the temperature for electrolysis approaches to 100°C, i.e., boiling point, a large amount of vapor is released from the cell. At the same time, considerable heat is released. We did not measure heat loss due to vapor release, and the ratio decreased to below unity if the contribution of the vapor became large. Meanwhile, again temperature for electrolysis was less than boiling point, the ratio approached unity. However, the ratio still showed a large fluctuation during normal cathodic electrolysis. It is considered that some excess heat generation continued to take place at the input voltage.

It has been clarified that the extraordinary excess heat generation is affected by many parameters, such as electrolysis and electrode material. It is dependent on the electrolysis temperature, the input voltage and the discharge time. No excess heat was generated at the beginning of plasma electrolysis even if the temperature and the input voltage were kept considerably high, such as above 85°C and 100 V respectively. However, after plasma electrolysis for more than several hundreds seconds, we confirmed large excess heat generation. We can say that if we could attain all of these factors, we would observe excess heat with 100% reproducibility. After plasma electrolysis for 1000 s, we determined the relationship between electrolyte temperature and input voltage.

Heat measurements were performed five times at 40 V, seven times at 70 V, and nine times at 80 V, 100 V, 150 V, 170 V, 200 V and 220 V. Excess heat was generated at more than 80 V after plasma electrolysis for several hundred seconds. The amount of excess heat generated usually increased with increasing electrolyte temperature. However, the generation exhibited fluctuation during the discharge, and a larger change at higher input voltage, higher temperature and longer discharge time. However, the amount of excess heat could not be determined at the input voltage greater than 200 V because of the large fluctuations. Thus, the amount of excess heat generated could no be plotted in the figure.

The relationship between voltage and the amount of excess heat produces is shown in Fig. 7, with temperature as parameter. Data are shown for the previously described tungsten foil cathode electrolyzed in a $K_2CO_3$–$H_2O$ solution. The plotted values are averages at a certain temperature for plasma electrolysis after showing excess heat generation. The abscissa shows input voltage, the ordinate shows excess heat in Watts where excess is defined as total output heat energy minus total input electrical energy. As seen in Fig. 7, with tungsten, excess heat generation begins when electrolysis voltage reaches 70–80 V, and it is virtually not detected at voltages below that range, i.e., the excess heat generated was below the error level. At 80 V, the amount of excess heat generated exceeds 20 W at temperatures higher than 70°C, and increases at even higher voltages.

Figure 8 shows the effect of the temperature of the electrolyte solution on excess heat production. These points are transformed from that in Fig. 7. Excess heat generated is shown in watts for a range of temperatures. In the case of electrolysis at 40 V, no excess heat generation is observed until the temperature exceeds 60°C. It is apparent that in the case of plasma electrolysis at 80 V, soon after the temperature exceeds 60°C, the amount of excess heat generated increases. At 70°C, excess heat power is 20 W. When the temperature reaches 97.5°C, the value rises to 40 W. In the case of plasma electrolysis at 170 V, at 30°C, the amount of excess heat generated exceeds 20 W. When the temperature reaches 97.5°C, the amount of excess heat increases to 75 W.

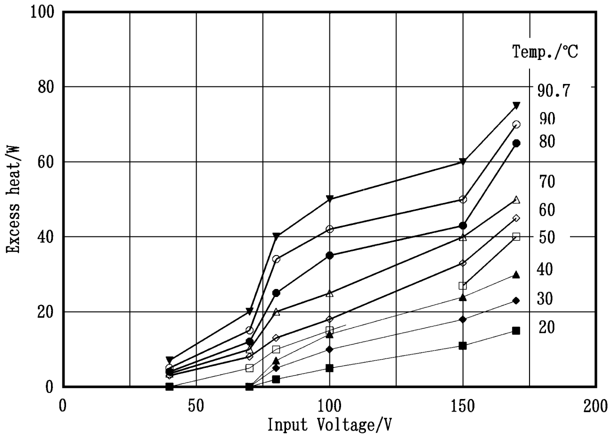

Fig. 7. Effect of the electrolyte temperature on the relationships between heat production and input voltage.

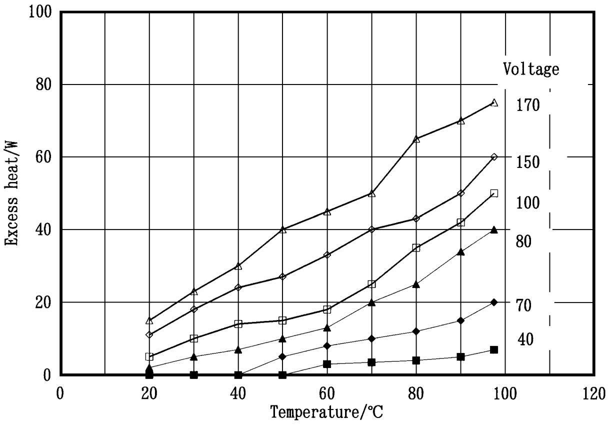

Fig. 8. Effect of the voltage on the relationships between heat production and electrolyte temperature.

## 4. Discussion

In evaluating heat production, it is necessary to determine whether the heat is produced by chemical changes. After discharge electrolysis, it is clear that the cathode material disintegrated and precipitated at the bottom of the cell in the form of fine particles. Because the cathode material was made of pure metal, the disintegration must have been caused by hydrogen corrosion as well as heat damage. Therefore, chemical changes cannot explain the generation of excess heat. Let us consider some hypothetical chemical reactions:

$$2W + 3O_2 = 2WO_3 + 200.84\,\mathrm{kJ}.$$

$$WO_3 + H_2O = H_2WO_4 + 179\,\mathrm{kJ}.$$

If 183.85 g of tungsten reacted, the maximum amount of heat generated by this reaction would be 380 kJ. The actual amount of excess heat measured by flow calorimetry was 54.4 kJ for the case of plasma electrolysis at an input voltage of 200 V for 3100 s. The mass of tungsten used in this experiment was 0.5 g or 0.00272 mol. If this entire mass of tungsten was oxidized, and a water-soluble hydrogenated tungsten, the total amount of excess heat generated would be just short of 1.03 kJ. Actually, the mass of tungsten consumed in the reactions described above was 0.1 g. If we assume hypothetically that all of this material reacted, the amount of excess heat generated would have been only 0.207 kJ or 0.38% of the actual amount of excess heat observed. The generation of excess heat in this experiment cannot be explained by a chemical reaction. This discussion was based on the assumption that tungsten underwent a chemical reaction, but in reality, the tungsten found at the bottom of the cell was recovered as pure metallic fine powder, i.e., no chemical reaction occurred. Furthermore, the decomposition of carbonates in an aqueous solution is an endothermic reaction; thus in this case, 274 kJ/mol of heat would be absorbed. Assuming that such a reaction indeed occurred, no excess heat would be produced. Ordinarily, when metal is transformed into a hydride, it produces heat on the order of 200 kJ/mol, the exact amount depending on the metal. If a hydride were formed, based on the amount of tungsten lost from the cathode, the excess heat from the reaction would be approximately 0.1 kJ, which would be simply too small to make a difference. In short, the actual amount of excess heat that may have been produced from potential chemical reactions is essentially nonexistent.

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