

Calorimetry 101 for Cold Fusion; Methods, Problems and Errors

Edmund Storms

Energy K. Systems
Santa Fe, NM

ABSTRACT

Application of calorimetry to cold fusion or LENR presents unique problems that have not been previously summarized. This paper discusses various calorimetric methods that have been applied to the subject and evaluates each in light of what has been discovered about their limitations and errors based on experimental studies. Such information is essential to a study of the effect and to evaluate the results.

I. INTRODUCTION

LENR (Low Energy Nuclear Reactions) is a new mechanism for initiating nuclear reactions within special solid materials without application of energy normally required to overcome the Coulomb barrier. When the mechanism is applied to the D-D fusion reaction, the better known term “Cold Fusion” is used. These reactions produce three kinds of evidence: electromagnetic radiation, nuclear products, and heat. The radiation is generally weak and most is absorbed before it can reach the detector. Nuclear products can be detected, but analysis is difficult because the products occur in such small amounts. Finally, the abnormally large amount of heat energy that is generated can be measured. This technique requires use of calorimetry, as described here.

Calorimetry is the measurement of heat energy. Although this is an old science that underpins much of thermodynamics and modern chemistry, when such measurements are applied to LENR, several unique problems become immediately apparent. For the LENR effect to be initiated, normal energy is frequently required as electric power to produce higher temperature, to generate hydrogen ions, or to stimulate the process in various ways. Consequently, the small amount of anomalous energy being sought is frequently superimposed on a large heat flux resulting from normal processes. As a result, the calorimeter must be able to handle large heat flux while being sufficiently sensitive and stable to see the small amounts of anomalous energy. This requirement has severely limited calorimeter design and has complicated evaluation of results. However, as better calorimetry has been applied to the problem, sufficient anomalous power has been reported to completely overwhelm uncertainties in heat measurement. This situation continues to improve as ways are found to generate increasing amounts of anomalous power.

Heat flux can be measured either by noting the temperature drop across a thermal barrier or by measuring the temperature rise of a material, generally a liquid. The first relies on thermal conductivity and the second uses the heat capacity of relevant materials. The isoperibolic and Seebeck methods use the former method and flow calorimetry uses the latter. These three methods will be examined here in detail.

A calorimeter needs to be calibrated using a known source of energy, the most convenient being Joule heat created at a resistor located within the cell or heat generated

during electrolysis of a “dead”¹ cathode. This energy must have the same effect on calorimeter behavior as does the process being studied. However, the calibration constant contains systematic errors in addition to normal random error. Both errors may be different from errors occurring when LENR heat is measured. Random error can be evaluated by noting the scatter in repeated calibration values, generally acquired over a range of applied calibration power. The much larger systematic error is more difficult to evaluate and depends on the calibration method and calorimeter design. Also, this error will slowly change with time as various uncontrolled variables change. As a result, data may appear to be very consistent yet be very wrong, sometimes in ways that are hard to evaluate.

This paper describes my experience designing and using three types of calorimeters and applying the designs to a search for heat generated by LENR in electrolytic cells, as pioneered by Pons and Fleischmann[2-4]. Rather than speculating about potential error, this paper examines experimental measurements of many real errors that must be considered. The sources of error found during these studies apply to all calorimetric methods used to study LENR.

II. DESCRIPTION

II.1 Isoperibolic Calorimetry:

Two general types of isoperibolic calorimetry have been applied to electrolytic

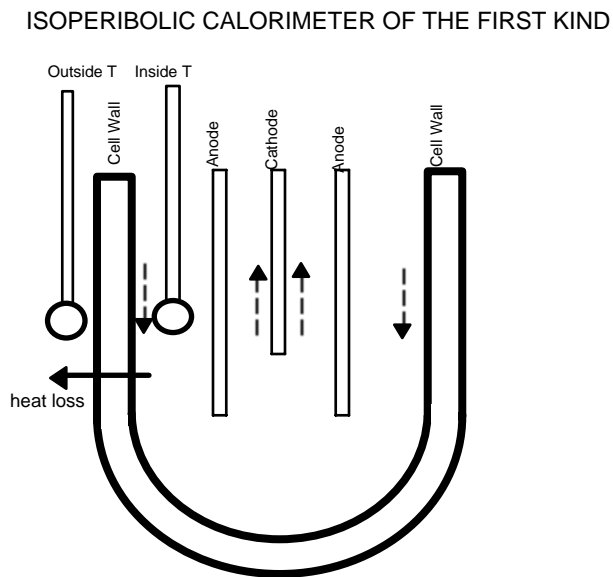


FIGURE 1. Cartoon of a Single-Walled Isoperibolic Calorimeter. Dashed arrows show the direction of heat flow caused by bubble action. The top of the electrolyte is warmer than the bottom because warmed water rises from the cathode-anode assembly and energy is lost through the wall as convection causes flow from the top to the bottom near the wall. The measured inside temperature very much depends on where the detector is located.

¹ Newly cleaned platinum does not produce anomalous energy when used as the cathode. However, if the platinum cathode is electrolyzed for sufficient time without cleaning, it may start to produce anomalous energy[1].

cells in which LENR is proposed to occur. For the first, called here single wall isoperibolic calorimetry (SWIC), temperature is measured within the electrolyte and this value is compared to the temperature outside the container, which is generally made of glass, as shown in Figure 1. This method is the least accurate, but the most commonly used of the methods that will be described here.

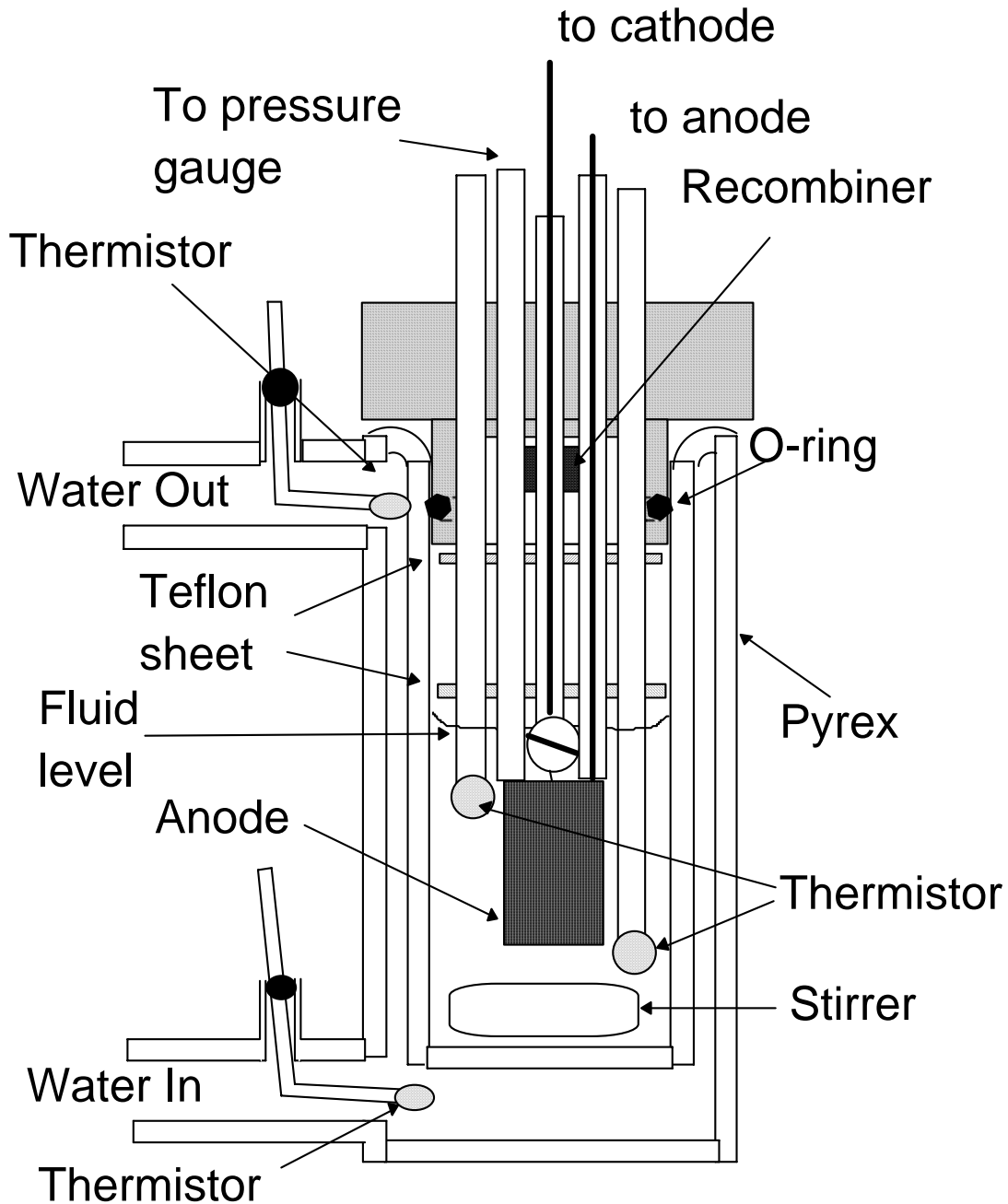


FIGURE 2. Drawing of an isoperibolic calorimeter using an external cooling jacket. Notice that temperature is measured at two locations within the electrolyte in this cell. This design is typical of cells used to obtain gradient data described in this paper.

The inside temperature is determined using thermistors or thermocouples, preferably multiple sensors at different depths and locations, while the outside temperature can be uniform and well known if the cell is contained in or surrounded by a constant-temperature environment. A drawing is shown in Figure 2 of an actual isoperibolic calorimeter. In this case, the cell is surrounded by a jacket through which water flows to maintain constant temperature. Other people have immersed their cells in a fluid bath or within constant-temperature air. The latter method is especially error prone because the true outside temperature at the thermal barrier is difficult to determine with sufficient accuracy.

Accurate calibration and subsequent measurements require the actual average temperature drop across the thermal barrier be equal to the measured temperature drop. Because this ideal condition is seldom achieved, the temperature error must be at least

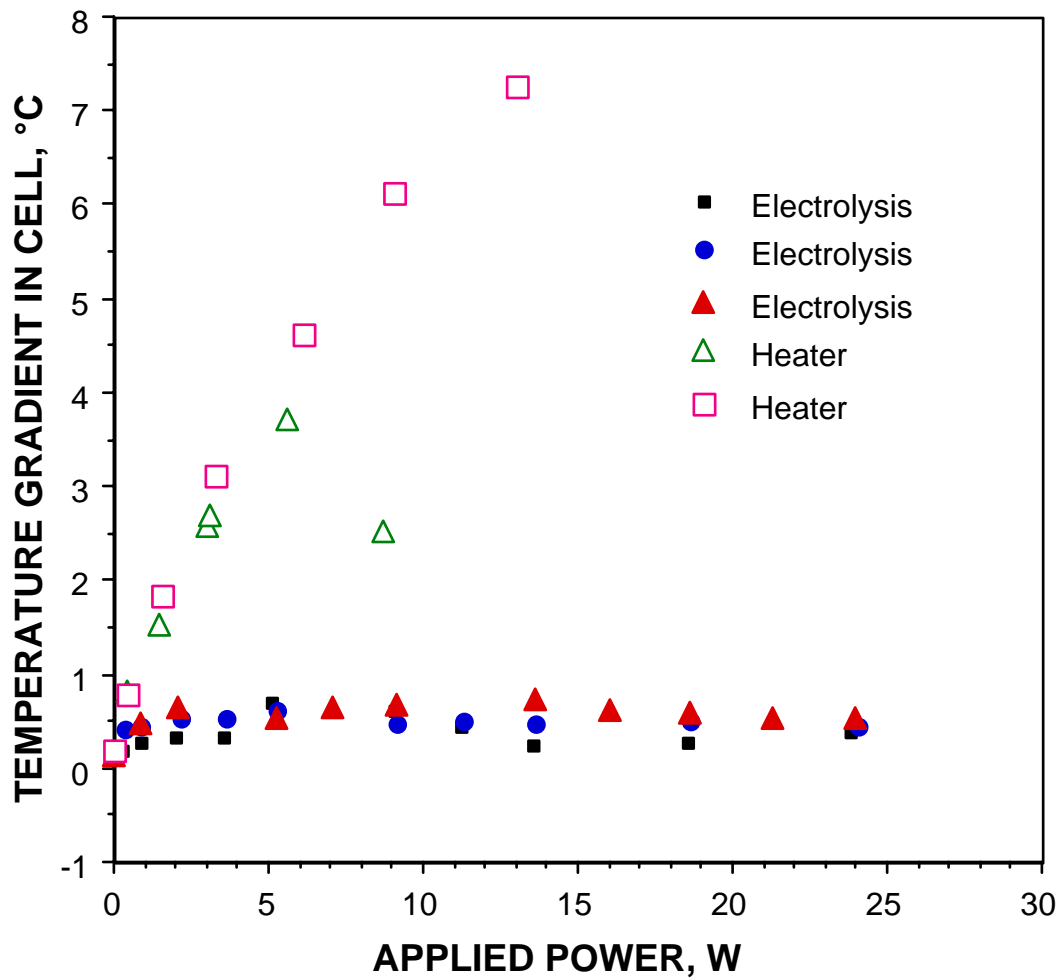


FIGURE 3. Comparison between the gradient within the electrolyte produced by electrolysis or by power applied to an internal resistor (heater) that is used for calibration.

independent of conditions within the calorimeter. Neither of these conditions is easy to achieve because random variations in thermal gradient cause unexpected fluctuations in ΔT , even when heat flux is constant. This criticism was raised very early in the field's history[5]. Figure 3 shows how the gradient within the electrolyte between the top and

bottom changes as power is applied to electrolytic action or to an internal resistor. Notice that the gradient is very small when electrolysis is used, because bubbles stir the liquid, but large when a heater is used. Application of even a small amount of electrolytic power

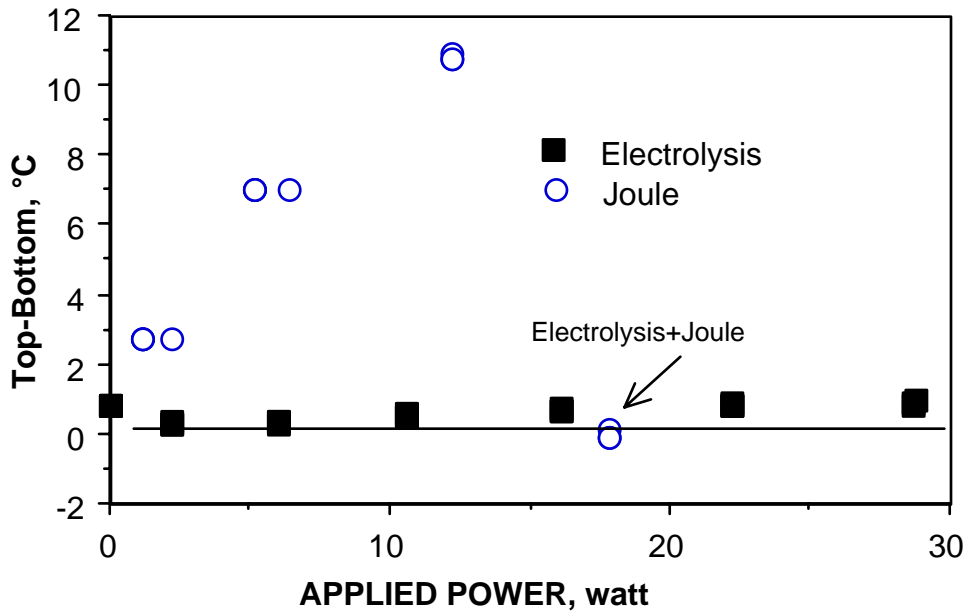


FIGURE 4. Temperature gradients produced using power applied to a heater alone; to electrolysis alone; and when heater power is combined with electrolysis.

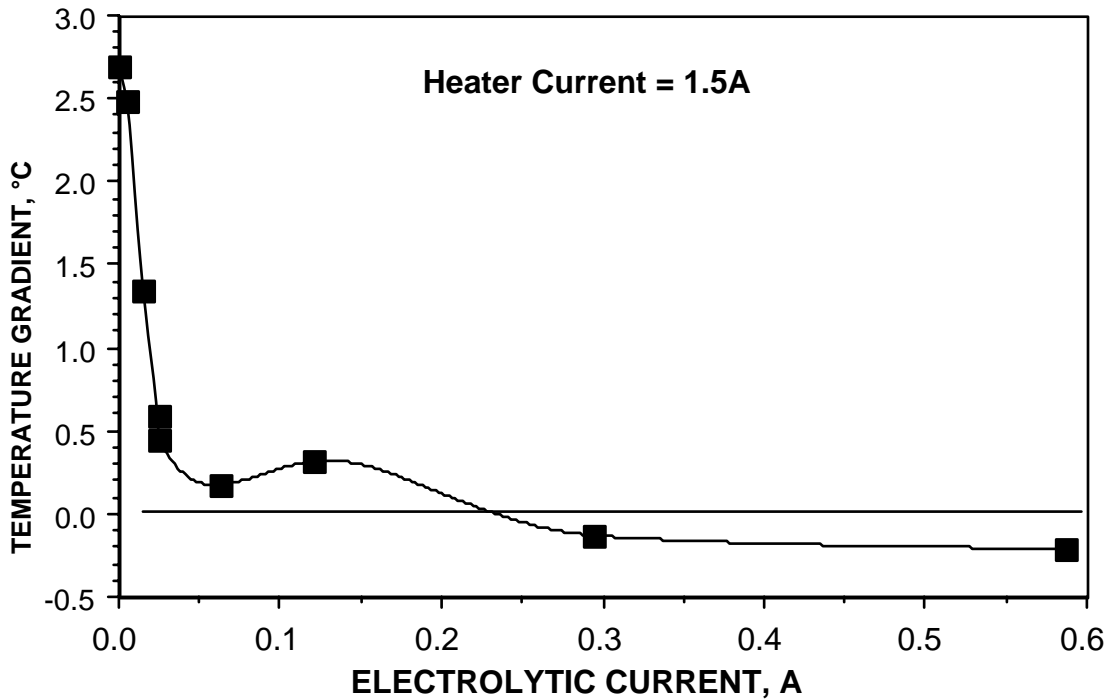


FIGURE 5. Effect of applying increasing electrolytic power to a fixed power applied using the heater. The temperature gradient is the difference between the top and bottom of the electrolyte. The heater power is about 10 watts.

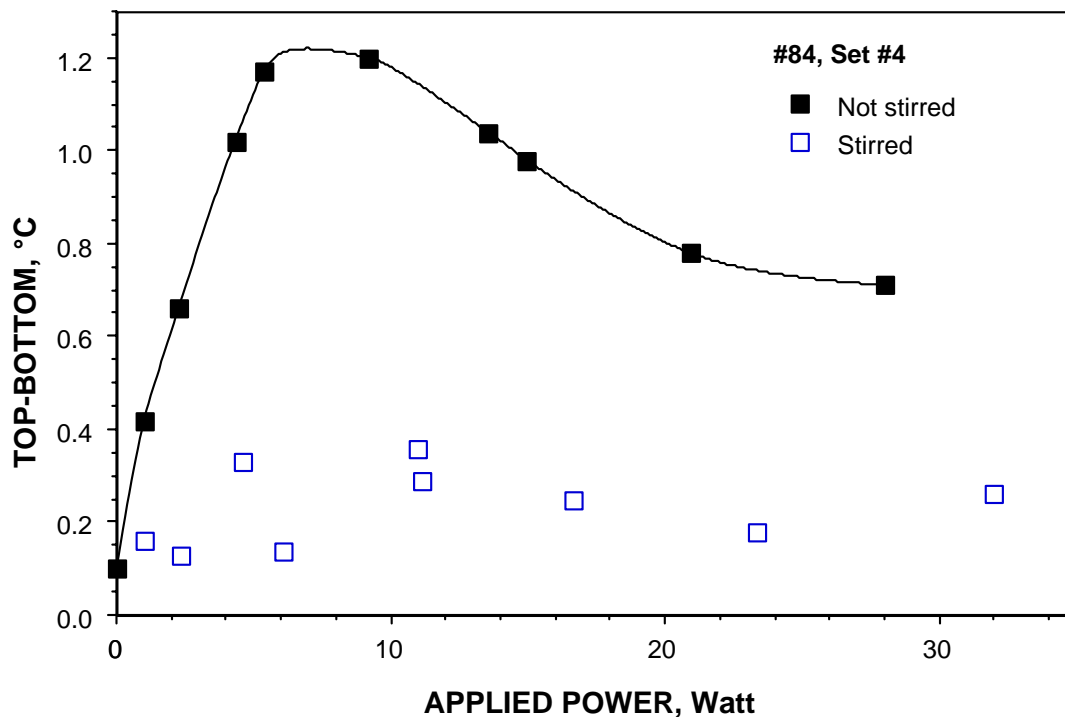


FIGURE 6. Effect of stirring on the gradient within a cell during electrolysis as a function of applied power.

along with heater power reduces the gradient to a value similar to that produced by electrolysis alone. Figure 4 shows what happens when electrolytic power is applied along with heater power. As shown in Fig. 5, applying even a small amount of electrolytic current can significantly reduce the gradient because bubble action reduces the gradient produced by the heater. This behavior was noted and utilized by Pons and Fleischmann during their early studies and it is why gradients were not important in their work, in spite of assumptions to the contrary[5, 6].

Stirring the electrolyte can reduce gradients, but introduces other problems. Stirring, as shown in Fig. 6, can even reduce the small gradient present during electrolysis. In addition, stirring makes the measurements more stable. Figure 7 compares calibration curves obtained using power applied to electrolysis alone and when power is applied to an internal resistor along with electrolysis. This figure shows that mechanical stirring will reduce but not eliminate the error introduced using resistor calibration.

Mechanical stirring, while reducing the difference between electrolytic and resistor calibration, introduces another error. Stirring reduces the thickness of stagnate fluid next to the barrier, which changes the overall thermal conductivity of the barrier. As a result, the calibration constant changes with stirring rate, as shown in Fig. 8. Consequently, when stirring is used, the rate must be held very constant. The gradient can also change gradually during the experiment causing apparent excess energy to develop. Figure 9 shows the gradient as a function of time. Such changes are very difficult to predict and can introduce serious systematic error if the cell is not frequently calibrated.

Application of external magnetic fields will also change the gradient because the path of ions moving between the anode and cathode will be changed, thereby causing

flow of heated electrolyte to change. These factors will change the temperature within the electrolyte at positions where temperature is measured.

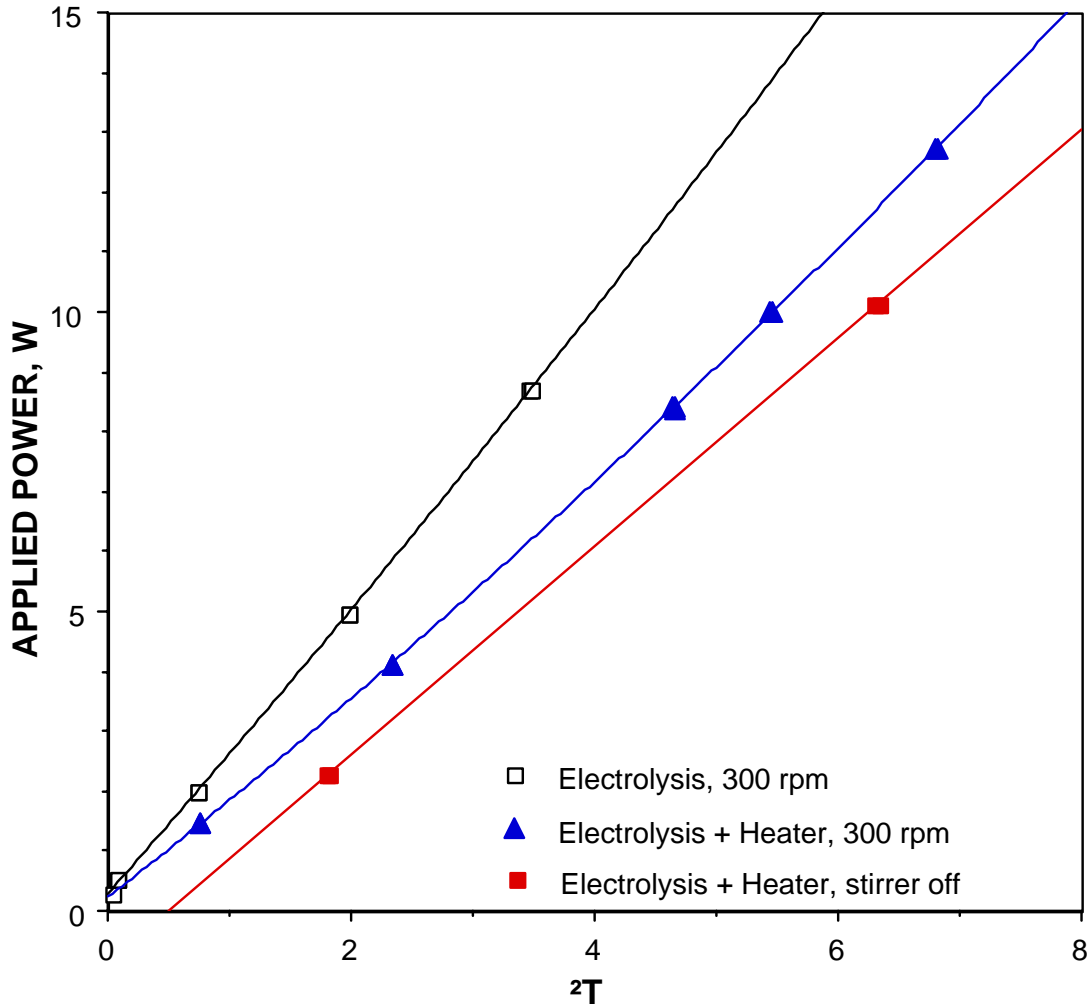


FIGURE 7. Calibration curves resulting from power applied to electrolysis or to an internal resistor plus electrolysis while the electrolyte is stirred or not stirred. Delta T is the temperature measured across the cell wall by averaging two thermistors located at the top and bottom of the electrolyte.

Pons and Fleischmann[7, 8] used a cell insulated by a silvered vacuum Dewar through which heat was lost mainly by radiation. Consequently, heat loss was proportional to ΔT^4 through part of the cell and proportional to ΔT through the lid. Energy was applied to a dead cathode in increasing steps and the resulting ΔT was used to calculate a single value for the effective thermal conductivity of the cell over a range of temperature. In addition, the cell was calibrated by applying a pulse of power to a resistor, which caused the temperature to rise and then fall in a manner determined by the heat capacity of the cell combined with heat loss from the cell. This calibration method had the advantage that it allowed sudden bursts of anomalous energy to be measured using the rate of temperature change, without having to wait for the cell to stabilize. Several evaluations [9-11] of the method concluded that their procedure was sufficiently accurate to justify some, but not all, of their claims for anomalous energy. However, other studies have not

used such a complex calorimeter or used this adiabatic method for calibration. Instead, steady-state measurements, where sufficient time is allowed for generated power and the resulting temperature to become constant, give results easier to evaluate.

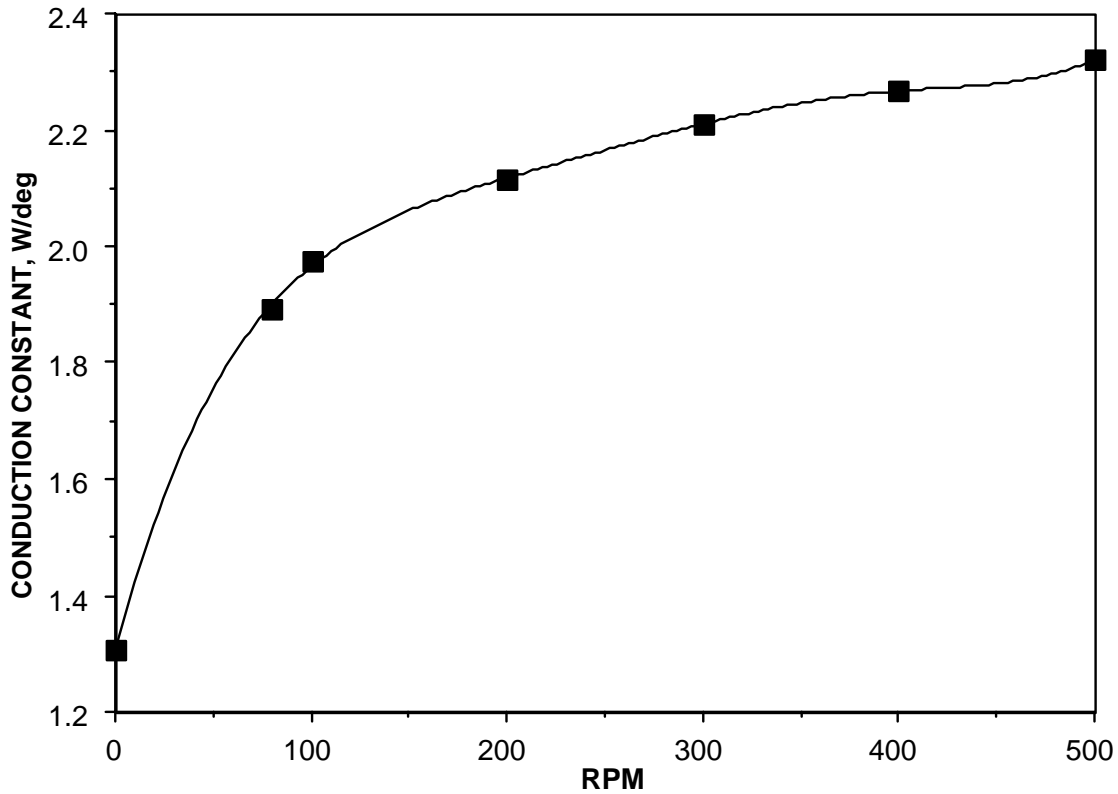


FIGURE 8. Effect of stirring rate on the calibration constant. The average temperature across the cell wall was based on the average of two thermistors located at the top and bottom of the electrolyte. The cell was stirred using a Teflon covered cross-shaped bar driven by a rotating external magnet. The calibration constant does not become constant at any practical stirring rate.

The outside temperature is generally uniform and well known, except when a cell is air-cooled. Air-cooling introduces additional uncertainty because the temperature immediately next to the container surface is not known and is subject to unstable convection currents even when a fan is used. As a result, loss of heat through the thermal barrier can be very unstable even though temperature of the surrounding air is constant.

Because these errors and ones described below are sensitive to uncontrolled variables even under the best of conditions, the method as commonly used can not be trusted to give absolute values to an accuracy better than ± 200 mW, although apparent changes in power at the 20 mW level can be detected. These characteristics make the method poor for making absolute measurements, but adequate for revealing small changes in anomalous power, provided they are part of a consistent pattern using many measurements and if the calorimeter is frequently calibrated using proper techniques. Fortunately, anomalous power is initially absent and grows relative to an initial constant background. Consequently, absolute values for background power are not required as long as the background

is stable. Even so, claims for anomalous heat based on this method cannot be trusted if they are less than about 100 mW.

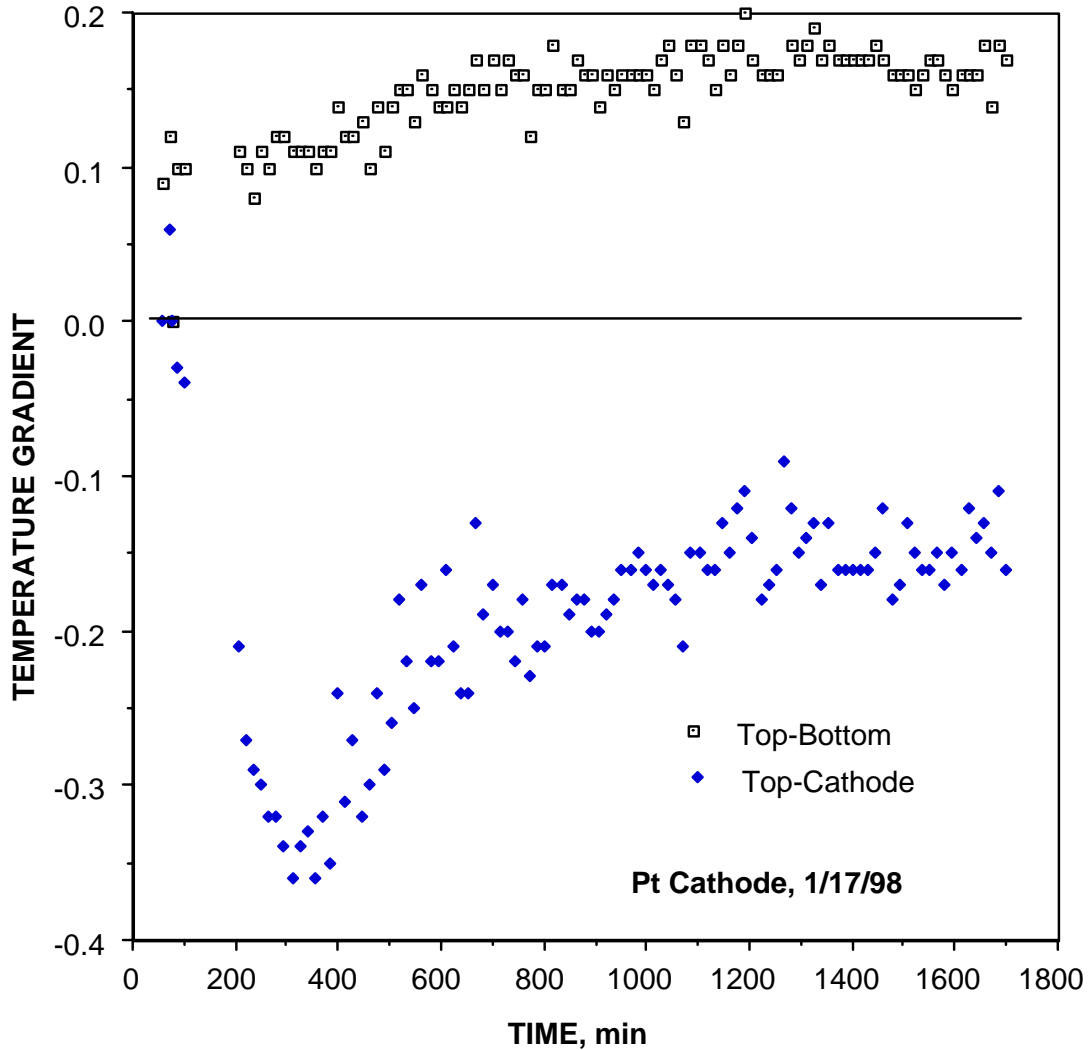


FIGURE 9. Observed changes in the gradient as a function of time. In this case, a thermistor was located at the cathode in addition to ones at the top and bottom of the electrolyte.

The second method, called double wall isoperibolic calorimetry (DWIC) avoids the gradient problem by using a second thermal barrier outside the cell. A cartoon is shown in Figure 10. Temperature is measured on the inside of this barrier, but outside of the container in which liquid electrolyte is located. Consequently, thermal gradients within the electrolyte have much less effect on measured temperature. As a result, this method is much more accurate than the former and can be made very sensitive, as described by Miles[13] and Huggins et al.[14, 15]. Only the former method (SWIC) is discussed here because its limitations are greater and its use is more common than the DWIC design, even though the latter design is much better. In addition, such cells tend to run hotter for the same applied power compared to the SWIC design, a condition that appears to improve energy production. Details about the design and characteristics can be found in the cited papers.

ISOPERIBOLIC CALORIMETER OF THE SECOND KIND

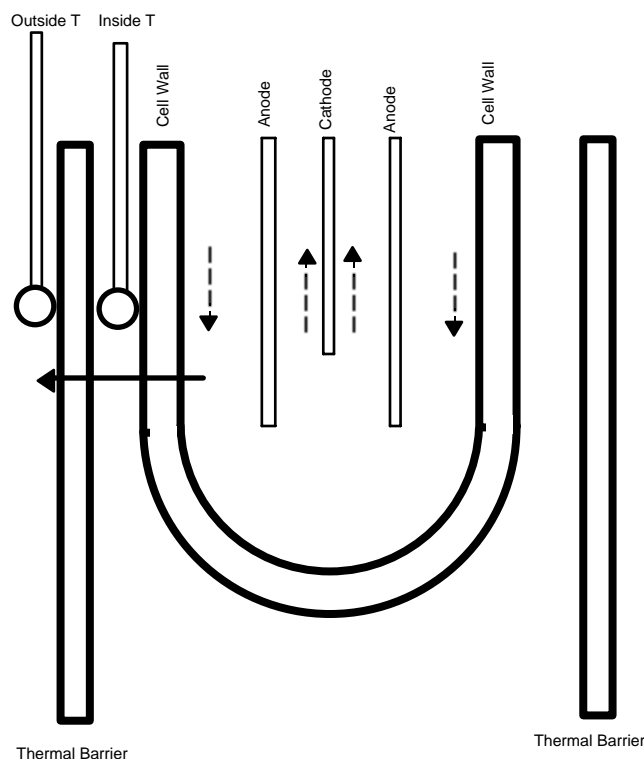


FIGURE 10. Cartoon of a double wall isoperibolic calorimeter. Arrows show the direction of heat flow caused by bubble action. The temperature shown as “Inside T” needs to be the average temperature of the cell, which can be obtained using several detectors located in a conducting metal jacket made of copper or aluminum.

II.2 Flow Calorimetry:

Flow calorimetry is more accurate and reliable than is SWIC because it is based on measuring heat energy used to raise the temperature of a known amount of fluid, generally water. Only three quantities need be measured; these being the temperature of fluid entering the calorimeter, fluid temperature leaving the apparatus, and the flow rate. Applied power is then plotted against the flow rate, F (g/min), times temperature increase of the fluid, ΔJ ($^{\circ}\text{C}$). Corrections must be made for the small amount of heat energy that leaves without being added to the fluid, generally from the cell lid. Generally, this loss is less than 2% of the total amount of energy being produced within the calorimeter and can be determined by applying a known amount of electrical energy to the cell. The stability of such calorimeters is excellent provided they are located within a constant-temperature environment. Because the calibration constant is independent of where heat is produced within the calorimeter, gradients within the electrolytic cell are unimportant. This assertion is easily demonstrated when heat, supplied from a resistor, is compared to heat generated by electrolysis, as shown in Fig. 11. These two methods generate heat in different locations because during electrolysis, bubbles reduce the gradient and heat is generated at the recombiner in addition to at the electrodes. In contrast, a resistor produces large gra-

dients and no heat is released at the recombiner or at the electrodes. Yet, the calibration constant obtained from the two methods is virtually identical.

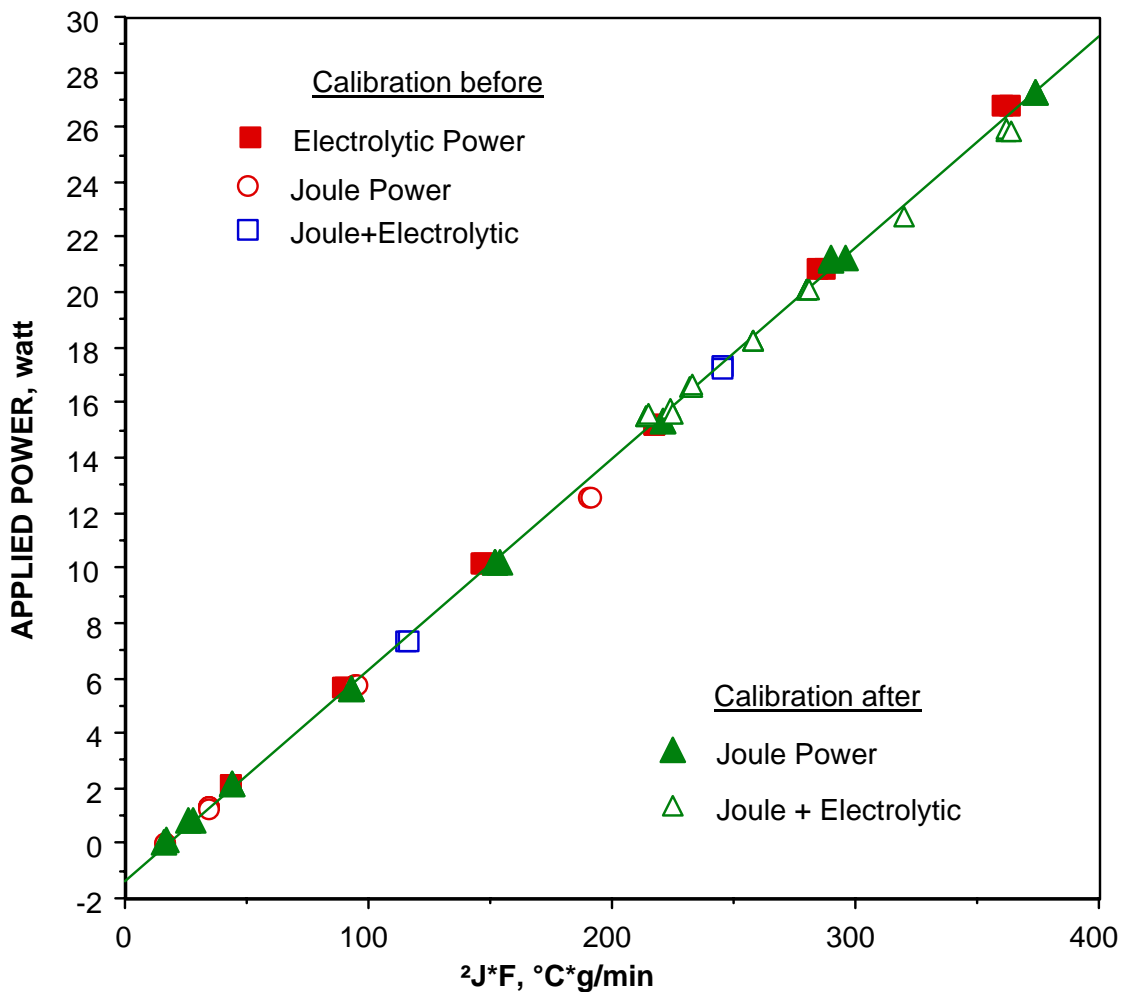


FIGURE 11. Comparison between values obtained by using electrolysis and/or Joule power. The before and after values were obtained during a study lasting hundreds of hours during which time a cathode produced excess energy. The electrolytic power was based on using a dead cathode.

A picture of a flow-type calorimeter is shown in Fig. 12 along with a drawing showing how the parts are related in Fig. 13. Constant-temperature cooling fluid is provided at a location near the input of the calorimeter by pipes containing rapidly flowing water, as shown in Fig. 14. A very small amount of this water is extracted by a

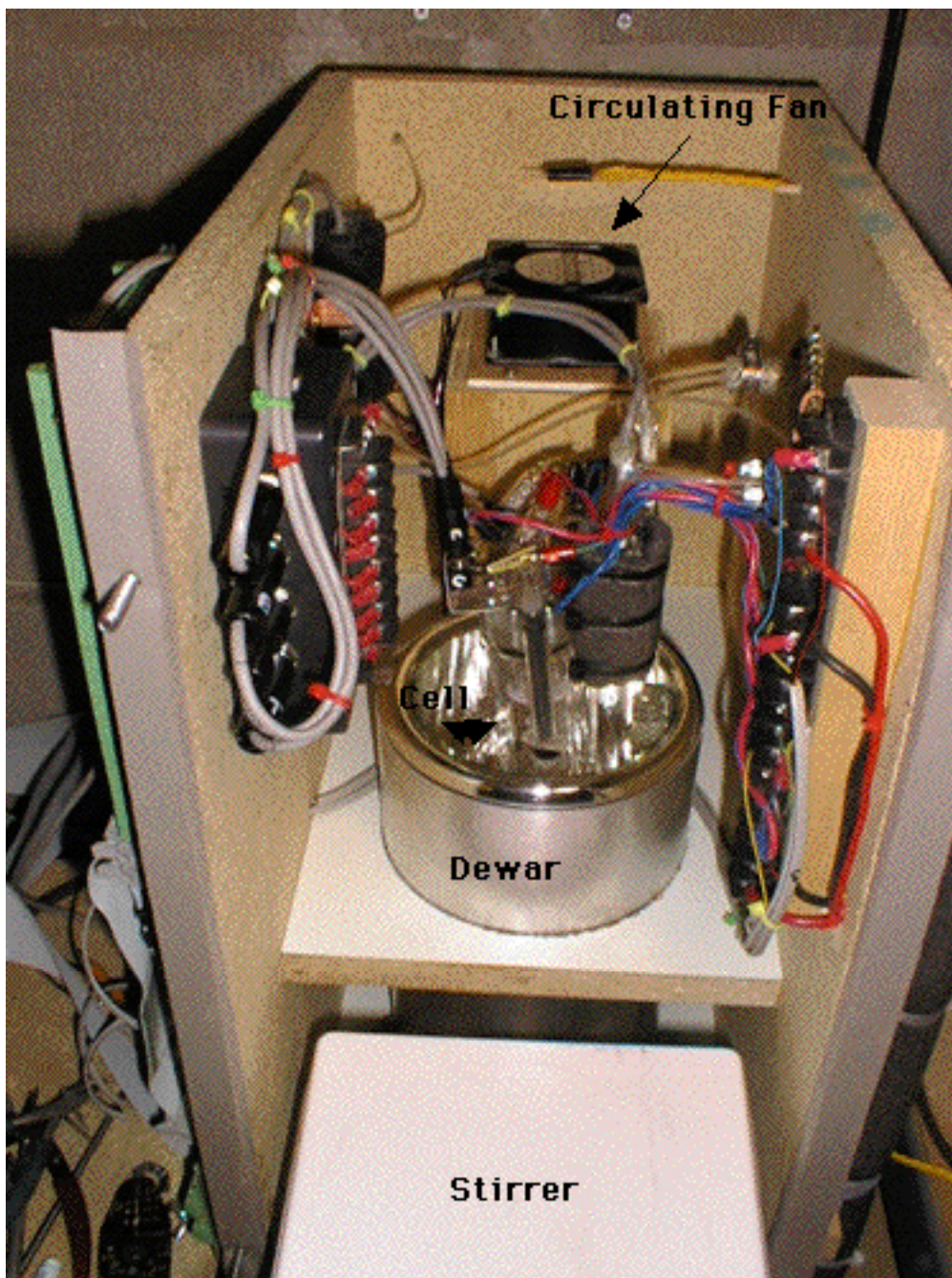


FIGURE 12. Picture of flow calorimeter. When the Dewar is raised, the stirrer is slipped under it, the top is sealed with an insulating lid, and the surrounding box is closed. As a result, the cell is thermally isolated and the whole apparatus is contained in an environment having a stability of $\pm 0.01^\circ\text{C}$.

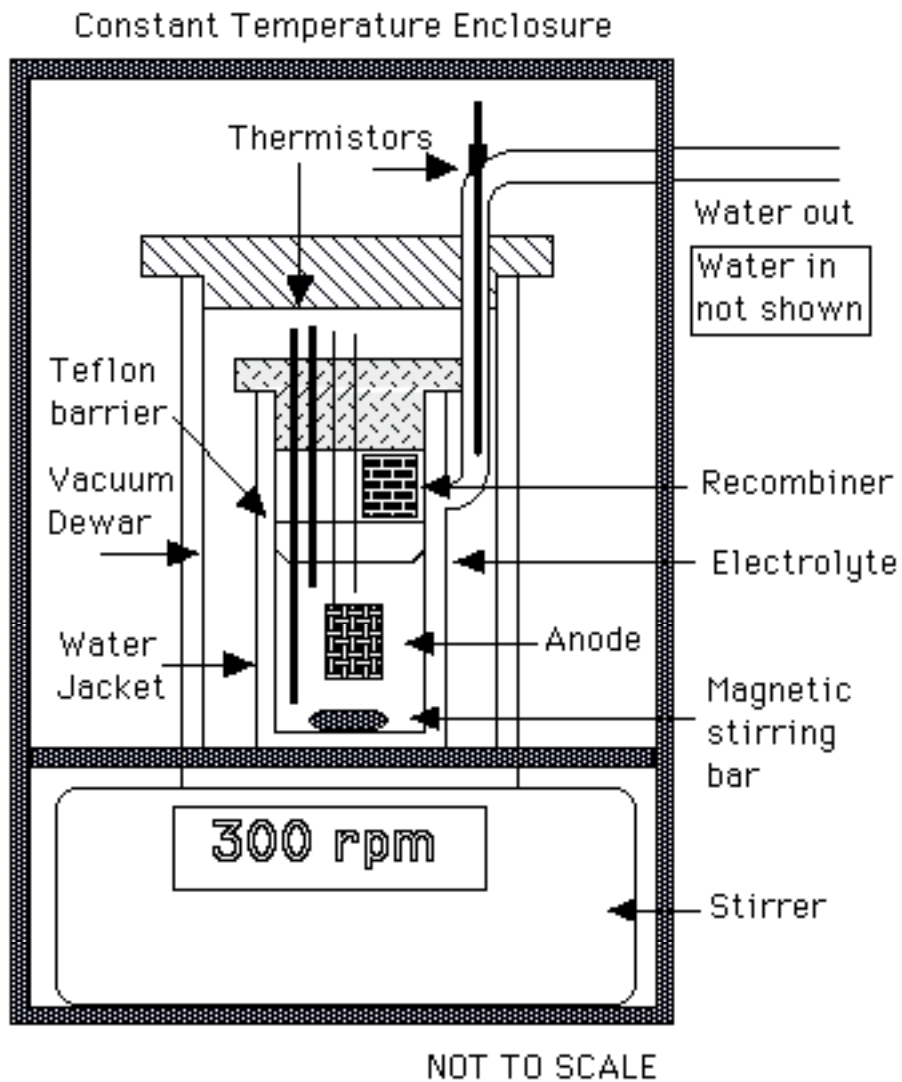


FIGURE 13. Drawing of the flow calorimeter.

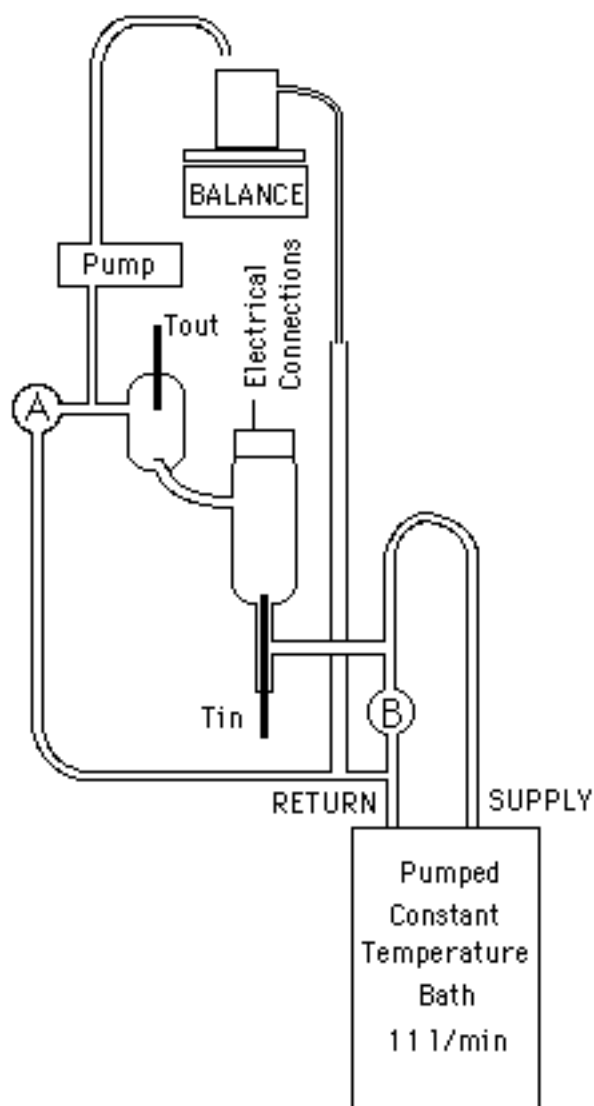


FIGURE 14. Diagram showing water flow. By using the valves “A” and “B”, water can be pumped by the bath directly through the cooling jacket to rapidly achieve a constant temperature or flow at a fixed rate determined by the constant rate pump shown near the top of the drawing. The rate is measured by collecting all water passing through the cell in the container located on a balance. This container periodically siphons back into the constant-temperature reservoir. The cell design shown here is different from the one shown in Figs 12 and 13.

precision pump² which is drawn through the calorimeter. Temperature is measured as water enters the jacket and again when it leaves using calibrated thermistors. With valve “B” closed and valve “A” open, full flow water is provide through the jacket to allow the calorimeter to be used in the isoperibolic mode. Flow calorimetry is done when valve “B” is open and valve “A” is closed. Water flow is measured after leaving the constant-flow pump by filling a container located on a balance. Weight is measured periodically

² Fluid Metering, Inc. 800-223-3388/www.fmipump.com

to determine the flow rate. The largest error in this method results from variations in flow rate.

The calorimeter is calibrated by supplying power either to an internal resistor or performing electrolysis of a “dead” electrode. Figure 11 shows typical calibration values. Experience has shown that the points generally differ from the least squares line by about ± 50 mW, generally because of variations in flow rate. In addition, variations in room temperature can change the amount of heat lost through the lid. For this reason, maximum accuracy is achieved when the calorimeter is contained in a constant-temperature environment, as was used in this design.

II.3 Seebeck Calorimetry:

Seebeck calorimetry uses thermoelectric converters within the calorimeter wall to sense the average temperature difference across the wall. The voltage generated by this difference is proportional to the amount of heat passing through the wall, provided the thermal conductivity of the wall is uniform and constant. The major error associated with this method occurs when the walls are not uniform with respect to thermal conductivity or to generated voltage for the same ΔT . If this is the case, the calibration constant will be sensitive to where the cell is located within the enclosure and to random factors that affect convection of enclosed air. Placing a fan within the Seebeck enclosure to force circulation of air can reduce this problem.

An additional problem is introduced if the outside of the wall is not uniformly cooled so that outside temperature is not independent of the amount of heat flowing through each part of the wall. This defect will effectively cause the wall to be nonuniform in its response to heat flow and be sensitive to external temperatures.

A commercial Seebeck calorimeter is available, shown in Fig. 15, which has been used by several laboratories with success. However, this device requires internal fans and a constant temperature environment to realize its highest accuracy. The uncertainty is ± 10 mW when the calorimeter is immediately calibrated using a resistor within the electrolytic cell. If the cell is placed as close as possible to the position used for previous calibrations and an average calibration equation is used, the uncertainty increases to ± 20 mW. In other words, even slight variations in the cell location will affect the calibration constant, albeit by a small amount.

A homemade calorimeter is shown in Fig. 16. This device uses PVC as a thermal barrier in which 1000 Fe-Constantan thermal couples are inserted and connected in series. The outside of the thermal barrier is in contact with flowing, constant-temperature water. This design is as accurate as the commercial device and is completely immune to changes in room temperature. Similar designs have been used with up to 50 watts of applied power.

Another variation based on the use of thermoelectric panels is shown in Figs. 17 and 18. This calorimeter is three times as sensitive compared to either the commercial device or the homemade example. Figure 19 shows a typical calibration with and without the use of an internal fan. The data show a scatter of less than ± 10 mW.



FIGURE 15. Picture of a Thermonetics Seebeck calorimeter³. The active enclosure contains three fans and is closed by the green lid sitting off to the back. After the Seebeck is closed, the surrounding box is closed by another lid, which allows the environment to be maintained at the same temperature ($20^{\circ}\pm 0.02^{\circ}$) as the cooling water provided to the Seebeck enclosure.

³ Thermonetics Co., Heinz Poppendiek, 7834 Esterel Drive, La Jolla, CA 92037.



FIGURE 16. Photo of a homemade Seebeck calorimeter based on use of thermocouples. A total of 1000 Type J wire thermocouples were placed in the thermal wall made of PVC tubing. The wires were butt welded on the inside and lead soldered on the outside. The outside surface was waterproofed so that constant temperature water could flow in the surrounding jacket. A muffin fan circulates air within the calorimeter when the lid is closed.

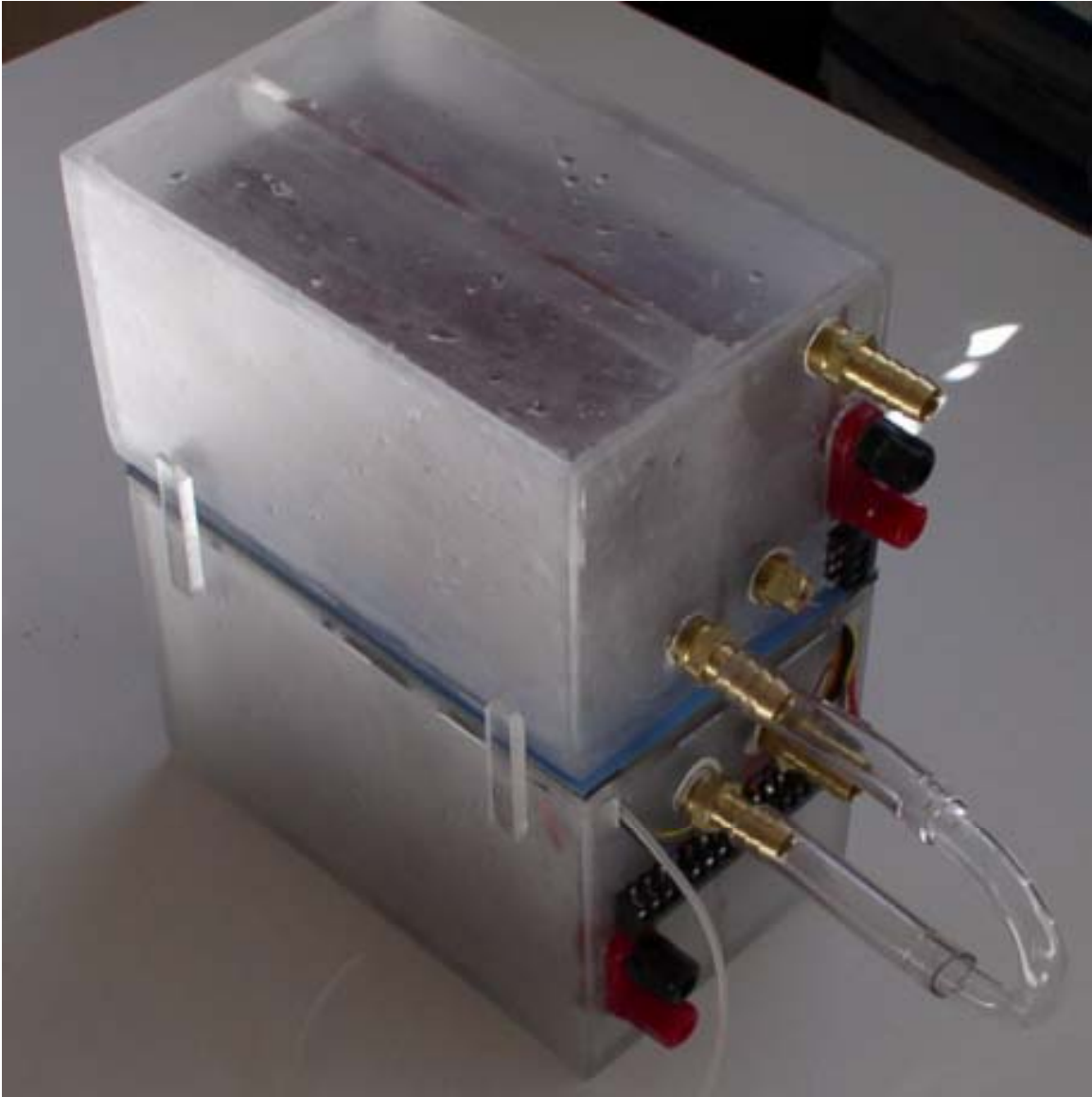


FIGURE 17. Photo of a homemade Seebeck calorimeter using 16 commercial thermoelectric panels.

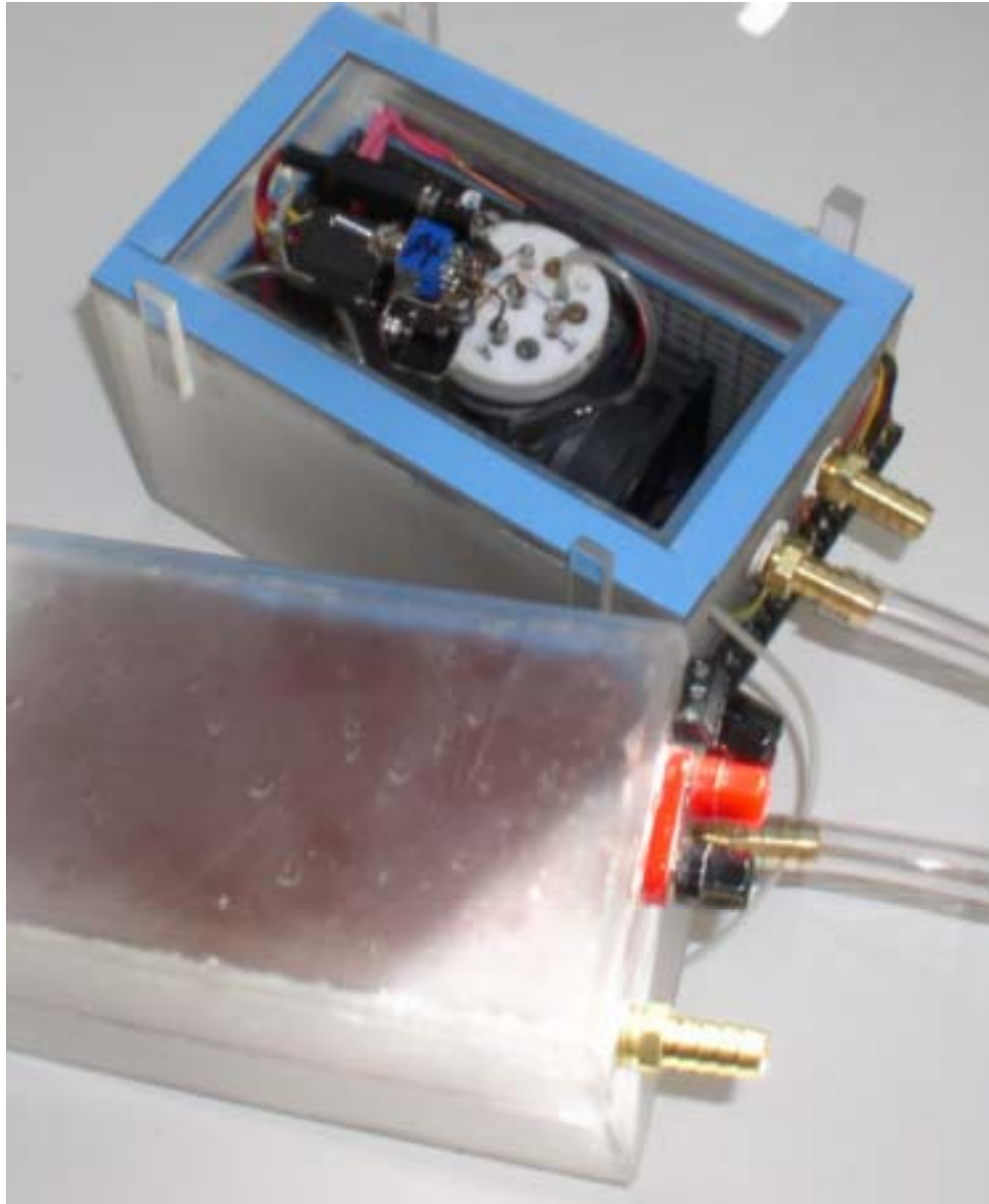


FIGURE 18. Open view of the Seebeck calorimeter made from thermoelectric panels. The top of the electrolytic cell is visible. Next to it is a small fan. Because the chamber is completely surrounded by flowing water, the device is completely inert to changes in room temperature. The active surface of a panel can be seen within the enclosure.

Although the Seebeck calorimeter is insensitive to many errors suffered by the other designs, one problem shown by the Seebeck also applies to other designs. Because power is normally applied to a cell either as constant current or constant voltage, if the cell resistance changes, the amount of applied power will also change. If this change occurs sufficiently rapidly, with a time short compared to the thermal time constant of the device, an indication of excess power may be seen. This effect occurs because applied power is measured immediately, while the loss of power from the cell takes time to be detected. When applied power, determined by the product of cell voltage and current, is

subtracted from power loss, determined by the Seebeck voltage, the apparent difference will not be correct. Figure 20 shows what appears to be excess power caused by the applied power change shown in Fig. 21. The corresponding negative power associated

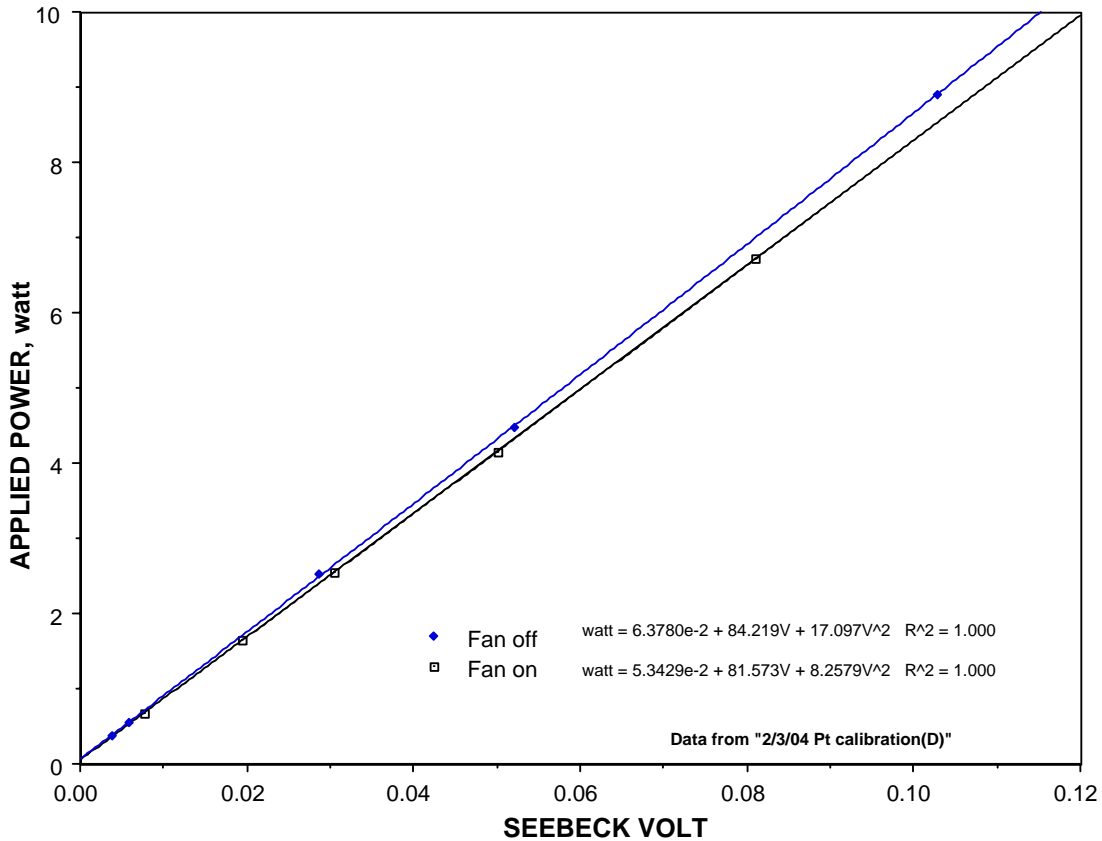


FIGURE 19. Typical calibration for the Seebeck shown in the previous pictures. The curves are not linear because voltage output is not linear with temperature. Use of a fan results in a greater voltage because all panels are not alike in their behavior.

with a return of applied power to its initial value might be missed if applied power changed at a sufficiently slow rate. As a result, only the positive component of the change would be seen and attributed to an exothermic reaction. Rapid changes in cooling water temperature can produce similar false indications of excess power. Because these and the other sources of error, false data can occur without warning. A person reporting such data must demonstrate awareness that such processes might be operating at the time of the study.

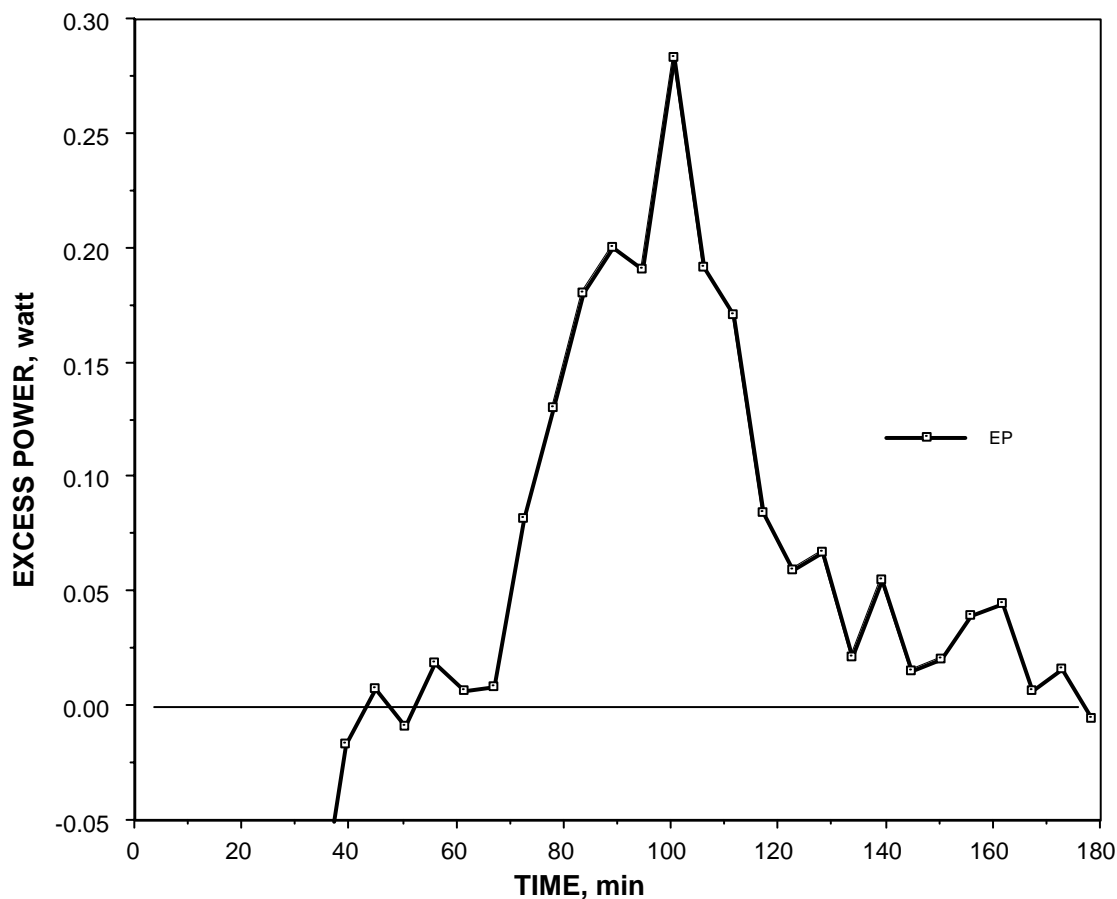


FIGURE 20. Apparent excess power created by an artifact.

II.4 Ways Calorimetric Data are used to Calculate Excess Heat Production:

It is important to understand that calorimetry is not an absolute measurement. All values are relative to the behavior when a known amount of power is applied to the device. Consequently, the only requirement for accuracy is for the behavior to remain constant between calibration and during the actual measurement. In other words, energy loss to the environment is not important as long as it is constant, and the value is known based on a suitable calibration.

Calorimetric behavior can be completely analyzed by applying very complex equations[3,6], as a number of authors have done. Such detailed analysis is useful to understand some of the variables expected to affect the results. However, most of the variables revealed by such analysis can be ignored when a suitable design is used. In other words, rather than attempt to correct for deficiencies using correction factors based on mathematical formulation, a better method is to design a device that does not exhibit these deficiencies. As an example of a correction for a deficiency, corrections can be made for variations caused by changes in room temperature by calculating a loss rate through that part of the apparatus that is not at constant temperature, generally the lid through which the wires pass. This method is not as satisfactory as placing the entire calorimeter in a constant temperature environment, including the wires. Such an arrangement insures that the heat loss rate is constant, hence has no effect on the results. As

another example, the generated gas can be allowed to leave the cell and corrections made as described later in the paper. This deficiency and potential error can be easily eliminated by placing a catalyst within the cell to cause all gas to form D₂O before leaving the cell. Worries that such materials would introduce harmful impurities into the cell have been groundless. This approach also eliminates changes in behavior caused by changes in liquid level. When all such deficiencies have been corrected in the design, excess power can be calculated using the simple equations shown below. Although a calorimeter is expected to show linear behavior, the various ignored variables result in nonlinear behavior that can be fit very well by a quadratic equation. Although the resulting constants in these equations have arbitrary meaning, accurate results require only that the constants not change between conditions existing during calibration and during the search for excess energy, a condition that is easy to evaluate and control.

1. SWIC and DWIC: Excess power = $A + B \cdot \Delta T + C \cdot \Delta T^2 - V \cdot I$ where A, B, and C are constants obtained from the calibration process, ΔT is the temperature drop across the thermal barrier, V (volt) is the voltage applied to the cell at the thermal boundary of the calorimeter, and I (ampere) is the current passing through the cell.
2. Flow-Type: Excess power = $A + B \cdot F \cdot \Delta T + C \cdot (F \cdot \Delta T)^2 - V \cdot I$ where A, B, and C are constants obtained from the calibration process, ΔT is the temperature increase of the flowing fluid, F (g/min) is the flow rate, V (volt) is the voltage applied to the cell at the thermal boundary of the calorimeter, and I (ampere) is the current passing through the cell.
3. Seebeck: Excess power = $A + B \cdot S + C \cdot S^2 - V \cdot I$ where A, B, and C are constants obtained from the calibration process, S (volt) is the voltage generated by the thermoelectric converters, V (volt) is the voltage applied to the cell at the thermal boundary of the calorimeter, and I (ampere) is the current passing through the cell. If a fan is used, power supplied to it also needs to be subtracted.

In all cases, excess power is detected when more heat leaves the calorimeter than is applied to the electrolytic cell.

These equations assume that DC power is being applied to the cell. The problem becomes more complex when AC power is applied. Because bubble action rapidly changes the resistance of the electrolyte, a small AC component is introduced into the DC output of the power supply, which does not occur when a calibration resistor is used. Experience shows that modern power supplies generate no more than 50 mV of AC superimposed on 15 V and 3 A of DC⁴, which introduces a trivial error when a resistor is used for calibration. If calibration is done using a dead cathode, which generates a similar AC component, this potential error cancels.

II.5 Effect Calorimeter type on the Observed Behavior:

The choice of calorimeter used for such studies determines the temperature experienced by the LENR environment, the time required to achieve steady-state, and the

⁴ Less AC component is introduced when applied power is reduced. Consequently, cells that generate anomalous power at lower applied power are much less affected by this potential error.

smallest amount of anomalous energy that can be believed. Additional considerations are cost and ease of use.

The amount of heat produced by a LENR reaction is sensitive to temperature at the spot where the reaction occurs. In an electrolytic cell, this location is the surface of the cathode. Each of the calorimeter types removes heat from the cell with different efficiency. Therefore, each type will show a different relationship between applied electrolytic power, resulting cathode temperature, and the observed excess energy. Because the LENR reaction is sensitive to temperature, the observed behavior will be different, depending on the kind of calorimeter used.

A calorimeter should respond quickly to changes in power so that bursts of anomalous power can be detected, in addition to requiring less time before data can be taken after changes are made. Generally, the smaller the cell, the more quickly the calorimeter will respond.

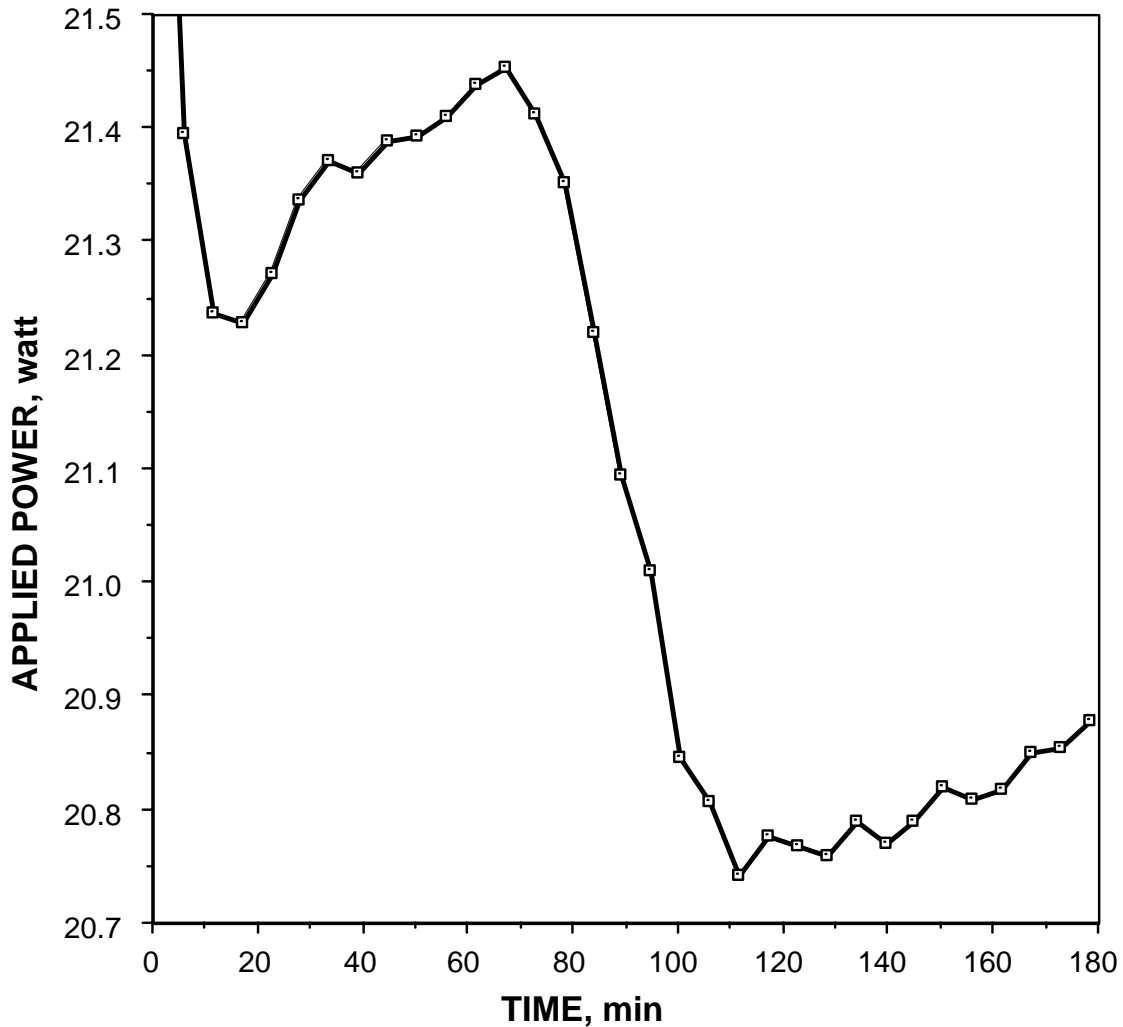


FIGURE 21. Example of a sudden change in applied power that produced an excess power artifact.

II.6 Consequences of Using Thermodynamic Open Cells:

In order to measure anomalous energy correctly, all energy produced in the calorimeter must leave the device only as heat. When the LENR effect is produced using electrolysis, D_2 (H_2) and O_2 gases are generated. Unless these are recombined back to D_2O (H_2O) within the calorimeter, they will carry chemical energy out of the device. Only if all generated gas is known to leave the cell can the amount of lost energy be calculated and added to the measured value. Otherwise, any unexpected recombination will be interpreted as excess power. Therefore, evaluating the error this effect introduces rests on knowing exactly how much, if any, gas leaves the cell. This problem is eliminated when a catalyst is placed in the cell. Such a design is called a thermodynamically closed system, which is frequently sealed from the atmosphere as well. The problem can also be solved by measuring the exact amount of D_2O that is lost during a known period of time at a known applied current.

The energy lost by H_2 and O_2 leaving the cell is calculated as follows.

When electrolysis occurs in a cell containing water, H_2 is produced at the cathode and O_2 is produced at the anode. The rate at which these gases are produced is determined by applied current (A) and is calculated using the following equation:

$$\text{Rate (moles of } H_2O \text{ decomposed/sec)} = A / (2 * 96489).$$

In other words, a current flow of 53.605 Ampere-hours or 53.605 Coulombs will decompose 1 mole of H_2O to give one mole of H_2 and 1/2 mole of O_2 .

The energy required to generate these gases is equal to the enthalpy of formation of water ($\Delta H=68,300$ kcal/mole) times the number of moles of H_2O consumed.

Consequently, the energy (E) used to create these gases can be calculated using the following equation:

$$E = \Delta H * A * t / (96489 * 2), \text{ where } E = \text{kcal of energy used during the time "t" (sec).} \quad (1)$$

The amount of lost energy can be calculated another way as follows:

$$E * 4.189 / t = \text{Power in watts being lost} \quad (2)$$

$$\text{Watts} = \text{volt} * \text{current} \quad (3)$$

Substitution of Equation 1 into Equation 2 and the result into Equation 3 gives, upon rearrangement, the following equation expressed in volts.

$$\text{Volt} = (68300 * 4.189) / (2 * 96489) = 1.48 \text{ volts}$$

When current applied to the cell is multiplied by this voltage, power being used to decompose water can be calculated for standard state conditions (STP). In other words, Equation 1 has been rearranged to allow the calculation to be made by a single multiplication. The voltage has no meaning except as a constant that results from combining

Equations 1, 2 and 3. If the conditions do not correspond to STP, small corrections will be required. A similar calculation can be made for D_2O to give a value of 1.54 V.

For convenience, this value is called the “neutral potential” for water decomposition because it is the theoretical voltage required to produce a current flow through a cell that results in decomposition of water. Real cells will require different voltages to initiate current flow, depending on conditions existing in the cell. Such measured voltages cannot be used to calculate the amount of energy lost from the cell unless the exact nature of the chemical reactions is known.

Unless the cell contains a catalyst known to completely convert all gas to liquid water, the amount of gas that leaves a cell can be variable and related to applied current, as shown in Fig. 19. Small areas of metal exposed to the gas can cause some recombination in excess of values shown here. Nevertheless, application of current above about 100 mA reduces the amount of recombination within the cell to insignificant values.

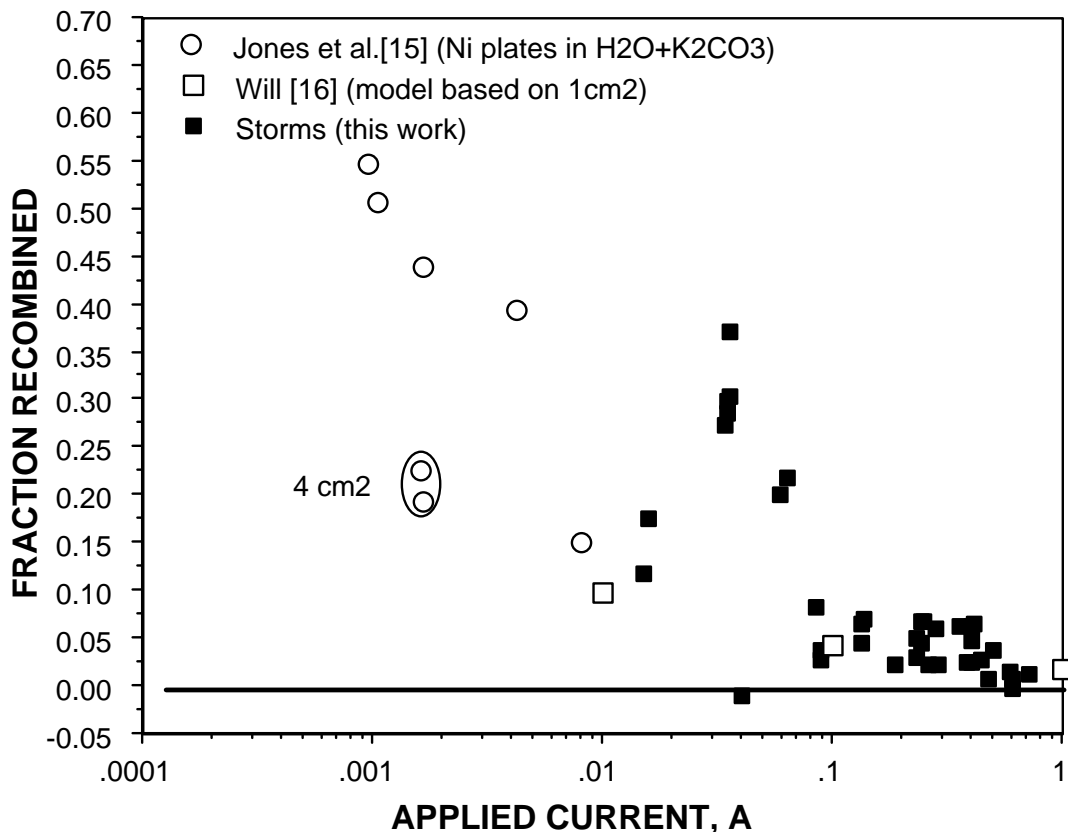


FIGURE 19. Relationship between applied current and amount of recombination within a cell in the absence of a catalyst.

In my work, the cells communicated to an oil reservoir, as shown in Fig. 20. This arrangement allows the D/Pd ratio of the palladium cathode to be determined because accumulation of orphaned oxygen, produced when D_2 reacts with the Pd cathode, trans-

fers mineral oil to the balance. Because this arrangement gives about $4200g^5$ of oil for each mole of D retained by the Pd, it provides a very sensitive method to determine the D/Pd ratio. Failure of the recombiner is immediately revealed by a steady increase in displaced oil even after the Pd has reached its maximum D/Pd ratio. The data (Storms) shown in Figure 19 was obtained by removing the catalyst and measuring the amount of generated gas using this arrangement.

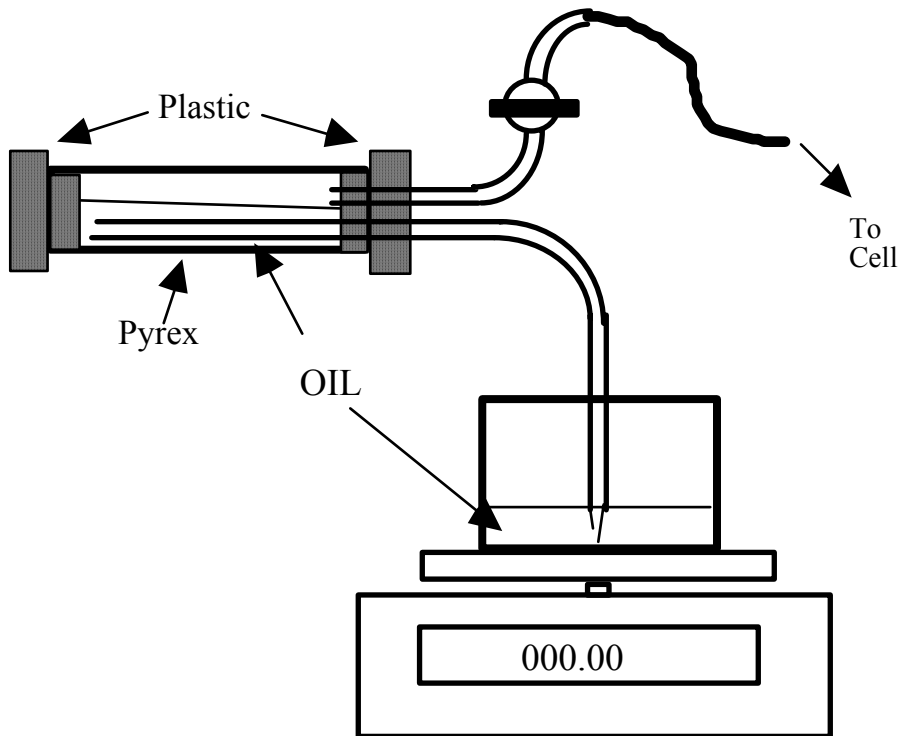


FIGURE 20. Drawing of the oil storage and weighing system. Any gas generated in the cell displaces oil onto the balance. Suitable calibration allows this method to measure the D/Pd ratio of the cathode to ± 0.001 , to determine the amount of recombination in the absence of a catalyst Fig. 19, and to demonstrate that the catalyst is working properly.

II.7 Consequence of Prosaic Processes Occurring Within the Calorimeter:

A number of prosaic processes have been suggested that have been previously evaluated by Storms[16, 17]. If real, these processes, as well as others that have not yet been suggested, have the potential effect of producing either extra energy that is interpreted as energy resulting from the proposed cold fusion processes, or using energy, which is frequently interpreted as an obvious error. A problem is created if the prosaic process absorbs energy for a while, hence is ignored, and then releases this energy, which is then interpreted as evidence for an anomalous effect. However, for such a process to operate, a chemical or physical mechanism must be present that can store and then release large amounts of energy. No one has yet identified such a mechanism when only Pyrex, D_2O , Pt, and Pd are present, the main constituents of a Pons-Fleischmann cell.

⁵ This number depends on atmospheric pressure. The quoted value is for average pressure at 8300 feet, the elevation of my laboratory.

Other methods, such as gas loading or ion bombardment, found to produce anomalous heat using different materials, would each have to be consistent with the proposed prosaic processes for the mechanism to be a plausible explanation. In addition, Rejection of the results based on prosaic processes requires that many different prosaic processes are operating, all giving the same result, or the same prosaic process is operating under many different conditions. So far, none of the suggested prosaic processes meet these conditions.

III. SUMMARY

Calorimetry applied to the LENR phenomenon has evolved since 1989 and is now close to the state of the art for measurement of energy production. The Seebeck method provides the most stable and most accurate method, as suggested previously by Bush[18]. Such calorimeters can now be made easily with very little cost or purchased from commercial sources. Nevertheless, even the simple single wall isoperibolic (SWIC) method can be made useful if factors that affect behavior are well understood and are taken into account when the results are analyzed. Unfortunately, reasons for early rejection of such data were based on a very limited and generally incorrect understanding of calorimeter behavior.

This study has resulted in the following issues and conclusions:

1. The SWIC method cannot be calibrated using an internal resistor to apply Joule heat. Accurate calibration can only be obtained using a dead cathode and passing current through the electrolyte. Stirring is beneficial.
2. Flow-type and Seebeck calorimeters can be calibrated using an internal resistor within the cell because the results are independent of where heat is produced within the electrolytic cell.
3. The major error in flow calorimeter involves achieving a uniform and known flow rate.
4. The major error in Seebeck calorimeter involves maintaining a uniform temperature at the outside of the thermal barrier and good circulation of air within the enclosure. Air-cooling of the outside cannot be relied on to give stable results.
5. A constant temperature environment, which is able to effectively carry the heat away, must completely enclose all calorimeters. Use of air-cooling as the major method to remove heat is not satisfactory and will not give stable results.
6. In general, the simpler the method and the less complex the data analysis, the more easily the results can be believed.

Numerous laboratories, using three different types of calorimeters having a variety of designs and characteristics, have studied the LENR effect and report the same anomalous behavior. This kind of reproducibility is much more significant than the ability of a particular researcher to make the effect work on demand, as many skeptics demand. Indeed, as conditions needed to create anomalous effects have become better understood, researchers who use this knowledge now produce the effect with good success.

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