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Research Article

Building and Testing a High Temperature Seebeck Calorimeter

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Abstract

A high temperature Seebeck calorimeter capable of operating at 200–300°C was built and tested. The testing used a glow discharge tube containing plated palladium on the side walls and a molybdenum central anode. Running with deuterium gas and high voltages demonstrated excess thermal power at levels of 5–10 W but no excess power was observed when natural abundance hydrogen was used. In addition to the normal Seebeck measurements, excess power was also observed using back-off power measurements of the enclosure heater containing the Seebeck. A resistive control heater was used to verify the system.

Keywords: Anomalous energy, Gas discharge reactor, High temperature Seebeck fabrication, Seebeck calibration, Seebeck calorimetry

1. Introduction

The design intent of the LENR prototype is to provide quality Seebeck-style calorimetry at reactor temperatures of 200–300°C. The reactor is a stainless-steel cylinder, 1-inch OD, 7/8-inch ID, one foot long, which is inserted into a copper rectangular block during operation. hydrogen-absorbing metals can be plated onto the interior walls of the cylindrical reactor or tubular metal/alloy inserts can be placed inside the cylinder for testing. Thermoelectric devices are mechanically attached to the sides, top, and bottom of the copper block. Aluminum heat fins are attached to the outside surface of the thermoelectric devices to provide a constant temperature interface. A commercial freezer surrounds the reactor and Seebeck assembly, capable of providing a constant temperature environment. A typical thermal enclosure set point is 28°C. The system was designed by Dennis Letts with additional design and prototyping by Mike Guerrina and Carlos Jobe of Apparent Technologies Inc., Austin, Texas.

1.1. Experimental setup (Fig. 1)

The system consists of three main components. (1) The instrument rack containing power supplies to drive the reactor, to heat the copper block, to power the thermal enclosure heaters, and to actuate electronic valves. (2) The thermal

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Figure 1. The instrument rack on the far left holds power supplies for system heat and fans plus the KEPCO 1000–0.2 MG power supply for the discharge. The rack also holds the lab computer that controls all instruments using LabView.

enclosure houses the high temperature Seebeck and the reactor; the enclosure holds ambient temperature at 28 $\pm$0.1°C. (3) A vacuum pump capable of reaching 9 $\times$ 10^{-8} Torr with a pressure control and measurement manifold attached to the side of the thermal enclosure. All vacuum connections are Swagelok VCR quality, ranging from 1/4 in. to 1 in. in diameter. Nickel gaskets with retainer clips are used on all vacuum connections. Various instruments are placed on top of the thermal enclosure for convenience; instruments shown are a Fluke 105B oscilloscope to monitor the discharge voltage and current, Keithley multimeters to provide redundant voltage and current readings, a magnetic ballast sits on top of the Keithley multimeters to provide current and voltage stability when the discharge is running. This serves to eliminate current spiking and makes the input power readings stable and reliable. The final instrument is an HP RF generator used with 4–10 W amplification to occasionally attempt RF triggering of exothermic reactions in the reactor [1]. The amplified RF is coupled to the high voltage DC discharge power by using a bias T built by Barth Electronics of Boulder City, Nevada.

1.2. Design and fabrication details

The LENR tube (LT) is shown in Fig. 2. The tube is made from 316L stainless steel, about 11 in. long, 1-inch OD and 7/8-inch ID. The end is orbital welded. The tube is sealed with a 1-inch VCR nut and gas is introduced to the reactor through a 1/4 in. stainless tube fitted with a 1/4 in. VCR connector. A 5 kV high voltage connector conducts high voltage DC to the reactor. Positive DC goes to the anode and the case is grounded negative, serving as the cathode. The reactor is plated in a separate bath using normal methods of electrochemical plating, discussed in more detail below. The reactor can reach high vacuum at 9 $\times$ 10^{-8} Torr. Motor magnets are fitted around the reactor body and provide a 230 G magnetic field at the reactor inner surface (not shown). The magnetic field at the inner wall was measured using an Alpha Lab model GM-1-ST gaussmeter. Magnets were placed around an open tube of 316L stainless steel with

Figure 2. Figure shows the reactor used for the experiments – a 316L stainless steel tube approximately one-foot in length with an outside diameter of one-inch. Swagelok VCR connectors are used to seal the unit capable of holding vacuum to 10^{-9} Torr. High voltage DC is supplied to the reactor via a 5-kV connector obtained from MPF Products. Clamshell motor magnets (not shown) are placed around the reactor during operation and provide 230 G on the inner wall of the reactor.

identical OD and wall thickness as the reactor to facilitate the measurement. A small field probe was inserted into the stainless-steel tube and the measurement was made at the inner wall with the magnets in place.

The reactor and its attached magnets are inserted into a central bore hole drilled into the $3 \times 3 \times 15$ in. copper rectangular block. The block is equipped with four Watlow heaters and four Omega thermocouples. The Watlow heaters can dissipate up to 800 W of power but the maximum power dissipated in practice is 300 W.

The thermoelectric devices are from Tecteg Manufacturing, Ontario, Canada; the devices in use are rated to 350°C and other devices can be obtained that can handle 850°C. The lower temperature devices were chosen because they had a shorter lead time. The thermoelectric devices are attached to the copper block using machined clips as shown in Fig. 4. Not all of the surface area are covered but the conversion from heat flow to voltage is very consistent and repeatable from experiment-to-experiment. The aluminum heat fins are attached to the copper block using Bellville washers to provide a constant force and consistent thermal contact. The washers are shown in Fig. 4 (inset).

Thermocouple and block heater placements are shown in Fig. 5. Thermal enclosure temperature is controlled by running the commercial freezer compressor in opposition to the heat produced by the Seebeck and a 450 W Watlow heater positioned above the fans against the back wall of the enclosure. Additional air stirring is provided by a large freezer fan in the ceiling of the enclosure. Enclosure temperature variation is less than ± 0.1°C (Fig. 6).

The 1/4 in. Watlow heater shown in Fig. 5 right balances against the freezer compressor to provide stable enclosure temperature. Interestingly, when excess power appears in the reactor, it flows out of the reactor and into the enclosure to assist the Watlow heater. Power provided to the Watlow heater declines (i.e. the power “backs off”) in quantitative agreement with the excess power reported by the TEC devices. This feature provides a dual-method calorimeter using independent measurement methods.

Figure 7 shows the Seebeck calorimeter in its thermal enclosure, with its bolted down lid equipped with TEC devices and heat fins. A Helmholtz coil surrounds the Seebeck and allows the imposition of up to a 40 G field onto the reactor inside the Seebeck. The coil can be used to stimulate LENR reactions or to cancel the earth’s magnetic field.

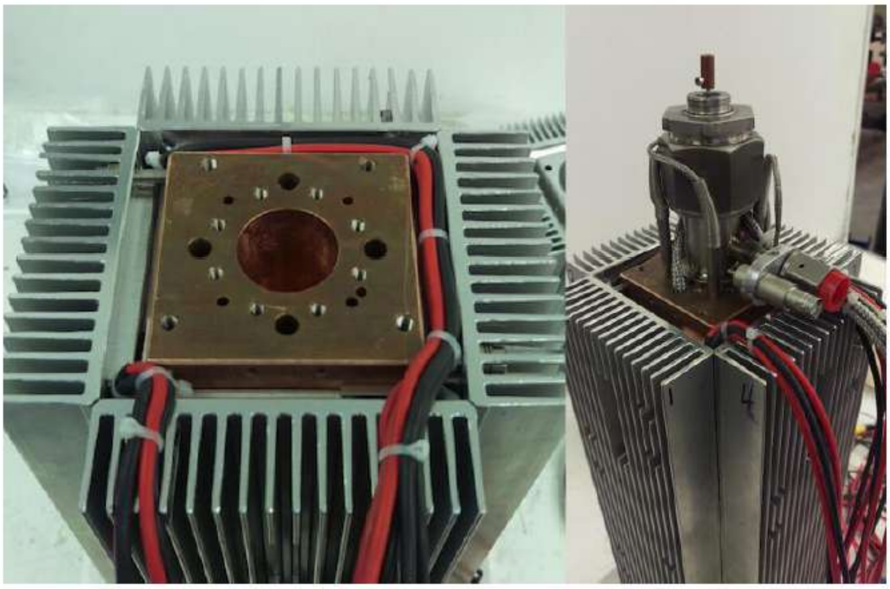

Figure 3. The left portion shows the copper block core of the Seebeck calorimeter. The reactor and attached magnets are placed into the central borehole. The larger 1/4 in. holes in the block hold the Watlow resistance heaters that provide minimum heating desired for the reactor. The 1/8th-inch holes are for Omega thermocouples. The right portion shows the reactor in place. A machined lid fits over the reactor and is bolted in place during operation.

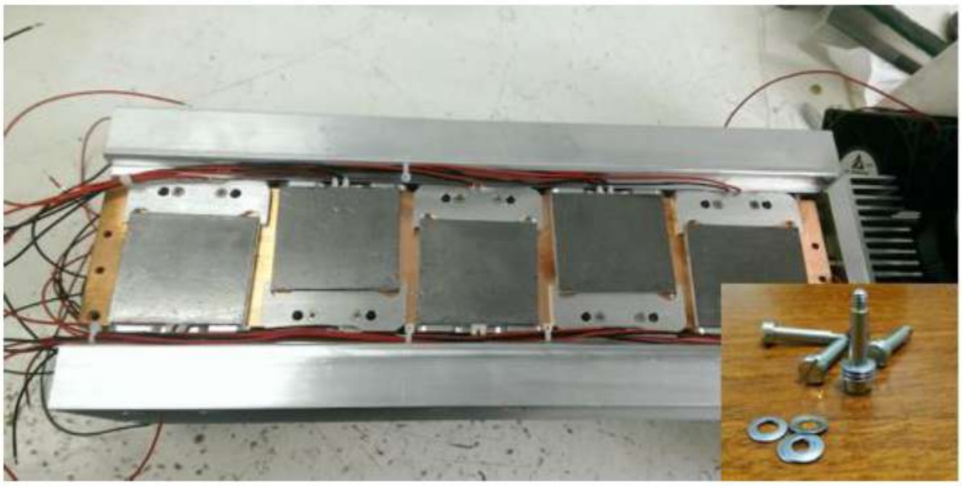

Figure 4. Figure shows how the thermoelectric devices are attached to the copper block using Bellville washers, shown in the inset. The Bellville washers provide a constant force to the heat fins as they press against the thermoelectric devices.

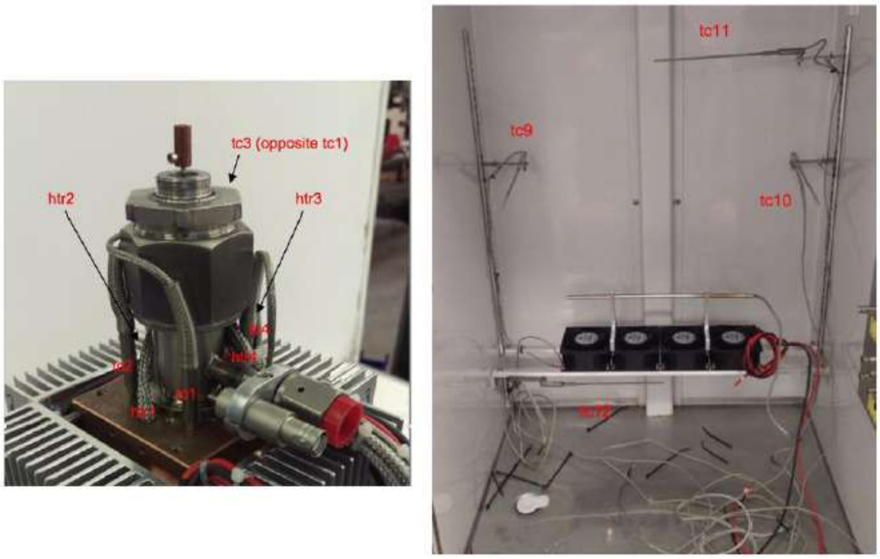

Figure 5. Left-hand side shows the positioning of four thermocouples (tc1–tc4) and four Watlow resistance heaters (htr1–ht4). Right-hand side shows the placement of four thermocouples (tc9–tc12) to monitor and control thermal enclosure temperature. Note the Watlow resistance heater above the four stirring fans that is used to keep the thermal enclosure at a constant temperature, as shown in Fig. 6.

The coil is controlled by Labview. The TEC devices are wired in series and voltage is sent to a datalogger through the enclosure panel, as shown by the red and black cabling. There are 12 thermocouples that are also read by a datalogger via the yellow type K connectors shown in Fig. 7. Electrical power to drive the enclosure heater, fans, and the reactor at high voltage is also passed through the panel. A single 1/4 in. vacuum/gas line connects to the reactor through

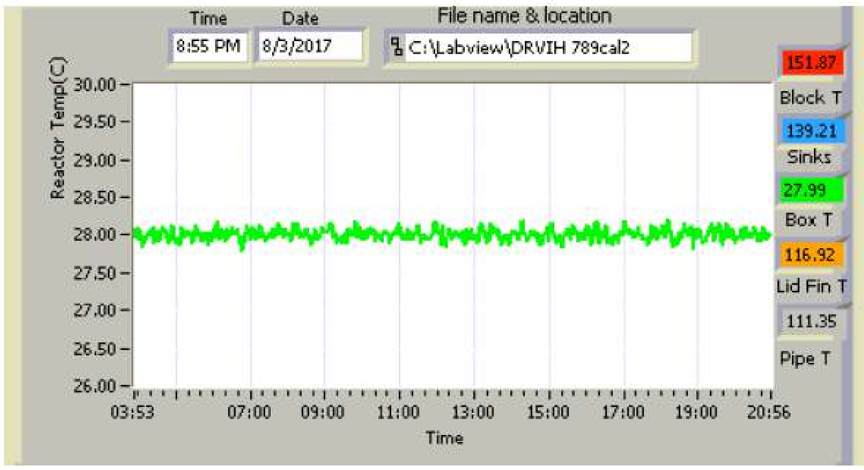

Figure 6. Figure shows the average temperature of the thermal enclosure over an 18-hour period.

Figure 7. Figure shows the Seebeck calorimeter with the bolted lid in place, circulating fans, and data cables connected at the enclosure interface. The Helmholtz coil can be used as a listening coil for RF/acoustic signals emanating from the reactor or to apply a 40-gauss magnetic field to the reactor. Of note: the reactor produces a 3.5 kHz signal when operating and has been detected using the Helmholtz coil and verified with an Agilent spectrum analyzer.

the side panel; three electronic valves can be actuated to selectively pump the reactor down in pressure, or to add deuterium/hydrogen to a desired pressure. In operation, a layer of high temperature insulation surrounds the Seebeck to boost internal temperature.

2. Calibration and Experimental Results

The calibration produced a calibration equation of $P(W) = 0.0651\times$ mV –167, where mV is the total voltage output of the Seebeck in millivolts less a constant term of 167. This equation was applied to the Seebeck output voltage and the result is shown in Fig. 10.

We also completed a calibration that combined data points using discharge power and resistive heater power with data points using resistive power only. This result is shown in Fig. 11.

Reactor #780 was plated with 0.48 g of palladium, on the inner wall of the cylindrical reactor. This was done using normal plating methods at 1 A, 50°C. 16 g of $PdCl_2$ 5% solution (Alfa-Aesar) was plated, which contained approximately 0.48 g of palladium. Plating depth was estimated at 5–10 μm over about 6 in. of the 11 in. reactor. Two-piece Clam-shell motor magnets were place around the exterior of the reactor during plating and operation. The magnetic field at the interior wall was measured at 230 G. From previous work, it is thought that an external magnetic

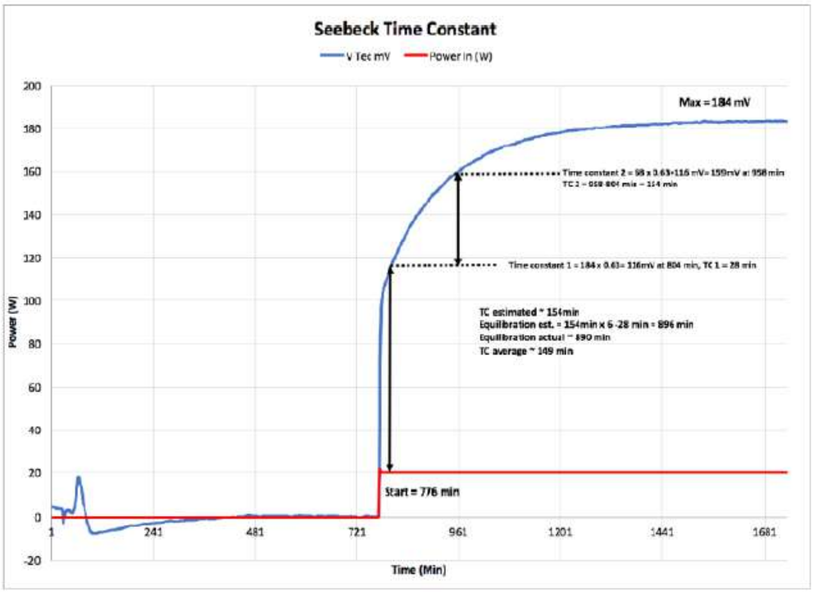

Figure 8. The Seebeck has dual time constants, the reason for which is not clear. The TEG manufacturer suggests it may be due to the fact that the thermoelectric devices are a composite of BiTe and PdTe. This plot is NOT for calibration, only to show the time constants of the Seebeck.

field influences excess power production via the Larmor precession frequency [2].

As Fig. 10 shows, the experiment began with light hydrogen in the reactor and a discharge power applied to the reactor of about 72 W (350 V, 200 mA). Power was in balance with zero excess power reported for about 15 h, demonstrating the calibration was sound. Near minute marker 1000, light hydrogen was pumped out of the reactor and replaced with deuterium. Excess power remained near zero as the high voltage was cycled off and on. Near minute marker 3600 deuterium was added to the reactor and power-out began to increase over the input power supplied to the discharge. As the experiment proceeded, discharge voltage was cycled off and on and deuterium was added to the reactor. Excess power reached a typical value of 5–6 W near minute markers 6000–7000, reaching a brief maximum of 10 W near minute marker 9600.

Experiment DRVIH 780 was significant because it clearly showed that a high temperature Seebeck could report relatively small power gains at higher than electrochemical temperatures, and that deuterium produces excess power but ordinary hydrogen does not.

2.1. Independent confirmation of excess power

During this experimental campaign, a single 450 W resistance heater was used to keep the thermal enclosure at a constant temperature (Fig. 6). It was also observed that when excess power/energy was present, electrical power/energy delivered to the heater declined over the same time period. This indicated that the excess power/energy produced by the reactor was assisting the resistance heater. Figure 12 shows the plot where this quantitative agreement can be observed.

The confirmation of excess power/energy is indicated by the gray shaded areas at the far end of the plot shown in

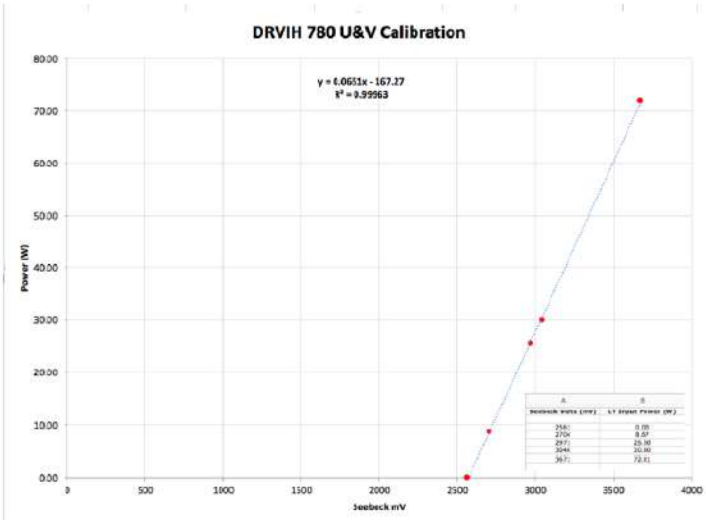

Figure 9. A calibration was performed for experiment 780 by adding power to resistive block heaters on top of a steady 200 W that provided baseline operating temperature of about 160°C. The result was a linear calibration plot shown in the figure. The Seebeck reports 2561 mV at zero discharge power because resistance heater power is supplied to provide a minimum operating temperature. Discharge power is applied in addition to baseline heater power.

Fig. 12. Excess power averaged 6 W over the minute markers 8600–10,974. Maximum excess power of 10 W was observed in this time period as well. The integrated excess power (gray area) under the red trace was 899 kJ; the inte-

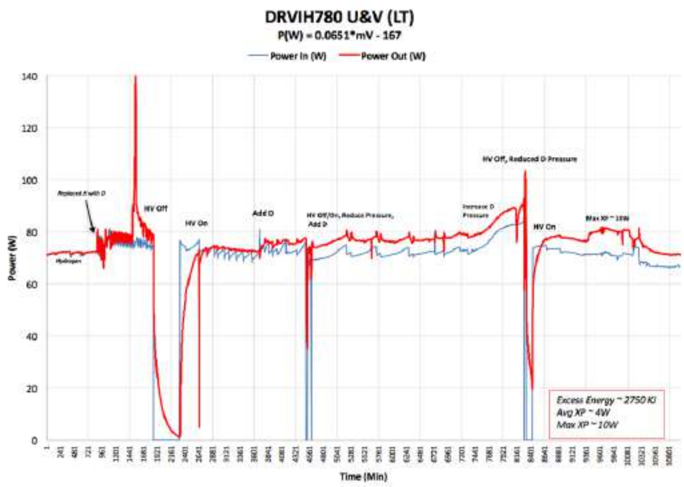

Figure 10. Figure shows a long run that produced significant excess power and energy. Of note is the beginning of the experiment where light hydrogen was present in the reactor. After the light hydrogen was replaced with deuterium, excess power appeared and slowly developed over the duration of the experiment that lasted for 7.6 days (11,000 min).

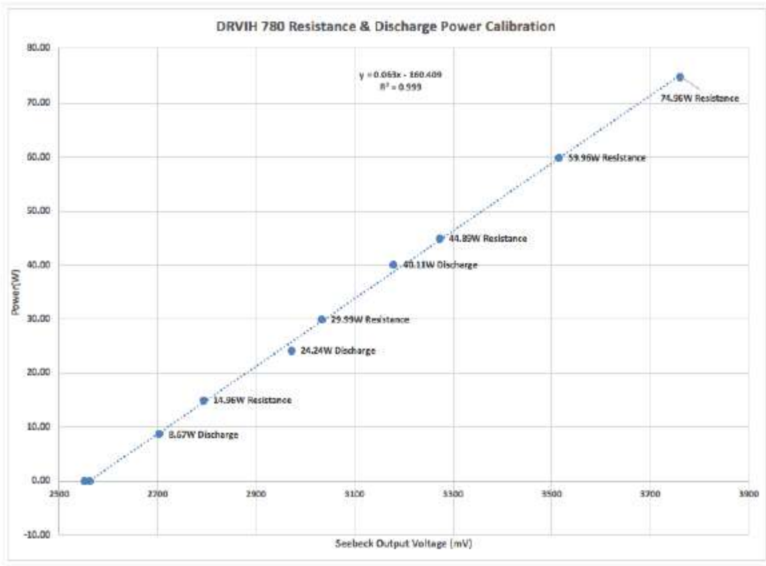

Figure 11. Figure shows a calibration made using resistive heating power alone and resistive heating power plus discharge power. The resistive heater only method shown in Fig. 9 produced a higher power output than the method shown in figure by about 1% over the length of the experiment. We chose to use the calibration based on resistive heating power but both calibration methods demonstrated significant excess power and energy.

grated decline in heater power (gray area) above the blue trace was 893 kJ. The difference in these two measurements is 0.7%. This confirms the excess power reported by the Seebeck using an independent measurement.

2.2. DRVIH 780 U&V confirmation via box heater power

To check the validity of the excess power confirmation method using the enclosure heater shown in Fig. 5 (right), Dr. Dennis Cravens of Cloudcroft, New Mexico suggested making a larger resistance heater to be placed inside the reactor tube. The eleven-inch reactor and six-inch resistance heater are shown in Fig. 13. The OD of the heater is approximately 0.86 in., which permits insertion of the heater into the reactor with a close sliding fit. The idea was to provide a simulation of heat generation in the reactor without using high voltage discharge methods. The heater, shown in Fig. 13, is rated at 450 W but only needed to provide 70–80 W of heat to simulate discharge power used to drive experiment 780 U&V.

DRVIH 790 was conducted in August 2017 to demonstrate that the amount of power/energy produced in the reactor could be observed as a decline in power/energy provided to the thermal enclosure heater shown in Fig. 5 (right).

2.3. Resistive power calibration runs

To help verify the measurements and to vet the system, a series of resistive heater calibration experiments were run. Although the calorimeter appears to be reproducible and correctly reports power over a wide range, a series of resistive runs were designed to make sure that there are no systematic errors unique to the use of high voltage or the LENR heat observed.

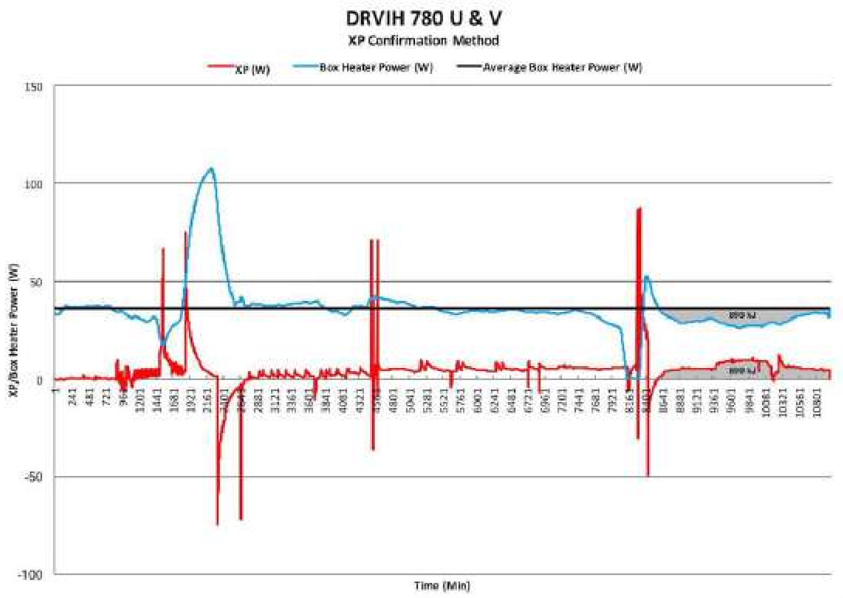

Figure 12. At the end of the plot shown in figure, excess power was produced at 5–7 W. This power was sufficient to assist the thermal enclosure heater, allowing Labview to "back-off" or reduce electrical power supplied to the resistance heater. In this case, the reduction of heater power was quantitatively equal to the excess power produced by the reactor, within experimental error. Note that gray areas in the plot show that the energy gain in the reactor was the same as the reduction of energy supplied to the heater.

A 15.2-ohm commercial heater (Tempco[a]) was machined to snuggly fit within the bore of the LENR tube (LT). This provided the ability to closely match the location and power levels of heat deposited via the LT during the 780

[a]Tempco Electric Heater Corp., http://www.tempco.com/Default.htm.

Figure 13. Figure shows the reactor and a custom fitted resistance heater used to verify that energy released in the reactor will assist in heating the thermal enclosure. In short, this is a method to simulate the release of excess power in the reactor and observe its effect on the thermal enclosure resistance heater.

U&V runs.

2.4. 200-Watt block heater calibration

Recall that 200 W of power applied to the large copper block holding the LT was common to the 780 U&V runs and most other experiments. The 200 W of power provides a higher operating temperature, which is conjectured to enhance power output from LENR reactors. The LT used for experiment DRVIH 780 U&V was replaced with an LT holding the resistive heater cartridge, and the baseline voltages from the TEG's were observed. The average input to the sum of the four block heaters was 200.45 W over the run with a standard deviation of 0.06 W. Using the same calibration constants for this resistive run as the 780U&V run, the Seebeck reported 201.79 W with a standard deviation of 0.06 W. This is a difference of 1.34 W.

Recall that there were multiple (10) experiments conducted between the 780U&V run and the DRVIH 790 resistive heater run with a time span of about 9 months. This shows that even with different tubes, configurations, and multiple opening and closing of the calorimeter, the power conversion from TEG voltage to output heat held to within 1.34 W on the 200 W heating of the block. This means the drift/repeatability of the calorimeter is within 0.5%, even with the slight differences between tube geometry. It should be noted that although the resistive heater element was matched closely to the LT, the heat parsing between the lid and copper block body are expected to be slightly different. The results of the block heating alone were then used as a recalibration point for the remaining resistive trials.

2.5. 200-Watt block heater with 70 W applied to the resistive LT heater cartridge

Once the recalibration was done for the resistive block heater input, it was possible to evaluate the claimed excess heat from the active 780 U&V run; 200 W of power was applied to the block heaters, and 70 W was applied to the LT resistive heater cartridge to match the electrical input powers applied to the 780 U&V run, which was 200 W to the block heaters and approximately 70 W to the LT in high voltage gas discharge. The average input to the LT resistive heater cartridge was 70.11 W with a standard deviation of 0.033 W and the calorimeter reported 70.23 W with a standard deviation of 0.053 W. That is to say, with the resistive block heater calibration in place from the previous block heater-only run, there was 0.12 W variation – well within an assumed conservative 0.5 W error bar. This showed that the system reported correctly over the reported range of experiment 780 U&V values.

2.6. A secondary check using the box heater data

In addition to the Seebeck readings, the box heater back-off power method can be used as a confirming measurement. The temperature control heater back-off measurements are thought to be less reliable than the Seebeck calorimeter measurements. The calorimeter is placed inside a constant temperature enclosure to allow for a stabilized outer reference temperature. The power required to keep the enclosure at a constant temperature can be used as a reality check for the measured power output from the calorimeter. The power applied to the heater cartridge used to control the chamber temperature is physically and temporally removed from the reactor, and hence potentially not as accurate as the calorimeter measurement in assessing the calorimeters total heat output. The amount of heat generated by the reactor and block heaters is supplied to the thermal enclosure. Thus, as the calorimeter emits more heat, less power input to the enclosure heater is required to maintain the enclosure temperature set point. A record of the power used by the enclosure heater can thus provide a proxy estimate of the power produced by the LENR reactor.

In the case of the 70 W of power applied to the LT resistive heater cartridge, the box heater back-off method reported 70.27 W with a standard deviation of 1.2 W over the run. When 76 W was applied to the resistive heater, the back-off method reported 75.91 W with a standard deviation of 0.46 W over the run (see Fig. 14). Again, this is

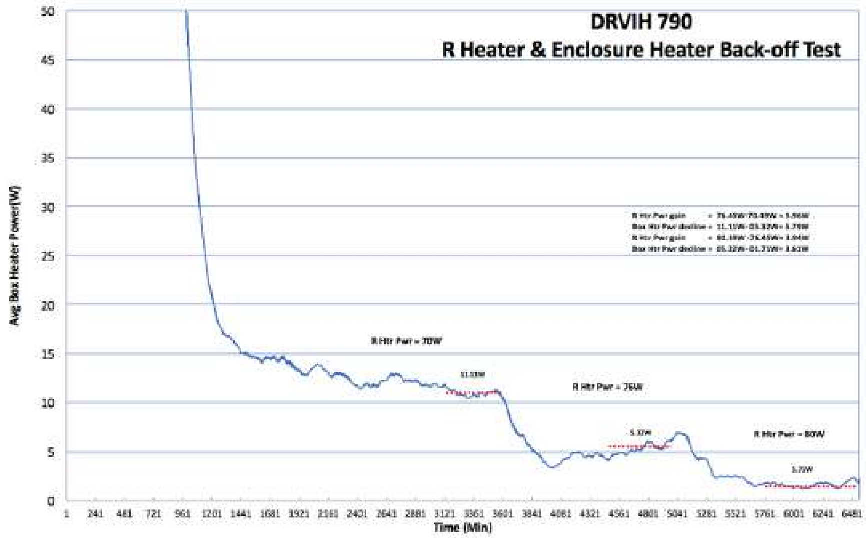

Figure 14. The plot shown in the figure shows how the thermal enclosure heater declines in power as a known electrical power is released inside the reactor using the resistance heater shown in Fig. 13.

a secondary measurement but convincingly establishes the ability of declining enclosure heater power as a means to estimate excess power produced by experiment DRVIH 780 U&V.

The plot shown in Fig. 14 demonstrates that power/energy supplied to the thermal enclosure heater declines in close quantitative agreement with the power/energy dissipated in the resistance heater located inside the reactor.

The tests revealed that when power to the resistance heater was increased by 5.96 W, the power supplied to the box temperature control heater declined by 5.79 W. The box heater power was averaged over a 500-minute interval. Energy added to the resistance heater was 5.9 6 W $\times$ 30,000 s/1000 = 178.8 kJ; energy reduction to the enclosure heater = 5.79 W $\times$ 30,000 s/1000 = 173.7 kJ. Agreement is within 3%. Accuracy might be improved with longer hold times at each step.

3. Evaluation of the Signal-to-Noise + Error Ratio

To evaluate the signal-to-noise ratio (SNR), the best data choice is DRVIH 790, the run with block heat and a resistive cartridge heater inserted in an empty LT tube. In this experiment, the output excess power (the residual) should be identically 0. Any deviation from 0 W of excess power (XP) is either error or noise. Figure 15 shows the XP from experiment 790. In this experiment, there are large dips and peaks that are associated with transients in the response of the system. These transient peaks and dips are excluded from the calculation of the standard deviation (σ) in this experiment with the caveat that one must only use the resulting statistic associated with settled regions in other experiments when comparing signal-to-noise.

The regions highlighted in yellow in Fig. 15 were those used to compute the standard deviation (σ) for the DRVIH 790 null experiment. The value calculated in Excel was $\sigma = 0.736$ W.

If this experimental value for the error + noise is applied to the XP from experiment DRVIH 780 U&V, the SNR can be calculated as XP/σ. This curve of SNR is plotted in Fig. 16.

As shown in Fig. 16, more than half of experiment DRVIH 780 U&V has excess power better than 6σ and in the

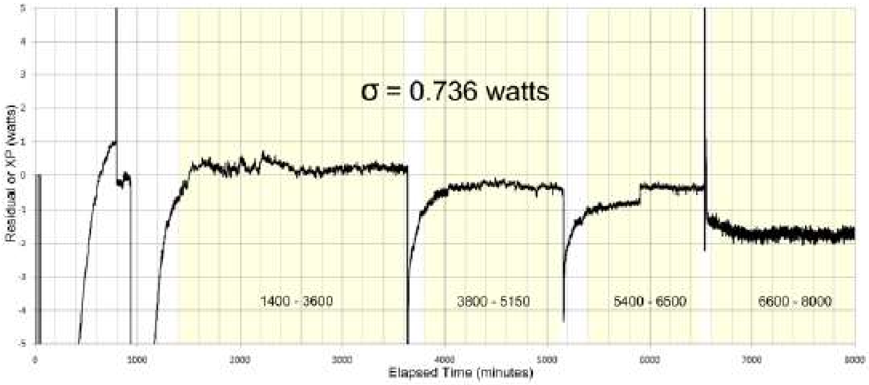

Figure 15. Figure shows the standard deviation for power produced in the reactor using the resistance heater shown in Fig. 13. We view the standard deviation as a reasonable measure of calorimeter stability.

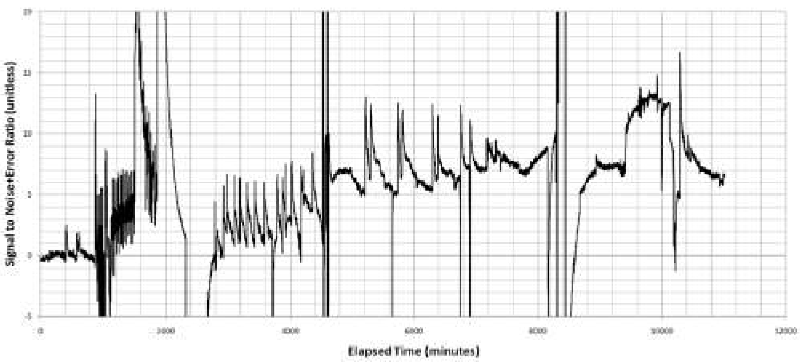

Figure 16. Figure shows the computed SNR over the entire experiment, which ranged from 6 to 12 σ, suggesting a very credible signal.

11-hour period from 9450 to 10,120 min has a SNR better than 12σ. The SNR for the excess heat in DRVIH 780 U&V provides good confidence that the measured excess heat is not a consequence of noise or error.

4. Conclusions

A high temperature Seebeck calorimeter can be successfully designed and constructed to make power measurements for gas-based LENR devices at or above 200°C. Glow discharge reactors are effective in loading and triggering exothermic reactions in deuterated metals, although the authors do not yet claim mastery over the methods.

The tests conducted by the authors support the idea that palladium deuteride produces excess power but palladium hydride does not. This is consistent with our previous work and results reported by the LENR community.

The work discussed in this paper also demonstrated that an acceptable redundant power measurement method is available by measuring and recording electrical power provided to the resistance heater used to maintain a constant ambient temperature within the system's thermal enclosure. It was demonstrated that power developed or applied within the reactor was quantitatively reflected in the reduction of electrical power consumed by the enclosure's resistance heater. This observation provides a dual-method calorimeter for LENR heat measurements.

Acknowledgements

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