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Ultrasonically-excited electrolysis Experiments at Energetics Technologies

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Abstract

Three electrolysis cells with built-in ultrasonic transmitters were developed by Energetics Technologies. The ultrasonic transmitters induce cavitation in the electrolyte in the vicinity of the palladium cathode for in-situ cleaning and activation of the cathode surface, generation of dislocations, assistance in loading and excitation of the Pd-D system. The ultrasonically assisted electrolysis cells are described and excess heat generating experiments using these cells are illustrated. All of these experiments used the Dardik's modified SuperWaves to drive the electrolysis. The reproducibility of excess heat generation obtained using the ultrasonically assisted electrolysis experiments approaches 80%, which is the highest of all types of electrolysis experiments performed at Energetics Technologies.

A significant amount of excess heat was generated and a very large Coefficient Of Performance (COP) was obtained in several experiments. The largest excess power obtained is 34 watts; the largest total excess energy is 3.5 MJ; the largest COP achieved is 3000%; and the longest duration of excess heat generation in a single experiment is 40 days. The largest amount of specific excess energy is 27 KeV per Pd or D atom. This is at least three orders of magnitude larger than the specific energy that can be generated by chemical reactions or that can be stored in the cell in the form of mechanical energy. The largest specific power generated is 70 W/g of Pd. For comparison, the average specific power in commercial nuclear fission reactors is between 20 to 50 W/g of uranium.

1. Introduction

The primary near-term objectives of the Energetics Technologies experimental program in the quest for developing commercial cold fusion energy sources are: (1) Improvement of the reproducibility of high power gain and high energy gain excess heat generation, and (2) Extension of the duration of excess heat generation. The program focuses on experiments with electrolytic cells that are driven by SuperWaves. [1-3]. The idea of using SuperWaves to enhance LENR (Low Energy Nuclear Reactions) was proposed by I. Dardik based on his vision of nature described in [4].

Several experimental approaches are being pursued in an attempt of achieving the near-term objectives, including the following:

- Optimization of the SuperWave pattern
- Modification of the cathode surface by special annealing-etching procedures jointly under development with ENEA Frascati and the University of Rome [5]
- Modification of the cathode surface by SuperWave glow discharge etching [3]
- Development of new types of cathodes [3]
- Use of ultrasound cavitation in the electrolyte in the vicinity of the cathode for in-situ cleaning and activation of the cathode surface, generation of dislocations, assistance in loading and inducing excitation in the Pd-D system.

This paper is an overview of the latter approach. The other approaches listed above were reported upon in preceding conferences [1-3]. Successful replication of earlier Energetics Technologies excess heat generating electrolysis experiments were achieved at both the SRI and the ENEA laboratories as reported in reference [6].

A description of the SuperWave principle can be found in previous publications [1-4] and will not be repeated here. Section 2 describes the electrolysis cells with ultrasonic transmitters developed and used by Energetics Technologies. Examples of excess heat generated in ultrasonic excited electrolysis cells are presented in Section 3. That is followed by a discussion, in Section 4, of the functions of the ultrasound cavitation. A summary of high excess heat generation results obtained so far in our experiments is given in Section 5.

2. Electrolysis Cells with Ultrasonic Excitation

Since its early days, Energetics Technologies planned to conduct experiments that combine ultrasonic excitation with electrolysis [1]. The designs of our electrolysis cells with ultrasonic excitation have undergone a number of conceptual variations.

Presently we have three cylindrical electrolysis cells designed to allow ultrasonic cavitation excitation. These cells are immersed in a water bath that incorporates a flow calorimeter. The ultrasonic transmitter or transmitters are located outside of the water bath. The entire system is housed in an incubator that maintains the experimental setup in a tightly regulated ambient temperature. The uncertainty in the determination of the excess heat, P_{ex} , using the calibrated mass-flow calorimeter is approximately 20 mW.

Experimental cells #1 and #2 use an annular piezo ceramic ultrasonic transmitter surrounding the water bath as shown in Fig. 1. The cathode-anode assembly used in these cells is shown in Fig. 2. The cathode is a palladium foil, $60 \times 3.0 \times 0.03$ mm. It is made at Energetics Technologies by rolling a 0.5 or 1.0 mm thick Pd wire. The anode is a helical platinum wire wound around the cathode over a perforated cylinder of Teflon (See Fig. 2).

Cell #3 uses four tubular ultrasonic transmitters located 90 degrees from each other as shown in Figs. 3 and 4. The design of the anodes was modified for this geometrical arrangement, as shown in Fig. 6 (compare with Fig. 2).



Figure. 1. Schematic of the Energetics Technologies electrolytic cell system with an annular ultrasonictransmitter; Cells #1 and 2. Flow calorimetry is performed by comparing temperatures T Inlet and T Outlet



Figure 2. The cathode-anode assembly used in the Energetics Technologies electrolytic cells #1 and #2 that have annular ultrasonic-transmitters



Figure 3. The hardware of the flow calorimeter of Energetics Technologies electrolytic cell #3 that incorporates four tubular ultrasonic transmitters



Figure 4. Energetics Technologies electrolytic cell #3 assembly installed inside a constant temperature incubator.



Figure 5. The cathode-anode assembly of Energetics Technologies electrolytic cell #3

The maximum power level and frequencies that the ultrasonic transmitters can operate at in the three electrolytic cells are summarized in Table 1.

Table 1. Characteristics of Energetics Technologies Electrolysis Cells with Ultrasonic Transmitters

Cell #	Type of transmitter	Frequency [KHz]	Max power [W]
1	Ring	16	15
2	Ring	38	15
3	Four tubes	30	60

3. Results

Table 2 gives a statistical summary of the electrolysis experiments performed during 2007 and 2008 using the three ultrasonic excitation electrolysis cells. Seventeen additional experiments failed because of mechanical problems: mainly palladium foil rupture caused by cavitation. The reproducibility of excess heat generation is quite high; it is higher than the reproducibility obtained in our previous electrolysis experiments that did not incorporate ultrasonic cavitation.

Table 2. Summary of Energetics Technologies Electrolysis Experiments Using Ultrasonic Excitation

Cell	Number of experiments	Number producing excess heat	Success rate
1	8	6	75%
2	5	4	80%
3	6	4	67%
Total	19	14	74%

Figures 6 through 11 show examples of excess heat generation measured in electrolysis experiments with ultrasonic excitation. In these experiments, ultrasonic excitation was applied for several periods, each lasting as long as 24 hours, while electrolysis power was continuously applied. The figures show: net input power, P_{inet} – the power delivered to the cell from the external power supply driving the electrolysis (P_{in}) minus the power consumed for decomposition of heavy water molecules; and P_{out} – the power transferred out from the cell as measured by the calorimeter. The Coefficient Of Performance (COP) is defined as (P_{out} - P_{inet})/ P_{in} .

Figure 6 shows that excess heat started in experiment ETUS3-5 about 5 days after the beginning of the experiment. The vertical pink spikes in the figure are heating effects due to the application of the ultrasonic transmitter and are ignored in the excess-heat analysis. Sometime between day 20 and day 30 of the experiment, the excess heat level was ~0.2 W, while the net input energy was ~1 W. Around the 31^{th} day, electrolysis was turned off, but excess heat generation continued and even increased up to ~0.5 W. This "heat-after-death" lasted for about 4 days, at which time (around the 35^{th} day) the electrolysis current was turned on again. At day 56, after ramping P_{in} up and down in a stepwise manner, P_{in} was turned off again but P_{out} continued for several days at a level of ~0.6 watts, before it started dropping. On the 60^{th} day the Pd cathode was replaced with a Pt cathode, following which P_{out} became zero. This proves that our calorimeter was well calibrated. It also proves that the excess heat measured after electrolysis was turned off was, indeed, heat-after-death.



Figure 6. Net input power (Pinet – in blue) and output power (Pout – in violet) in ultrasonically excited electrolysis experiment #ETUS3-5 in cell #3

Figure 7 shows the evolution of P_{inet} and P_{out} in experiment #ETUS3-6. The ultrasonic transmitters were turned on 4 times, for 24 hours each time, while the electrolysis power was set at a low P_{in} level of less than 0.2 W. After the first session of ultrasonic excitation the output power gradually dropped to zero. After the second session of ultrasonic excitation P_{out} dropped to

zero and then started increasing. The third session was soon started¹. After the 3rd session of ultrasonic excitation P_{out} dropped to zero at which time the 4th session of ultrasonic excitation was applied. P_{in} dropped to zero, then increased up to ~1 W, and then gradually declined. The duration of excess heat generation was 17 days and the maximum COP exceeded 500%. At about 2,400,000 seconds (approximately 28 days) P_{in} was turned off. Following this P_{out} dropped to zero. Applying P_{in} again did not succeed in reviving the excess heat generation. These last two steps again provide strong evidence that the excess heat recorded earlier in this experiment is real, and not a result of improper calibration.



Figure 7. Net input power (Pinet – in black) and output power (Pout – in red) in ultrasonically excited electrolysis experiment #ETUS3-6 in cell #3. Ultrasound (US) was applied in 4 sessions, each lasting about 24 h

Similar features are observed in the three additional experimental results shown in Figs. 8 through 10.

¹ In retrospect, it would have been preferable to wait longer before applying the 3rd session.



Figure 8. Net input power (Pinet – in black) and output power (Pout – in red) in ultrasonically excited electrolysis experiment #ETUS1-17 in cell #1



Figure 9. Net input power (Pinet – in black) and output power (Pout – in red) in ultrasonically excited electrolysis experiment #ETUS2-11 using cell #2



Figure 10. Net input power (Pinet – in black) and output power (Pout – in red) in ultrasonically excited electrolysis experiment #ETUS3-20 using cell #3



Figure 11. Net input power (Pinet – in black) and output power (Pout – in red) in ultrasonically excited electrolysis experiment #ETUS3-21 using cell #3

4. Unique Characteristics of Ultrasonic Excited Electrolysis

Unique characteristics of ultrasonic excited electrolysis experiments include the following:

- Very high deuterium loadings (D/Pd > 0.95) is achieved, while applying low current density
- The deuterium stays in the palladium a long time after shutdown (the β phase is stable)
- Sub-micron sized pits are found on the surface of palladium cathode, in high density
- Craters with signs of melting (and some craters without melting) are found on the surface of the palladium cathodes

A comparison between Figs. 12 - 14 and Figs. 15 and 16 illustrate the fact that the application of ultrasonic cavitation, together with the application of SuperWaves electrolysis, enables very high deuterium loading using exceptionally low current densities. This remarkable increase in the deuterium loading may be attributed to the following phenomena induced by cavitation:

- Cleaning various deposits from the cathode surface
- Activating the cathode surface
- Increasing the cathode effective surface area



Figure 12. Very high D loading in Pd is obtained in ultrasonically excited electrolysis when driven with low current density – example 1



Figure 13. Very high D loading in Pd is obtained in ultrasonically excited electrolysis when driven with low current density – example 2



Figure 14. Very high D loading in Pd is obtained in ultrasonically excited electrolysis when driven with low current density – example 3



Figure 15. D loading in Pd without ultrasonically excited electrolysis experiment is lower even at significantly higher current density – example 1



Figure 16. D loading in Pd without ultrasonically excited electrolysis experiment is lower even at significantly higher current density – example 2

Figure 17 compares the rate of deuterium desorption from two Pd cathodes after turning electrolysis off. The sample in the top plot was subjected to ultrasonic excitation, while the sample in the bottom plot was not. The difference is remarkable. Note that from the time the Pd foil was removed from the cell to the beginning of the X-Ray diffraction analysis used to measure the D/Pd atom ratio, the D/Pd ratio in the palladium foil in the bottom plot dropped from more than 0.9 to ~0.4, while the D/Pd ratio in top plot (palladium foil exposed to ultrasonic cavitation) remained close to 1.0. During the D/Pd analysis period, the rate of desorption from the palladium foil that was exposed to cavitation is far slower: the β phase appears to be stable for over 100 days. This unique phenomenon may be due to the formation, by cavitation, of a high concentration of defects in the palladium. These defects can act as potential deuterium traps causing slow deuterium desorption.



Figure 17. Rate of deuterium desorption from a Pd cathode that was subjected to ultrasonic cavitation ("US activation") (top), versus a Pd cathode that was subjected regular electrolysis (bottom)

Figure 18 compares the surface of the Pd cathode after ultrasonic assisted electrolysis experiment #ETUS3-6 (left) with the surface of the cathode of electrolysis experiment #64 (right) that was not exposed to ultrasonic cavitation. The morphology of the two cathodes is very different. The cavitation introduces considerable changes in the structure of the Pd surface. Regular electrolysis (right) produces a structure consisting of slip bands formed in the course of plastic deformation of the palladium, due to deuterium absorption and resulting lattice expansion. Cavitation plus electrolysis (left) leads to the formation of a cellular structure. This effect results in activation of a surface and creates a high concentration of defects – potential deuterium traps.



Figure 18. Comparison of Pd cathode surface after experiment ETUS3-6 (left) and ETE-64 (right; no ultrasonic) – both gave excess heat. Secondary electron microscope image magnification of x8000

Craters of various shapes and dimensions were formed on the surfaces of several of the palladium cathodes subjected to ultrasonic excited electrolysis. Figure 19 shows samples. Some of the craters show clear signs of palladium melting on and near the surface. The craters are typically several microns in diameter and several microns deep.



Figure 19. Example of craters found on the surface of palladium cathodes that were subjected to electrolysis with intermittent application of ultrasound cavitation.

Consider, for example, the crater at the top center of Fig. 19. It is ~4 microns in diameter and ~6 microns deep. The amount of energy required to melt the mass of palladium from this crater (ignoring heat losses via conduction to the surrounding palladium and to the electrolyte) is on the order of 0.1 milli-Joules. This is many orders of magnitude smaller than the measured excess heat, which was on the order of tens to thousands of kilojoules. Remember, though, that the palladium is in direct contact with the electrolyte, and the heat transfer rate from the palladium to the electrolyte should be very high. So it is surprising that some spots in the cathode even reach the melting point of Pd (1554°C).

The craters identified so far have been found in a very small fraction of the total cathode surface that can be scanned using a SEM. Better diagnostics will be needed to obtain statistically significant information on the number and types of craters, and their spatial distribution.

5. Summary of Best Excess Heat Generating Experiments at Energetics Technologies

Table 3 summarizes selected performance characteristics of the eight electrolysis experiments that so far generated the largest amount of excess power, P_x (previously referred to as excess heat), or excess energy, E_x . The average "specific excess power," given in watts per gram of palladium that was exposed to the electrolyte, is a measure of the utilization effectiveness of the palladium. The largest average specific excess power obtained so far – nearly 70 W/g of Pd, is even higher than the typical specific power in commercial fission reactors – 20 to 50 Watts per gram of uranium. The "specific excess energy," expressed in kilo-electron-volt generated per palladium atom or per deuterium atom in the cathode (the ratio of D to Pd atoms in the cathode is nearly 1), is an indicator of whether or not the excess heat could be chemical or mechanical (stored energy) in origin.

The maximum specific excess energy obtained in our electrolysis experiment is over 20 KeV per Pd or D atom. This is to be compared with heat of desorption of D from the Pd lattice of ~0.3 eV per D atom; heat of D oxidation of ~1.3 eV per D atom; heat of molarization of ~2.2 eV per D atom; heat of melting (an upper bound on the possible mechanical energy storage in the Pd lattice) of ~0.2 eV per Pd atom and heat of evaporation of Pd of ~4 eV per Pd atom. All of these are three to four orders of magnitude smaller than the specific excess energy measured. This provides a strong yet indirect indication that the excess energy generated in the experiments reported above is, indeed, of nuclear origin.

Experiment	56	64a	64b	GD-141	US1-15	US3-05	US3-06	US3-21
Cathode source	ENEA	ENEA	ENEA	ET	ET	ET	ET	ET
Excess energy	3.1	1.1	> <mark>3.5</mark>	2.4	0.19	1.1	1.32	0.026
(MJ)								
Maximum excess	3.6	<mark>34</mark>	32	14	0.25	0.7	0.9	0.165
power (W)								
Maximum COP	80	2500	>1500	75	600	<mark>3000</mark>	525	650
(%)								
Duration of excess	300	17	80	90	280	<mark>960</mark>	445	55
power (hr)								
Average excess	2.9	<mark>18</mark>	>11	7.5	0.19	0.3	0.82	0.13
power (W)								
Average specific	11	<mark>71</mark>	>43	29	4	6	15	24
excess power								
(W/gm Pd)								
Specific excess	13	5	>15	11	4	22	<mark>27</mark>	13
energy (KeV/Pd								
atom)								

Table 3. Selected Characteristics of the Eight Energetics Technologies (ET) Electrolysis Experiments that Generated Largest Amount of Excess Power or Excess Energy. The highest value in each row is highlighted in yellow.

6. Conclusions

In-cell exposure of palladium cathodes to ultrasound cavitation, combined with SuperWave electric current driven electrolysis, was found to enable remarkably high deuterium loading with surprisingly low current density. The rate of deuterium desorption from palladium cathodes removed from ultrasonic-assisted electrolysis cells was found to be remarkably slow: the palladium remained in beta phase loading for many days. The outer layer of palladium foils exposed to ultrasonic cavitation experiences a large plastic deformation that is characterized by a highly pitted rough surface. Craters showing clear signs of palladium melting were found on palladium cathodes that underwent ultrasonic excitation during electrolysis. Better diagnostics will be required to analyze these craters.

The most reproducible excess heat generation of all experiments performed so far at Energetics Technologies has been obtained with ultrasonic excitation. Several episodes of "heat-after-death" were observed during some of the ultrasonically excited experiments. It is necessary to optimize the application of the ultrasound to minimize the energy needed to generate the cavitation versus the amount of excess energy generated. The mechanism by which ultrasonic excitation intensifies the excess heat also needs to be thoroughly investigated.

Significant amounts of excess power and excess energy were generated and very large Coefficient Of Performance (COP) were obtained in several of Energetics Technologies experiments. The best performance parameters obtained so far are:

- Excess energy 3.5 MJ
- Excess power 34 W
- COP 3000%
- Duration 40 days
- Specific energy 27 KeV per Pd or D atom
- Specific power 70 W/g Pd

The latter can be appreciated when compared against the 20 to 50 W/g of uranium that is achieved in large commercial fission power reactors.

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