LENR at GRC

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BACKGROUND: “Cold Fusion”?

Headlines 1989

Two electrochemists…

Martin Fleischmann
Stanley Pons

claimed to have tapped nuclear power in a simple electrochemical cell.

"It could be the end of the fossil fuel age: the end of oil and coal. And the end, incidentally, of many of our worries about global warming."

-- Sir Arthur C. Clarke
BACKGROUND: The Advantage of Fusion

Burning Coal:
• $C + O_2 \rightarrow CO_2 \ (4 \text{ eV})$

Fission Power Reaction:
• $^{235}U + n \rightarrow ^{236}U$
  $\rightarrow ^{141}Ba + ^{92}Kr + 3 \cdot n \ (170 \text{ MeV})$

Fusion Processes:
• $D + D \rightarrow T \ (1.01 \text{ MeV}) + p \ (3.02 \text{ MeV})$
• $D + D \rightarrow ^3He \ (0.82 \text{ MeV}) + n \ (2.45 \text{ MeV})$
• $D + D \rightarrow ^4He \ (73.7 \text{ keV}) + \gamma \ (23.8 \text{ MeV})$
• $D + T \rightarrow ^4He \ (3.5 \text{ MeV}) + n \ (14.1 \text{ MeV})$
• $D + ^3He \rightarrow ^4He \ (3.6 \text{ MeV}) + p \ (14.7 \text{ MeV})$
  – $D = ^2H, \ T = ^3H$
• Fusion is at least 13% more productive per mass of fuel (without the nasty waste products)
**BACKGROUND:** Purifier Schematic

- Johnson Matthey HP Series palladium membrane hydrogen purifier
- Used in the semiconductor industry and applications where ultra-high purity hydrogen is required (to 99.9999999%)
- An at-hand substitute for a palladium electrolytic cell
BACKGROUND: 1989 Cold Fusion Experiment

EQUIPMENT
Hydrogen purifiers are made using Palladium membranes

EXPERIMENT
After evacuating purifier, it was loaded with deuterium gas at pressures up to 250 psig.

Purifier temperature and neutron count monitored for several months—non electrochemical variant of Pons-Fleischmann experiment
BACKGROUND: 1989 Cold Fusion Experiment

Results:

• Temperature increase noted while gas was loaded into palladium cell, for both D & H

• Neutron detector counts did not differ significantly ($\leq 2\sigma$) from background in any run (Monitored with BF$_3$ w/ Polyethylene ["Snoopy"] detectors).

• Temperature increase noted when D unloaded at end of experiment

• Compared to hydrogen gas as the experimental control: 15°C increase in purifier temperature consistently seen with D$_2$ that was not seen with the H$_2$ control when gasses were unloaded from the purifier.

Published:

• Fralick, Decker, & Blue (1989) NASA TM-102430

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BACKGROUND: $\text{H}_2\text{O-Ni-K}_2\text{CO}_3$
Electrolytic Cell

**Experiment:**
- Investigated reports of significant long-term excess heat in light water-Ni-$\text{K}_2\text{CO}_3$ electrolytic cells
- Two 28-liter electrolytic cells for tests, one active cell for electrolytic tests, second inactive cell for reference thermal measurements
- Tested at several dc currents and a pulse mode current

**Results:**
- Apparent current-dependent excess heat exhibited when tested in all modes
- Excess heat consistent as heat from hydrogen-oxygen recombination catalyzed by the Pt and Ni electrodes within the cell
- Did not reproduce the large excess heat reported in literature
  - Gain Factors of $<1.7$ @ GRC vs. $>10$ in literature
BACKGROUND: Sonoluminescence

Experiment

- Sonoluminescence with Palladium-Chromium (PdCr) Thin Films Over Platinum (Pt) RTD (Resistance Temperature Device) Traces on Alumina

Result

- No Crater seen in H₂O, Crater Formation seen in D₂O
- Large Grain Failures usually seen in thin films due to mismatches in coefficients of thermal expansion at high temperature (~1000°C)

BACKGROUND: Changes from 1989 to 2009

- Previous NASA D-Pd experiment (Fralick, et al.; 1989) looked for neutrons (saw none) – but saw anomalous heating
- NASA H₂O-Ni-K₂CO₃ Electrolytic Cell experiment (Niedra et al, 1996) Apparent current-dependent excess heat consistent as heat from hydrogen-oxygen recombination
- NASA Sonoluminescence Experiment (Wrbanek, et al) - Cratering seen with heavy water, not seen with light water
- After 1989, Cold Fusion research evolved into research in “Low Energy Nuclear Reactions” (LENR), primarily at U.S. Navy, DARPA & various Universities

2009: NASA IPP-sponsored effort to:
- Repeat the initial tests to investigate this anomalous heat
- Apply GRC’s instrumentation expertise to improve the diagnostics for this experiment
- Establish credible framework for future work in LENR
**APPROACH:** Flow System Schematic

**System Line Valves**
- **Open**
- **Closed**

**All Valves Swagelok SS-4H unless otherwise indicated**

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APPROACH: 2009 Test Apparatus

- Johnson Matthey HP-25 hydrogen purifier
  - Purifier Filter contains a ~50g heated Pd-25%Ag membrane
- Load Filter by flowing hydrogen gas into the purifier
- Unload Filter by pumping the gas out of the purifier into a sample bottle
- Turn off filter heater for a time when Loading & Unloading
- Monitor changes in temperature, neutron/gamma background
- Repeat with deuterium gas; Compare results
RESULTS: Temperatures vs. Time

Observation Temperature for H2 Load

Loading

Temperature (°C) vs. Time (s)

Observed Temperature for H2 Load

Unloading

Temperature (°C) vs. Time (s)

Observed Temperature for H2 Unload

Hydrogen

Deuterium

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RESULTS (continued): Temperature vs. Time

Results of GRC IPP investigation: a) the temperature data is shown for H2 and D2 unloading (left); b) the calculated thermal power in/out is given with the net anomalous heating (right).
Hypotheses

“Pet Theories” (i.e., Hypotheses where proponents already convinced peer-reviewed journals):

- Electron Screening (Parmenter & Lamb)
- Band States (Chubb & Chubb)
- Shrunken Hydrogen (Maly, Vavra & Mills)
- Ultra Low Momentum Neutrons (Widom & Larsen)
- Dislocation Loops (Hora & Miley)
- Bose-Einstein Condensates (Kim)

Do any of these encompass all reported observations?

- More than one effect may be occurring
2011 Effort: Monitor temperature and pressure simultaneously for different rates of unloading
Future Tests?: Stirling Laboratory Research Engine (SLRE) at Cleveland State University

### Parameters

<table>
<thead>
<tr>
<th>SLRE</th>
<th>SLRE</th>
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</thead>
<tbody>
<tr>
<td><strong>Design Power, hp (kw)</strong></td>
<td>12 (9)</td>
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<tr>
<td><strong>Design Pressure, psi (N/mm²)</strong></td>
<td>1000 (7)</td>
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<tr>
<td><strong>Working Gas</strong></td>
<td>H2/He</td>
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<tr>
<td><strong>Cylinder Bore, inch (mm)</strong></td>
<td>2.87 (73)</td>
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<tr>
<td><strong>Piston Stroke, inch (mm)</strong></td>
<td>2.12 (54)</td>
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<tr>
<td><strong>Hot Gas Temperature, F (°C)</strong></td>
<td>1400 (760)</td>
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<tr>
<td><strong>Cold Gas Temperature, F (°C)</strong></td>
<td>150 (65)</td>
</tr>
<tr>
<td><strong>Drive System</strong></td>
<td>C’ Shaft</td>
</tr>
</tbody>
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**Photo courtesy Professor Mounir Ibrahim. Used by permission**

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Schematic of the Stirling Laboratory Research Engine at Cleveland State University

LENR Energy to Rotational Power Research Facility

Research: Theory, Computational Dynamics, Reactor diversity, matrix elements, size, scale, rates, materials, blends, catalysts operational limits, device interfacing, HX, shielding, controls, instrumentation, communications, safety and more

Device Diversity
Brayton Open/Closed Rocket
Space / Terrestrial power Thermoelectric Stirling (illustrated) and more

Theories
Widom-Larsen Rossi Piantelli Bose-Einstein Condensate And more

LENR Thermal Energy Source
Pd – D2 test matrix Ni – H2 test matrix

Controller Unit

Drawing courtesy Professor Mounir Ibrahim. Used by permission

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Future Power Source? Free-Piston Stirling Engine Schematic with D/Pd Energy Source
Benefits for NASA

• Replace $^{238}\text{Pu}$ as power source in deep space missions
  o Currently in short supply
  o Now depend upon foreign sources
  o Perhaps 5 years to supply our own
  o No money in new budget to restart domestic production

• Replace fission reactors as power source for human habitation missions
  o No radioactive waste
  o No radioactive material accident hazard on launch
References


- Liu, Bin; Li, Xing Z.; Wei, Qing M.; Mueller, N.; Schoch, P. and Orhre, H. “‘Excess Heat’ Induced by Deuterium Flux in Palladium Film.” The 12th International Conference on Condensed Matter Nuclear Science, Yokohama, Japan, Nov. 27 – Dec. 2, 2005

References (cont.)


