Chapter 9

Conclusions

9.1 Our Test Campaigns in Numbers

As laid out in chapter 2, we attempted to follow any seemingly credible report that could lead us to AHE. We replicated all major published electrochemical LENR experiments, even those with weak evidence of AHE. On top of that, we designed our own experiments in order to create conditions that had been reported to be conducive to AHE. When performing replications, we either re-created the original experiments as close as possible, including the calorimeter, or we abstracted it and performed the experiment in our own, well characterized calorimeters. After all, a scientific phenomenon should be agnostic to the diagnostic tools used to observe it.

Exact replications include those of Staker [105] and Barham [106]. Replications with the sample geometry, composition and stimulation closely resembling the original paper, but placed in our closed-system calorimeters (as opposed to lower performing open system calorimeters) include Letts [104, 271, 272], Staker [105], Storms [113, 299, 300], Energetics [102, 270], McKubre [101, 110], Miles [301], Hubler [302], Boss [32, 72, 106]. Additional experiments were more loosely based on literature reports (e. g., Fleischmann and Pons [26]) or were novel experiments motivated by our quest to find the right conditions for AHE (e. g., by enhanced loading or minimizing or maximizing lattice defects). Overall, we investigated over 500 samples and performed a total of over 200,000 h (23 sample years) of calorimetry. Almost 90 % of the samples and over 95 % of the calorimeter hours were accumulated in closed system calorimeters, which are significantly more precise and less error prone than the open system calorimeters widely used in the LENR literature. Fig. 9.1 shows an overview of the number of samples and the accumulated duration of AHE tests (calorimetry on potentially AHE-active samples, not including calibrations and reference experiments, nor the numerous samples and time spent optimizing hydrogen loading outside of calorimeters).

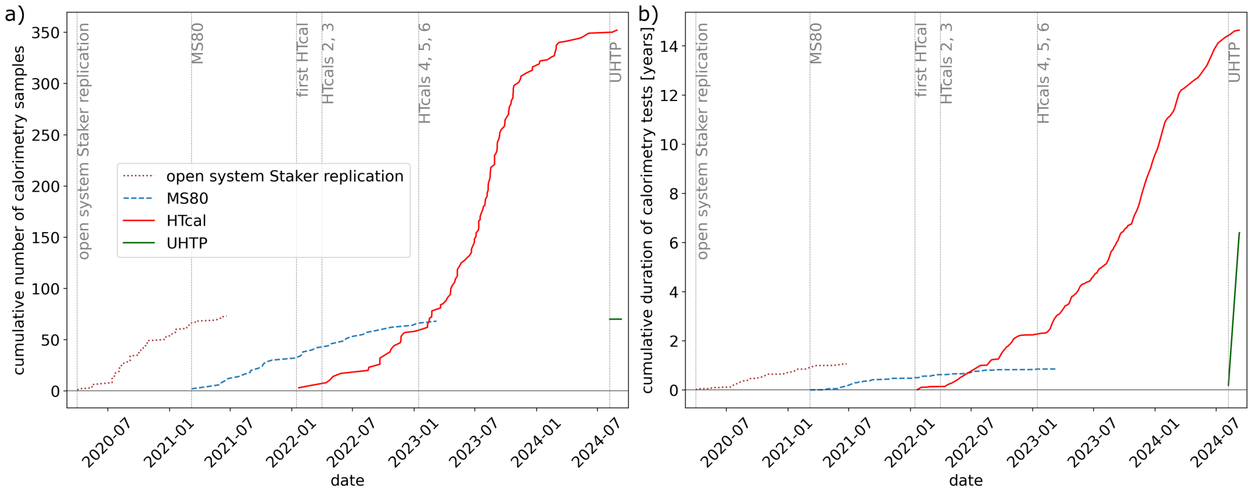

Fig. 9.1: History of calorimetry experiments in search for AHE within the Callisto project, grouped by calorimeter type. a) Accumulated number of samples; b) Accumulated number of calorimeter years.

9.2 List of False COPs

Unsurprisingly, while performing these several hundred experiments, we have observed numerous incidents in which the apparent COP deviated from unity to various degrees. However, we have been able to track down each and every single case so far to a classical explanation, i. e., an explanation not requiring the presence of LENR. The most frequent elevated COP we have observed in closed system calorimetry was due to recombiner malfunction, resulting in a temporary accumulation of oxyhydrogen in the headspace, which then would recombine spontaneously after a certain pressure buildup, resulting in a prolonged small heat suppression followed by a short and comparatively larger heat release. This error is easy to identify using the pressure data. In open system calorimetry, the most common error was a change in thermal properties due to changes in electrolyte level, rendering the calibration invalid. This error could be diagnosed using continuous video surveillance of the cells. Across all calorimeters, we have seen frequent hardware failures, especially temperature sensors (RTDs), owing to the corrosive electrolyte. In most cases, the failure is obvious, but in some cases, the sensor would continue to produce data that was deceptively close to the real data, or it would even recover. We mostly overcame this problem by potting sensors in epoxy resin and introducing redundant sensors.

A complete list of all observed false COPs is provided below:

1. Incorrect accounting in COP calculation due to input power measurement error: Assembly errors (e. g., incorrectly wired pins in the electrical passthrough); corrosion of wire insulation in long duration tests; incorrectly specified power from source measure units or input power devices can lead to accounting errors in the COP calculations. High-frequency inputs (AC or pulsed) are particularly error-prone. Another source of error is the measurement of input voltage not at the thermal system boundary. This is especially a concern for wires carrying large currents (e. g., electromigration). This category can cause any level of COP error, in both thermodynamically open and closed calorimeters.

2. Changes to the thermal transfer coefficient of the calorimeter (output heat measurement error):
    - Changes to liquid level and electrolyte foaming: In certain thermodynamically open calorimeters, liquid level variations and electrolyte foaming both cause changes to the thermal transport properties of the calorimeter. We have observed consequent false COPs as high as 1.6 in our Staker replication experiments.
    - Environmental temperature instability: Good calorimetry requires temperature stability of the surrounding enclosure(s) on the order 100 mK for valid, high-precision measurements. When the surrounding environment temperature changes, the heat transfer of the calorimeter will be impacted.
    - Calibration drift: Heat flow measurements often rely on accurately and precisely measuring temperature, or some other proxy for heat flow. Whether using thermocouples, RTDs, or Seebeck sensors, all are susceptible to component failure, placement errors, and offsets which can drift over time.
    - Insufficient understanding of reactor design: We characterized temperature heterogeneity in some replicated isoperibolic calorimeters. Certain designs can lead to false COPs on the order of 1.3.
3. Unlocking stored energy via chemical reactions: We have observed at least two types of chemical reactions in the headspace to date: Oxyhydrogen recombination and hydrocarbon combustion. These reactions produce large near-instantaneous heat releases, which can present as a temporarily elevated COP. There is the possibility that slower timescale corrosion reactions are releasing heat in certain experiments.
4. One-off experimental errors: Equipment malfunctions, calculation errors, incorrect analysis code, etc. can lead to false COPs. This is especially true if sensors are non-redundant and experiments involve manual steps (such as manually changing EC current or manually reading voltmeters).

9.3 Call for Quality Research

Since its inception in 1989, the field of LENR research has been on the fringes of science, often mocked as pseudo science. Several DOE reviews have concluded that there is no evidence of LENR that withstands the rigor of scientific standards, though the most recent DOE review has resulted in a modest funding of 10 M$ for LENR research through ARPA-E [303]. Many times, researchers have complained about their field being stigmatized, e. g., as "voodoo science" or "pathological science".

The truth is that the quality of almost all papers in the field is very low compared to most other fields of science. Even if the LENR effect is accepted to be erratic, rendering replications almost impossible, the vast majority of papers does not fulfill the standards of publication in the common scientific journals. Let alone high impact journals – which would be justified given the consequences if a positive LENR result held to common scientific standards was reported. Hence, almost all LENR papers are found in dedicated marginalized journals and conferences, e. g., *Journal of Condensed Matter Nuclear Science*, *Current Science*, *New Energy Times*, or *International Conference on Cold Fusion*, all of which have minimal requirements for publication.

After carefully studying the LENR literature, we found that the most common shortcomings are (with examples):

- No rigorous peer review and no team work. There is a large body of work published in papers with a single author. However, most modern science, in particular experimental work, is done in teams. Close collaboration between researchers could make sure that fewer mistakes are overlooked and that data is being treated without preconceived notions. Rigorous review processes could ensure minimum scientific standards for published papers.

- Most papers lack control experiments or a thorough characterization of their calorimeters. Even when accepting that the effect is spurious and hard to replicate, control experiments (with light water or a platinum cathode that does not form a hydride) could illuminate the accuracy of the calorimeter and expose potential sources of error.

  – McKubre claims that the calorimeter had an accuracy of 0.4 %. Yet, the noise alone is on that level, let alone systematic offsets [110].

- Often, calorimetry is performed in a poor manner.

  – The heat flow is not stable before starting the experiment or the baseline is not shown [271,302].

  – Conditions are changed rapidly, much faster than the thermal time constant of the calorimeter [104].

- Many researchers claim that certain additives, stimulations or other experimental features are critical to the production of AHE. However, no control experiments with the feature absent are shown.

  – The SRI replication of the Energetics *superwave* experiments found that even with constant EC current (no *superwaves*), the COP was 5 [270].

  – Letts' early paper was using a single laser, reporting that visible light can trigger AHE [271]. His later papers use two lasers, reporting that beat waves in the THz regime can trigger AHE [104,272].

  – Oftentimes, sample preparation procedures are rather intricate, with up to 17 steps. No data is presented showing that this sample preparation is critical to generating excess heat [104].

  – Hagelstein stated that "it was important to not see an exothermic response when the beat frequency was below 8 THz" [104], based on his hypothesis of optical phonon resonances triggering AHE. However, Fleischmann and Pons reported AHE without stimulation by optical phonons.

- Many times, data is presented in a poor format. Plots are missing axis labels or units, or are not intelligible [93,102,270,271,304].

- Most studies use their own home-built calorimeters. While this might be due to budget restrictions and is not necessarily a problem, it requires careful characterization of the instrument and published documentation thereof to provide a confidence interval for the excess heat. As shown in chapter 2, it is possible to build a simple, yet reliable and accurate calorimeter in-house. However, many designs reported in the literature have shortcomings (e. g., single sensor potentially exposed to corrosive electrolyte, open system calorimeter, recombiner placed outside of the calorimeter [270], disagreement between calorimeters [103]).

- Conclusions are highly speculative or not supported by data. In some cases, they are in conflict with the data presented.

- An independent analysis of the excess heat data tabulated in Letts' report [104] shows no systematic relationship between excess heat and beat frequency (Fig. 7.37), contrary to the paper's conclucions.
- In Hubler's recent ICCF contribution [302], inconsistent data was reported, where in a flow calorimeter, the output temperature was reported to be larger than the input temperature, even though the cell temperature did not exceed the jacket temperature, suggesting the heat source was not the cell.
- In Staker's report of COP = 2 [93], the temperatures vary greatly and inconsistently when the EC currents are adjusted slightly (e. g. from 444 mA to 435 mA).

- Researchers report replicability of the effect, but fail to back this up with data [304].
- Experiments are insufficiently described to allow to be replicated. Essential details are left out, structures of papers are chaotic [106], important details are made available only in personal communication [113].
- Independent replications have typically failed at replicating excess heat [273]. However, this might also be caused by the inability to perfectly replicate experiments if they are insufficiently documented. Replications with the original party involved have been reported to be successful though [270].

If the field of LENR research aims to be taken seriously by other disciplines, it needs to play along and fulfill the criteria set up by the mainstream scientific community.

9.4 Outlook

The field of LENR has been guided by experimental findings, with no commonly accepted theoretical foundation predicting the effect. Given the lack of guidance by theory, our focus has been on replicating experiments with reported excess heat. We have observed apparent excess heat many times, with similar magnitudes as reported by others. However, every single time we have been able to trace it back to a classical explanation. Over the course of performing hundreds of experiments, we have unearthed a plethora of artifacts that can cause false excess heat signals. With significantly more sophisticated hardware and data processing than in most historic excess heat reports, we have been able to greatly reduce the frequency of the occurrence of false signals in our calorimetry campaigns, but we were not able to completely eliminate these false signals (section 9.2). We deduce that previous researchers, often equipped with fewer diagnostics and less redundancy, must have encountered similar false signals. Combining this with the lack of scientific rigor in the field (section 9.3), we conclude that there is no unambiguous observation of excess heat caused by LENR that holds up to common scientific standards. We therefore recommend terminating LENR research.