MOAC – A High Accuracy Calorimeter for Cold Fusion Studies

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Abstract

Calorimetry is conceptually simple but considerable effort is required to reduce systematic errors to acceptable levels. Since 1989, we have designed and constructed a dozen calorimeter systems for cold fusion research. Each of these systems provided valuable experience in error detection and correction. The culmination of our efforts, an instrument with a design accuracy of 0.1% relative, is nicknamed MOAC (Mother Of All Calorimeters). This paper provides a brief description of MOAC.

1. Introduction

One of the most important effects associated with cold fusion is excess heat. In order to measure excess heat a special calorimeter is required; one that simultaneously measures both the electrical power into the cell and the heat power out of the cell. Most of the calorimeters routinely used in chemical studies are unsuitable for this purpose because they only measure the heat power or energy released by the specimen.

For cold fusion research it is desirable to have a calorimeter with high accuracy so that small effects can be studied. Unfortunately, high-accuracy calorimetry is not easily achieved. It is especially difficult to realize accuracy better than 1% relative. Compared to a calorimeter with 1% accuracy, at least an order of magnitude more effort is required to achieve 0.1% accuracy. [1]

2. Measurement Strategy

MOAC operates on a simple principle. Flowing water is used to extract the heat from the cell. The flow rate and the temperature rise of the water are measured. The product of the temperature rise, the flow rate, and the specific heat of water yields the heat power being extracted from the cell. This approach is commonly referred to as flow calorimetry. In addition, MOAC simultaneously measures the heat output of the cell by isoperibolic calorimetry. In this technique, which is based upon Newton's Law of Cooling, the heat output power is assumed to be proportional to the temperature difference between the electrolyte and the gently stirred air that surrounds the cell. These two independent methods of heat power measurement provide important insights into the thermal behavior of cold fusion cells.

3. Construction

Despite its simple concept, MOAC is not a simple instrument. Two independent computer-based data acquisition systems monitor a total of forty-five parameters, including twenty-two separate temperatures. Fourteen analog outputs, driven by proportional-derivative feedback algorithms, control various critical parameters.

Figure 1 shows a simplified block diagram of the system.

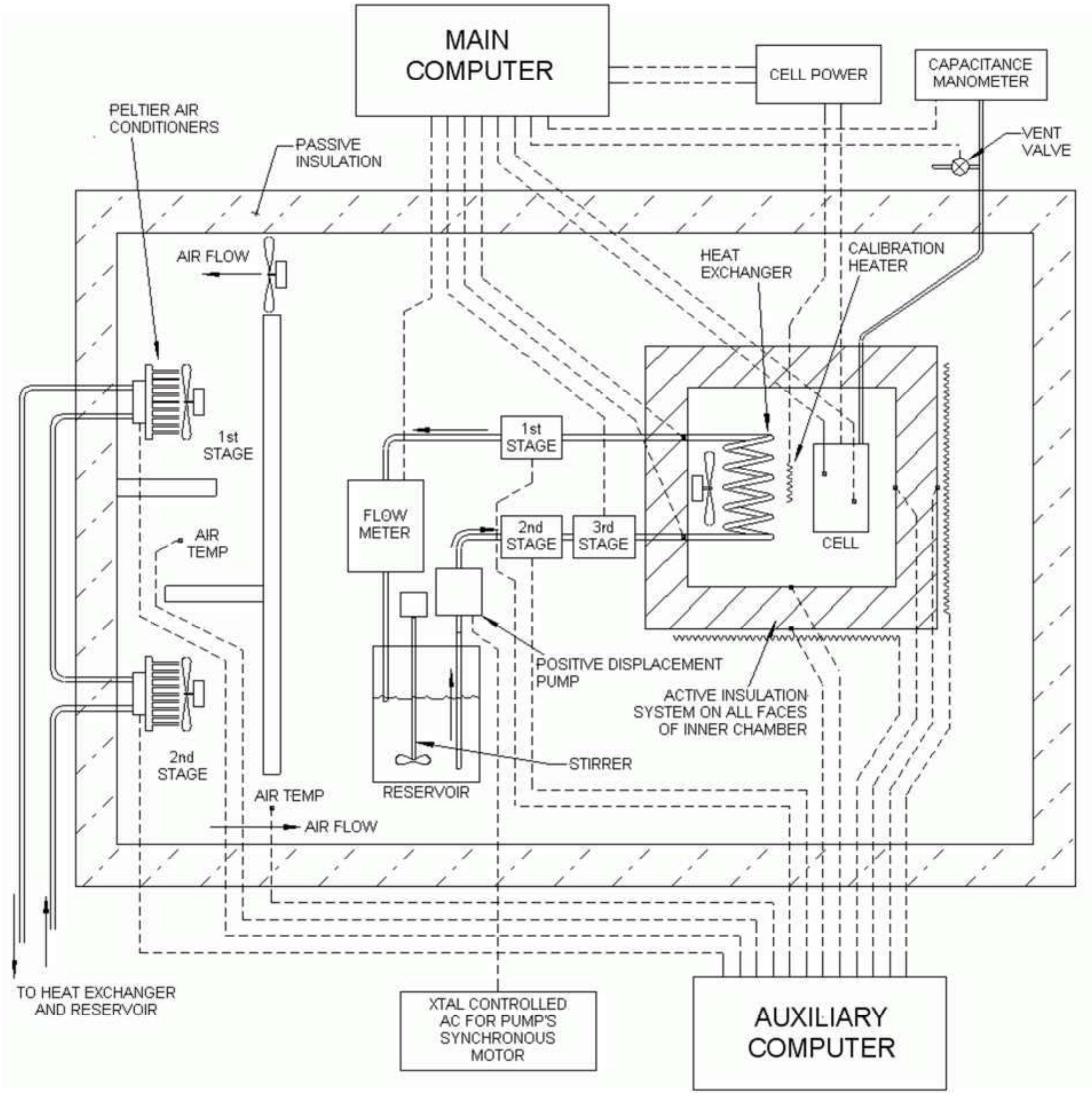

Figure 1. Block Diagram of MOAC

The cell is placed in the calorimetry chamber (CC) with a liquid-air heat exchanger and a small fan. The CC walls are active insulation (AI) panels made almost perfectly insulating by a system that heats the outer surface of each of the six wall panels so that its temperature matches that of the corresponding inner surface.

A three-stage Peltier temperature regulator controls the temperature of the water entering the heat exchanger. A positive-displacement pump produces a stable flow of about 2.5 gm/s. This flow rate gives MOAC a nominal sensitivity of about 10 W/°C. A flowmeter consisting of an automated batch weighing system measures the flow rate periodically. A large insulated environmental enclosure (EE) houses the entire system. Air circulates over the calorimetry apparatus and then is ducted to a two-stage Peltier air conditioner where its temperature is tightly regulated before it re-enters the enclosure.

Figure 2 is a photograph of the entire system. The CC is the light blue box visible inside the wooden environmental enclosure. Also visible through the door window is the water reservoir and the flowmeter. Under the computer bench is a bank of DC power supplies. Under the bench that supports the EE is the water reservoir and heat exchanger for the Peltier air conditioners.

Figure 3 shows the interior of the CC. On the right is the cell, in this case our standard calibration cell. On the left is the liquid-air heat exchanger and fan. Between the heat exchanger and the cell is the permanent calibration heater. In the foreground at the bottom is a trap that collects any liquid ejected from the cell.

Figure 2. Overall View of MOAC

Figure 3. Calorimetry Chamber

3.1. CC Input Power

Input power is determined by the input voltages and currents of the devices within the CC:

$$P_{in} = V_{in} \cdot I_{in} \tag{1}$$

where V_{in} is the voltage at the boundary of the CC, and I_{in} is the current through the device. In the case of multiple devices, the total power is the sum of the individual device dissipations.

3.2. CC Output Power

The rise in water temperature across the heat exchanger and the mass flow of the water are used to determine the power dissipated in the CC:

$$P_{flow} = \Delta T \cdot \Gamma \cdot c \tag{2}$$

where: $\mathbf{\Delta T} = \mathbf{T}_{out} - \mathbf{T}_{in}$ + Sensor Offset; $\mathbf{\Gamma}$ = the mean flow rate in gm/s; and c = 4.1796 J/gm-°C at 25 °C. The values $\mathbf{T}_{out}$ and $\mathbf{T}_{in}$ are the averages of the temperatures indicated by the individual sensors in each dual-thermistor sensor assembly at the boundaries of the CC.

For calibration, accurately known electrical power levels are applied to any or all of several devices inside the CC: the permanent calibration heater in the air (R1); a standard control electrolysis cell (E); and a second calibration heater immersed in the electrolyte (R2). These three heat sources are operated singly and in combination at different power levels for extended periods to acquire the calibration data. The readings are used in a statistical regression analysis to obtain the coefficients **a** (intercept: watts) and **b** (slope: dimensionless) which are then used in the calorimeter power equation:

$$P_{flow(cal)} = a + b \cdot P_{flow} + \text{wire loss} \tag{3}$$

The term *wire loss* is the measured heat loss due to the thermal conductivity of the copper wires entering the CC through the bottom ports. When 10 W is dissipated in the chamber, the wire loss is typically about 60 mW.

4. Performance

The primary measure of MOAC's performance is its overall measurement accuracy. When recently calibrated, MOAC can achieve the original design goal of +/- 0.1% relative accuracy.

A typical value for **b** is 1.0005, which reflects the fundamental nature of this approach to calorimetry and also shows that MOAC's thermal design is successful in removing heat from the chamber only via the flowing water.

Another important aspect of performance is specimen versatility. MOAC excels in this area by producing precisely the same reading on a wide variety of heat sources. The size, shape, temperature, and location within the chamber have very little effect on the measurement.

A clear demonstration of this specimen versatility is the observed deviation of three heat sources (R1, R2, and E) about the calibration line; typically +/- 5 mW. A study was conducted in which a calibration heater was operated at 15 watts at several different locations within the CC. For all the reasonable locations, the difference between electrical input power and heat output power was 12 mW or less (i.e. within 0.1% relative). When the calibration heater was placed in one of the extreme corners of the chamber, the heat output power read 25 mW lower than the electrical input power (i.e. a 0.2% error).

4.1. Errors

MOAC exhibits both random and systematic errors. The random errors appear to be a combination of electrical noise and digital granularity in the temperature measurements. This conclusion is supported by the fact that fixed precision resistors located within the environmental enclosure report about the same jitter as the thermistors. Even with 100-reading averages comprising each observation, these errors produce a jitter in the temperature signals of about +/- 0.0005 °C. Given MOAC's 10 W/°C sensitivity and the fact that inlet and outlet water temperatures are measured independently, this jitter corresponds to almost +/- 10 mW in the heat output power signal. Fortunately, MOAC's thermal time constant is about one hour so it is permissible to apply additional averaging to the signals to reduce this jitter to negligible levels.

The systematic errors are more complex. When MOAC was first commissioned in the summer of 2004, it readily achieved 1% relative accuracy. However, numerous systematic errors prevented it from approaching the design goal of 0.1% accuracy. It took nearly 2 years of intensive testing and evaluation to find and eliminate these errors.

For the first few months of operation we observed mysterious perturbations in the heat output power reading. We finally determined that these perturbations were due to the sudden expulsion of an air bubble in the liquid-air heat exchanger in the CC. We solved this problem by installing three air traps at strategic locations in the calorimetry water loop.

Another problem that caused noticeable short-term drift was instability in the water flow rate. We initially constructed MOAC with a pump system from FMI that was advertised to provide a highly stable flow rate. Once we identified pump speed variations as the problem we abandoned the FMI controller and tried a custom closed-loop speed control that employed a digital tachometer. That worked better but the brushes in the DC pump motor caused undesirable speed perturbations. After trying another type of DC motor with similar results we abandoned DC motors altogether and installed a synchronous AC motor powered by the 120VAC 60Hz mains. Small line frequency variations were clearly visible in the measured flow rate. Finally we conquered the flow rate stability problem by constructing a crystal-based 60Hz power supply for the synchronous motor. The result is a flow rate whose stability is typically +/- 0.02% relative.

For the first 6 months of operation, MOAC required a **b** calibration coefficient of approximately 1.01. In other words, we were losing 1% of the heat from the chamber. We tracked this loss down to the power and signal wires passing through the walls of the chamber. Our wire bundles were not adequately thermally clamped at each wall so ambient air temperatures were having an unexpected influence. We solved this problem by instrumenting the wire bundles with temperature probes located at each wall of the CC. The measured temperature difference from these probes is used to calculate the wire loss term used in equation 3. After this correction was implemented, the b coefficient typically comes out between 0.999 and 1.001; in other words, within 0.1% of unity.

At the time of this writing, MOAC is quite reliable and readily achieves 0.1% accuracy when recently calibrated. The largest remaining source of error is the drift exhibited by the thermistors used for the critical inlet and outlet water temperature measurements. The observed drift is usually quite slow and is only a fraction of the manufacturer's specification. That is, the thermistors are performing significantly better than the manufacturer's guarantee but we can still see their drift. Because of this drift, MOAC requires recalibration, usually only a change in the **a** term, once every month or two.

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A longer version of this paper, including construction details and interesting calorimetric results, is located at http://www.earthtech.org/experiments/ICCF14_MOAC.pdf

References

1. McCullough & Scott, "Experimental Thermodynamics, Calorimetry of non-reacting systems", D.W. Butterworth, London, p. 9, Vol. 1, 1968