An Airflow Calorimeter for LENR Measurements

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These notes describe the design, construction, and performance of an airflow calorimeter suitable for LENR enthalpy measurements with a heated cell. For a Mizuno-type replication, for example, airflow calorimetry is good choice because it permits the cell to maintain a relatively high temperature (as compared to water cooling) while at the same time affording accurate measurement of energy generated either due to Joule heating or exothermic reactions within the cell. The calorimeter has a resolution of ~0.2 °C, corresponding to a power resolution of 2 Watts, and a maximum power handling capability of ~300 Watts.

Calorimeter Mechanical Description

The calorimeter consists of a box constructed of 1.5” metalized polymer foam, such as can be purchased for building insulation. The pieces of foam are cut on a table saw and then glued together with silicone adhesive, An additional aluminized, woven fiberglass fabric is applied to all interior surfaces to further reduce heat loss through the walls and to improve the mechanical integrity of the interior walls. The cell sits on aluminum mounting brackets that hold it off the floor. Inlet and outlet ports are fabricated from 1.5” ABS pipe and are secured to the insulating foam with silicone adhesive. The inlet port has a 12 VDC fan situated inline with the hot/cold diodes located upstream of the airflow. These two diodes form part of a closed loop feedback system that guarantees a constant thermal mass per unit time. Location of the hot/cold diodes is critical. The hot/cold diodes are located such that any heating from the former does not affect the latter.

Holes in the calorimeter wall are provided to route heater wires and ¼” SS lines to the gas/vacuum manifold. A 2-piece metal cover fits over the SS line and minimizes the amount of air that can bypass the outlet port.

The cell itself consists of a 8” x 2.75” CF nipple where one end cap terminates to a ¼” VCR fitting and the other to a 1.33” CF flange. A vacuum tight fit is provided by silver welding a 0.375” thermowell into the 1.33” CF fitting. All connections on the high vacuum side (which includes the cell) are either, silver brazed stainless, VCR fittings or CF flanges. The thermowell may be used either for a thermocouple or for a cartridge heater.

Heating may be achieved either by placing a cartridge heater in the thermowell or by wrapping a heater blanket around the cell’s exterior. The latter method was chosen because it provides a more uniform heating and does not require that the heating element temperature exceed the cell’s internal temperature. It was observed that a 6” cartridge heater had to be operated near its max temperature to achieve a 150 °C temperature on the exterior of the cell.

External heating is provided by wrapping approximately 20 feet of 22 Ga ceramic insulated nichrome around the cell and then securing it in place with Saureisen type 78 ceramic cement. The room temperature resistance of the nichrome wire is about 1Ω/foot. With this configuration it is possible to achieve cell temperatures in excess of 300 °C without overheating the heater element.

The power delivered to the heater wire is measured using a 4-wire configuration. Voltage is monitored at the point where the heater wires enter the calorimeter. Current is measured by a 10 mΩ shunt, and power is simply the product of I*V. A Sorensen DCS 150-7 supply (150VDC, 7A) is used as a power source for the heater.

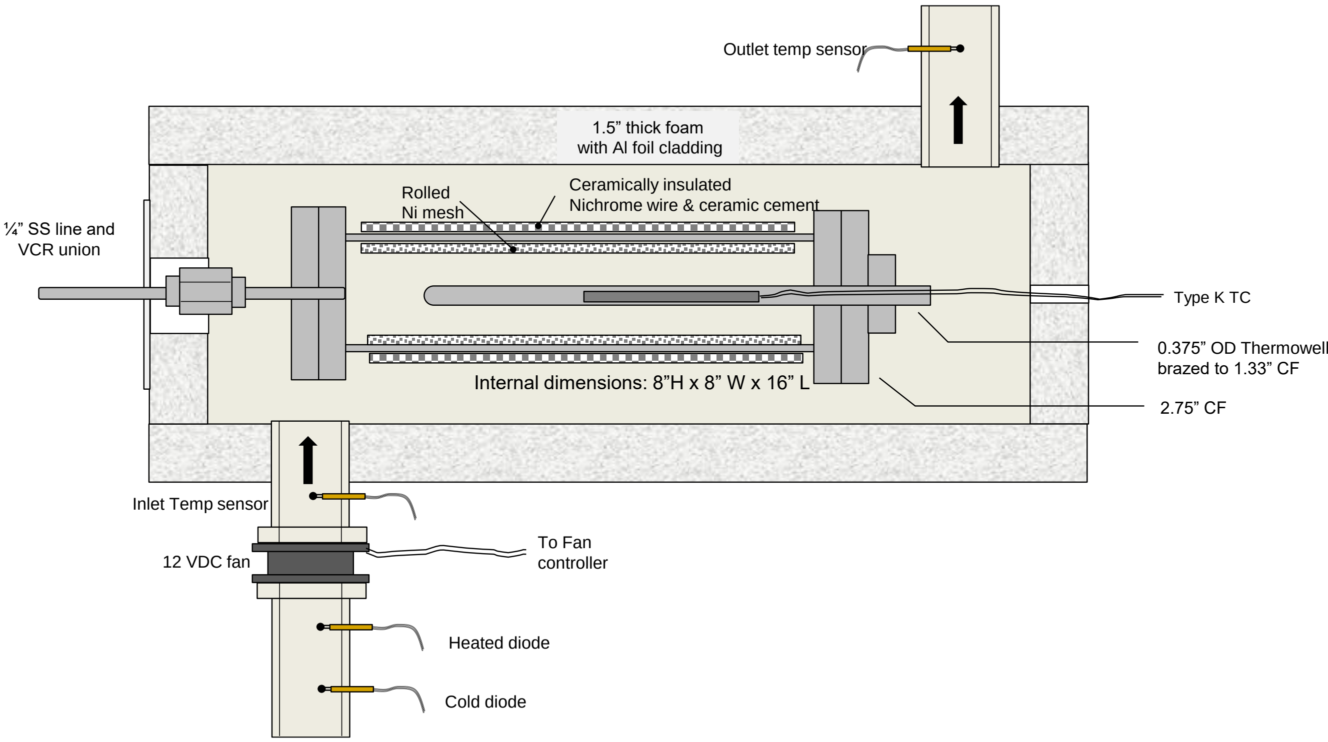

Figure 1: Calorimeter Enclosure and Cell

While not strictly necessary for calorimetric purposes, the setup has provision to measure the approximate temperature of the Ni mesh. Given that Joule heating is applied externally to the cell and excess enthalpy (if any) will occur on in or on the Ni, the coaxial location of the thermocouple will give an accurate temperature measurement of the Ni itself. Measurement of excess enthalpy is achieved by measuring the inlet/outlet temperature difference and comparing it to a dry run calibration

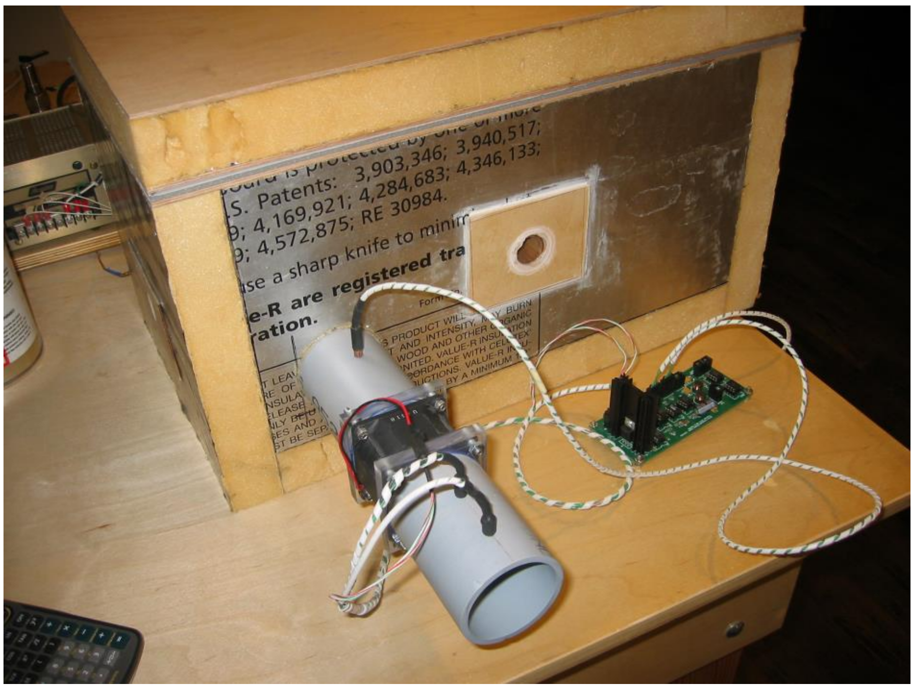

Figure 2: Calorimeter Enclosure showing fan, temp sensors on inlet port

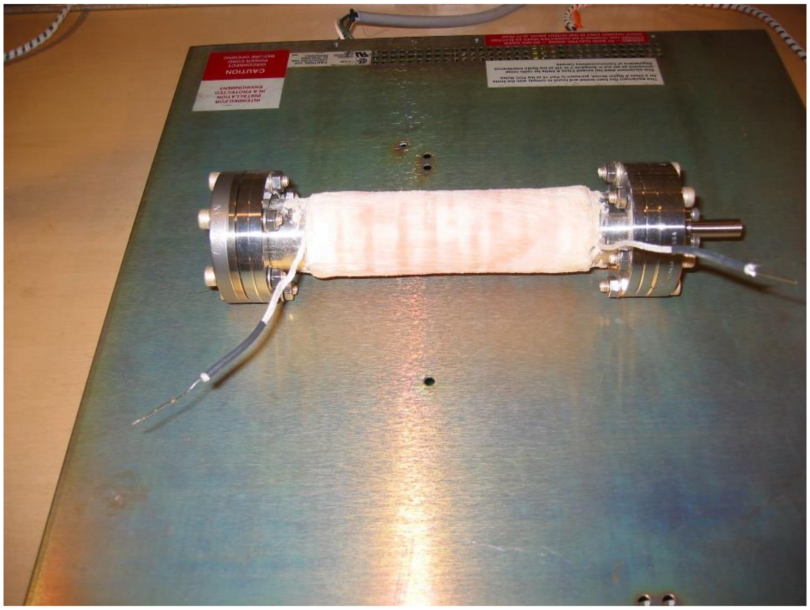

Figure 3: Cell with heater jacket

Calorimeter Theory of Operation

As mentioned earlier, the calorimeter operates on the basis of maintaining a fixed thermal mass flow per unit time. Given this property, the temperature difference between inlet and outlet ports will vary linearly with the amount of heat generated internally within the calorimeter. This linear response is guaranteed by means of a fan controller consisting of closed loop feedback configuration with two sensor diodes (one heated and one not) and an adjustable precision voltage source. An error amplifier behaves as an operational amplifier, trying to maintain a 0V difference between these two inputs. Higher fan speeds will reduce the delta T between the two diodes, while lower speeds will increase the delta T. Note that it is not necessary for the fan speed vs. delta T to be linear, since it resides inside the feedback loop.

Multiple sources of power vs. Toutlet – Tinlet nonlinearity exist. The most significant arises due to expansion of air in the calorimeter. When power is applied to the cell heater the air inside the calorimeter expands, thereby creating a back pressure. This effect is in addition to the back pressure due to the finite size of the outlet port Nonlinear behavior may also occur due to ambient temperature, altitude, and humidity differences between runs. The feedback loop configuration guarantees a linear response despite changes all such conditions.

Fan Controller Power Supplies

The fan controller requires regulated +15V 1A and a -15V 100 ma supplies. Any typical linear OEM supply will suffice. Additional filtering is furnished by L1, L2 and C1-C4. A precision voltage of 5.000 V is required to furnish power to the heated diode as well as to provide a 5.00V reference for the instrumentation amplifier U3. Instrumentation amplifiers are employed for both the input/output temperature sensors as well as the hot/cold diodes in order to improve electrical noise rejection.

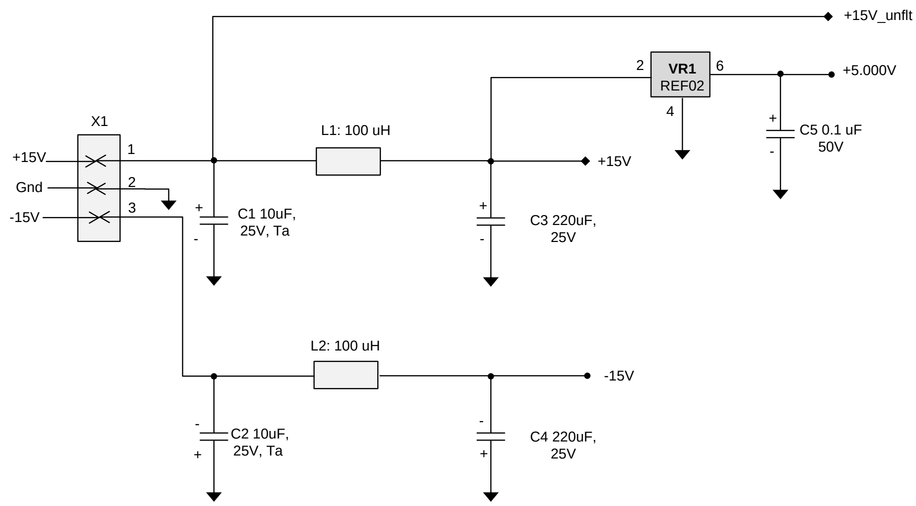

Figure 4: Filtered Power Supply and 5.000V Source

Error/Buffer Amplifiers

Error/buffer amplifiers consist of an instrumentation amplifier, U3, and a buffer stage U4/Q1. One diode, the hot diode, is thermally bonded to a 750Ω, 1/4W film resistor, such that when the fan is operating, yields approximately a 5°C junction temperature difference between the two diodes. The heater resistor is powered by the precision 5.000V voltage reference. A 5°C difference equates to approximately 10 mV difference in Vfd. R3-R6 forward bias the two diodes, and R7, POT1 permit fine tuning of the voltage delta between hot and cold diodes, thereby allowing the fan speed to be set.

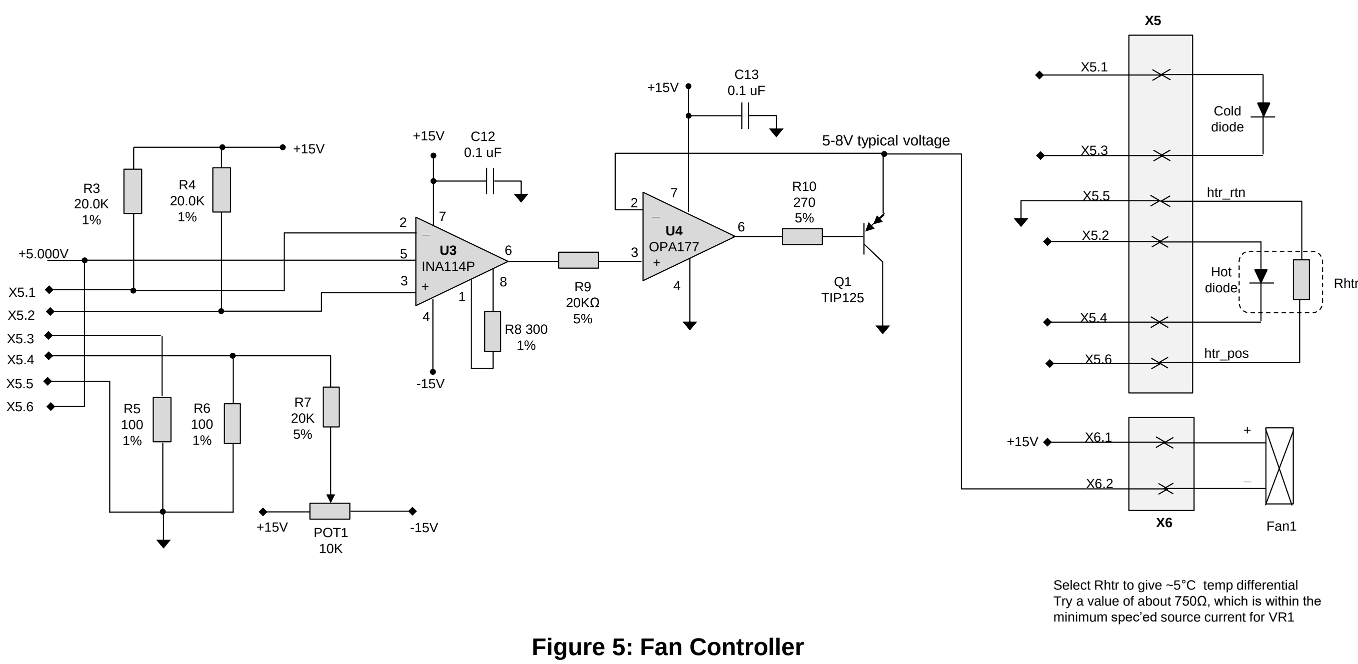

Figure 5: Fan Controller

U3, U4, and Q1 comprise a differential amplifier, a buffer amplifier, and an emitter follower, respectively. The open loop gain of U3 is set by R8 to be large (approx. 168). Ideally, we would like the open loop gain at DC to be much higher than the equivalent closed loop gain. The combination of U4, and Q1 form a buffered emitter follower, where Q1 is a PNP Darlington device. The choice of a Darlington was driven by the need to match the relatively low drive current of U4 to the ~1A load of the fan. Note that the buffer stage is configured such that a unipolar power supply is sufficient. This is realized by tying the fan V+ to +15V and permitting the fan V- input to vary between approximately 3V (fast speed) and 8V (slow speed)

Inlet/Outlet Port Sensors

A pair of LM35 precision temperature sensors is used to monitor inlet and outlet temperature difference. Each drives an INA114 instrumentation amplifier where the gain is set to 10.00. This yields a 100 mV/°C sensitivity over a 2°C – 100 °C range. In typical use the temperature range is substantially less: inlet temperature is ~23°C, and outlet temperature is maintained below 50°C to avoid damaging the calorimeter insulation. Instrumentation amplifiers (with true differential inputs) were selected to minimize errors introduced by voltage drops between +Vs and Gnd. Differential inputs also minimize any common mode noise.

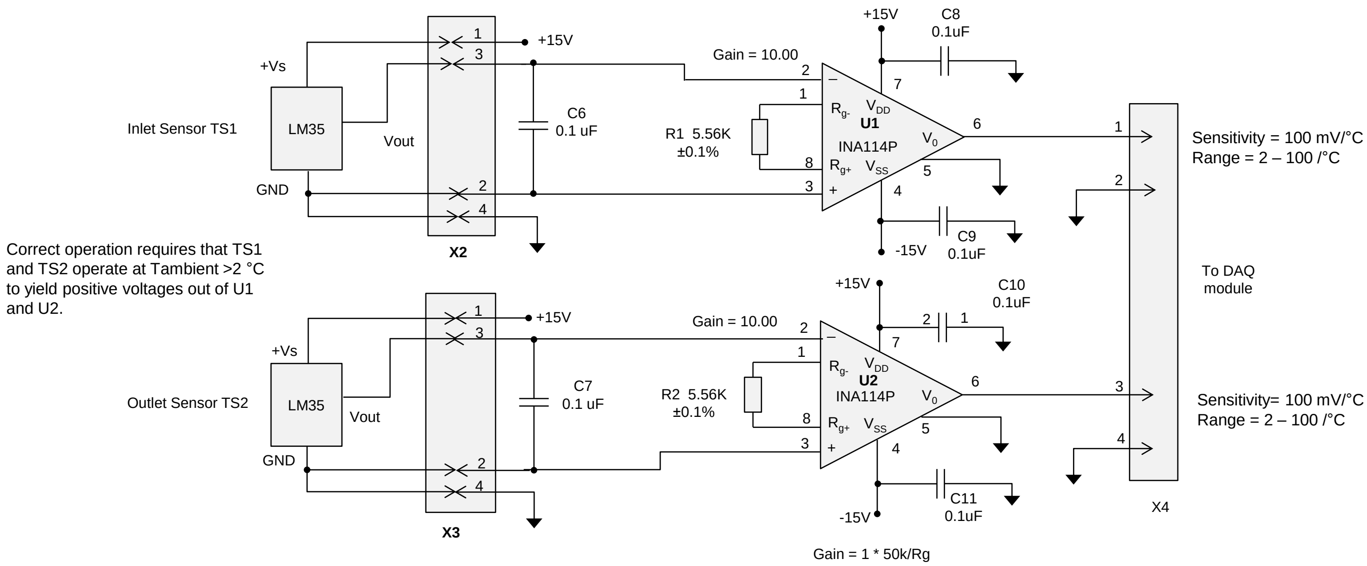

Figure 6: Inlet/Outlet Temperature Monitor Circuit

The circuit assembly for the fan controller and inlet/outlet temperature monitor circuits is shown below. On the left side is a heatsink attached to Q1. The various headers at the top of the circuit board connect to power, the hot/cold diodes, and the inlet/outlet temperature sensors. On the middle left may be seen a small blue component which is the trimpot for adjusting the fan speed.

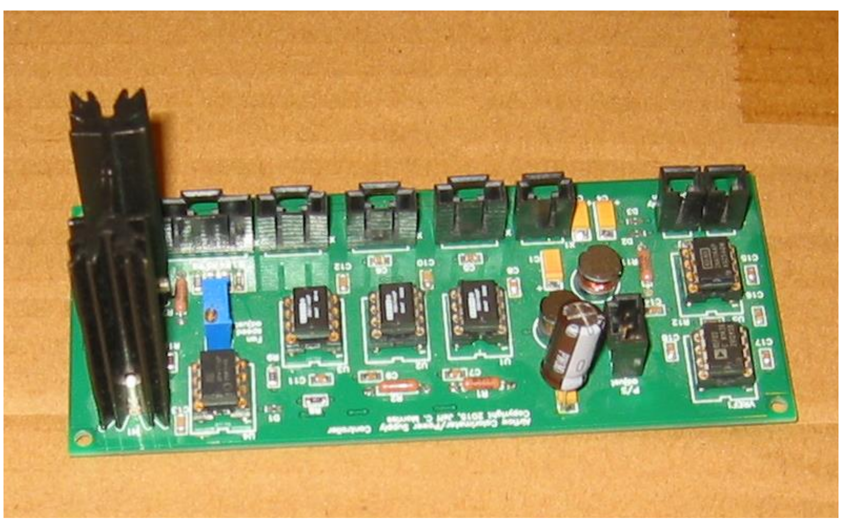

Figure 7: Fan Controller Assembly

Performance Results

The following plot demonstrates the ability of the fan controller to produce a linear power in vs. delta T out. The Y-axis plots the temperature difference between the input and output LM35 sensors, while the X-axis plots DC power, in watts, applied to the heater. The 1st order fit is given by the 0.0908 and 1.1628 coefficients. Note the excellent fit to a 1st order polynomial as is evidenced by $R^2 \approx 1$. The small offset (1.1628) between the two temperature sensors, evidenced by a nonzero Y-intercept, is due to temperature tolerance error between the sensors. It is easy, however, to remove this error while still maintaining an excellent power vs. temperature linearity.

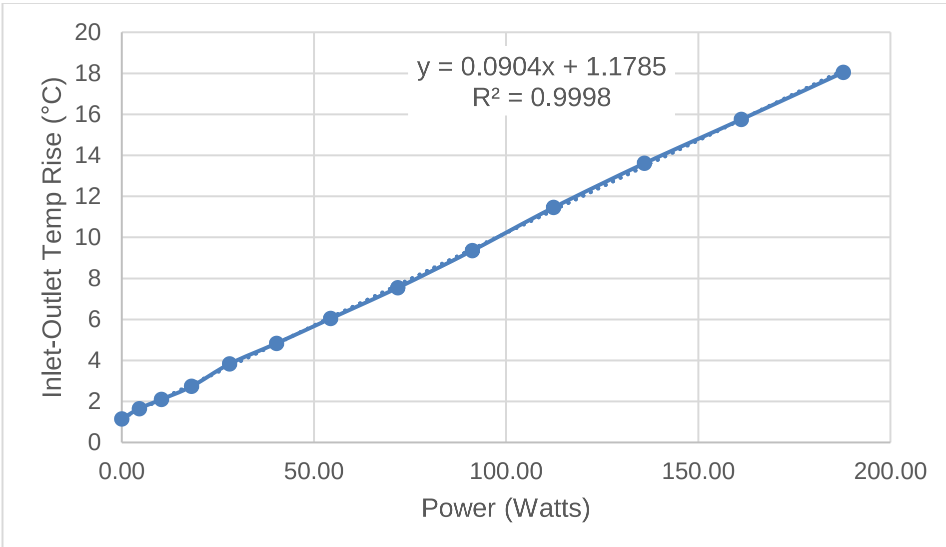

Figure 8: Temperature Rise vs. Applied Power

If the cell temperature (as measured by a TC in the thermowell) is plotted against the applied power a somewhat linear plot results. The rolloff at higher power settings may be attributed to the fact that more heat is escaping through the calorimeter walls. A second order polynomial yields an excellent fit, however.

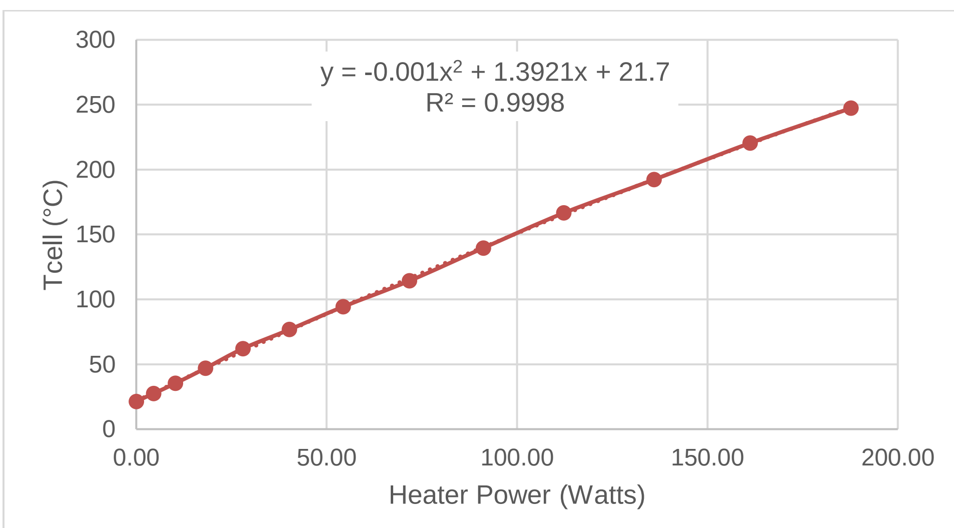

Figure 9: Tcell vs. Applied heater power

Next steps and improvements

Observations with an empty cell show that the power vs. inlet/outlet temperature difference is linear and repeatable. What has not yet been done is to perform a parallel evaluation characterizing measured airflow and heat loss through the calorimeter walls. This approach would provide a more fundamental confirmation of the calorimeter's characteristics. In principle, however, since an empty and a loaded cell present identical surfaces, (same cell used for both) any excess heat should appear as an additional temperature rise and can therefore be correlated to the power vs. inlet/outlet temperature curve. Therefore the primary approach outlined in these notes should provide sufficient accuracy and repeatability.

For a given heater power the inlet/outlet temperature measurements does show some amount of variation over time spans of a few seconds. This variation corresponds to approximately 0.1 °C RMS and can be mitigated by time averaging temperature readings over a time span of several minutes. A next step will be to connect the inlet/outlet temperature sensors to a DAQ module such that temperature readings can be averaged and, if necessary, statistically characterized.