Uppsala Clean HME Calorimeter

Bo Höistad, Per Sjöberg, Józef Złomańczuk
Uppsala University

Abstract

A calorimeter based on circulating water in a double walled stainless steel cylinder has been constructed to measure anomalous heat production generated in hydrogen/deuteron -metal fuel systems. The calorimeter can measure power, based on increased water temperature and water flow rate, in the range from 10 W to 1 kW coming from a reactor tube placed in the center of the calorimeter. The accuracy is slightly better than 10 W in the whole power range. In addition, the temperatures at the reactor center are measured with several thermocouples. The experimental set up is arranged to have redundancy in all parameters being measured. The calorimeter gives immediate response of the watts coming from the reactor tube. All parameters are logged to a data file. The data can be analyzed both on- and off-line with an advanced specially written data visualization and analysis program.

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Contents

Introduction

The Uppsala calorimeter has been constructed to measure anomalous heat production in hydrogen/deuteron -metal fuel systems. This anomalous heat is expected to have its origin in Low Energy Nuclear Reactions (LENR). The calorimeter is designed to pick up excess power in the range from 10 W to 1 kW, and give an accuracy slightly better than 10 W in the whole power range. In addition, the temperatures at the reactor center will be measured with several thermocouples. The experimental set up is arranged to have redundancy in all parameters being measured.

A cross section of the calorimeter is schematically shown in figure 1 and a detailed description of the components is given in the following section and appendix.

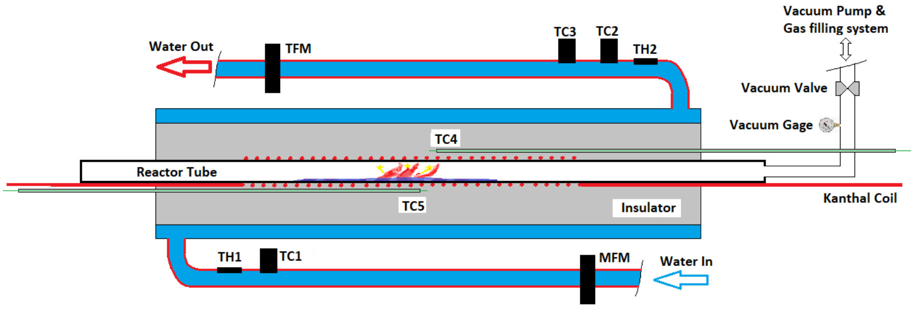

Figure 1. Schematic view of the calorimeter.

The calorimeter is based on measuring water circulating in a hollow cylinder surrounding a reactor tube. The incoming and outgoing water temperatures are measured at each reactor temperature. Accordingly, the heat from the reactor tube can easily be calculated. The fuel in the form of powder or a bulk cylinder is inserted in a vacuum tight Alumina ceramic reactor tube. An example of a reactor tube being used in the calorimeter is shown in figure 2.

Figure 2. An example of one reactor tube being used.

The fuel can be pre-treated while in place in the reactor tube. For example, if the fuel consists of metallic nickel the oxide layer on the surface can be removed by flushing hydrogen gas into the reactor tube at a certain temperature. Moreover, the ability for the nickel powder to absorb hydrogen can be monitored by studying how the gas pressure changes when the hydrogen is introduced in the reactor tube at some chosen temperature.

If the fuel is prepared in the form of oxides or carbonates in order to obtain a certain nano- structure, the reduction can be made in the reactor tube by of a number of “pumping out and refill with hydrogen gas and heat” cycles in order to remove the oxides and carbonates from the fuel. These cycles are carried out in a controlled way, i.e. the gas pressure, temperature, delivered power and released heat are measured and stored in data files for on-line or later off-line analysis.

After the fuel "activation" the rector tube is filled with hydrogen (H_2 or D_2) and the temperature is increased step-wise up to 800 – 1200ºC. The released heat is controlled by measuring temperature of the water flowing in and out of the calorimeter together with measurement of the water flow rate.

Temperatures are measured with thermocouples (TC1-TC5) and thermistors (TH1, TH2), and the water flow with magnetic (MFM) and turbine (TFM) flow meters. The power is delivered to the coil either from custom designed power supply (CPS) or from a commercial SM112-13 power supply, both controlled with dedicated on-line programs.

Overview of the instrumentation in the calorimeter set-up

Below, in figure 3, is a schematic view of the instrumentation in the calorimeter set-up. A detailed specification of each instrument is given in the appendix 1 referring to the numbers in figure 3.

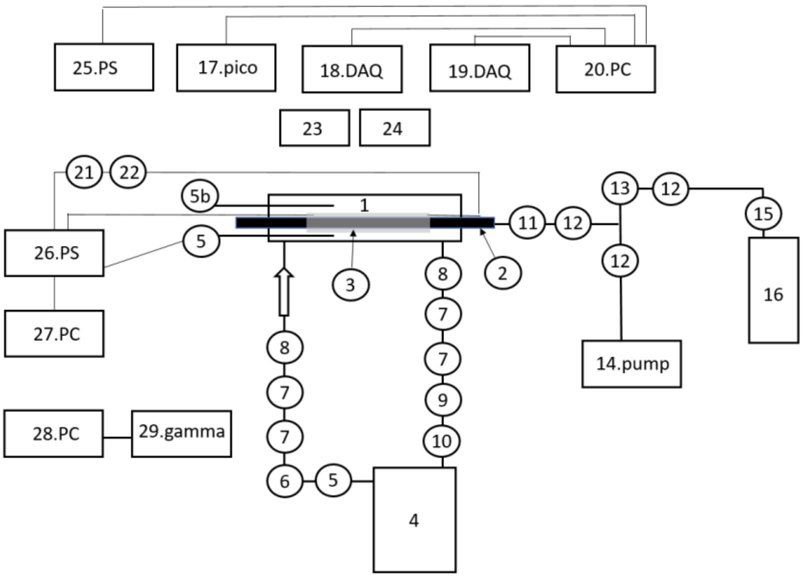

Figure 3. Schematics of the instrumentation in the experimental set-up.

The calorimeter consists of, two concentric stainless-steel tubes, outer tube: 38 cm long, 90 mm OD, inner tube: 38 cm long, 72 mm ID. The hollow space between the cylinders is 16 mm. A rail between the inner and outer cylinders guides the water to circulate around in the inner space. The calorimeter is insulated with 10 mm Armaflex on the outside and about 12 mm high temperature resistant fiber insulation wool on the inside. The purpose of the inside insulation (gray in fig 1) is to regulate the outgoing water temperature. The less insulation the higher the outgoing water temperature, but the more power is required to heat up the reactor tube. Typically, it takes about 300 W to reach a reactor temperature of 660 degrees. In this case, with the water-in temperature being 20.5 degrees one gets the water-out temperature 22.8 degrees for a flow rate of about 0.9 liter per min. If one wants larger difference between the incoming and outgoing water temperatures one has to play with the thickness of the insulation wool and the water flow rate. Considering the precision in each measurement, the numbers given above is a judicious choice of an optimal parameters set.

The heating coil around the reactor tube consist of a Kanthal wire typically 2 or 2.5 mm thick. The length of the wire is adopted to give a resistance of about 1 to 1.2 Ohm in order to match the in-house built power supply. The power supply gives pulses of 50 Volt and the output power is regulated by the length of the pulse. Note that the current in the pulses is high, 50 Amps. The power supply can be programmed to give pulse frequencies in the range 10 to 5000 Hz and with arbitrary polarity. In addition, it can be set to operate in an on-off mode in an arbitrary temperature interval. This feature is implemented in order to expose the fuel for a constant temperature gradient, which might facilitate the onset of a LENR reaction. The power supply and its software is specially developed for our purpose and it is built in-house.

We also have a commercial power supply SM 120-13 from Data Elektronika borrowed from Volvo. This power supply can deliver 120 volt and max 13 Amp, and thus 1.56 kW in DC mode. Using this power supply the resistance of the heating coil has to be matched to the output accordingly.

The current I(t) and voltage V(t) given to the heating coil are measured separately and the input power is obtained from an integration of the product $V(t)\cdot I(t)$. In this way any phase shift between the current and voltage due to induction in the heating coil is considered. Moreover, the power calculation is independent of the resistance in the heating wire which has a weak temperature dependence.

Reactor tubes of several different dimensions can be used in the calorimeter. One example is shown in figure 2. As appears from this figure the reactor tube must have end-pieces for gas inlet and fuel insert. The attachment of these end-pieces has to be vacuum tight, stand high temperatures and be removable. We use a special high temperature resistant epoxy to glue the end pieces to the reactor tube. However, the glue can tolerate a maximum temperature of about 300 degrees and the end pieces therefore have to be placed outside the calorimeter. If one heats the end-pieces to up to about 600 degrees the epoxy degrades and they can easily be removed.

The pressure in the reactor tube can be kept to about 10^{-2} mbar for several days without pumping. The maximum pressure is safely 10 bar. At 15 bar there is a risk that the end-piece will fly off which has happened once. The maximum temperature gradient the alumina tube can sustain is about 10 degrees per minute. It is important not to create cracks in the tube when under high pressure with hot hydrogen gas. In that case the hot hydrogen gas will self-ignite when spurting out to the surrounding air, which has happened once causing a scary big flame.

Since the reactor tube has its end-pieces outside the calorimeter it doesn't collect all heat from the reactor. About 25% is lost to the air outside the calorimeter. Exact how much is lost depends on the heat transport to the end, which is dominated by the heat conductivity of the reactor tube. Since the heat conductivity for alumina decreases with higher temperature the heat loss to the air via the end-pieces becomes less at higher temperature. However, the effect is rather small. Anyway, it is important to make a background test with inactive fuel before each investigation of excess heat from a fuel which might give rise to excess heat. Moreover, it is absolutely necessary to study both the reactor temperature and the heat from the calorimeter simultaneously in order to see how they correlate. Those values must both deviate from the expected values for a given input power in order to claim excess heat from the fuel.

Excess heat is indicated when the COP factor, output heat /input heat, deviates from the expected value with inactive fuel (about 0.75), e.g. fuel but vacuum in the reactor tube. The COP factor is measured continuously while heating the reactor tube. The hope is of course to find irregular variation in the COP factor at some temperature.

We emphasize that in our experiment aiming at measuring a very implausible phenomenon, it is mandatory to have high precision and redundancy in all measured parameters.

Regarding the variety of reactor tubes which can be used in the calorimeter one of them deserves special remark, since it allows very high temperatures. It consists of a solid coil of special Kanthal type material named Mini Superthal. This material can stand a temperature up to 1525 degrees. It has long life time and can be kept in air at hot temperatures. A casted coil is imbedded in a special insulating fiber cylinder shown in figure 4. The Alumina reactor tube is inserted in the fiber covered coil, and the whole package can be inserted in the calorimeter. The Superthal material has a very strong temperature dependent resistance, so it is very necessary to measure current and voltage independently, as is standard in our set-up. The Mini Superthal heating element is fabricated specially for our experiment.

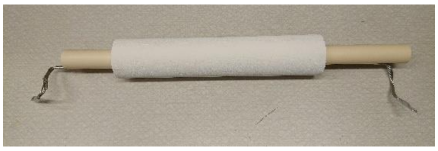

Figure 4. The Mini Superthal heating element with an Alumina reactor tube inserted inside the coil. The metal strings are connections to the solid coil inside the fiber cylinder.

Data acquisition and control systems

Electrical connections

The components of the Data Acquisition System (DAQ) and signal connections are schematically presented in figure 5 below.

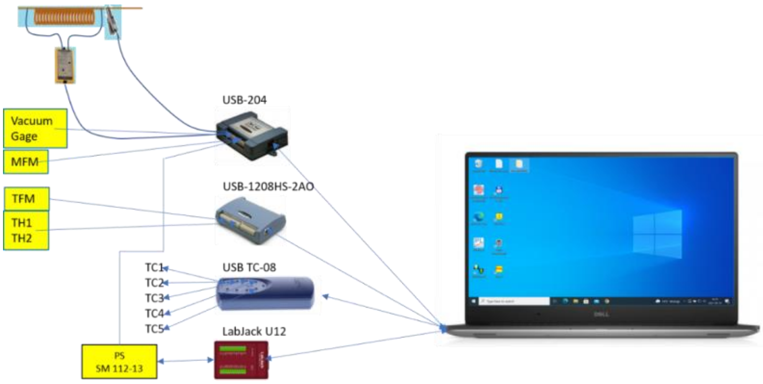

Figure 5. Components of the Data Acquisition System (DAQ) and signal connections.

USB-204

The following signals are connected to the screw terminals of the USB-204.

Table 1. USB-204 terminals

Signal	Screw terminal
Voltage applied to the coil, U	AI0
Current in the coil, I	AI1
Output Voltage from SM112-13, VU	AI2
Output Current from SM112-13, VI	AI3
Vacuum Gage	AI4
Magnetic Flow Meter, PIN 4 (see below)	CNT

Figure 6. Pin assignment of the magnetic flow meter.

USB-1208HS-2AO

This module is at present used for the temperature measurement with thermistors. The connection diagram is shown in figure 7 below.

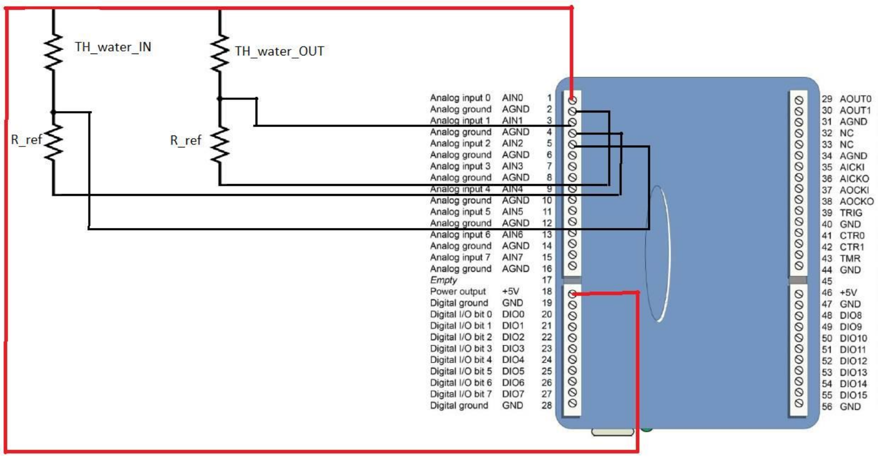

Figure 7. Connection diagram of signals to USB-1208HS-2AO. R_ref has a resistance of 10 kΩ.

It is also used to measure the rate of water flow with the turbine flow meter (TFM) connected to the counter input CNT0 as shown in figure 8.

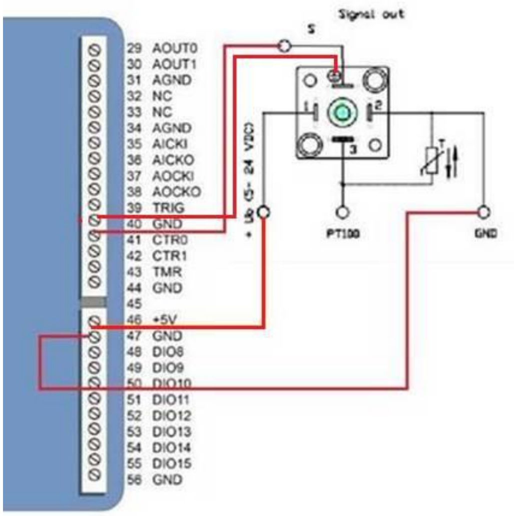

Figure 8. Connection of the turbine flow meter (TFM) to the USB-1208HS-2AO.

USB TC-08
The thermocouples TC1-TC5 are connected to 1-5 inputs of the TC-08 unit.

LabJack U12
This unit is used to control the output voltage of the SM112-13 power supply. The wiring is shown figure 9.

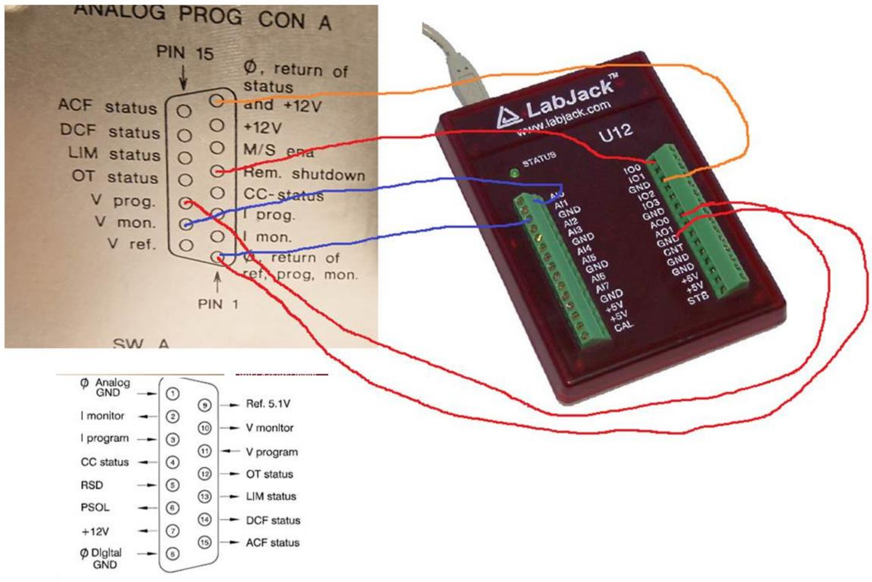

Figure 9. Diagram of SM112-13 control with the LabJack unit.

During testing the analog output AO0 has been damaged and the Vprog input of the SM112-13 has been connected to AO1.

Software

Data Acquisition DAQ

For all four modules, USB-204, USB-1208HS-2AO, TC-08 and LabJack U12, there are drivers and libraries in C provided by manufacturers so the DAQ program has been written in C as WIN32 application. It consists of 5 modules, DAQ.c (at present DAQ_3.c), read_mc.c, read_pico.c, b_probe.c and control.c. The whole project is built and maintained under MS Visual Studio 2019 and Windows 10 operating system.

The DAQ.c module is a main program, which initializes all units and controls the readout with timer events. The timer frequency is set to 1 Hz so the USB modules are read once per second and the readouts are saved to a data history file. The name of the history file contains date and time of start of the DAQ program so it is easy to find the relevant data. After starting the program, the window appears as shown in figure 10 to the left below.

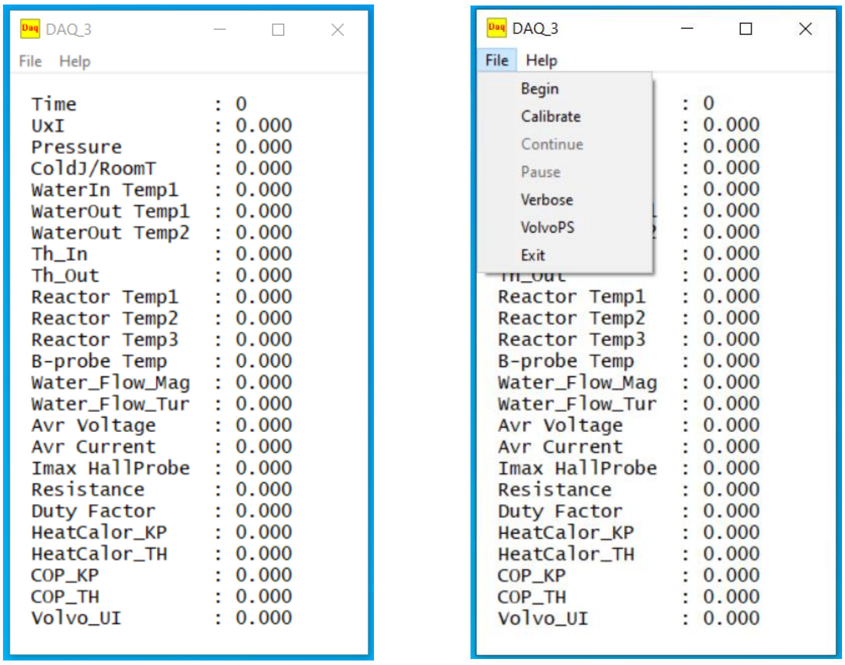

Figure10. Graphical user interface of the data acquisition program.

To start data taking one should select Begin in the file menu (figure to the right above).

The File/Calibrate item opens dialog box with “Edit” fields corresponding to several calibration constants.

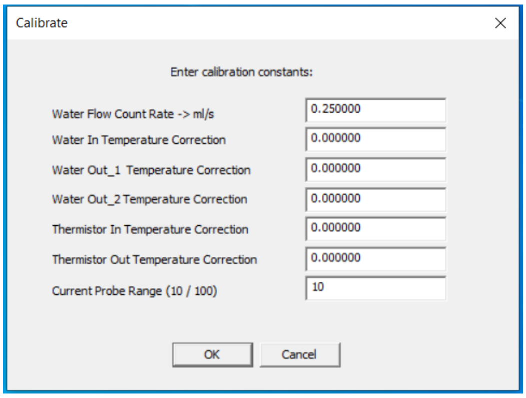

Figure 11. Calibration dialog box.

The File/Verbose menu item is provided for testing purposes. Once selected it saves all samples in the analyzed buffer to a text file hist.txt.

The File/Volvo menu item opens a new window showing minimum and maximum values of voltage and current delivered by the SM112-13 power supply (borrowed from Volvo hence the name). Also calculated average power and duty cycle are shown.

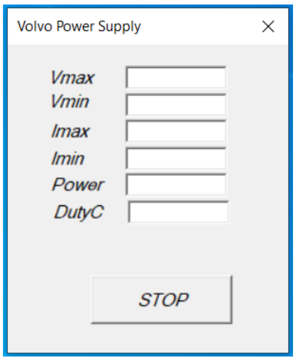

Figure 12. Volvo power supply (SM112-13 power supply) readouts.

SM112-13 control program

SM112-13 is controlled by a dedicated program PowerSupply located in [\\130.238.237.239\c:\Lenr\PowerSupply](\\130.238.237.239\c:\Lenr\PowerSupply).

Field Code Changed

Like DAQ it is a WIN32 application. The GUI of the program is shown below (left). The File menu has two items, File/Start and File/Exit. The File/Start invokes a dialog box shown below to the right and File/Exit sets the SM112-13 output voltage to zero and terminates the program.

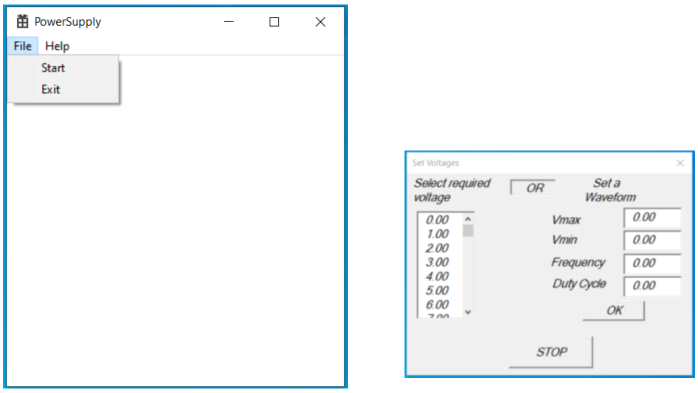

Figure 13. Graphical user interface of the SM112-13 control program (left) and a dialog box for setting up operation parameters.

The two options in the dialog box, “Select required voltage” and “Set a waveform” allow one to set either DC voltage in the -1-120V range or rectangular pulses with desired amplitudes, frequency and duty cycle.

Visualization and analysis software

Histogram viewer in C

Originally the program written for on-line control of nuclear physics experiments carried out at the Celsius storage ring in Uppsala. Later it was modified to visualize and analyze data obtained with the Uppsala calorimeter. It is a WIN32 application written in C.

Histogram viewer in Python

PyHistView is a new program written in Python which also can be used to visualize and analyze data from the Uppsala calorimeter. It makes use of a powerful Python libraries like Matplotlib and PySimpleGUI which, in principle, makes development easier than writing programs in C.

Calorimeter testing

There are numerous reports on anomalous heat production (AHE) in metal-hydrogen systems. However, the reported results show that observed values of AHE are rather small so the system designed to verify some of such experiments must be sufficiently sensitive and accurate. In what follows there are some results of extensive tests of the calorimeter performance regarding measurement of the input power and heat flow.

The calorimeter power supply (CPS) delivers rectangular pulses with constant amplitude of 50 V and adjustable width. The frequency can be as high as 5 kHz. The output power is regulated by changing the duty cycle. In order to measure the power, the USB-204 is used in sampling mode with sampling frequency of 100 kHz per channel. In order to improve the performance, sampling is done by USB-204 in background mode using function cbAInScan(), which is filling one of two buffers autonomously. When the actual buffer is filled the one filled before is being analyzed. The input power, P, is calculated using formula:

$$P = \sum_{k=0}^{n} u_k i_k$$

where u_k and i_k are samples obtained for analog inputs AI0 and AI1 of USB-204 unit respectively and n is the number of samples. Similarly, power delivered by SM112-13 power supply is calculated using samples corresponding to analog inputs AI2 and AI3.

An example of samples of U and I delivered by CPS corresponding to 1 cycle is shown in figure 14 below. CPS was delivering bipolar pulses with frequency close 800 Hz and with a duty cycle about 8%.

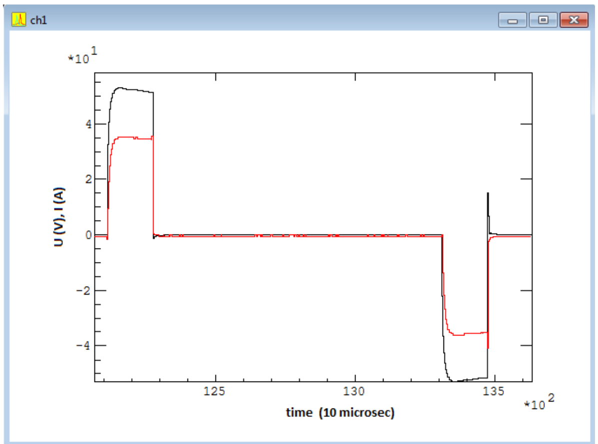

Figure 14. An example of samples of U and I delivered by CPS corresponding to 1 cycle.

Signals corresponding to temperature, water flow and pressure change slowly and are therefore read once per second.

The reactor tube is heated by a Kanthal coil wound around the tube. The power P delivered to the coil converts to heat which flows through the insulating layer to the water circulated in the calorimeter. The ends of the reactor tube extend beyond the calorimeter and part of the heat is dissipated to the air outside of the calorimeter. The temperature difference between the area in the close vicinity of the coil and water depends on the thermal resistance of the insulating layer and the fraction of heat escaping to the air from the ends of the reactor tube. The reactor temperature as a function of the input power is presented in the figure 15 below.

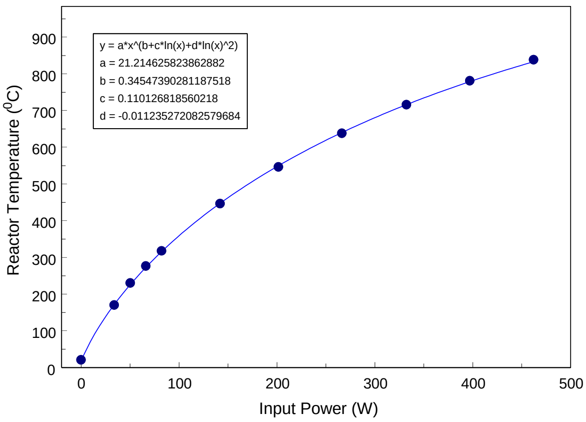

Figure 15. Dependence of the reactor tube temperature on delivered power – closed circles. Line is a fit to the measured points.

After the input power is turned on, the calorimeter is heated up and eventually a steady-state is reached when the heat absorbed by the circulating water and dissipated to the air through the ends of the reactor tube becomes equal to the delivered input power. For such a state one could write

$$\Delta T = R \cdot F$$

where ΔT is temperature difference between circulating water and the coil, *R* is the thermal resistance and F the heat flow. From figure 15 above follows that *R* decreases with increasing temperature. However, dependence of the thermal resistance of the alumina tube increases with increasing temperature (see for instance paper by David Stanley Smith et al.[1]). As a consequence, the ratio of the part of heat transferred to the water to the part transferred to air may increase with temperature.

Heat flow to the water, P_{cal}, is calculated using temperature difference between water entering calorimeter, T_{in}, water flowing out, T_{out} and the rate of water flow, R_{wf} (in ml/sec)

$$P_{cal} = 4.1868 \cdot (T_{out} - T_{in}) \cdot R_{wf}$$

where 4.1868 is a conversion factor between cal/sec and W.

Measurement accuracy

Measurement accuracy of the power delivered to the calorimeter has been estimated in a special test run. The input power was delivered by the CPS but, in addition, inside of the reactor tube an auxiliary coil was inserted delivering 10 W of extra power. This power was switched on and off at various temperatures of the reactor tube to simulate occurrence of the extra heat in the calorimeter.

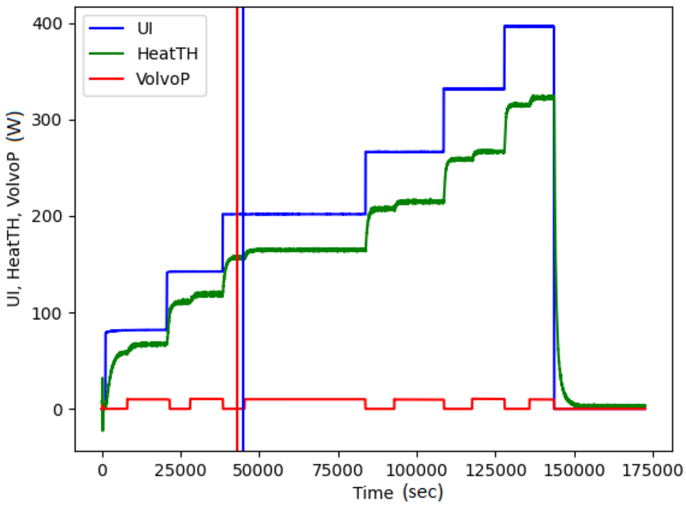

Figure 16. Dependence of *P* (denoted UI in the figure), P_{cal} (HeatTH), and extra power of 10 W (VolvoP) on time obtained for history_Thu_Aug_26_09_08_44_2021.txt. Two vertical lines, red and blue, indicate interval over which average values of the displayed parameters are calculated. Figure obtained with the presentation and analysis program PyHistView.

[1] David Stanley Smith et al., High Temperatures - High Pressures, 2003/2004, volume 35/36, pages 93 - 99

As one can see the heat flow to the calorimeter water is always smaller than the input power which points out to the fact that part of the heat is dissipated though the ends of the reactor tube. To see it in a more quantitative way, average values of the presented parameters are calculated together with standard deviations. Average values are calculated in the intervals defined by two markers which can be freely moved over the histogram area. Care should be taken to select intervals, which correspond to times when the steady state conditions have been reached, i.e., just before the time when the input power or the extra power was changed. The average values and standard deviations are saved in a spreadsheet file named average.txt. Average.txt obtained for the data presented in figure 16 is given in table 2 below.

Table 2. Average values of parameters presented in figure 16.

x_low	x_high	UI	UI_sg	RT1	RT1_sg	HeatTH	HeatTH_sg	VolvoP	VolvoP_sg
6660	7462	8.143e+01	1.272e-01	3.496e+02	6.058e-01	5.833e+01	8.834e-01	2.001e-03	1.110e-05
18855	20139	8.189e+01	5.223e-02	3.803e+02	6.468e-03	6.723e+01	9.958e-01	9.857e+00	1.197e-03
26557	27680	1.424e+02	6.350e-02	5.050e+02	3.671e-02	1.109e+02	1.678e+00	2.010e-03	2.972e-05
36024	37469	1.424e+02	5.934e-02	5.248e+02	1.563e-02	1.191e+02	1.585e+00	1.034e+01	1.307e-03
43245	44689	2.019e+02	8.640e-02	6.162e+02	4.063e-02	1.567e+02	1.147e+00	2.337e-03	1.390e-04
80954	82558	2.019e+02	7.644e-02	6.311e+02	1.077e-02	1.646e+02	7.856e-01	9.968e+00	1.345e-03
90581	92026	2.663e+02	1.561e-01	7.127e+02	1.625e-02	2.074e+02	1.154e+00	2.424e-03	1.553e-04
105825	107269	2.664e+02	1.521e-01	7.244e+02	1.491e-02	2.146e+02	1.078e+00	9.657e+00	1.524e-03
115613	116897	3.315e+02	2.231e-01	7.945e+02	8.062e-03	2.590e+02	1.281e+00	2.398e-03	1.641e-04
125562	127167	3.315e+02	2.606e-01	8.053e+02	1.320e-02	2.667e+02	7.730e-01	1.025e+01	9.088e-03
133906	135029	3.963e+02	2.755e-01	8.643e+02	1.289e-02	3.150e+02	1.041e+00	2.404e-03	1.580e-04
141287	142731	3.963e+02	2.791e-01	8.735e+02	2.275e-02	3.228e+02	1.138e+00	9.728e+00	4.608e-03

X_low and x_high represent the left and right limits of intervals over which the average values and standard deviations are calculated. It should be noted that the parameter readouts are saved to the history files every second, so difference between x_high and x_low represents also the number of points over which the average values are calculated. The standard deviations, STD, represent spread of measured parameters around the mean values and in order to estimate the errors of mean values one divides STD over square root of the number of points. As number of points, x_high – x_low, ranges between ~800 and ~2500 the statistical errors of mean values given above fall well below one permille.

The figure of merit in search for anomalous heat production is the ratio between observed and delivered power COP (Coefficient Of Performance) $= \frac{P_{cal}}{P}$. Values of COP calculated using data from table 2 are given in table 3.

Table 3. Values of COP calculated using data from table 2.

P10W	COP10W	sigma10W	P	COP	sigma
81.89	0.821	0.00028	81.43	0.716	0.00028
142.40	0.836	0.00025	142.40	0.779	0.00027
201.90	0.815	0.00008	201.90	0.776	0.00012
266.40	0.806	0.00009	266.30	0.779	0.00009
331.50	0.805	0.00005	331.50	0.781	0.00009
396.30	0.815	0.00006	396.30	0.795	0.00007

The first 3 columns represent cases with extra power on and the remaining 3 cases without extra power. The “sigma10W” and “sigma” columns represent statistical errors of COP values calculated using the total derivative method and the errors of mean values discussed before. The data from table 3 are shown in figure 17 below.

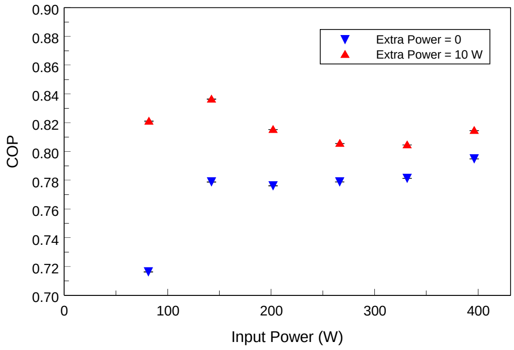

Figure 17. Dependence of COP on input power with extra power on and off.

Data in the last raw of table 3 show that even at the highest temperature close to 900^{0}C, increase of COP caused by 10 W of extra power is clearly seen. The increase of COP equal 0.02 is several orders of magnitude greater than estimated error.

It should be stressed that discussed results have been obtained in a special situation when the extra heat appears abruptly so it manifests itself as a sharp step in the distributions of heat flow measured by the calorimeter. If the extra heat develops slowly and cannot be identified as an increase of heat flow when input power is kept constant long enough to reach steady state, then the calorimeter response has to be compared to the response obtained in a background run, i.e., run without fuel. In such situations systematic errors play major role and care must be taken to achieve good reproducibility of the calorimeter response. It turns out to be a rather difficult task since the calorimeter response depends on factors like placement of the reactor tube inside the calorimeter, size of the reactor tube outside the calorimeter or position of thermocouples inside the calorimeter. Somewhat arbitrarily it has been assumed that systematic errors related to such factors do not exceed 10 W.
The way to reduce systematic errors is to reduce heat loss to the ends of the reactor tube by placing one or both ends of the reactor tube inside the calorimeter. However, that implies that one has to solve the problem with attaching the end pieces of the reactor tube so that they can stand a temperature up to 1200 degrees.

Concluding remarks

The presented calorimeter has been used in several test experiments to search for anomalous heat production appearing from various metallic compounds exposed to hydrogen/deuteron gas at different temperature and pressure. So far, no excess heat has been discovered from any fuel compound, but many more tests experiments remain. The technical performance of the experimental set-up has been stable and reliable, although occasional malfunctioning of individual components has certainly occurred. However, such errors have immediately been discovered owing to the redundancy in the experimental parameters. The strength in the present experimental apparatus is that any occurrence of excess heat coming from the fuel must show up in the independent measurements of the reactor temperature and the heat recorded by the calorimeter. That condition eliminates false interpretations of a change in temperature or heat as being due to heat production in the fuel.

Acknowledgements

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The development of the calorimeter has gratefully been supported financially during the years by generous contributions from Energiforsk - The Swedish Energy Research Centre, Volvo Trucks, Hydrofusion and since August 1, 2020 the EC Horizon2020 Framework Program, project number 951974. Roland Pettersson is gratefully acknowledged for his important contribution in the early stage of this work.

Appendix 1

Detailed specification of the instruments and some technical equipment

The numbers refer to labels in figure 3.

2. Ceramic tube, Al_2O_3 , Supplied by Keranova AB, Keranova , dimensions , accessed 20211216

3. Kanthal wire 3.0mm OD, supplied by Entech Energiteknik AB, HEM - Entech Energiteknik AB , accessed 20211216.

4. Thermo-Chiller, HRS018, from SMC Corp. , SMC Products (smcworld.com) , accessed 20211217.

Field Code Changed

5. Thermo couple, K-type, From Jumo, part nr: 901250/32-1043-1,5-200-11-2500/000 Mineral-insulated thermocouples | JUMO. Supplied by Elfa Distrelect 901250/32-1043-1,5-200-11-2500/000 | Jumo Mantlat termoelement -200 °C 1200 °C Typ K NiCr-Ni | Elfa Distrelec Sverige , accessed 20211216.

Field Code Changed

Field Code Changed

6. Magnetic inductive flow meter, MVM-005-QA, from Mass Flow Online B.V. , Magnetic Flow Meter [0.25 .. 5 lpm, 4 .. 20 mA] - Mass Flow Online (massflow-online.com) , accessed 20211217.

Field Code Changed

7. Thermocouple, K-type, From Jumo, part nr: 901250/32-1043-1,5-200-11-2500/000 Mineral-insulated thermocouples | JUMO. Supplied by Elfa Distrelect 901250/32-1043-1,5-200-11-2500/000 | Jumo Mantlat termoelement -200 °C 1200 °C Typ K NiCr-Ni | Elfa Distrelec Sverige , accessed 20211216.

Field Code Changed

Field Code Changed

8. Thermistor NTC 10kOhm, from TDK Electronics, [NTC Sensor Assembly / Systems | TDK Electronics - TDK Europe](), Supplied by Elfa Distrelect [B57500K0103A001 | EPCOS Termistor NTC 10kOhm 500mm | Elfa Distrelec Sverige]() , accessed 20211217. (Connected to no 23 and 18)

9. Mechanical flow meter

10. Low flow Flowmeter, FCH-m-POM-PT100 , from B.I.O-TECH e.K. , [FCH-m-POM -6,0 LPM 97478779, PNP, PT 100: B.I.O-TECH Flowmeter (btflowmeter.com)]() , accessed 20211217.

11. Pressure Transducer DMU 02, part no: 32806, from Afriso , [Pressure transducers DMU 02 Industrial version - Afriso - Afriso]() , accessed 20211217. (Connected to no 24 and 19)

Field Code Changed

12. Valve SS-3NTRS4, Swagelok, [Stainless Steel Severe Service Union Bonnet Needle Valve, 0.35 Cv, 1/4 in. Swagelok Tube Fitting, PTFE Regulating Stem | Severe-Service Needle Valves, N and HN Series | Needle and Metering Valves | Valves | Swagelok](), accessed 20211216.

Field Code Changed

13. Pressure gauge.

14. Vacuum pump, Leybold TriVac D4B ,

15. Gas regulator

16. Gas Tube

17. Thermocouple data logger, TC-08, 8 channels, Pico Technology, TC-08 Thermocouple data logger | Pico Technology accessed 20211216.

18. DAQ. USB-1208HS-2AO, 8-channel DAC from MC Measurement Computing, USB 13-Bit, High-Speed DAQ Devices - Measurement Computing (mccdaq.com) , accessed 20211217

Field Code Changed

19. DAQ. USB-204, 8-channel DAC from MC Measurement Computing, USB 12-Bit DAQ Devices with 8 Analog Inputs - Measurement Computing (mccdaq.com) , accessed 20211217.

Field Code Changed

20. Dell laptop

21. A622 100 Amp AC/DC Current probe, Tektronix Inc. , Current Probes | Tektronix , accessed 20211217.

Field Code Changed

22. Differential Voltage Probe, Testec TT-SI9001, from Testec Elektronik GmbH, Testec Elektronik GmbH - Qualität – Sicherheit – Erfahrung. , accessed 20211217.

23. Electronic connection for the thermistors (nr 8)

24. Electronic connection for the pressure traducer (nr 11)

25. Power supply (Volvo) connected to 31. LabJack.

26. In-house built power supply - CPS

27. Acer Laptop

28. Laptop

29. Gamma detector, Gammadata, Home » Gammadata - Improving science , accessed 20211217.

30. Personal Neutron Bubble Detector, BD-PND sensitivity high, 20-40b/mrem. BTI Bubble Technology Industries Inc. BD-PND – Personal Neutron Dosimeter | (bubbletech.ca) accessed 20211216.

31. ADC, Labjack U12, Meilhaus Electronic, U12 | LabJack. Supplied by Elfa Distrelect: LABJACK U12 | Meilhaus Minimätlab USB 30 kanaler | Elfa Distrelec Sverige accessed 20211216.

Additional items

a. Valve SS-4BK-V51, Swagelok, Stainless Steel Bellows Sealed Valve, Gasketed, PCTFE Stem Tip, 1/4 in. Female Swagelok VCR Face Seal Fitting, SC-11 Cleaned | General-Service Bellows Valves, B and H Series | Bellows-Sealed Valves | Valves | Swagelok , accessed 20211216.

b. JB Weld, J-B Weld Twin Tube | J-B Weld (jbweld.com) , accessed 20211216

Field Code Changed

c. Cotronics Durapot™ 810 Thermally Conductive and Electrically Resistant Cement, High Temperature Adhesives and Epoxies, Ceramics, Insulation, Epoxies and Epoxy (cotronics.com) , supplied by GA Lindberg ChemTech AB, COTRONICS DURAPOT 810 (galindberg.se)