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Investigation of anomalous heat production in Ni-H systems

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Summary. — Anomalous heat production in a nickel rod loaded with hydrogen has been reported by Focardi *et al.* (*Nuovo Cimento A,* **107** (1994) 163). We have investigated this phenomenon by repeating the experiment. We found the results previously published to be consistent with our observations; namely we measured higher temperatures for the same input power when hydrogen is absorbed during a heating cycle. Nevertheless this temperature rise does not appear to correspond to an increase in heat production. We have added a temperature sensor to the container of the experiment. The temperature of the container follows the same temperature with input power curve irrespective of whether there is an anomalous absorption of hydrogen or not; therefore we have no evidence that this temperature increase corresponds to another source of heat. In conclusion, we have observed all the effects discovered by Focardi *et al.*, but our results imply that there is no production of power associated with the absorption of hydrogen by nickel

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1. - Introduction

The anomalous production of heat in various systems has been searched for since the experiment of Fleischmann, Hawkins and Pons [1]. Recently there has been considerable excitement over the results published by Focardi, Habel and Piantelli [2], They reported that after several loading cycles, where they loaded a nickel rod with hydrogen gas, they observed excess heat when the rod was above 178°C. Furthermore they found that this heat imbalance was stable and that they produced 44 W continuously for 24 days (90 MJ total) until they switched the device off. They further commented that they were examining the reaction (p, D) as a candidate for the heat generation reaction, where D is that naturally contained in hydrogen.

Let us first consider the fusion of pD, we find the following:

$$pD \rightarrow {}^3He + \gamma \text{ (the energy of } \gamma \text{ is } 10^{-12} \text{ J).}$$

Focardi *et al.* reported that their container was 10 cm long, with 5 cm diameter (*i.e.* 0.2 l). They filled it to 0.5 A of H_2; this is $9{\cdot}10^{-6}$ kg of H_2 *i.e.* $6{\cdot}10^{21}$ atoms of H. As 1:6000 H naturally appears as D, there are 10^{18} atoms of D. Thus if all the possible D were converted and all the energy captured, we would have 1 MJ available. They reported that they obtained 90 MJ, and the device was still running when it was switched off. Thus the reaction pD appears to be an unlikely candidate.

Nonetheless the production of 90 MJ of energy warrants attention. We have repeated their experiment in order to understand the origin of this heat imbalance.

2. - Description of the experimental apparatus

We constructed a container from stainless steel pieces, normally used for vacuum systems. The container was 12 cm long, with 8.5 cm diameter. One end was sealed by a flange piece 1 cm thick. We had electrical feed-throughs and various pipe fittings put into this flange. The electrical feed-throughs were to supply the power to the heater coil. One pipe fitting was used to supply gas to the cell (usually hydrogen) while the remainder of the pipe fittings allowed thermocouples, used to measure the temperature at various points, to be connected to the external monitor. The coil was 42 turns of 1 mm thick platinum wire, wound in a 1.8 cm diameter. The coil was held in the centre of the container with three ceramic rods. The rod was of 6 mm diameter nickel, at each end we used a short section of ceramic tube to hold it in place at the centre of the heater coil. At one end of the rod we drilled a 1 mm diameter hole 3 cm deep. Into this hole we pushed a thermocouple temperature sensor until it reached the end. At the other end of the container we had a reduction flange and then a 30 cm long stainless steel flexible tube connected to a vacuum pump and pressure sensor. We used three thermocouple sensors, one inside the nickel rod, one attached to the centre of the platinum coil and one connected to the outside of the container. We also recorded the ambient temperature.

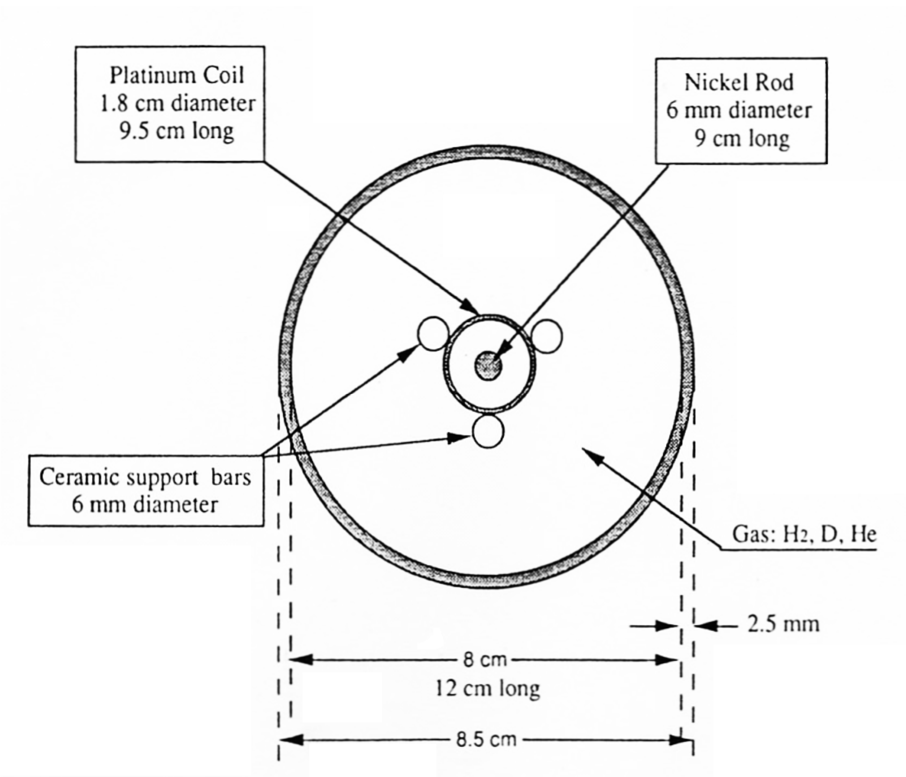

Fig. 1. - Cross-section of our experimental set-up.

Initially one thermocouple was connected to the end of the coil. At this position often the coil temperature was lower than the rod temperature. We assumed that this was due to the thermal losses, since the ends of the coil were connected to the lower temperature of the container via the electrical connections. We thus attached the thermocouple sensor to the centre of the coil; we believe this position to have the highest coil temperature. A cross-section of the assembly is shown in fig. 1. We mounted the assembly on a bench in our laboratory; cooling was provided by normal air convection.

Thus our device consisted of a platinum heater, with a thermocouple attached to the centre of the coil. Located inside this heater we had a nickel rod, with a thermocouple mounted inside the rod. This was mounted inside a stainless steel container which has a thermocouple attached to the outer surface. The container could be pumped out to a vacuum of 10^{-6} Torr with a turbo-molecular pump, or filled with a gas, usually hydrogen, but some cycles have been performed with deuterium and helium. Heat can be supplied to the system by passing a current through the heater coil. We monitored the current and voltage supplied to the heater and thus could measure the power supplied and the resistance of the heater coil.

3. - Loading cycle

Our loading cycle was defined as filling the container with 360 Torr hydrogen and ramping the power up and then down. We stepped the power in roughly 25 W steps. We found that after each change of power we had to wait 2 hours or so for thermal equilibrium to be reached. At each step in power, after thermal equilibrium had been reached, we recorded the input power, the pressure, the temperature of the heater coil, the rod and the temperature of the stainless steel container. We measured the pressure of the gas at the end of the loading cycle when the apparatus had regained ambient temperature; if there was a reduction of pressure from the initial value (usually 360 Torr) we defined the cycle as an absorption cycle. If there was an increase in pressure we classified it as a desorption cycle. In fig. 2 we histogram this difference in pressure.

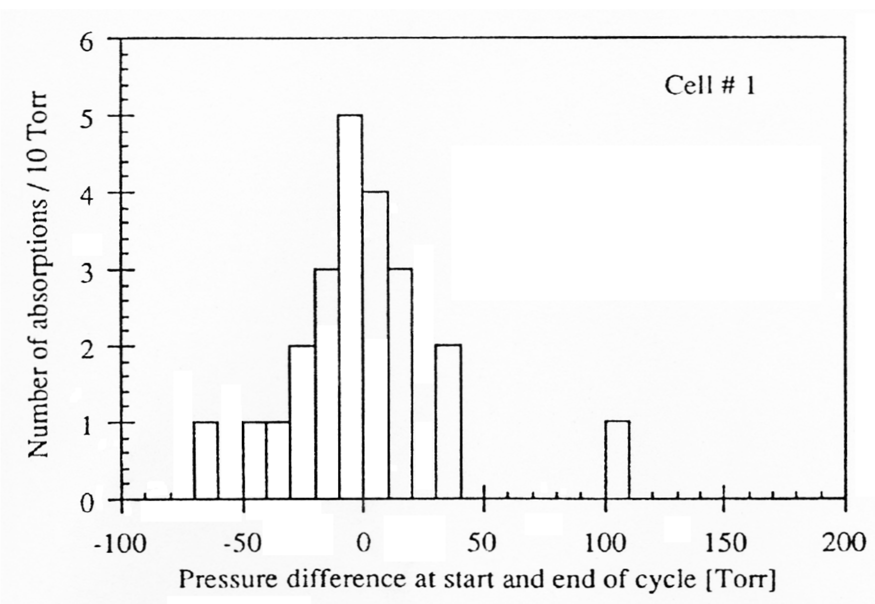

Fig. 2. - Histogram of absorption Δ*p* (difference between hydrogen pressure in the beginning and at the end of the cycle at room temperature).

4. - Observation of absorption

Focardi *et al.* do not specify exactly what they consider a loading cycle or at which point in the cycle the hydrogen absorption occurs. In order to understand when the hydrogen is absorbed during the cycle, we monitored carefully the gas pressure inside the cell and the temperature while waiting for thermal equilibrium after each step of power. On some occasions we observed absorption of hydrogen: the gas pressure started to decrease while the temperature of both the coil and the rod increased. In fig. 3 we show the pressure and the temperature of the coil and the rod as a function of time for the first step of power. The initial pressure of hydrogen in the cell was 360 Torr; time 0 is the moment when we applied power of 32 W to the system. The pressure initially rises as does the temperature. However after 5 min, there starts to be a drop in pressure with increasing temperature; this indicates absorption, which started to be obvious at a temperature of 145°C of the coil and 65°C of the rod and stopped at a temperature of 200°C of the coil and 120°C of the rod. The following step in power is also shown in fig. 3; we see that the pressure increases as usual. In this particular cycle there was desorption of hydrogen later in the loading cycle; this cycle was eventually classified as a desorption cycle using the difference of initial and final pressure as described above.

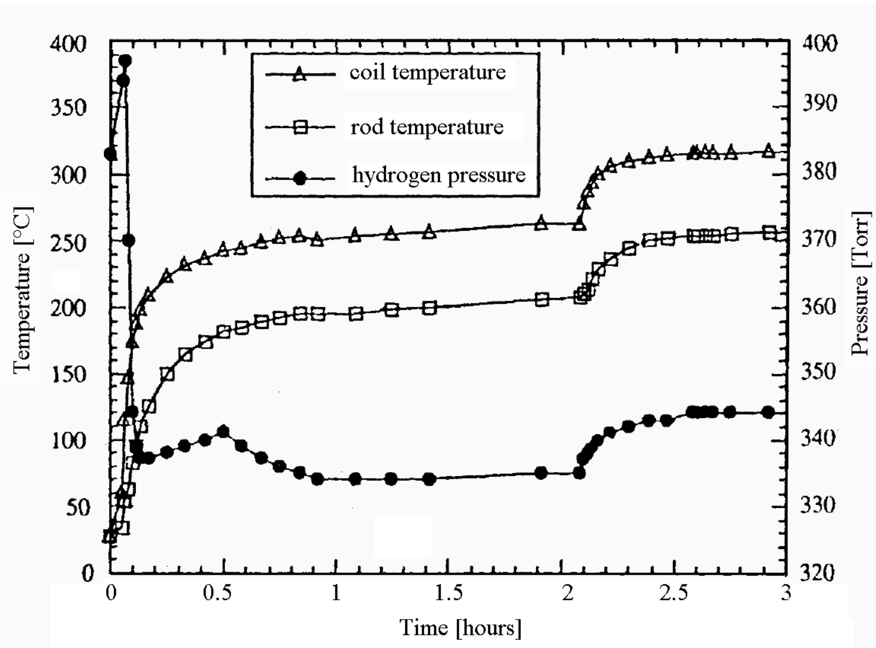

Fig. 3. - An anomalous absorption cycle: hydrogen pressure, coil temperature and rod temperature vs. time during the first step in input power (32 W).

In fig. 4 we show the temperature of the coil, the rod and the container as a function of the input power for no absorption (Δp = 0 Torr), Δp = 100 Torr and Δp = 13 Torr. For the case of 100 Torr absorption, both the coil and the rod reach higher temperatures than for the no absorption case, for the same values of input power. However the temperature of the container has the same relationship to input power independently of whether there is absorption or not.

Prior to this 100 Torr absorption the following procedure had been performed: after a number of heating and cooling cycles, the cell was evacuated, it was then heated for 24 hours to a rod temperature of 500°C and finally left to cool with simultaneous pumping with the turbo-molecular pump to obtain a vacuum of 10^{-6} Torr for 24 hours. Subsequent loading cycles performed after this 100 Torr absorption cycle showed no absorption. We tried to reproduce this absorption phenomenon by repeating the steps that had preceded its observation, namely emptying, heating and pumping to 10^{-6} Torr with the turbo pump. On occasions we had some smaller absorption or none.

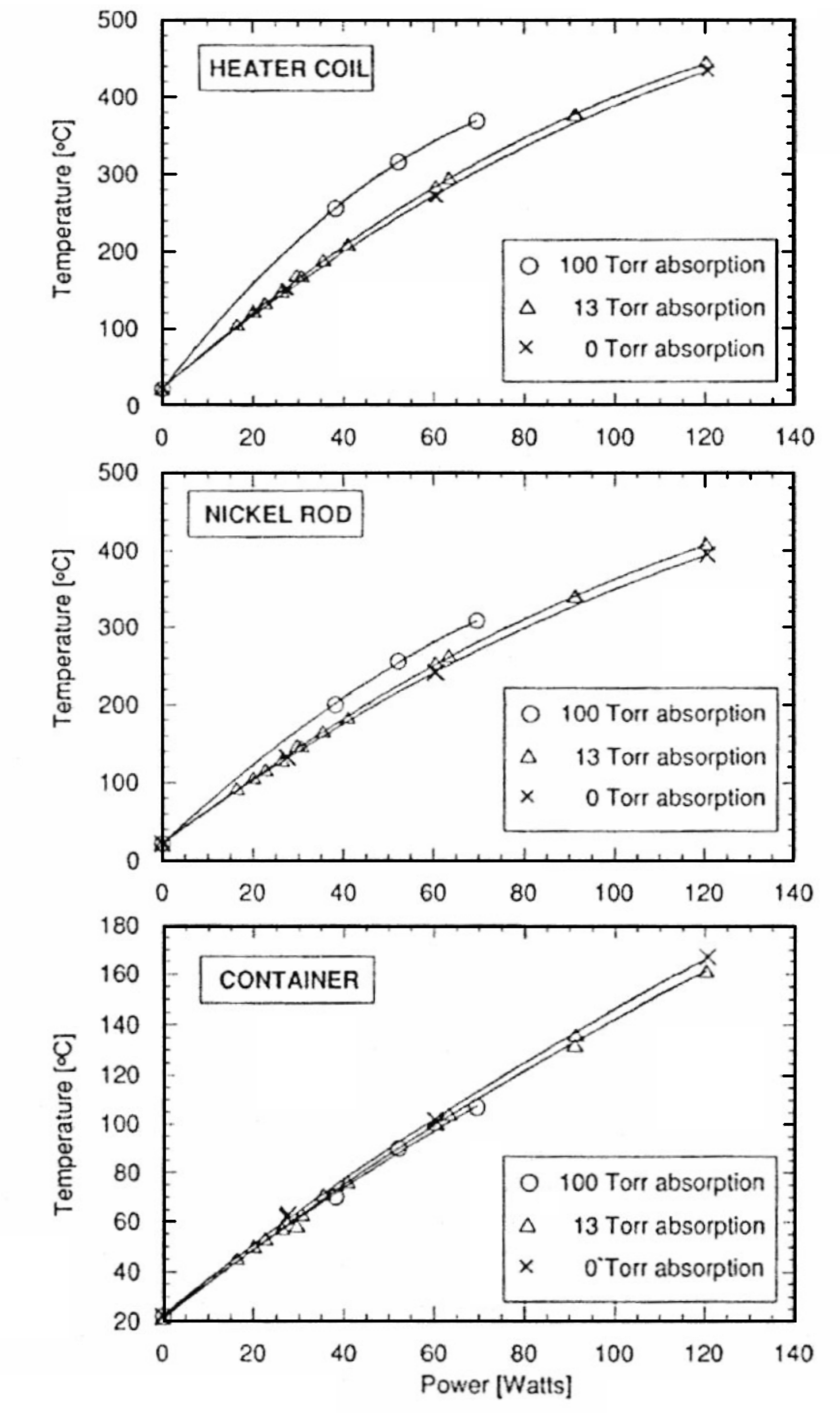

Fig. 4. - Coil, rod and container temperature vs. input power for 3 cases (Δ*p*/3 = 0,13 and 100 Torr); coil material is platinum.

In the case of absorption there is less gas in the cell than the quantity initially put in; this can change the thermodynamic equilibrium state of the apparatus, and possibly could be the cause of the elevated temperature of the rod and coil. In order to clarify this point we checked the behaviour of the system for different values of initial pressure. Figure 5 shows the temperature of the coil and the rod as a function of the input power, for 173 Torr, 280 Torr, 363 Torr and 500 Torr initial gas pressure. As can be seen there is a small variation of coil or rod temperature with gas pressure within this range. However, for the case when there is 100 Torr absorption one should compare the 3 curves corresponding to 173, 280 and 360 Torr initial pressure; one can easily see that the variation in pressure could explain a variation of several degrees, but the effect (as shown in fig. 4) is of the order of 60°C.

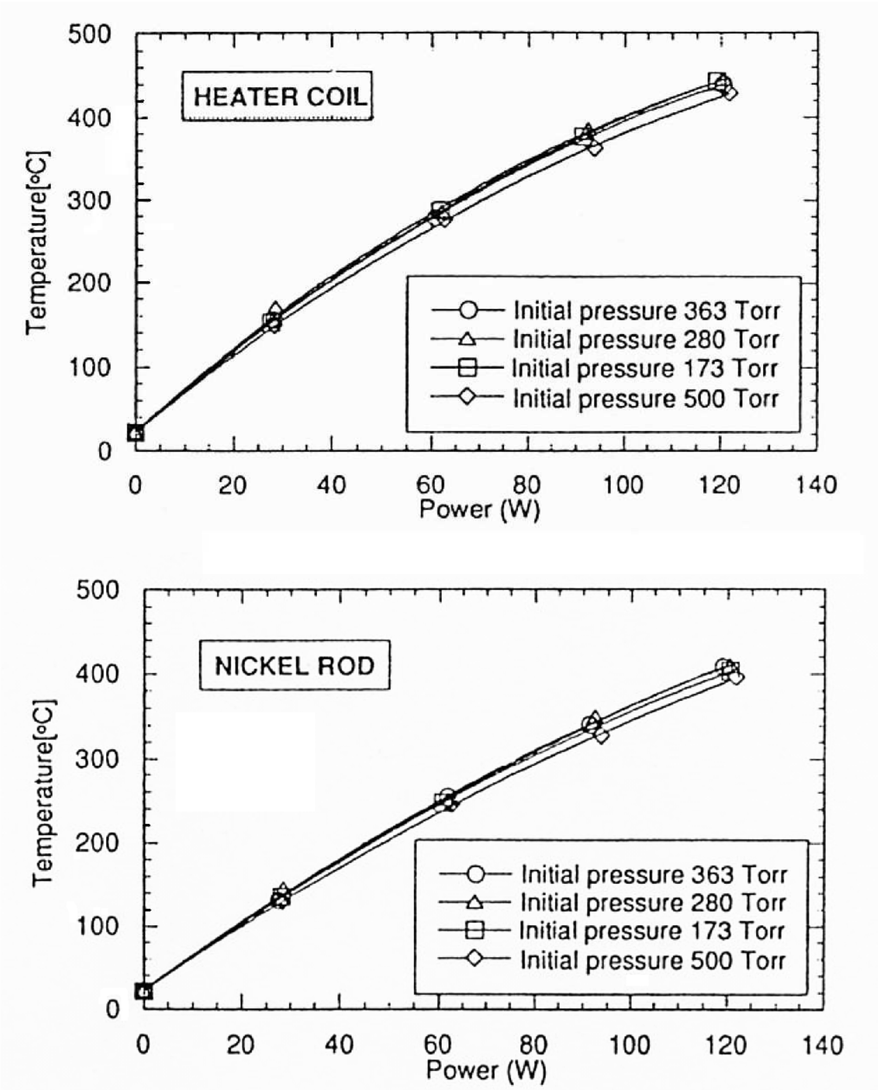

Fig. 5. - Coil and rod temperature *vs.* input power for initial hydrogen pressure 173, 280, 363 and 500 Torr.

We cycled this cell for over a year, and tried to trigger loading cycles that had a large absorption using the procedure stated above. However we found that we could not; all cycles had small absorption or desorption and the temperature of the rod and coil had the same relationship to input power as the lower curve in fig. 4. (There may have been some other anomalous absorption cycles at the beginning of the experiment when we were still trying to define what we called a loading cycle). We have opened the apparatus and examined the heater coil and nickel rod. There was a grey deposit on much of the interior due to zinc extracted from various brass pieces used to make various electric connections. The surface of the nickel rod was examined with an electron microscope and compared to nickel rod that had not undergone this experiment. In general, the electron microscope showed that the rod used for the experiment was smoother than the virgin rod; this smoothing could be due to the heating cycles.

5. - Cells 2 and 3

We found that this phenomenon of absorption of hydrogen was not reproducible. We also could not be absolutely sure which component inside our cell was responsible for the absorption. In our effort to understand the absorption of hydrogen, we constructed two more cells similar to the first one, as described in sect. 2, but using different metal combinations. Cell number 2 had a stainless steel heater coil and a nickel rod; cell number 3 had a platinum heater coil and a stainless steel rod.

With cells number 2 and 3 we followed the same loading procedure as with cell number 1. Repeated cycles with cell number 2 showed an anomalous absorption cycle similar to that of the first cell. This cycle happened after the same procedure of emptying, heating and pumping to a vacuum of 10^{-6} Torr as described above. Figure 6 shows a histogram of the absorption (*i.e.* the difference between initial and final pressure at room temperature for each cycle). The negative values correspond to desorption of hydrogen.

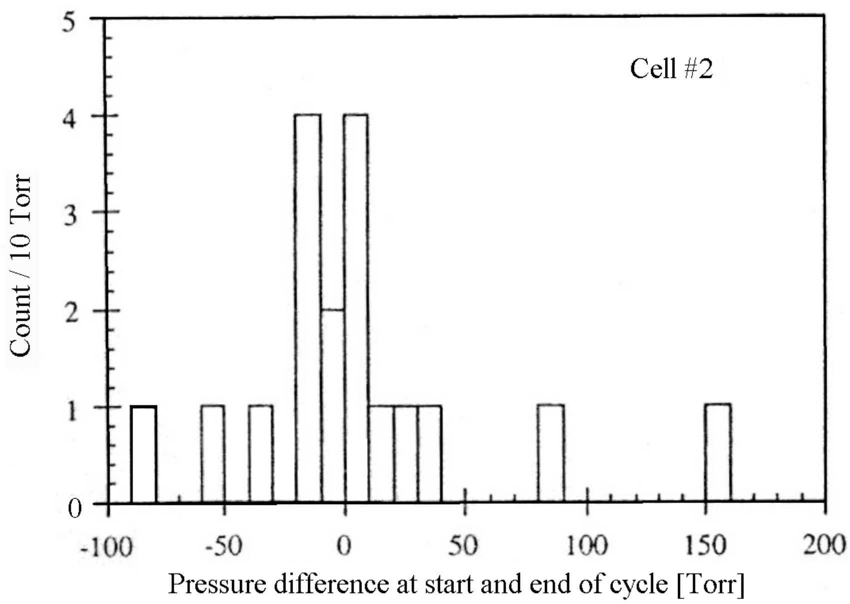

Fig. 6. - Histogram of absorption, Δ*p* (difference between hydrogen pressure in the beginning and at the end of the cycle at room temperature) for cell number 2.

In fig. 7 we show the temperature of the coil, the rod and the container as a function of the input power for no absorption (Δp = 0 Torr), Δp = 150 Torr and Δp = 30 Torr (for cell number 2). The results are similar to cell number 1; both the coil and the rod reach higher temperatures when there is this anomalous high absorption than for the cycles having small or no absorption. Also, similarly the temperature of the cell container *vs.* input power for the 3 cases (Δp = 0, 150 and 30 Torr) shows no variation, indicating no excess heat.

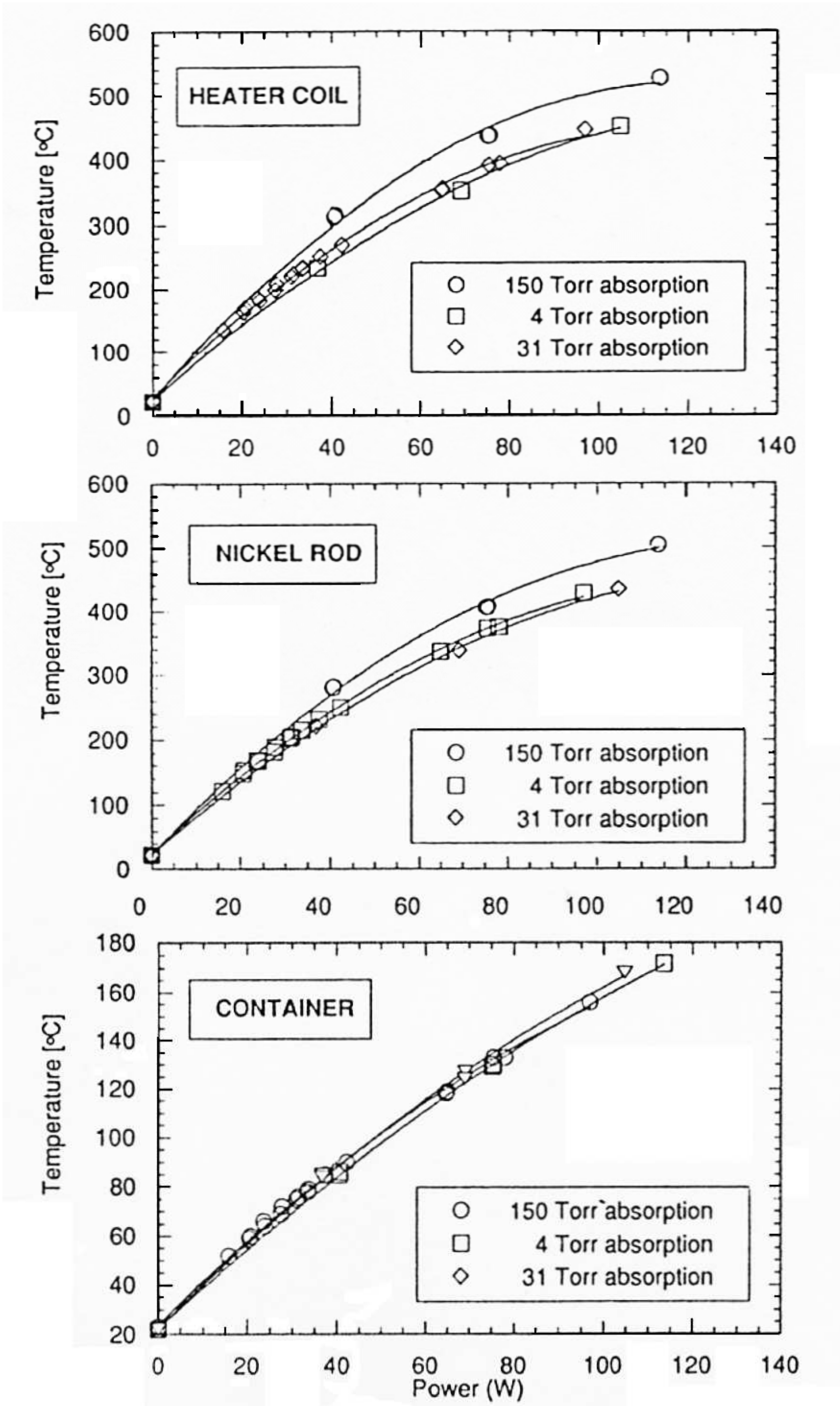

Fig. 7. - Coil, rod and container temperature *vs.* input power for 3 cases (Δp = 0, 30 and 150 Torr) for cell number 2.

Repeated cycles with cell number 3 have shown no absorption. In fig. 8 we show a histogram of the absorption. We have also tested the behaviour of the cell when we have a vacuum inside. When there is no hydrogen inside the cell, the rod and heater coil reach higher temperatures (several hundred of degrees) than for the case of 380 Torr hydrogen, for the same values of input power. This is similar to the observation of Focardi *et al.* In addition we monitored the temperature of the container; this showed the same relationship whether there was a vacuum inside the container or whether it was filled with hydrogen. This is in agreement with the observation in cells number 1 and 2, where the temperature of the container is the same whether there is a large (anomalous) absorption or not. Therefore this confirms our belief that there is no excess heat, but only local temperature variations within the cell.

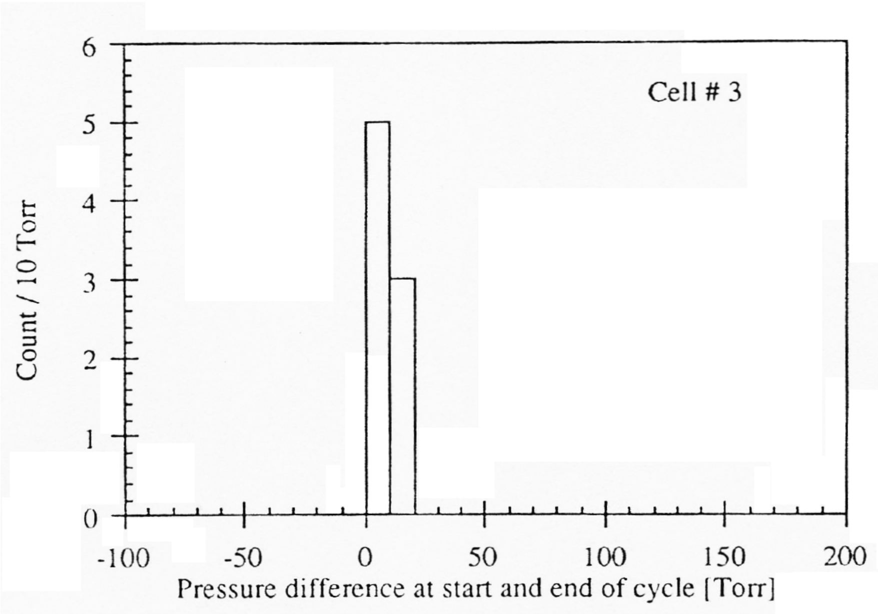

Fig. 8. - Histogram of absorption, Δ*p* (difference between hydrogen pressure in the beginning and at the end of the cycle at room temperature) for cell number 3.

6. - Additional tests

While trying to understand the absorption of hydrogen, we made other tests. One test was for gas leaks, using a special precision apparatus (which is used for the LEP vacuum beam pipe). This showed no detectable leaks.

In addition, we made two cycles with helium during which no absorption was observed, i.e. the helium pressure at the beginning and at the end of the cycle was the same. Of course two cycles is rather low statistics; however it shows that we have a leak-free system, and there is no absorption when we expect no absorption.

Finally, we made three cycles with a mixture of 50% deuterium-50% hydrogen. Unfortunately no absorption was observed during these cycles and also there was no temperature deviation from the «standard» curve.

7. Summary and conclusions

We have built an apparatus similar to that of Focardi *et al.* This apparatus has a similar temperature to power relationship to the data published by Focardi *et al.* We have observed a similar increase in rod and heater coil temperature as reported by Focardi *et al.* during loading cycles which had an anomalous absorption of hydrogen. However, since we recorded the temperature of the container (Focardi *et al.* do not mention making such a measurement) we cannot attribute this rise in temperature to an extra source of heat. We believe that the rise in temperature must be due to a change in the thermal characteristics of the nickel bar correlated to the phenomenon of hydrogen absorption.

The fact that no absorption has been observed with cell number 3 (stainless steel rod, platinum coil) and that the behaviour of cell number 2 (nickel rod, stainless steel coil) is similar to that of cell number 1 (nickel rod, platinum coil), indicates that it is the nickel rod that is responsible for the absorption of hydrogen.

In addition, the phenomenon of hydrogen absorption proves to be non-reproducible from one loading cycle to the next and we have been unable to define the trigger condition that guarantees an anomalous absorption cycle.

REFERENCES

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