Hydrogen refuelling station with integrated metal hydride compressor: layout features and experience of two-year operation

LOTOTSKYY, Mykhaylo[1]; DAVIDS, Moegamat Wafeeq[1]; SWANEPOEL, Dana[2]; LOUW, Gerhard[2]; KLOCHKO, Yevgeniy[1]; SMITH, Fahmida[3]; HAJI, Fatema[3]; TOLJ, Ivan[1,4]; SITA, Cordellia[1]; LINKOV, Vladimir[1]

1 *HySA Systems Competence Centre, South African Institute for Advanced Materials Chemistry (SAIAMC), University of the Western Cape, Bellville, South Africa*

2 *TF Design (Pty) Ltd, Stellenbosch, South Africa*

3 *Impala Platinum Ltd, Springs, South Africa*

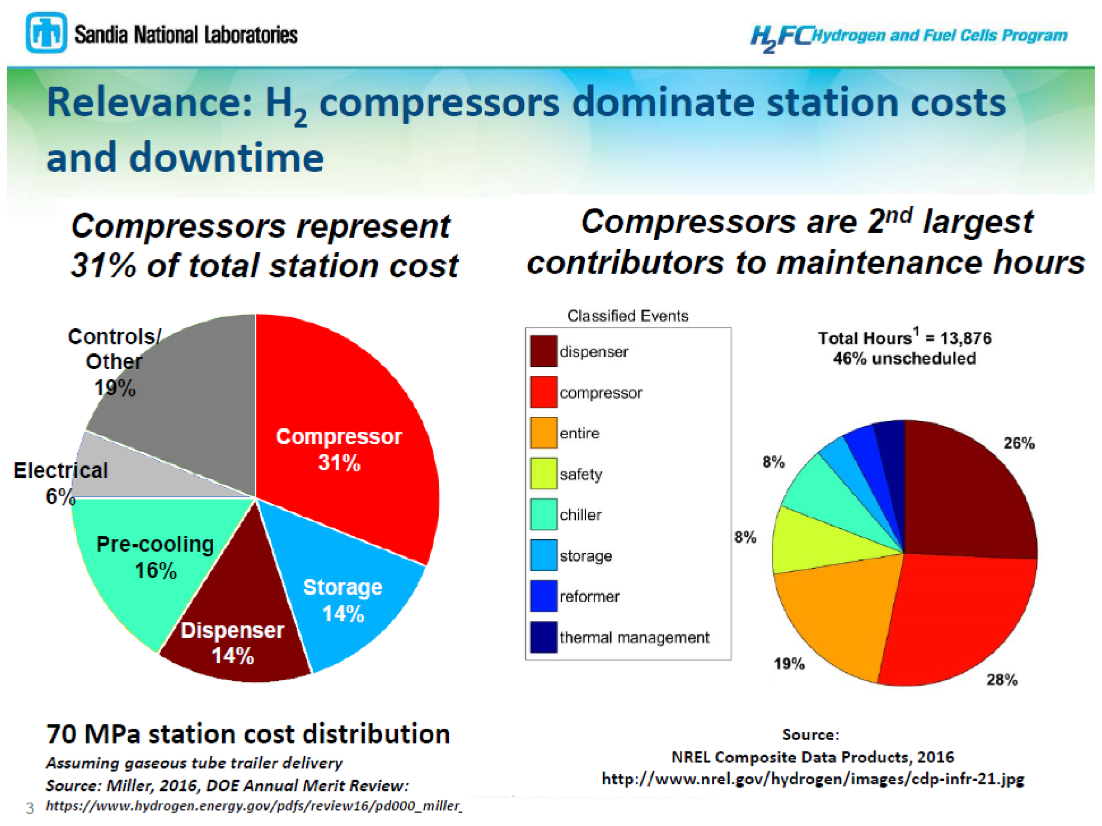
4 *University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Department of Thermodynamics, Split, Croatia*

In [1,2] we reported about development of metal hydride (MH) extension tank for fuel cell powered forklift, along with H_2 refuelling station with integrated MH compressor. An overview of the MH compressors developed at SAIAMC and HySA Systems can be found in [3].

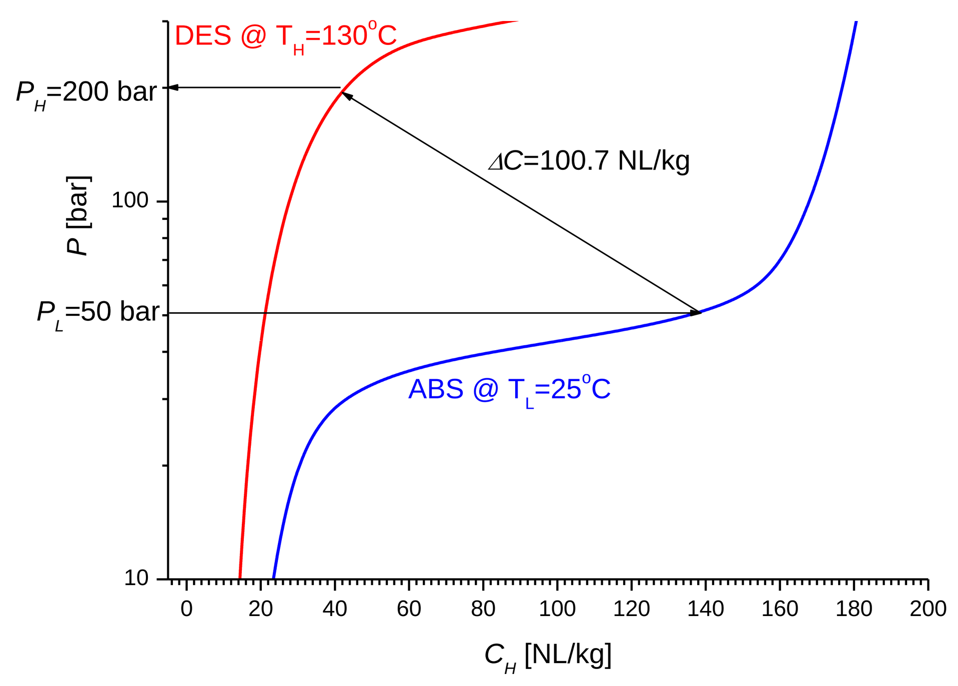
Here, we present the details about layout and operation of the H_2 refuelling station at Impala Platinum refineries in Springs, South Africa, since its start-up in October 2015 (officially launched on March 31, 2016). The station provides H_2 dispensing at the pressure up to 185 bar and uses pipeline H_2 (P~50 bar) available at the customer site. H_2 compression to P=200 bar with productivity up to 13 Nm³/h is provided by the integrated 1-stage metal hydride (MH) H_2 compressor which uses steam (T~130 °C) for the heating and circulating water (T~20 °C) for the cooling; both steam and water are also available from the customer infrastructure. The station also includes H_2 dispenser, buffer tank (standard gas cylinder pack), and control block on the basis of Siemens Program Logic Controller (PLC) which provides fully automated system operation. Switching H_2 and steam / water flows is carried out with the help of remotely controlled, pneumatically actuated valves and auxiliary check valves. The H_2 discharge line is also equipped with a safety relief valve for H_2 venting if overpressure (>210 bar) takes place. Additionally, at P=200 bar the control block switches the system into standby mode when both MH compression modules are cooled down and their gas manifolds are connected to the H_2 supply line. The H_2 dispensing is independent on the compressor operation and takes from 6 to 15 minutes.

Motivation and background

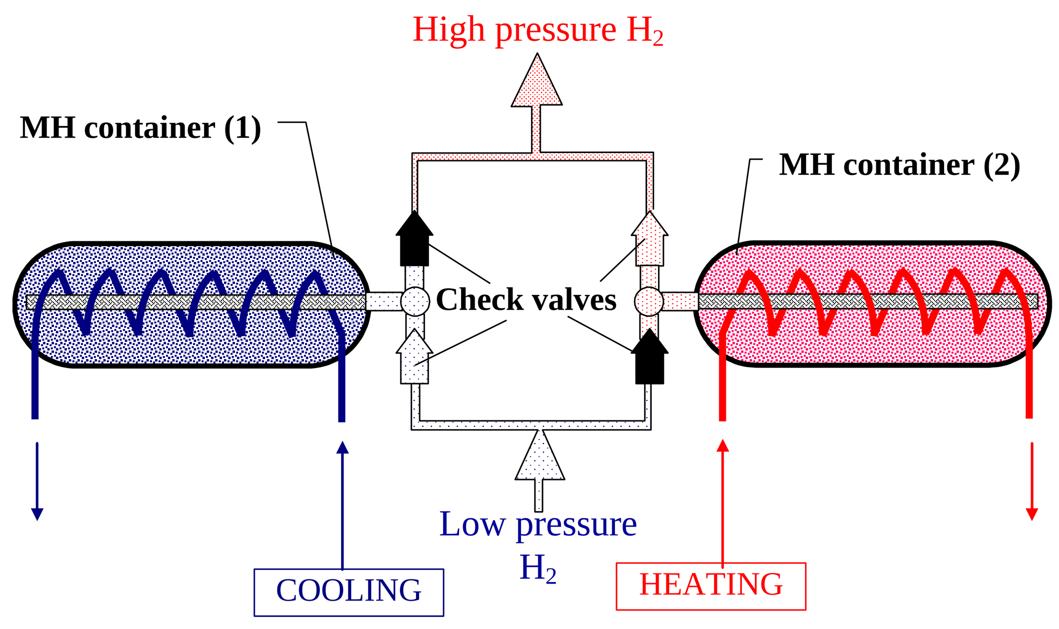
- Hydrogen compression is a main contributor in the capital and operational costs in the H_2 refuelling infrastructure [4].
- The use of MH for thermally-driven H_2 compression can provide efficient solution to mitigate this challenge [5].
- MH compressors are particularly promising for industrial customers who possess necessary infrastructure including pipeline H_2, sources of low-grade heat, etc. [3,6].



Contribution of hydrogen compression in the capital cost and maintenance of hydrogen refuelling stations [4].



Pressure – composition isotherms for H_2 –$Ti_{0.65}Zr_{0.35}(Mn,Cr,Fe,Ni)_{2+x}$ system illustrating thermally-driven hydrogen compression using MH [3]. This MH material was selected for the use in the H_2 reuelling station described below.

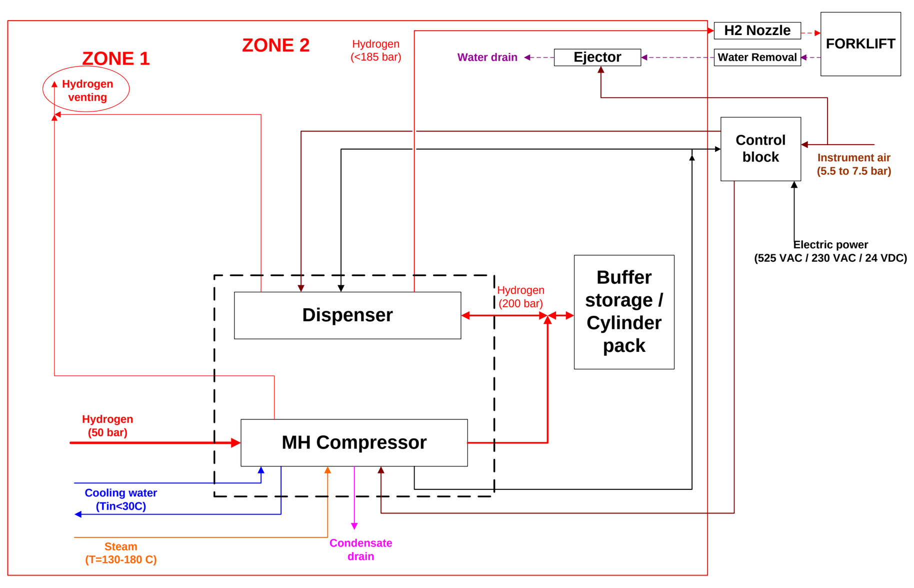


A simplest one-stage MH H_2 compressor. Periodic heating and cooling of MH containers (1) and (2) provides permanent H_2 compression [5].

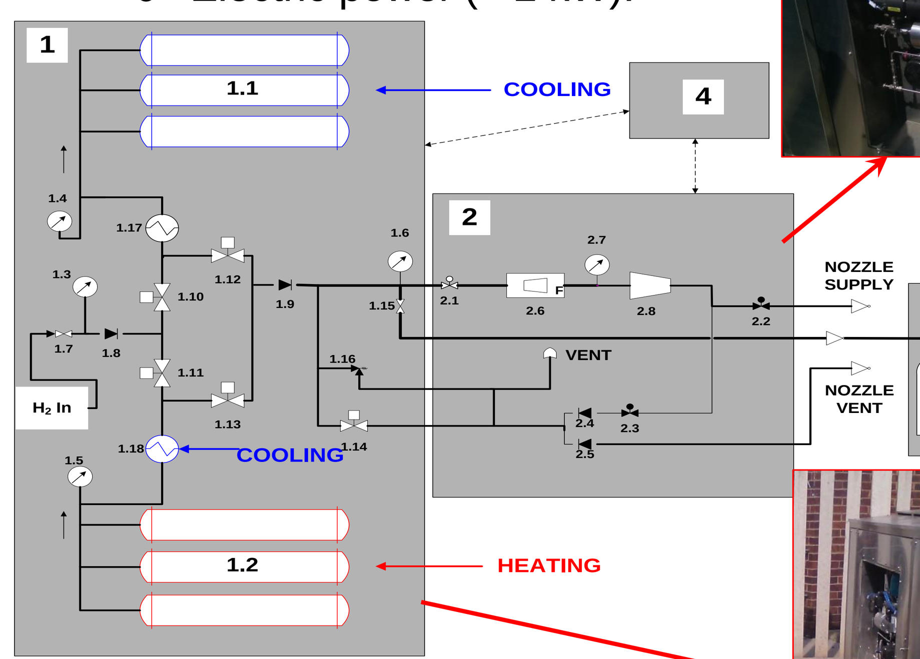
Refuelling station with integrated MH compressor: Features

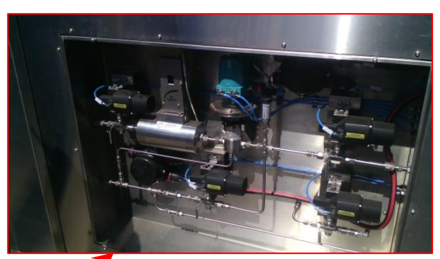
- H_2 dispensing at P=185 bar (~10 min ramp followed by ~5 min holding).
- Maintaining high H_2 pressure (200 bar) for the dispensing system by the integrated thermally driven MH H_2 compressor.
- Certified for the operation in the industrial environment (SA safety regulations).

- Uses services available at the customer's site:
  - Pipeline H_2 (50-60 bar);
  - Low-grade steam (~140 °C);
  - Cooling water (15-20 °C);
  - Compressed air (5.5-7.5 bar);
  - Electric power (< 2 kW).



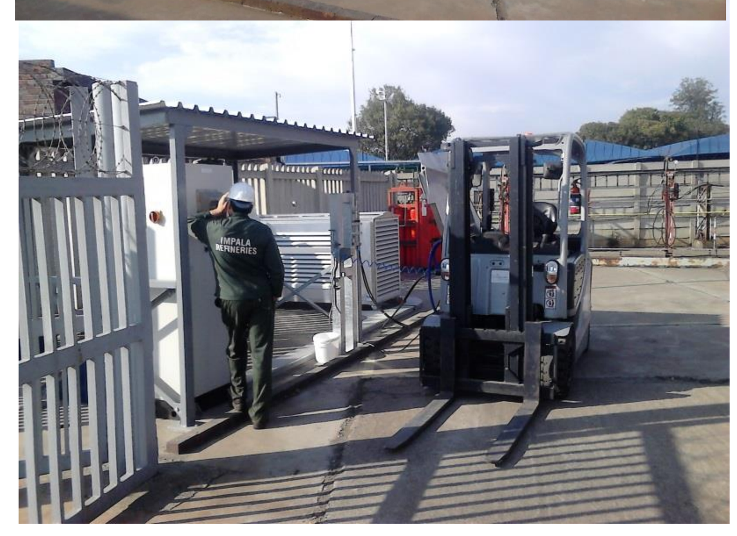
General layout of H_2 refuelling station with integrated MH compressor



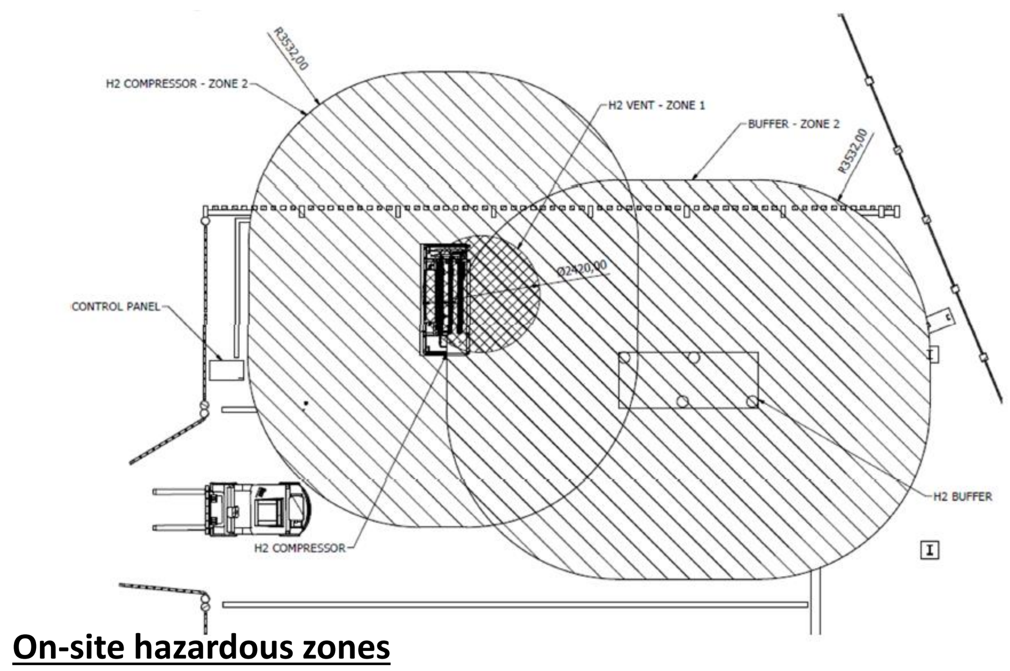


Simplified gas piping diagram of the refuelling station:

1 – one-stage MH compressor comprising of two compression modules (1.1, 1.2), pressure sensors (1.3…1.6), manual shut-off valve (H_2 input, 1.7), check valves (1.8, 1.9), remotely controlled shut-off pneumo-valves (1.10…1.14), manual shut-off valve (H_2 output, 1.15), safety relief valve (1.16) , H_2 coolers (1.17, 1.18); **2 – H_2 dispenser** comprising of remotely controlled shut-off pneumo-valves (2.1…2.3), check valves (2.4, 2.5), H_2 mass flow meter (2.6), pressure sensor (2.7), remotely controlled pressure regulator (2.8); **3 – buffer**; **4 – control system**



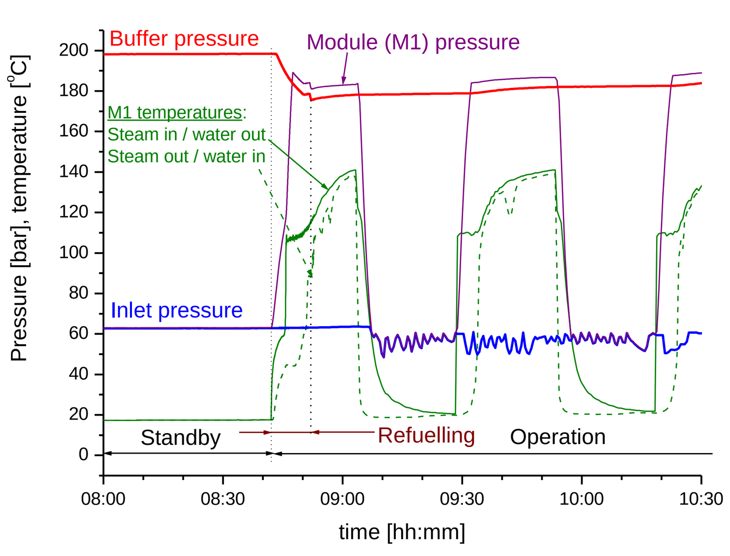
Assembling (top) and operation (bottom) of the H_2 refuelling station at Impala Platinum refineries

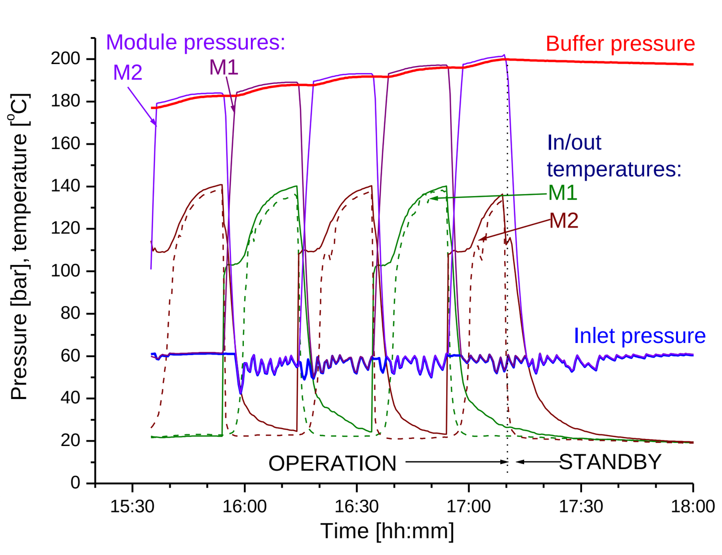


On-site hazardous zones

The station is characterised by simplicity in design, operation and service; higher safety and reliability; noiseless operation; and *lower capital and operating costs* than high-pressure (350-700 bar) hydrogen refuelling stations available on the market. These benefits are due to: (i) lower H_2 dispensing pressure which enables the use of standard gas service components; (ii) slow pressure ramping which prevents overheating of the supplied H_2 and, thus, eliminates the requirement for deep cooling; (iii) the replacement of a mechanical H_2 compressor with the MH one.

On-site operation





Typical operation of the 1-stage MH compressor at Impala Platinum (buffer size 900 L)

- Steam heating (130 °C), water cooling (15..25°C).
- H_2 compression in the range 50 – 200 bar.
- Productivity up to 13 Nm³/h.
- PLC control; automated switch in standby when achieving 200 bar in the receiving buffer.
- Automatic switch to standby mode at P(H_2)>200 bar

- In uninterrupted operation at the customer site since October 2015.
- Summary of the operation until December 2017:
  - Operating hours (H_2 compression) – 3900;
  - Standby hours – 7200;
  - H_2 dispensed – 800 Nm³.
- Number of H_2 fuel cell forklifts in service – 1 (Plug Power FC module + HySA Systems H_2 storage MH extension tank).
- Typical malfunctions, mainly resulting in the drop of the MH compressor productivity:
  - Contamination of the pipelines with very fine powder of the MH material. Resolved by the installation of inline filters (less than 0.01 μ grade) in addition to 0.5 μ grade filters in the MH containers;
  - Malfunctions of the control system due to: (i) failures of electric components and (ii) errors of pressure sensors used for a feedback in the control of gas valves;
  - Slow decrease of the productivity possibly caused by the accumulation of gas impurities in the system. The problem has been addressed by carrying out periodic (after every 5 full cycles) H_2 venting from the compression modules at the beginning of the heating cycle. Additionally, regeneration (~5 hour long H_2 venting from the heated modules followed by H_2 absorption in the cooled modules during 2 hours) was carried out every 3-5 months resulting in the full recovery of the compressor's productivity.
- **On-site operation have shown the feasibility of application of MH H_2 compression technology in medium-pressure (up to 200 bar) refuelling of FC forklifts. We have demonstrated several ways to further optimise the system performance towards increase of reliability, productivity and efficiency.**

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