Diamond-encapsulated metalic hydrogen for energy storage

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October 9, 2024

Abstract

Here I present a hypothetical means of energy storage by encapsulating metalic hydrogen inside diamond spheres. The resulting material has specific energy of 666kJ/kg, which is 2 orders of magnitude below the specific energies of common chemical fuels such as coal or ethanol. As an extra case based on my previous paper, the metalic hydrogen is turned into rydberg matter which yields a specific energy of 4MJ/kg, 2.5 to 5 times lower than that of coal.

In conclusion encapsulating metalic hydrogen in diamond doesn't appear to be a viable means of energy storage. No method of manufacturing such diamond capsules of metalic hydrogen is discussed.

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1 Thin walled pressure vessels

According to the Pressure Vessel wikipedia page, the stress in thin-walled pressure vessels, ie. those in which the diameter is at least 10 times greater than the thickness of the vessel wall (sometimes cited 20 times instead) cal be calculated by the following formula:

$$\sigma = \frac{pr}{2t}$$

Where:

- σ is the stress in the walls of the pressure vessel - the material must be capable of withstanding tensile stress at least this high for the vessel not to fail at the given pressure
- p is the internal pressure, ie. pressure of the fluid the vessel would contain
- r is the internal radius of the vessel, ie. radius of the spherical volume in which the fluid can be stored
- t is the thickness of the vessel wall

The formula can be rearranged to solve for required thickness of the wall:

$$t = \frac{pr}{2\sigma}$$

Where σ is set to the tensile strength of the material used for the vessel.

In practice the design should be derived with some safety factor, ie. made to theoretically be able to contain pressure some amount higher than the intended, as otherwise we are operating at exactly the point of failure.

2 Diamond & Metalic hydrogen

Metalic hydrogen had been found to not be metastable by studies that claimed it's observation. The pressures at which hydrogen is known to become metalic is somewhere between 477Gpa and 491Gpa.

Accordign to the study "Metallic hydrogen: The most powerful rocket fuel yet to exist" by Isaac F Silvera and John W Cole, recombination of the hydrogen from metalic form would release 216MJ of energy per kilogram of hydrogen undergoing this reaction.

In the same study a density for metalic hydrogen is given as 0.7gm/cm^3 (0.7g/cm^3, 700kg/m^3) but explicitly noted as an assumption. That density is 10 times that of liquid hydrogen, and I will take the same assumption.

Given that information, the specific energy of metalic hydrogen would be:

$$\frac{E}{V} = 216MJ/kg \times 700kg/m^3 = 151200MJ/m^3 = 151.2GJ/m^3 = 151.2kJ/cm^3$$

In that case if metalic hydrogen is formed into a sphere, the energy contained in that sphere can be calculated using this formula:

$$E = \frac{4}{3}\pi r^3 \times 151.2GJ/m^3 = r^3 \times 633.345GJ/m^3$$

And for purposes of later calculations, for some exact energy the required radius of the sphere would be calculated as such:

$$r = \sqrt[3]{\frac{E}{633.345GJ/m^3}}$$

Most observations of metalic hydrogen had been achieved by using Diamond Anvils, from which I assume Diamond might be the right material for containing unstable metalic hydrogen. According to the wikipedia page about diamond, the density of diamond is 3500kg/m^3, it's compressive strength is 130GPa, and it's tensile strength is 89GPa.

3 1MJ metalic hydrogen diamond capsule

To contain 1 MJ of energy in a sphere of metalic hydrogen, the required radius of the sphere is, from earlier presented formula:

$$\sqrt[3]{\frac{1MJ}{633.345GJ/m^3}} = 0.011644474m \approx 11.645mm$$

The metalic hydrogen must be kept under at least 491Gpa (I assume high end of the earlier stated range) and I will apply a safety factor of 1.1, so the shell should be able to contain 540.1GPa of pressure. In that case, shell thickness from earlier presented formula:

$$\frac{1.1 \times 491Gpa \times 11.645mm}{2 \times 89GPa} = 0.03533407m \approx 35.334mm$$

There appears to be far more diamond in the capsule than metalic hydrogen.

Volumes of the metalic hydrogen and diamond in the capsule:

$$V_{hydrogen} = \frac{4}{3}\pi \times (11.645mm)^3 = 6615mm^3$$

$$V_{total} = \frac{4}{3}\pi \times (35.334mm + 11.645mm)^3 = 434310mm^3$$

$$V_{shell} = V_{total} - V_{hydrogen} = 427695mm^3$$

Mass of the hydrogen and diamond, based on earlier presented density of diamond & assumed density of metalic hydrogen:

$$M_{hydrogen} = 700kg/m^3 \times 6615mm^3 = 0.0046305kg = 4.6305g$$

$$M_{shell} = 3500kg/m^3 \times 427695mm^3 = 1.4969325kg$$

$$M_{total} = 0.0046305kg + 1.4969325kg = 1.501563kg$$

Given that the contained energy should be 1MJ, the energy density of such a metalic hydrogen capsule would be:

$$1MJ/1.501563kg = 0.665972723MJ/kg \approx 666kJ/kg$$

This specific energy is 2 orders of magnitude below that of chemical fuels.

4 100kJ metalic hydrogen diamond capsule

Repeating the calculations from before for a 10MJ sphere of metalic hydrogen. The radius of the hydrogen sphere:

$$\sqrt[3]{\frac{10okJ}{633.345GJ/m^3}} = 0.005404886m \approx 5.405mm$$

Shell thickness:

$$\frac{1.1 \times 491Gpa \times 5.405mm}{2 \times 89GPa} = 0.016400228m \approx 16.4mm$$

There again appears to be far more diamond in the capsule than metalic hydrogen.

Volumes of the metalic hydrogen and diamond in the capsule:

$$V_{hydrogen} = \frac{4}{3}\pi \times (5.405mm)^3 = 661.418mm^3$$

$$V_{total} = \frac{4}{3}\pi \times (16.4mm + 5.405mm)^3 = 43426.7mm^3$$

$$V_{shell} = V_{total} - V_{hydrogen} = 42765.282mm^3$$

Mass of the hydrogen and diamond, based on earlier presented density of diamond & assumed density of metalic hydrogen:

$$M_{hydrogen} = 700kg/m^3 \times 661.418mm^3 = 0.000462993kg \approx 423mg$$

$$M_{shell} = 3500kg/m^3 \times 42765.282mm^3 = 0.149678487kg \approx 150g$$

$$M_{total} = 0.000462993kg + 0.149678487kg = 0.15014148kg$$

Given that the contained energy should be 100kJ, the energy density of such a metalic hydrogen capsule would be:

$$100kJ/0.15014148kg = 0.666038459MJ/kg \approx 666kJ/kg$$

The specific energy of the capsules appears to be constant regardless of size so long as other parameters don't change.

5 Conclusions

When the metalic hydrogen capsules are made with a safety factor of 1.1, ie. to be able to contain 1.1 times the required pressure for metalization of hydrogen, the specific energy from them will be near 666kJ/kg.

I was not able to find a chemical fuel with low enough specific energy to be comparable, but Coal when burned releases 10 to 20 MJ of energy per kilogram. The 1MJ capsule has a shell of diamond that masses 1.5kg so in theory the diamond shell if burned would release 15 to 30 MJ of energy (at obvious downside of requiring oxygen at the right concentration), which is 15 to 30 times more than is in the metalic hydrogen it contains.

I don't know of a process through which one could manufacture such a spherical diamond capsule of metalic hydrogen.

While metalic hydrogen itself has a high specific energy, an order of mangitude above most chemical fuels, encapsulating it in diamond does not appear to be one of the ways it could be put to good use as means of energy storage.

6 Extra: application of rydberg matter

Rydberg matter appears to be controversial, regardless I previously described encapsulating rydberg matter in carbon nanotubes, which yielded good results.

In that document I used liquid hydrogen, whereas here metalic hydrogen 10 times denser is used. If the hydrogen here could be excited in the right way specific energies in the range of 1.3GJ/kg are achievable.

In that case, the 1MJ capsule, which contains 4.6305g of metalic hydrogen & as a whole masses 1.5kg, would hold 6MJ instead. This achieves a total specific energy of roughly 4MJ/kg, which is in the order of magnitude below coal.