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Gas Marble Production

Small volumes of gas encapsulated by microparticles for gas storage and manipulation

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Aims

- Reproduce and verify gas marble phenomena using microparticles, surfactant and hydrophobic particle treatment.
- Investigate factors influencing particle strength and stability to identify important factors for gas marble lifespan.
- Explore methods for faster production of gas marbles and storage of gases other than air, including hydrogen for fuel cells and CO_2 for carbon capture devices.

Introduction

Coating liquid droplets with hydrophobic particles results in a small volume of liquid, trapped in a spherical structure. Since their discovery in 2001 by Aussillous and Quéré, the curious nature of these liquid particles has been well investigated.[1] Potential uses include fluid transport in microreactors, pollution sensing and water storage.[2]

In 2017, Timounay et al. produced a similar phenomena, a volume of gas enclosed by microparticles. Gas marbles exhibit even more remarkable properties than liquid marbles, able to sustain 10× the force internally and externally.[3]

Gas marbles have incredible potential use in H_2 storage, a field which is becoming more critical with the rise of hydrogen fuel cells. The traditional method of using gas canisters is energy intensive when compressing and the canisters are heavy. Newer technology, such as metal hydride storage, has expensive material cost, are heavy and require great temperatures to release.

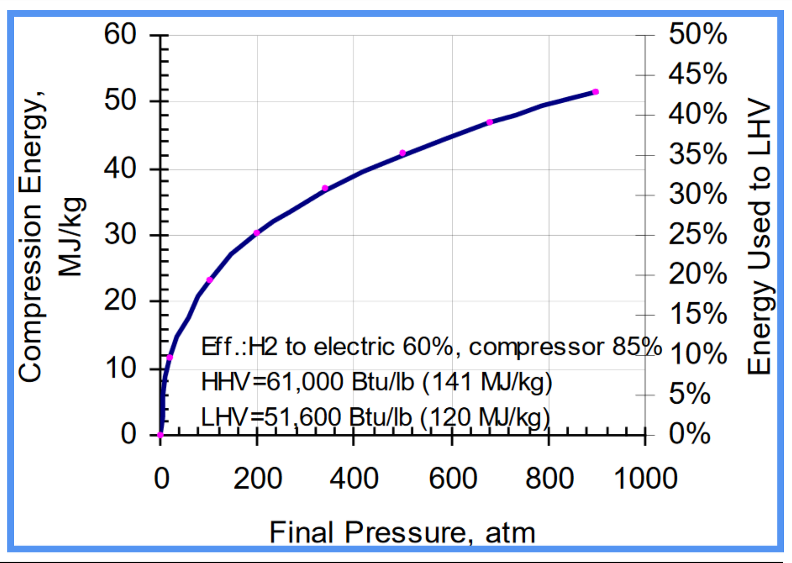

Figure 1. Energy used to adiabatically compress H_2 for storage in a canister.[4]

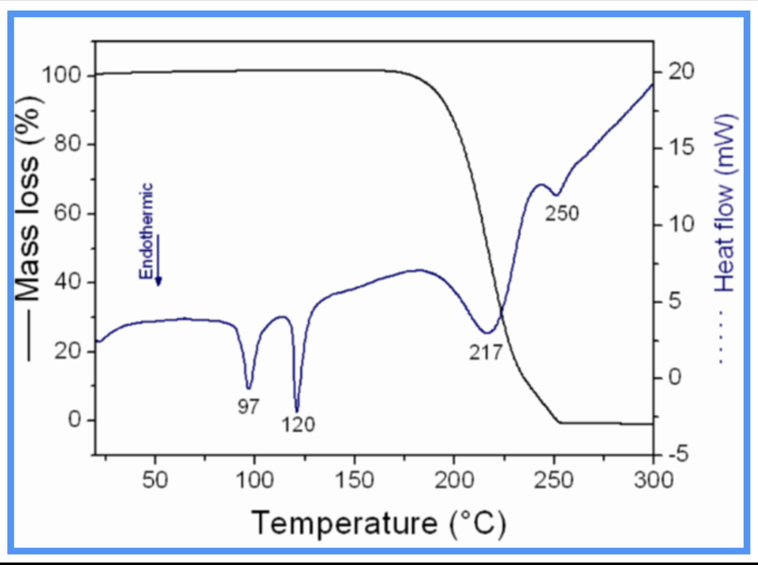

Figure 2. Temperature required to release bound H_2 from $NaBH_4$ with Ni catalyst.[6]

Why are gas marbles so strong?

The remarkable strength of gas marbles is suggested to originate from the boundaries between the outer gas, liquid meniscus between two particles and the inner gas.[3] The gas volume inside means there are two gas-liquid boundaries. The strength at this boundaries originate from the surface tension of the liquid which explains the use of a surfactant solution.

The surface tension of the liquid provides a cohesive force which gives rise to the increased strength over liquid marbles and armoured bubbles as the two gas-liquid boundaries form two menisci, one on the outer layer and one on the inner layer.

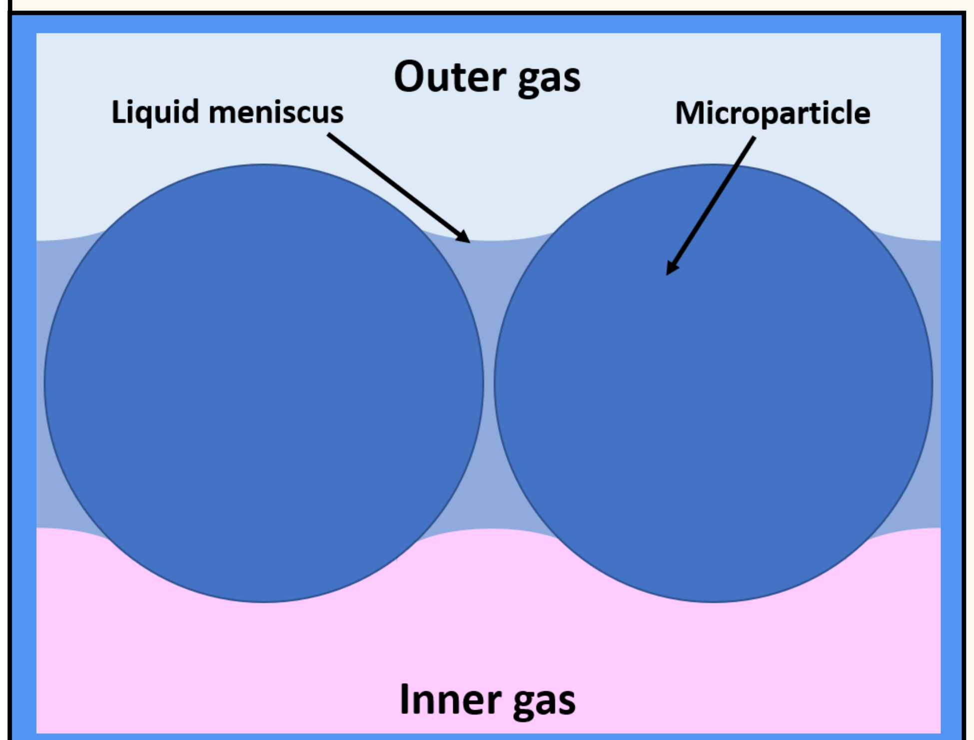

Figure 3. Cross section of marble shell, showing the two liquid-gas boundaries.

Without sufficient hydrophobicity, the particle raft required in production cannot be formed. However, it appears the particles can be too hydrophobic, with to reluctancy to form a marble as particles slip off the bubble.

It was observed that creating larger marbles, using a larger frame, lowered stability. This could be attributed to a more sparse particle coverage, resulting in a breakdown of the cohesive forces.

Production Method

Gas marbles are produced in a similar way to blowing a bubble. A frame is dipped into a surfactant solution with a microparticle raft floating on top. As the frame is lifted through the raft a bubble is formed, covered in microparticles. Rather than blowing the bubble, the force is provided by the weight of the particles which also acts to form a sphere, fully enclosing the gas.

The frame used was a simple wire bent into a circle. PMMA beads were used as the microparticles, with a diameter of 200 - 400 µm. The surfactant solution was a soap and glycerine solution and to make particles more hydrophobic, a perfluorobutanesulfonic acid (PFBS) spray. The rudimentary nature of the materials used indicate the simplicity of production.

Results

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Figure 4. Process of gas marble production. In (a), the particle raft and wire frame can be seen. In (b), the wire frame is submerged under the raft (frame drawn on for clarity). In (c), the wire frame has been pulled upwards and a gas marble has formed.

Conclusions

- Gas marbles may be produced using a very simple method, analogous to blowing a bubble, with simple materials. The process requires the surfactant solution to create a stable bubble and the particles to form a raft on the surface.
- The origin of the gas marbles' strength is primarily due to the cohesive forces of the two gas-liquid boundaries. Hydrophobicity of the particles and marble size are important for stability.
- Further experimentation must be done to investigate the potential for gas marbles of H_2 or CO_2 and potential for faster production using many connected frames.

Summary

Gas marbles have incredible potential gas storage. As hydrogen fuel cells become more ubiquitous, the need for efficient hydrogen storage is increasing.

Traditional methods of hydrogen storage include compressed gas cylinders, which pose a significant hazard, and storage in hydride complexes which are expensive and require high temperatures (up to 500°C) to release the bound hydrogen. Both are particularly heavy due to the metals required.[4]

Gas marbles are safe, have demonstrated low permeability[5] and are light, particularly important for H_2 powered vehicles.

References

1. P. Aussillous and D. Quéré, Nature (London) 411, 924 (2001)
2. J. Tian, T. Arbatan, X. Li, W. Shen, Chem. Commun. 46, 4734-4736 (2010)
3. Y. Timounay, O. Pitois, F. Rouyer, Phys. Rev. Lett. 118, 228001 (2017)
4. L. K. Heung, Using Metal Hydride to Store Hydrogen (2003)
5. Y. Timounay, E. Ou, E., F. Rouyer, Soft Matter, 2017, 13, 7717 (2017)
6. M. Christan, K. F. Aguey-Zinsou, ACS Nano 697739-7751 (2012)