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1. Introduction to hydrogen in aerospace applications

Timeline of hydrogen (H₂) within aerospace:

1783 – First hydrogen balloon flight
1954 – Hydrogen peroxide
1966 – Hydrogen batteries in satellite (NTS-2)
1966 – Hydrogen used as a rocket fuel (Atlas-Centaur launch vehicles)
1969 – Hydrogen cryocooler on Mariner 6
2011 – Lange Aviation/DLR Antares H3 – hydrogen fuel cells (piloted and unmanned), 6000 km, >50 hrs

Why we need H₂ in aerospace:
- Climate change
- Depletion of fossil fuels
- Lots of emissions in upper atmosphere

Therefore

Solution:
- Storage of H₂
- Very low energy per unit volume => density must be increased.

Desired properties of materials:
- Light
- High surface area
- Robust
- Large pore volume
- Good cycle life

E.g.
- Metal-organic frameworks (MOFs)
- Activated carbons
- Polymers of intrinsic microporosity (PIMs)
- Polymeric microporous materials

2. Research focus 1: Flexible MOFs

All conventional models assume a fixed pore volume, but:

We have created a mathematical model for this to fit to experimental isotherms:

\[ n_a = V_a (\rho_a^{\text{max}} (\text{isotherm equation}) - \frac{P}{ZRT}) \]

Initial assumption:
\[ V_a = V_a^0 (1 + aP + bP^2 + ...) \]

Clear positive trend observed

3. Research focus 2: Design curves

Direct comparison of adsorption vs. compression.

\[ m_k = \frac{m_k}{V_c} = \left(1 - f\right)\rho_a f_{\alpha 0} + f_{\alpha 0} \frac{\theta_a \rho_a}{\theta_0 (\rho_0 V_a + 1)} \]

- Can get out a critical pressure, under which adsorption stores more hydrogen than compression in the same volume.
- Need to do mass of hydrogen over mass of the system to account for additional weight of adsorbent.

4. Research focus 3: Neutron scattering

Using inelastic neutron scattering to characterise H₂ adsorption in a novel way, and verify our experimental data.

- As seen, there is a very good match between the two sets of data.
- We are now going to try with different materials and at higher pressures.

5. Future work

- Continuation of stated work.
- Multipurpose Simulation Code (MUSIC) – to model H₂ uptake at conditions inaccessible in the lab.
- Looking at whole containment systems for H₂ adsorption

6. Outcomes for EADS

- To bring key data on potential materials for H₂ adsorption.
- Growing importance for Astrium, Cassidian and Airbus.

References:

77 K Carbon bead data from the HTP

Temperature / K

40 30 20 10 0

0.00 0.02 0.04 0.06 0.08

Pressure / MPa

0.00 0.02 0.04 0.06 0.08

Mass of hydrogen adsorbed per volume of container / g cm⁻³

Pressure / MPa

f=0
f=0.25
f=0.5
f=0.75
f=1

Adsorption favoured
Compresssion favoured

H₂ pressure / MPa

50 55 60 65 70 75 80

-0.15
-0.10
-0.05
0.00
0.05
0.10

α / MPa

3.45 3.60 3.75 3.90 4.05

7.5 8.0

H₂ Uptake (μ mol)

60 40 20 0

20 40 60 80

Log pressure