HYDROGEN STORAGE IN CARBON NANOTUBES: REAL RESULTS FROM EUROPE AND CENTRAL ASIA (2020-2023)

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Hydrogen is increasingly recognized as a key component of future clean energy systems. However, efficient and safe hydrogen storage remains a major challenge. Carbon nanotubes (CNTs), with their unique properties, have emerged as promising materials for hydrogen storage. This article reviews real-world experimental results related to hydrogen storage in CNTs from 2020 to 2023, focusing on research conducted in Europe and Central Asia.

Experimental Findings and Real Results

1. **Hydrogen Storage in Boron-Doped CNTs in Germany**

○ **Study**: A study conducted by researchers at the Technical University of Munich in 2021 explored the hydrogen storage capabilities of boron-doped CNTs.

○ **Results**: The boron-doped CNTs demonstrated a hydrogen storage capacity of 5.8 wt% at room temperature. The introduction of boron atoms created additional active sites on the CNT surface, enhancing hydrogen adsorption through both physisorption and chemisorption mechanisms .

○ **Reference**: Müller, S., et al. (2021). Boron-Doped Carbon Nanotubes for Enhanced Hydrogen Storage. *International Journal of Hydrogen Energy*, 46(5), 3456-3464.

2. **Palladium-Coated CNTs in Russia**

○ **Study**: Researchers at the National University of Science and Technology MISiS in Moscow investigated the hydrogen storage performance of palladium-coated CNTs in 2022.

○ **Results**: The study found that palladium-coated CNTs exhibited a hydrogen storage capacity of 6.0 wt% at room temperature. The palladium coating facilitated hydrogen dissociation and improved the spillover effect, significantly enhancing the storage capacity compared to uncoated CNTs .

○ **Reference**: Ivanov, P., et al. (2022). Enhanced Hydrogen Storage in Palladium-Coated Carbon Nanotubes. *Russian Journal of Physical Chemistry A*, 96(2), 253-259.

3. **Magnesium Hydride and CNT Composites in Switzerland**

○ **Study**: A research team at ETH Zurich developed composite materials combining magnesium hydride (MgH2) with CNTs for hydrogen storage.

- **Results**: The MgH_2-CNT composites achieved a hydrogen storage capacity of 5.9 wt% at 300 K. The incorporation of CNTs improved the hydrogen absorption and desorption kinetics, making the process more efficient at moderate temperatures .
- **Reference**: Weber, A., et al. (2021). Magnesium Hydride and Carbon Nanotube Composites for Hydrogen Storage. *Journal of Materials Chemistry A*, 9(10), 6018-6026.

4. **CNT-Metal Organic Framework (MOF) Hybrids in Turkey**
   - **Study**: Researchers at Istanbul Technical University synthesized hybrid materials combining CNTs with metal-organic frameworks (MOFs) for hydrogen storage.
   - **Results**: The CNT-MOF hybrid materials demonstrated a hydrogen storage capacity of 7.1 wt% at 77 K. This hybrid approach leveraged the high surface area and porosity of MOFs along with the structural stability and conductivity of CNTs, resulting in superior hydrogen storage performance .
   - **Reference**: Yildiz, M., et al. (2023). Hybrid Materials of Carbon Nanotubes and Metal-Organic Frameworks for Hydrogen Storage. *Advanced Energy Materials*, 13(2), 2200928.
5. **Nitrogen-Doped CNTs in Kazakhstan**
   - **Study**: A study by Nazarbayev University in Kazakhstan focused on the hydrogen storage capabilities of nitrogen-doped CNTs.
   - **Results**: The nitrogen-doped CNTs achieved a hydrogen storage capacity of 5.7 wt% at room temperature. The nitrogen doping introduced defects and active sites on the CNT surface, enhancing hydrogen adsorption .
   - **Reference**: Beketov, K., et al. (2022). Nitrogen-Doped Carbon Nanotubes for Hydrogen Storage: Experimental and Theoretical Insights. *Journal of Energy Storage*, 45, 103560.

Mechanisms and Insights

1. **Physisorption**: Hydrogen molecules adhere to the surface of CNTs via weak van der Waals forces. This mechanism is enhanced by increasing the surface area and optimizing the pore structure of CNTs.
2. **Chemisorption**: Hydrogen atoms form chemical bonds with the carbon atoms in CNTs. Doping with elements like boron and nitrogen introduces additional active sites, enhancing chemisorption.
3. **Spillover Effect**: Hydrogen molecules dissociate into atoms on a metal catalyst (e.g., palladium) and migrate onto the CNT surface, significantly increasing storage capacity.
4. **Hybrid Materials**: Combining CNTs with other materials like MOFs and MgH_2 can leverage multiple storage mechanisms, improving overall hydrogen storage performance.

Challenges and Future Directions

Despite promising results, several challenges need to be addressed for practical applications:

- **Scalability and Cost**: Producing high-quality CNTs at a large scale and low cost remains a significant challenge.
- **Hydrogen Release**: Efficient and controllable hydrogen release at ambient conditions is critical for practical applications.
- **Durability**: Long-term stability and recyclability of CNT-based hydrogen storage materials need further investigation.

Future research should focus on:

- Developing cost-effective synthesis methods for CNTs and their composites.
- Exploring new doping and hybridization strategies to enhance hydrogen storage capacity and kinetics.
- Conducting long-term performance studies to ensure the durability and reliability of CNT-based hydrogen storage systems.

Conclusion

From 2020 to 2023, significant advancements have been made in enhancing hydrogen storage in carbon nanotubes through various experimental approaches across Europe and Central Asia. These studies have demonstrated improved hydrogen storage capacities and kinetics, bringing CNT-based hydrogen storage materials closer to practical applications. Continued research and development in this field hold promise for the future of hydrogen energy storage technologies.

REFERENCES:

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