Feasibility Pilot Study on Optimizing Hydrogen Storage Tanks: Insights from Computational Fluid Dynamics and Finite Element Analysis

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INTRODUCTION

Hydrogen storage systems play a crucial role in advancing clean energy solutions. However, challenges related to safety, efficiency, and storage capacity remain significant. As a pilot study to explore potential solutions, this work focuses on adsorbed hydrogen storage tanks utilizing activated carbon, aiming to address these challenges through advanced Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA). The novelty lies in integrating a Dubinin-Astakhov adsorption isotherm into a CFD model via User-Defined Functions (UDFs), enabling precise simulation of hydrogen adsorption dynamics during charging, dormancy, and discharging processes. This approach offers insights into optimizing storage conditions and reducing material stress for broader applications in renewable energy and transportation.

EXPERIMENTAL/THEORETICAL STUDY

The CFD model incorporates mass, momentum, and energy conservation equations, simulated using ANSYS Fluent. UDFs were developed to modify boundary conditions and implement the adsorption isotherm. Three simulations were conducted with varying initial pressures and dormancy durations. FEA was performed using SolidWorks and FEMAP to assess structural integrity under loading conditions derived from the CFD simulations. Comparisons were also made with a tank model excluding porous media to evaluate the benefits of adsorption.

RESULTS AND DISCUSSION

The study demonstrates that adsorption significantly reduces internal pressures, enhancing safety and allowing the use of thinner tank walls. For instance, simulations revealed a 20% pressure reduction compared to tanks without porous media, lowering stress on the material. Temperature distribution analysis showed that adsorption minimizes thermal gradients, improving system stability. The FEA results confirmed the structural integrity of the tank under various conditions, with reserve factors exceeding safety thresholds. These findings validate adsorption-based storage as a superior alternative to traditional compressed gas systems.

CONCLUSION

This research establishes a robust framework for optimizing hydrogen storage systems. By integrating CFD and FEA techniques, it provides actionable insights into improving tank safety, efficiency, and performance.

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