Knowledge Sharing on Optimization of Metal Hydride Tanks for Hydrogen Storage through Heat

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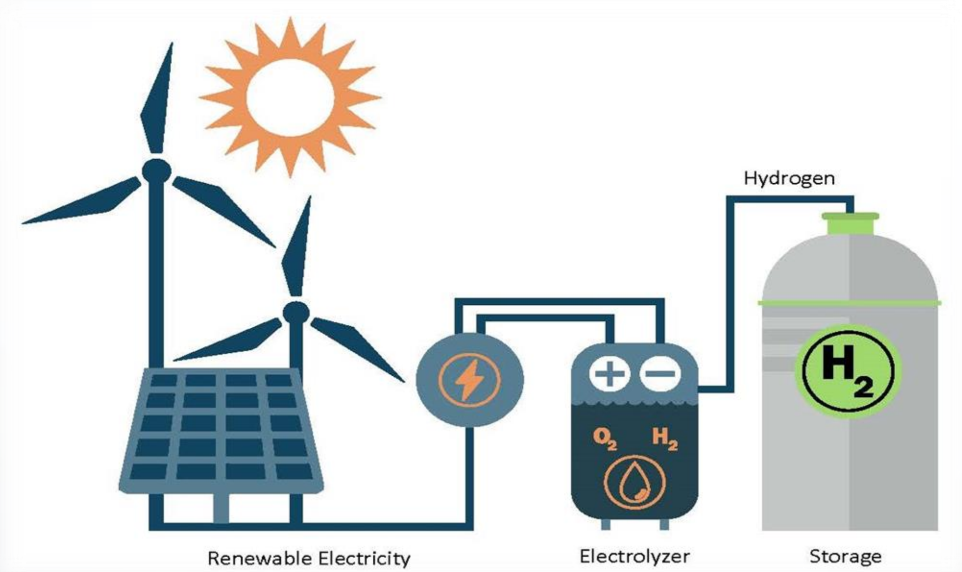
Introduction

- Hydrogen has a long history as an energy carrier, from early fuel cell demonstrations and internal combustion engines in the 19th century (Birol, 2019). Today, hydrogen is viewed as a promising alternative to fossil fuels due to its potential to diversify energy supply, reduce pollution, and lower greenhouse gas emissions (Bao et al., 2013, Mellouli et al., 2010). It can be produced using various methods, including water electrolysis powered by renewable energy, making it a clean and sustainable energy option.



Energy.gov. (2025).

Metal Hydride Tanks

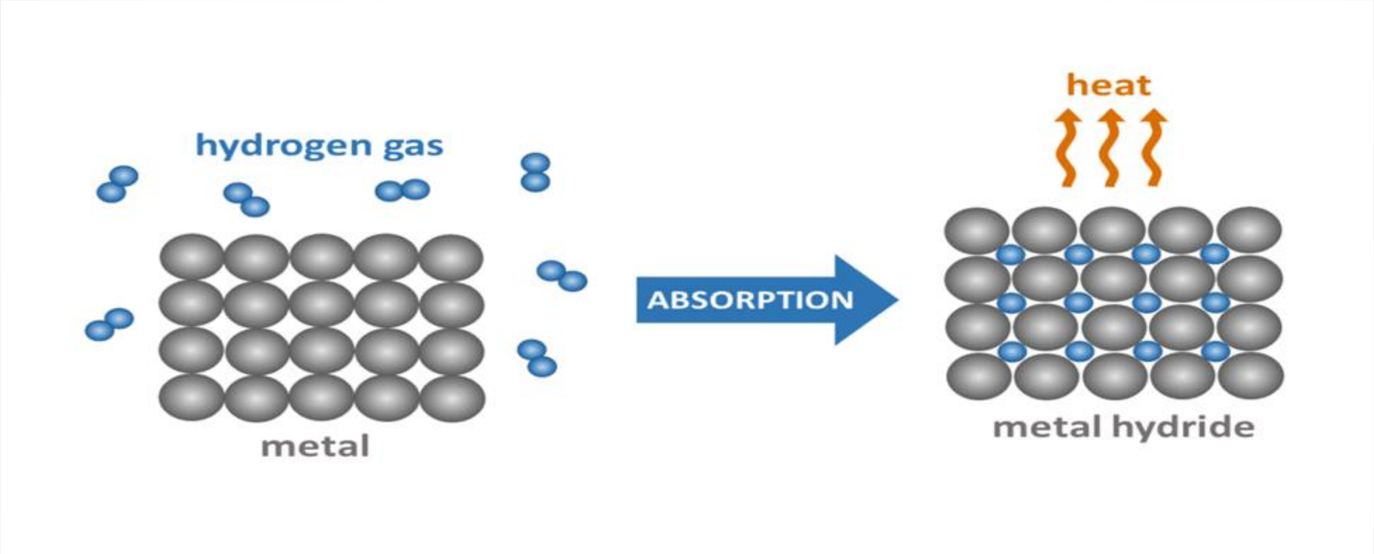
1. **Challenges:**

- One of the key challenges in utilizing hydrogen as an energy source is its safe and efficient storage. Hydrogen has a low energy density per unit volume, making its storage difficult in gaseous or liquid form.
- Effective storage solutions must address issues related to pressure, temperature, material compatibility, and energy losses to ensure economic and practical viability. Metal hydride tanks have emerged as a promising solution for safe and efficient hydrogen storage.

2. Proposed solution: Metal hydride tanks have emerged as a promising solution for safe and efficient hydrogen storage. Due to its high volumetric energy density, low operating pressures, and improved safety compared to conventional storage methods. Lanthanum-nickel alloy (LaNi5) was used.

Metal Hydride Tanks

Role of Metal Hydride (MH) Tanks in Hydrogen Storage



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The optimization of MH tanks involves understanding heat and mass transfer processes, which influence the hydrogen absorption and desorption rates. The main aim of this study was to simulate the impact of key operating parameters volume, length, height of the finned spiral heat exchanger on the performance of a metal hydride tank for hydrogen storage. COMSOL software, mathematical equations for hydrogen absorption was used to predict hydrogen charging flow rates while looking at the effect of different properties of finned spiral heat exchanger .

Metal Hydride Tanks

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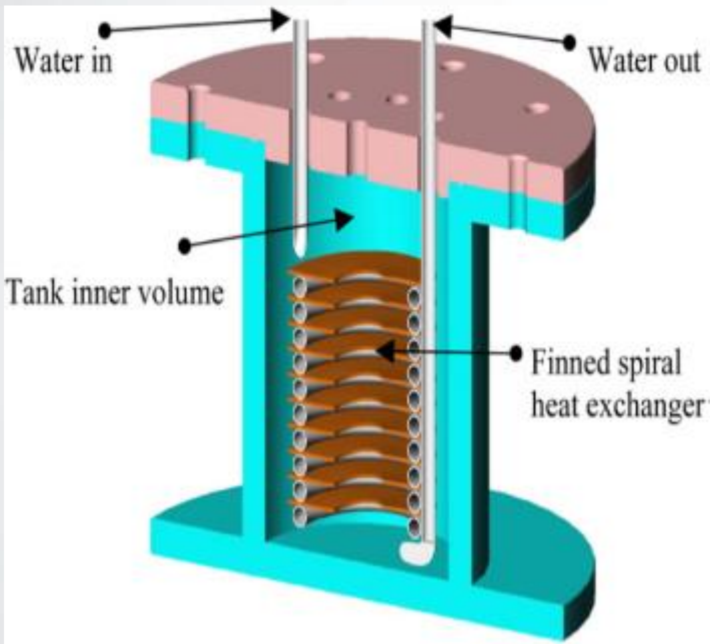

Figure 1: Metal hydride tank(Mellouli et al., 2010)

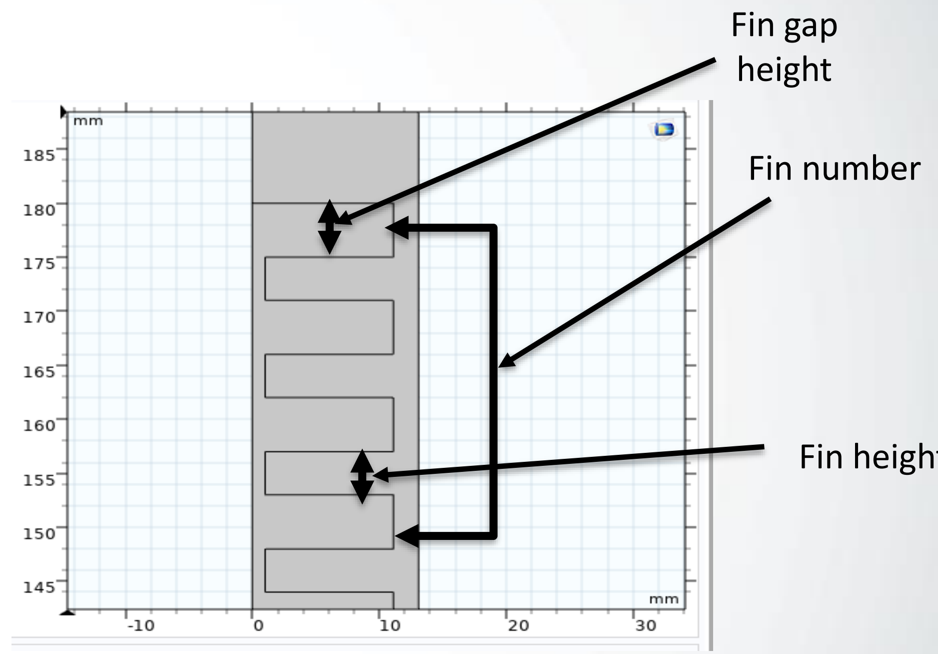

Figure 2 : Metal hydride domain

Methodology Summary

- **Research & Design:**
  - Extensive research ensures commercial viability and security of metal hydride (MH) storage.
  - Key design parameters include spacing, size, and number of heat-conducting plates inside the tank.
  - Mathematical modeling and simulation (COMSOL) analyze hydrogen absorption and desorption rates.

Model Assumptions:

- Since the pressure within the bed is moderate, hydrogen is treated as an ideal gas.
- The temperature of the solid and the gas are the same (local thermal equilibrium).
- There is no heat loss or gain to/from the environment because only the heat transfers between the MH and the HTF are evaluated.
- The temperature of both the gas and the solid is the same (local thermal equilibrium).
- Initial hydrogen content in the tank is 10%.
- Tank dimensions: MH container length = Fin numbers *(Fin height + Fin gap)

Methodology

- **Hydrogen mass balance equation:** $\frac{\partial(\varepsilon\rho_g)}{\partial t} + \nabla\left(\rho_g \overrightarrow{U_g}\right) = -\dot{m} \cdots\cdots (1)$

$$\overrightarrow{U_g} = -\left(\frac{k}{\mu_g}\right)\nabla P \cdots\cdots (2)$$

$$\dot{m} = C_a exp\left(\left(-\frac{E_a}{R_U T}\right) ln\left(\frac{P_g}{P_{eq}}\right)(\rho_{sat}^m - \rho^m)\right) \cdots\cdots (3)$$

- **Momentum balance:** $\frac{\partial(\varepsilon\rho_g)}{\partial t} + \nabla\left(-\rho_g\left(\frac{k}{\mu_g}\right)\nabla P_g\right) = 0 \cdots\cdots (4)$

$$K = C_k \times d_p^2\left(\frac{\varepsilon}{1-\varepsilon}\right)^2 \cdots\cdots (5)$$

- **Equilibrium Pressure:** $P_{eq} = exp\left(\left\{\frac{\Delta H}{R_U T} - \frac{\Delta S}{R_U} + (\varphi \pm \varphi_O)tan\left[\pi\left(\frac{X}{X_f} - \frac{1}{2}\right)\right] \pm \frac{\beta}{2}\right\}\right) \cdots\cdots (6)$

- **Energy equation:** $\left(\rho C_p\right)_e \frac{\varphi T}{\varphi t} + \left(\rho_g C_{pg}\right)\vec{U}.\nabla T = K_e \nabla^2 T + Q \cdots\cdots (7)$

Results

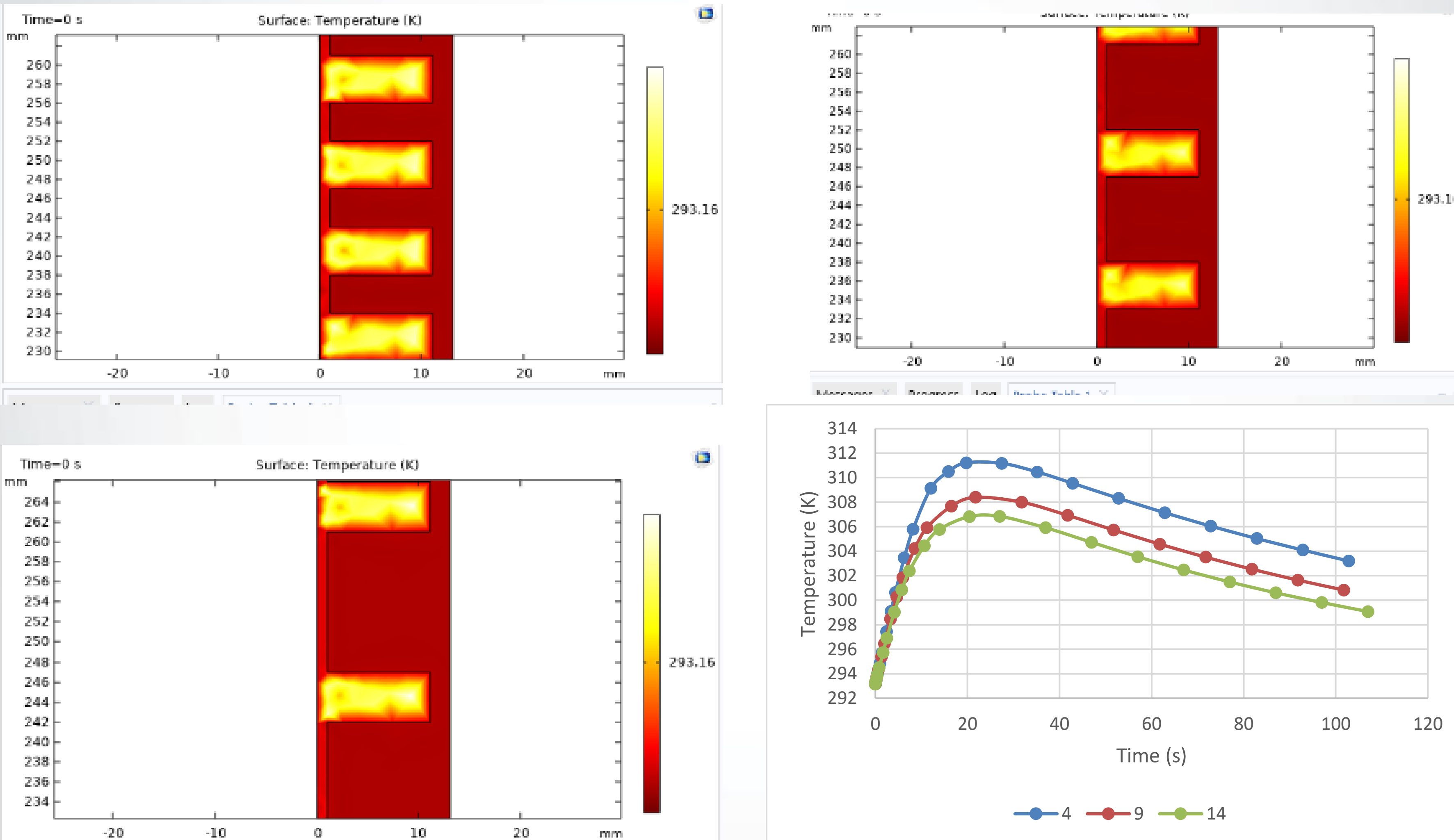

Figure 3. Temperature assessment for three sets of fin gap height parameters (4 mm, 9 mm and 14 mm) in MH storage tank.

Results

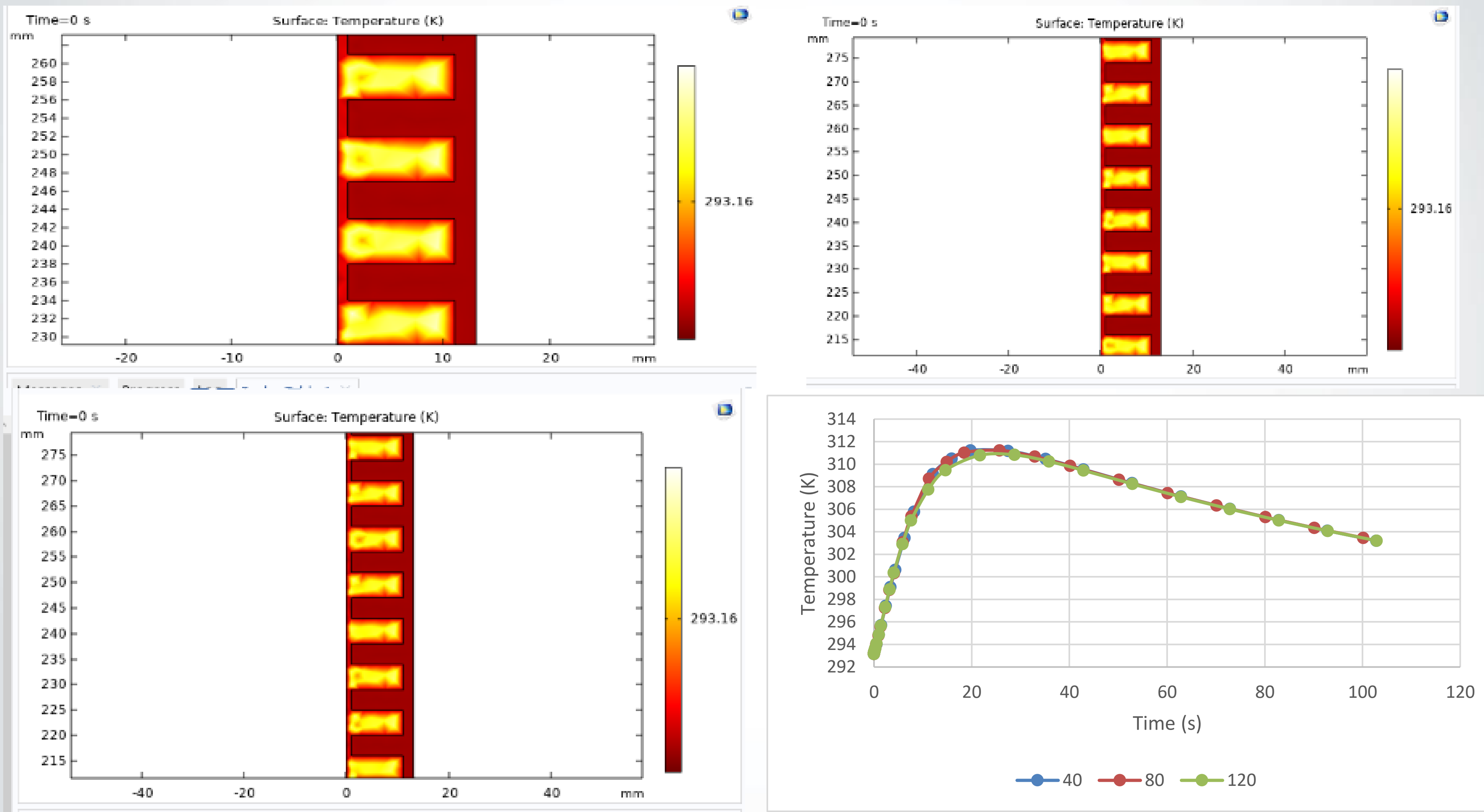

Figure 4: Different fin numbers (40, 80, & 120) to evaluate the performance of MH tank as storage of hydrogen.

Results

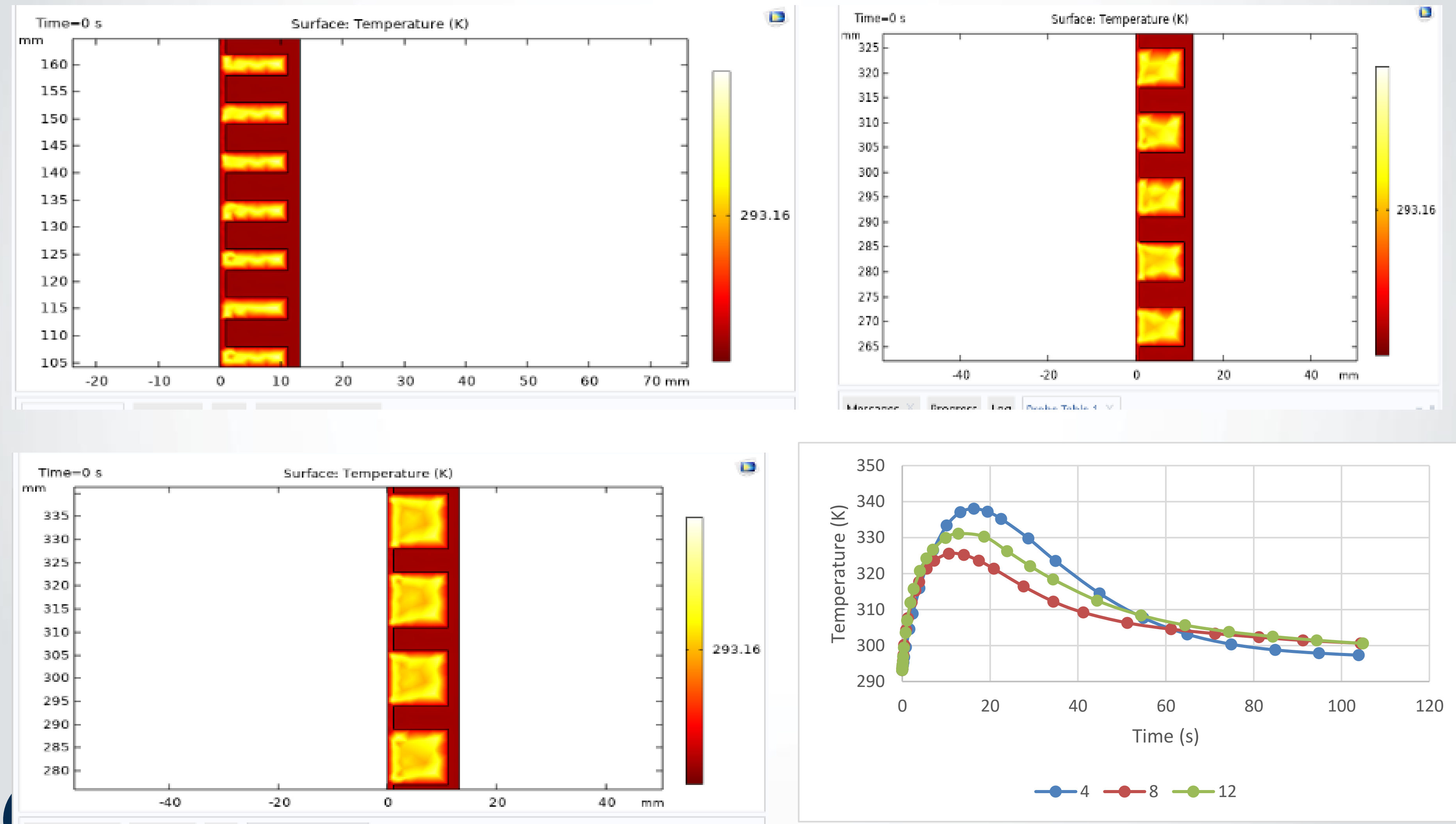

Figure 5: Different fin thickness (4, 8, 12 mm) to evaluate the performance of MH tank as storage of hydrogen

Discussion

- **Main Results/Findings:**
  - Optimal fin gap height (9 mm) enhances hydrogen absorption by managing temperature distribution. The ideal number of fins (80) improves heat transfer, accelerating absorption. Fin thickness (4 mm) shortens conduction paths, increasing cooling efficiency.
- **Challenges Observed:**
  - Variations in fin parameters significantly impact hydrogen absorption rates. Excessive or insufficient fin spacing and numbers slow absorption, while heat loss reduces efficiency.
- **Mitigation Plan:**
  - Optimize fin configurations using COMSOL simulations to balance heat transfer and absorption rates. Minimize energy loss by refining design parameters and improving thermal management.
- **Key Learnings:**
  - Fin height, number, and thickness are critical for optimizing MH hydrogen storage. Proper tuning of these parameters enhances efficiency, ensuring faster hydrogen absorption and effective heat dissipation.

Conclusion

- **Summary:**
  - Mathematical models for hydrogen absorption and desorption were developed and solved using COMSOL software in order to predict charging hydrogen flow rates 2.7 kg/m^3 s and discharging flow rate of 2.5 kg/m^3 s . To attain 90% of the maximum H2 capacity, a 2D symmetrical model was utilized to simulate a variety of MH tank geometry parameter for hydrogen storage

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Thank you!