An Experimental Study to Validate Optimum Distance Between Metal Hydride Tanks WithStaggered Arrangement for Effective Thermal Management

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Abstract
The aim of this work is to validate the results of numerical calculations for staggered metal hydride banks with the pitch-to-diameter ratio of 0.06 and 0.07 at the Reynolds number of 6000 and 12000. The optimized metal hydride tank array frames as per the results of theoretical study have been fabricated and experimental tests are carried out on the designed system. The effects of operating parameters such as tank pressure, ambient temperature and equilibrium on system performance were studied. The experimental results are compared with the theoretical model and validation is found between the two. It is also experimentally demonstrated that metal hydride storage tanks are strongly affected by the array geometry for maximum heat transfer, especially for small pitch arrays at high Reynolds numbers. The results show good agreement with the available theoretical data. The thermal behavior results for the given parameters showed that the metal hydride reservoirs placed with optimum spacing have heat transfer capability of more than 75% of their theoretical capacity. It was experimentally shown that the overall efficiency of the fuel cell-metal hydride system can potentially be increased by simple geometrical arrangements. In addition, it is important to consider the potential contribution to commercially available work such as automotive.

Keywords: Metal Hydride, Optimization, Heat Management, Thermal Imaging, Experimental validation

I. Introduction

Metal hydrides have been extensively used in green vehicles due to good energy density and low operating pressure. Their performance and life cycle are related by temperature. If possible, more than one tank should prefer to obtain effective heat management because of the extra heat transfer area. Additionally, when one tank is used, the system's performance will be affected by the performance of the metal hydride tank. For this reason, it is important to use as more as possible the tanks. Also, occupied space and investment costs should be considered and competed economically with cheap hydrocarbons for mobile applications. Because end-users want economic and reliable vehicles in terms of price.

All the work on this subject has been made in consideration of a single tank. Omrani at al. designed and positioned horizontally the nine metal hydride tanks in two parallel rows in a well-insulated air box. Mahmoodi at al. was studied experimentally to increase the desorption performance of a metal hydride tank using new novel geometric configuration of heat pipes. They focused especially effects of heat pipe number and fin in metal hydride tank. Kumar at al. studied absorption/desorption characteristics of a metal hydride tank with 99 cooling tubes. Tarasov at al. used multiple metal hydride tanks in experiments. Lototskyy at al. developed an assembly of the metal hydride containers staggered with heating/cooling tubes. But it does not contain any data related to tank arrangements. Almost all did not focus on the effect of array geometry of metal hydride tanks.

The goal of the current study is to prove experimentally that ideal distance exists in metal hydride array according to the results of theoretical study (Hilali et al., 2018).

II. Experimental Set-up and Procedure

In the present study, the LaNi5 alloy filled with metal hydride tanks with staggered arrangement as shown in Fig. 1 are considered.

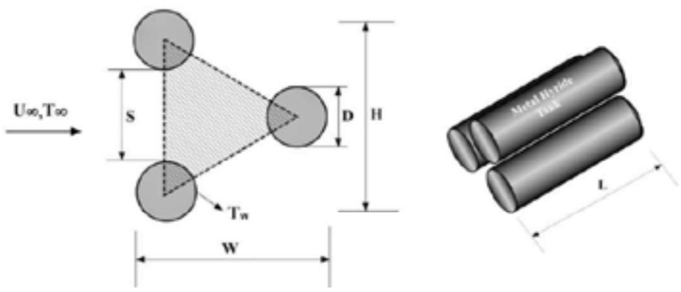


Fig. 1: Schematic of the staggered arrangement

Hilali et al. found the existence of an ideal distance for the largest heat transfer rate. The heat transfer rate is formulated for the extreme distances, i.e., large distance and small distance. Then the ideal distance is found by balancing the formulas.

$$\left(\frac{S_{opt}}{D}\right) \cong 4.\mathrm{Re}_D^{-0.47}.\mathrm{Pr}^{-0.21} \quad (1)$$

As shown in Fig. 2 and 3, the experimental setup consists of an axial fan with frequency controller, an air heater with temperature controller, an air flow meter, a fuel cell system, metal hydride storage tanks, black coated aluminum plates and a thermal imaging camera with SuperResolution. The fuel cell system is based on the 1200 W Nexa power source including energy management module and electronic loader.

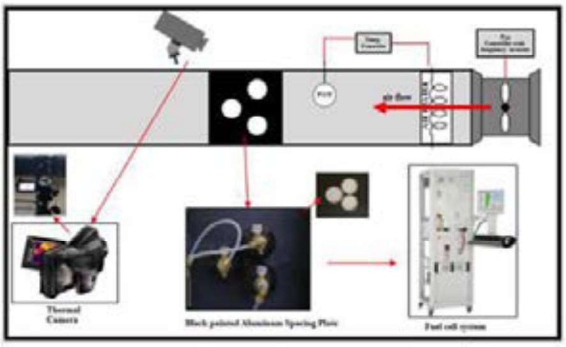


Fig. 2: Schematic of the experimental setup

Fig. 3: Photograph of the experimental setup

The present study consists of two stages determined by perforated plates; each of them evaluates the heat transfer rate separately based on different ambient temperatures (300 K & 310 K), Reynolds numbers (6000 & 12,000) and equilibrium pressures (60 kPa & 120 kPa). In each of the two stages, two plates were used with a spacing of 5 and 6 mm between the tanks. These plates were selected according to previous results of theoretical study. The tank pressures were obtained by operating the fuel cell up to the specified values under the constant load using an electronic loader.

III. Results and discussions

The solid lines drawn on the plate in Fig. 4 were used to plot the temperature profile using the thermal image data along the lines to compare the results of the theoretical study. The contours in Fig. 5 show the temperature distribution over the plate area according to the solid lines for relevant variables. The results of CFD and the experimental results are shown on the left side and the right side of Fig. 6, respectively.

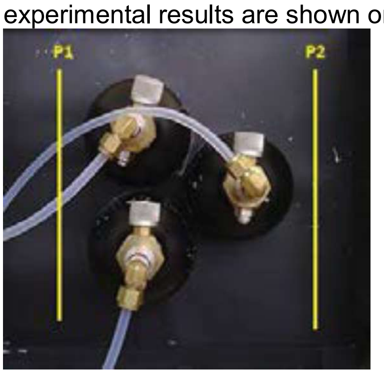
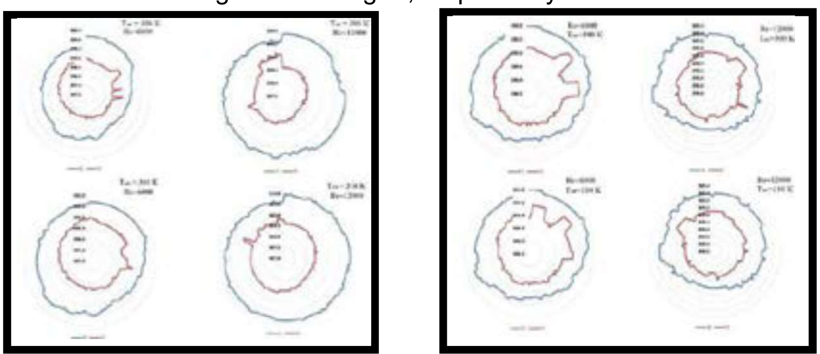


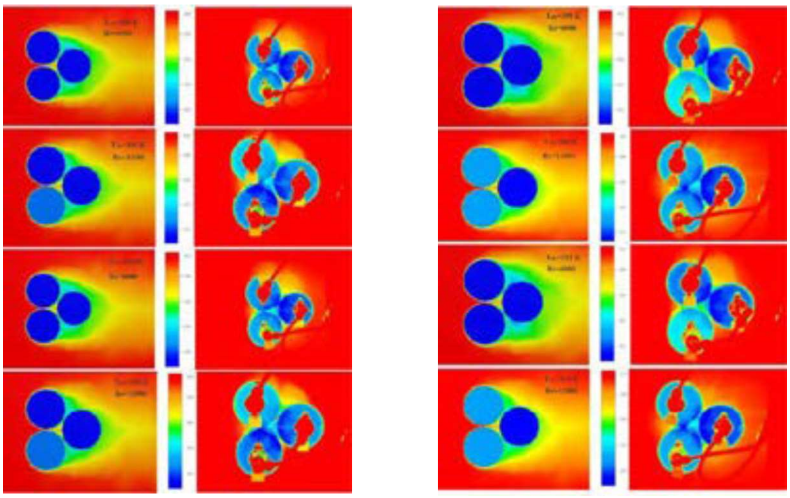
Fig. 4: Measurement planes on the plates



(a) (b)

Fig. 5. The captured temperature profiles over the face of plates (a) for Peq=60 kPa (b) for Peq=120 kPa

Fig.5 shows the temperature distributions on the surface of the plate along each vertical line (P1&P2) at Peq=60 kPa and 120 kPa, respectively. The blue counter indicates the inlet air temperature, and the red counter indicates the outlet air temperature. The difference between the blue and red counters indicates the heat transfer rate of the metal hydride reservoirs. As the figures show, the temperature difference is approximately between 0.5 and 1 K depending on the Reynolds number. As the Reynolds number increases, the temperature difference increases. These results are in agreement with the results of another study by the author. Fig. 6 states that both contours agree well, thus verifying the validity of the model. As can be seen, both contours agree and the small differences are a consequence of the thermal camera measurements and the many uncertainties associated with the experimental setup, since the simulated values are calculated under ideal conditions.



(a) (b)

Fig. 6. The visual comparison of CFD results and experimental results (a) for Peq=60 kPa (b) for Peq=120 kPa

V. Conclusions

The thermal management of metal hydride storage devices (MH) separated by the ideal distance is discussed In this study.The varying inputs namely air velocity, pressure and ambient temperature were considered as the main parameters to affect the temperature distribution during discharge. The data output as a result of the thermal response for the input parameters discovered the importance of optimizing an ideal spacing between the metal hydride tanks, as it plays a critical role in the ability to transfer heat above 75% of the theoretical capacity. Therefore, the study concludes that an optimal spacing between the metal hydride storage devices has positive effects on the thermal conductivity of the proposed system as it critically improves the effective thermal management. The main conclusions of this study imply through our experiments that the heat transfer is directly related to the optimal spacing. The experimental and theoretical results of this work can provide a direction for the characterization of a metal hydride storage system.

References

Hilali, İ., Karadag, R., Bulut, H., & Aktacir, MA. A study on ideal distance between staggered metal hydride tanks in forced convection. International Journal of Hydrogen Energy, 43(38), 17970–17977 (2018).

Kumar, A., Raju, N. N., Muthukumar, P., & Selvan, P. V. Experimental studies on industrial scale metal hydride based hydrogen storage system with embedded cooling tubes. International Journal of Hydrogen Energy, 44(26), 13549–13560 (2019).

Lototskyy, M., Tolj, I., Klochko, Y., Davids, M. W., Swanepoel, D., & Linkov, V. Metal hydride hydrogen storage tank for fuel cell utility vehicles. International Journal of Hydrogen Energy, 45(14), 7958–7967 (2020).

Mahmoodi, F., & Rahimi, R. Experimental and numerical investigating a new configured thermal coupling between metal hydride tank and PEM fuel cell using heat pipes. Applied Thermal Engineering, 178, 115490 (2020).

Omrani, R., Nguyen, H. Q., & Shabani, B. Thermal coupling of an open-cathode proton exchange membrane fuel cell with metal hydride canisters: An experimental study. International Journal of Hydrogen Energy, 45(53), 28940–28950 (2020).