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Quarterly Progress Report

Project Title: Solid State Hydride System Engineering

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Project Objective: The objective of this effort is to quantify the fueling station heat rejection requirements to service typical metal hydride fueled automobiles.

Background:

A typical hydrogen refueling station was designed based on DOE targets and existing gasoline filling station operations. The purpose of this design was to determine typical heat loads, how these heat loads will be handled, and approximate equipment sizes.

For the station model, two DOE targets that had the most impact on the design were vehicle driving range and refueling time. The target that hydrogen fueled vehicles should have the equivalent driving range as present automobiles, requires 5 kg hydrogen storage. Assuming refueling occurs when the tank is 80% empty yields a refueling quantity of 4 kg. The DOE target for 2010 of a refueling time of 3 minutes was used in this design. There is additional time needed for payment of the fuel, and connecting and disconnecting hoses and grounds. It was assumed that this could be accomplished in 5 minutes. Using 8 minutes for each vehicle refueling gives a maximum hourly refueling rate of 7.5 cars per hour per fueling point.

Status:

Fueling Station

The number of pumps at a gasoline filling station varies greatly. Small stations may have 2 to 4 pumps (4 to 8 fueling points since most pumps can be fueled simultaneously from both sides). A typical neighborhood gasoline station may have 8 pumps (16 fueling points). A large station as on an interstate or major highway, may have as many as 24 pumps (48 fueling points). This first design is based on a hydrogen station with 8 pumps (16 fueling points).

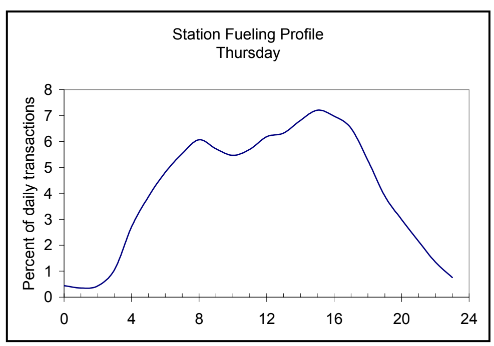

Figure 1 Gasoline Filling Station Weekday Fueling Profile

Information from Chevron reveals that gasoline filling stations follow a relatively repeatable fueling profile. During weekdays there are two peaks at 8 am and 3 pm with the second peak being the largest and lasting between 2 pm to 6 pm. A typical Thursday profile is shown in Figure 1. The days with the two highest gasoline sales are Thursday and Friday.

For the purposes of this design, it was assumed that there would be at least one hour per day when all the fueling points (2 cars per pump) would be in use. The size of the cooling equipment was based on this one-hour maximum loading. An estimate of daily demand was calculated from the one-hour peak demand being equal to 7% of daily fuel needed. For the aforementioned design system, this gives a maximum hourly fuel demand of 480 kg of hydrogen and a daily demand of 6,800 kg of hydrogen.

Although there is significant heat energy liberated during recharging of a hydride storage tank, operating parameters limit the temperature rise to only a few degrees above the normal operating temperature of 100 ºC. Due to the relatively low temperature of the fluid cooling the recharging tank, very little, if any, beneficial heat can be recovered. If the hydride in the bulk storage unit operates at a significantly lower temperature than the vehicle storage unit, there may be opportunity to use some of this waste heat.

Hydrogen Storage

When refueling a hydride storage tank, significant energy is released in the form of heat. The amount of heat released is based on the heat of formation for the particular hydride being used. Hong[1] postulated in his patent documentation that the heat of alloy hydride formation should be between -15 kJ/mol and -40 kJ/mol. When it is less negative than -15 kJ/mol, the alloy hydride is not stable enough for charging the metal hydride electrode at room temperature. On the other hand, the alloy hydride is too stable, making discharging too difficult for room-temperature discharge, when the ΔH value exceeds -50 kJ/mol. Rather than considering a specific hydride, the energy balances investigated used a generic hydride with a heat of formation of -27.5 kJ/mol. ([1]K. Hong (1991) US Patent 5,006,328.)

Station Design

The design presented here assumes the hydride in both units operate at the same temperature and all heat generated must be dissipated to the environment. The dissipation facility must be sized to handle the maximum heat generated, which would be during the hours of maximum refueling. Refueling the bulk storage tank would require the same amount of cooling but would not require a separate heat dissipation facility. The bulk storage tank would be regenerated and consequently cooled during off hours when there is excess cooling capacity in the dissipation facility. During times of vehicle refueling the bulk storage tank may require heat input. Waste heat from the compressor can be used but may not be enough. Additional heat from burning a side stream of hydrogen may be necessary. This portion of the design is not included in the model. The major components of this simulation are shown in Figure 2.

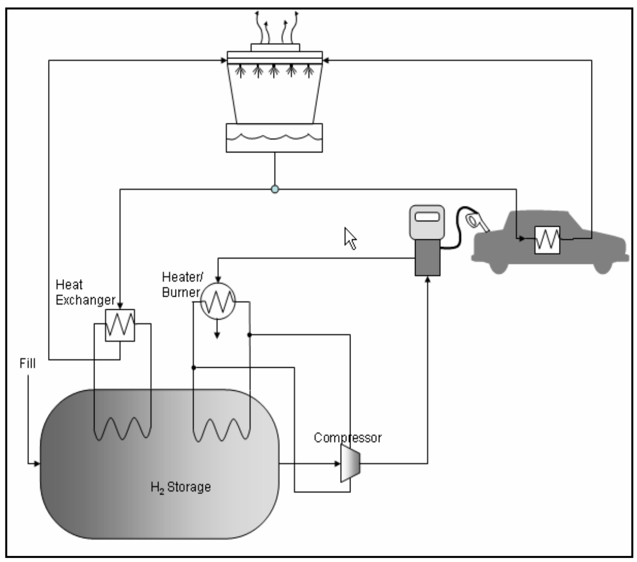

Figure 2 Simplified hydrogen fueling station

Cooling Requirement

Using the design parameters, 6.5 gigajoules (GJ) of heat must be dissipated or stored during each hour of maximum fueling. Since the generated heat during refueling is produced at a low temperature, there are no normal reuse or storage options. The most common and cost effective facility for dissipating this type of heat is a cooling tower. The 6.5 GJ/hr of heat to be dissipated corresponds to a cooling load of 517 tons. There are no standard dimensions for cooling towers. Sizes are unique to each manufacturer. Based on experience and standard rules of thumb, a 500-ton cooling tower will be approximately 20 feet long, 12 feet wide and 18 feet tall and be composed of 2, 4 or 6 cells. A cooling tower this size is small by industrial standards but may be significant when added to fueling stations. The tower's footprint of 20' by 12' will have to be extended by at least 10 feet to accommodate the recirculation pumps and ancillary equipment. Towers must be sited such that there are no interferences to air flow into and out of the tower. It would be possible to elevate the tower above structures at the station if adequate support is available. The tower in this design would require two 2,000 gpm pumps (1 operating, 1 back-up) for cooling water recirculation (1,551 gpm). Over 28,000 gallons of make-up water will be needed each day and over 5,800 gallons of blowdown water will be discharged to the sewer every day.

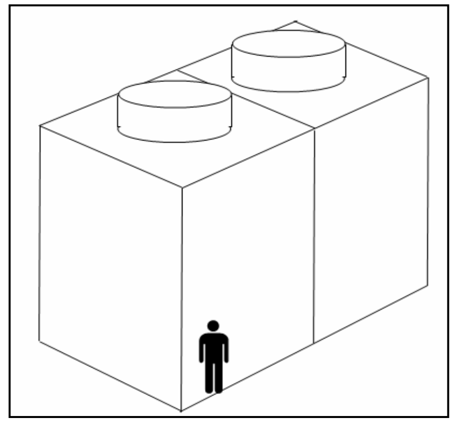

Figure 3 Relative size of cooling tower

Legionella pneumophila bacteria thrives in poorly maintained cooling towers. These bacteria are the cause of Legionnaires' Disease and the less deadly Pontiac Fever. The majority of cases of Legionnaires' Disease have been traced back to poorly maintained cooling towers and evaporative cooling units. Therefore, cooling tower water chemistry must be properly maintained with appropriate chemical additives.

Bulk Hydrogen Storage

The other major addition to a refueling facility is bulk hydrogen storage. Gasoline filling stations prefer to keep a 3 to 7 day supply on hand in case of bulk delivery interruptions. For this design it was decided that a 3-day supply of hydrogen should be kept on hand and that refueling of the bulk storage unit would take place each night during periods of low-volume vehicle refueling. This way the equipment used to dissipate the heat generated during the refueling of vehicles can be used to dissipate the heat generated when refueling the bulk storage tank.

General rules of thumb indicate that 1 kg hydrogen occupies:
91.2 L at 152 bar (2,200 psi)
27 L at 689 bar (10,000 psi)
14 L as a liquid
10 L in a metal hydride.

20,000 kg, hydrogen would occupy:

152 bar (2,200 psi)	1,914,000 L	(470,000 gal)
689 bar (10,000 psi)	540,000 L	(140,000 gal)
Liquid	280,000 L	(73,333 gal)
Metal Hydride.	200,000 L	(50,000 gal)

Typical gas station gasoline bulk storage tanks hold 15,000 gallons (57,000 L). Bulk storage of hydrogen in either a metal hydride or in liquid form is closest in volume to today's bulk storage. Using compressed hydrogen would require significantly larger facilities than those used today.

Conclusions

The maximum hourly heat generated along with the associated cooling load is given in graphical form in Figure 4. The maximum heat is linear with respect to fueling sites. Each fueling site generates approximately 0.4 GJoules /hour of heat. Heat generated is also linear with respect to Heat of Reaction (Figure 5).

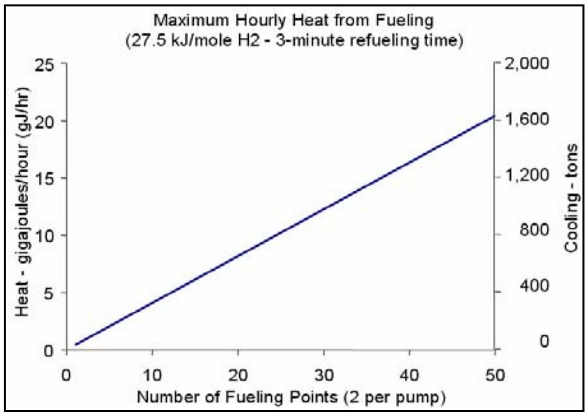

Figure 4 Fueling Heat per fueling point.

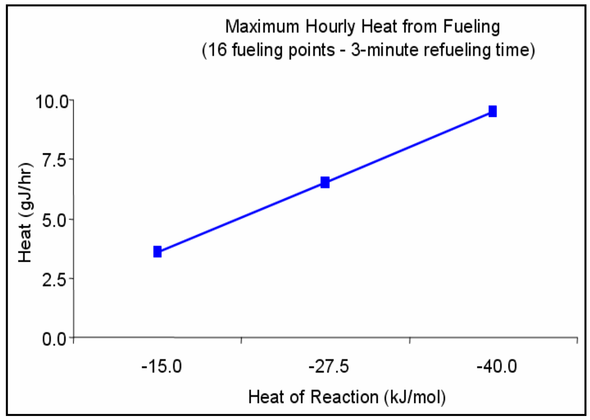

Figure 5 Fueling Heat for various Heats of Reaction

Heats of reaction of -15, -27.5 and -40 kJ/mole H_2 yield maximum hourly fueling heat load (for the assumed 16 fueling points) of 3.6, 6.5 and 8.9 GJoules per hour respectively. This corresponds to cooling loads of 282, 517 and 752 tons respectively.

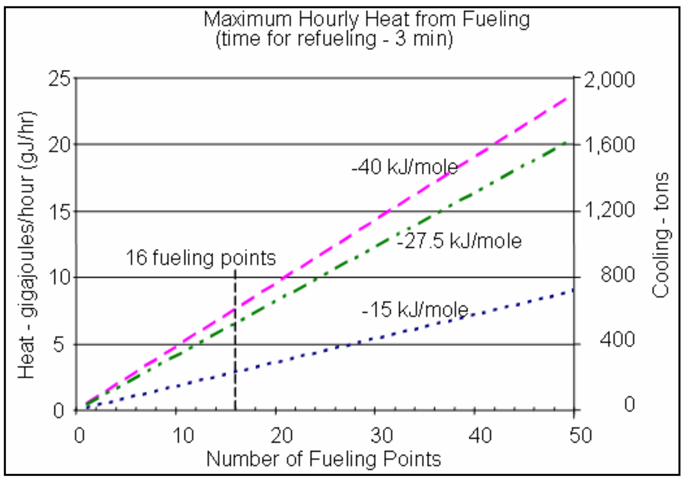

Figure 6 Fueling Heat and Cooling Loads for various Fueling Points and Heats of Reaction