Hydrogen Detection Tape Saves Time and Lives

NASA Technology

From the Apollo missions through the Space Shuttle Program, NASA has relied on liquid hydrogen as a fuel source for the upper stages of its rocket launches. The reason is simple: Hydrogen is the most efficient propellant there is. Measure for measure, it provides more thrust than any other fuel source.

But harnessing that energy requires a great deal of technological know-how on the Agency's part. For one, keeping hydrogen in its liquid state means maintaining it at a temperature below -423 °F. The element must also be insulated from external heat sources during launch, lest it begin to evaporate. Then there's the persistent threat of leakage. As the smallest and lightest of atoms, hydrogen escapes through the tiniest of cracks. That makes it a hazard, as the element is highly flammable, to the point where high-pressure joint leaks can cause combustion. As a result, detecting leaks is a top priority, but it's also a challenge, because the gas—and the flame it emits—are odorless and colorless.

Given those stakes, imagine the task of having to monitor liquid hydrogen as it flows through a few miles of pipeline—which is what NASA had to do in preparation for every Shuttle launch, when hundreds of thousands of gallons were transferred from a holding tank to the launch pad for fueling. In the Apollo days, detecting a flame from one of those leaks was accomplished by using the "broom" method, whereby workers would take a broom and walk around with the head stretched out in front of them. If the head began to burn, there was a leak. Later, during the launches of the 1980s and '90s, they used ultraviolet sensors to detect flames; to find non-burning leaks they began utilizing electrochemical and combustible gas sensors.

But a major problem with those instruments is they can only offer up a general area for a leak. "Sometimes a sensor would go off and, because the leak is in an area with a lot of hydrogen transfer lines, they would have a hard time finding it," says Luke Roberson, a research scientist and principal investigator of the project in the Chemistry Branch, Materials Science Division at Kennedy Space Center. "So they asked us if we could develop a way of locating a leak visually."

Technology Transfer

It just so happens that, in 2003, not too long before that request, the Florida Solar Energy Center (FSEC) at the University of Central Florida (UCF), about an hour's drive from Kennedy, had received a grant from the Agency to lead a hydrogen research program. Robert Youngquist, head of Kennedy's applied physics lab, reached out to one of the grant's principal investigators, Dr. Ali Raissi, and a collaboration was struck between the two organizations and also the Polymer Science and Technology Laboratory to advance a new gas detection technology.

In order to detect hydrogen visually and passively, Raissi conceived of developing a chemochromic tape, meaning the tape would change color upon exposure to the element. To accomplish this, his team worked with a Japanese patent that utilized the palladium oxide (PdO) and titanium oxide (TiO_2) class of pigments. In short, PdO and TiO_2 are mixed together into a powder, and when hydrogen is present, the powder changes color. The problem with this particular recipe, according to FSEC chemist Nahid Mohajeri, who worked on the technology, was that the color change was slow and it didn't produce a noticeable enough change. "We had to do a lot of work adjusting the chemistry so that the color change is fast and visible to the naked eye."

Much of the adjusting was done to the TiO_2 mixture, which Mohajeri calls the "support," as the actual color-changing chemical reaction occurs between PdO and hydrogen. But the color of the support is important because it has to contrast with that of the reaction so a person can clearly see it. Also, in its various iterations, the support can either speed up or slow down the chemical reaction process. Therefore, the team had to develop an iteration of the pigment that had the right color contrast, supported a very fast reaction, and could be applied to a silicone-based tape, which provided the necessary encapsulation properties.

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After about two years, the pigment formulation was completed, at which point Kennedy worked to improve and advance the technology for a broad range of applications, including Shuttle launches, which required a more robust version of the technology, as the tape had to be stable in cryogenic environments, protected against flammability, and weather-resistant. To meet those challenges, Roberson, along with fellow NASA scientists and inventors Janine Captain, Martha Williams, LaNetra Tate, and Trent Smith, among others, devised an encapsulant made of Teflon and other matrices instead of silicone. They then tested the new iteration of the tape successfully on cross-transfer lines, fuel cells, and other NASA sites.

Its dependability assured, the technology was first implemented on STS-118, which, as it happens, had an incident where a leak developed at the launch pad. The area sensor technology detected the presence of hydrogen, but the tape enabled crews to pinpoint the exact location of the leak. Afterward, the tape was used for every launch up until STS-134—Space Shuttle Endeavour's final spaceflight and the program's penultimate mission.

As a result of developing the hydrogen-detection tape, the Agency and UCF filed for and were subsequently