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Hydrogen Sensors for Energy Applications

J.R. Stetter[1,2], M.W. Findlay[1], D. Peaslee[2], T. Russ[2], V. Patel[1], B. Meulendyk[1], and E.F. Stetter[1,2]
[1] KWJ Engineering, Inc., 8430 Central Avenue Suite C, 94560 Newark, CA, USA
[2] SPEC Sensors LLC, 8430 Central Avenue Suite D, 94560 Newark, CA, USA
Corresponding Author: jrstetter@gmail.com

Summary:

Over the recent decade, H_2 has become more and more important for multiple industries. The fuel industry especially has been increasing their efforts to use H_2, a carbon-free fuel source. Since H_2 may be a significant indirect contributor to climate change and global warming, a device capable to detect and, more importantly, quantify leaks along the supply chain to both prevent H_2 product loss but also assess impacts on our atmosphere must be develop. Ideally, these devices and "apps" are adaptable to various concentration ranges, environments, and both fixed stations and mobile/wearable devices.

Keywords: Hydrogen, indirect greenhouse gas, electrochemical sensor, nano-TCD, IoT-capable

Background, Motivation and Objective

Since the colorless and odorless gas Hydrogen, H_2, has increasingly important applications in new pollutant free energy sources, like batteries and fuel cells for cars and satellites, to remove friction-heat in turbines, as cryogenic fuel in rockets as well as a lift gas in weather balloons [1], the demand for H_2 sensors has been increasing as well. As every other energy source, H_2 has certain drawbacks. Firstly, if mixed with air, H_2 is flammable, or even explosive above a certain threshold (4 – 75 V%) [1]. Secondly, and more importantly, H_2 was found to be an indirect greenhouse gas [2]. It is called an indirect greenhouse gas because H_2 on its own does not do much damage, however, the products of the reactions involving H_2 in the troposphere and stratosphere are problematic: (i) H_2 reacts with OH radicals in the troposphere resulting in higher lifetimes of methane by effectively reducing the amount OH radicals that can react with methane, (ii) the oxidation of H_2 ultimately leads to the formation of tropospheric O_3, and (iii) the reaction of H_2 in the stratosphere results in an increase in water vapor resulting in an increasing infrared radiative capacity which lead to warming effects [2].

The severe effects H_2 has on the climate require a strict control of possible H_2 sources. In order to cover all applications throughout the H_2 supply chain – including production, transport, storage, and use – a high volume of adaptable monitoring devices that are IoT capable are needed. The adaptable monitoring devices must be capable to detect very small concentrations (low ppb levels) as well as high levels of H_2 while being deployable in fixed stations, portable, mobile, wearable and distributable applications. Prior work has introduced the use of amperometric H_2 sensors [3] in safety applications and herein discussion is extended to low-level environmental monitoring applications.

To summarize, the primary H_2 sensor applications include: 1) safety because H_2 is flammable and explosive, 2) process control for purity and mixed methane-hydrogen feedstocks, and 3) environmental concerns about secondary greenhouse effects.

Experimental Methods

There are two primary technologies for H_2 detection reported here including a small, ultra-low power, high sensitivity electrochemical sensor and a nano-TCD sensor for higher concentrations. The small, low-cost electrochemical sensor is capable of H_2 detection at ppb-levels while requiring next to no power [3]. The nano-TCD sensor combines the superb detection range of 100 ppm to 100 % H_2 of currently available TCD devices while consuming significantly less power than current TCD because of its lower mass.

The devices were exposed to controlled levels of H_2 in air in one of our standard measurement systems. The sensors were operated at room temperature and in 50% RH air and alternatingly exposed to H_2/air mixtures (50% RH). Sensor characterization of sensitivity, selectivity, response time and stability are measured to calibrate the devices and interpret data from field measurements.

Results

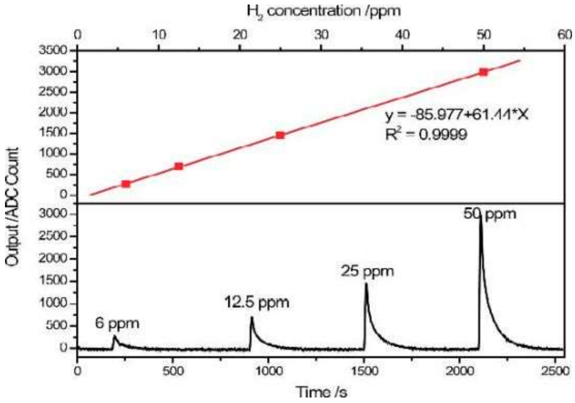

Figure 1: bottom: output of the electrochemical sensors in the presence of varying concentrations of H_2. Top: calibration curve of the sensor output shown at the bottom.

The results of the small, ultra-low power electrochemical sensor are promising (Figure 1). We observed a linear correlation between the output and the H_2 concentration at low level exposure. We were able to detect low ppm levels of H_2 in air with relatively rapid response.

The results obtained with the nano-TCD were similarly promising. Due to experimental limitations, we were not able to measure the response to H_2 concentrations greater than 2% as of now. However, the data in Figure 2 clearly shows a linear dependence of the output (resistance) on the concentration.

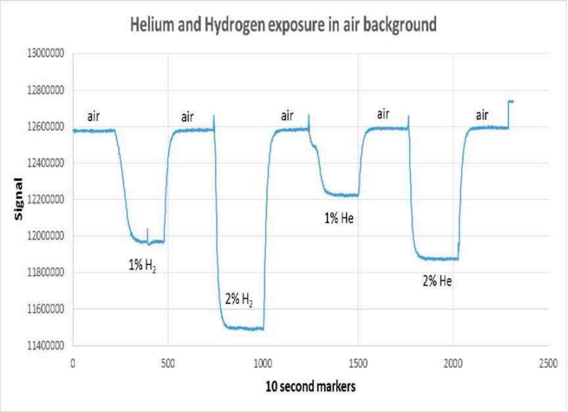

Figure 2: output of a nano-TCD sensor in the presence of various H_2 and He concentrations

Conclusion

The electrochemical sensor shows promising results for ppb-level detection of H_2 in ambient conditions. Similar observations are made for the nano-TCD exposed to high levels of H_2. These two sensors integrated into a single device could provide accurate measurements for concentrations from lower than 1 ppm to 100%. This would allow for environmental assessments as well as safety applications. Both sensors are low power and could be packaged in a simple, low-cost and intrinsically safe package heretofore not possible. The differing selectivity of the sensors can reduce false alarms. Additional studies of the sensor characteristics over time, temperature, and RH will provide data for autocorrection of concentration readings. And there are additional ways to optimize the sensors as they are prepared to be deployed in arrays of devices that can communicate with user interfaces and provide spatial and temporal details about H_2 concentrations in the vicinity of leaks. Data from arrays of local low-cost sensors can be combined with atmospheric data and in AI/ML developed models to locate the leak source as well as provide quantitative data on amount of leaked H_2. This work and the future planned measurements will show that combining these two types of sensors can provide flexible and adaptable sensing devices for a range of applications from fixed site to low-cost, low-power distributed applications.

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