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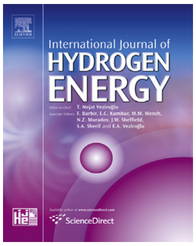

Design of fuel cell systems laboratory for hydrogen, carbon monoxide and hydrocarbon safety

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ABSTRACT

As research and development efforts in the area of fuel cells and hydrogen based energy accelerate, a large number of accidents have occurred in research laboratories. In this context, a design methodology for a simple, scaleable, modular and human-independent system for hydrogen, carbon monoxide and hydrocarbon safety in research laboratories is valuable. We have designed, developed and operationalized such a system in a preexisting generic laboratory space. In this paper, we provide details of the mechanical, electrical and control aspects of this laboratory. We use CFD analysis to design a ventilation system, and to locate gas detectors for optimum detection time. The gas detectors, actuators, a real-time controller and other electrical components are part of a safety monitoring system that continuously gathers information, processes this information and takes appropriate action to safeguard personnel and equipment in real time. This fully operational safety laboratory is now a University-level research hub for all fuel cell (and other energy related) research activities, and is also one of a kind in the region. We also expect that the experience gained in this endeavor will be useful to other researchers in building a safe workplace.

Introduction

Hydrogen as an energy carrier, and fuel cells as energy conversion devices have gained traction recently in the context of the shift toward more efficient and less carbon-intensive energy solutions. Broadly, the most common fuel cell systems can be classified according to the primary fuel used: 1) hydrogen based, 2) hydrocarbon based, and 3) solar energy (water-electrolysis) based [1]. For each type of fuel cell system, a great number of research efforts are underway in industry, academia and governments to overcome challenges, reduce cost and commercialize the various technologies involved [2–5]. These research efforts often involve component or system testing in the laboratory, with a concomitant generation or consumption of hydrogen. In case of hydrocarbon based fuel cell systems, carbon monoxide and hydrocarbons (such as methane, ethane, propane, ethanol, methanol, diesel and gasoline) are also involved in addition to hydrogen [1].

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Nomenclature and abbreviations

B	body force vector
F_c	convective term vector
F_{vis}	viscous term vector
g	gravitational acceleration, m s^{-2}
g_i	gravitational acceleration, m s^{-2}
p	pressure, Pa
u, v, w	x-, y- and z- components of velocity, m s^{-1}
ρ	density, kg m^{-3}
τ	shear stress, Pa
ACH	air changes per hour
CFD	computational fluid dynamics
CFM	cubic feet per minute
cRIO	compact real-time input output
DAQ	data acquisition
HDPE	high density polyethylene
HMI	human machine interface
LEL	lower explosive limit
RAM	random access memory
RCCB	residual current circuit breaker
TTL	transistor to transistor signal

Due to the experimental nature of work, gas connections (to, from and within the test setup) are often disconnected and reconnected multiple times. Reactors are also opened and re-sealed repeatedly, resulting in sub-optimal gas sealing. Also, safety codes and procedures in the design and operation of these experimental test rigs are not as strictly enforced as in industrial settings, due to the nature of the organizations where this research is being conducted, and because experimental research outcomes cannot be known in advance. Hence, there is an increased risk of these gases accidentally leaking into the laboratory atmosphere during testing. The explosive and toxic nature of these gases, coupled with their odorlessness and colorlessness, makes it imperative for researchers to put in place both preventive and reactive mechanisms that allow safe conduct of experimental research.

However, there is evidence to support the claim that many research laboratories are not designed to handle gas leakages; a database collated by Weiner and Fassbender [6] showed that a large fraction of all hydrogen related accidents happened in laboratories. This could be due to the fact that researchers conducting experimental research may not have the necessary expertise to design and implement a safety system, and may also lack easy access to facility design professionals due to institutional or budgetary constraints. An additional factor may be lack of awareness or complacency, especially since the quantity of hazardous gases that are typically handled in a laboratory is small relative to industrial settings. Therefore, a simple procedural description of the design and operationalization of a safety system for a laboratory is useful. The above study also highlights the role of learning from previous safety incidents that add to the collective base of knowledge for better safety in workplaces [7,8].

We have been carrying out experimental research in the fuel cell systems laboratory (hereafter referred to as "the lab") at the Indian Institute of Technology Gandhinagar (located at Ahmedabad in Gujarat, India) since it has been operationalized in Summer 2013. Prior to this, we have designed, built (or procured) and installed all the mechanical, electrical and software components that form part of the safety system. Until now, this system has helped twice to prevent accidental (unnoticed) leakage, accumulation (and possible eventual explosion) of hydrogen. At the time of designing this system, the aim was to develop a system that converges to a safe state from a potentially hazardous state through a fast, human-independent mechanism. The system level design and major components (Fig. 1) reflect the multi-disciplinary nature of safety.

Computational Fluid Dynamics (CFD) simulations were used to understand air flow patterns inside the laboratory, which in turn helped in positioning and orientation of the fresh air louvers as well as the exhaust duct vents. These CFD simulation were also used to place gas detectors, so that time lag between start of leakage and start of detection is optimized (with a fixed number of detectors).

A ventilation system is necessary to prevent the accumulation of harmful gases (when a leakage occurs) inside the laboratory. The design of this ventilation system needs to be sensitive to the geometric shape, size and layout of the laboratory space, so as to minimize the possibility of poorly ventilated pockets of gas concentration. It is important to note that given a shape and size, the location of these poorly ventilated pockets where potential gas accumulation can occur may be different for different gases. For example, hydrogen is expected to accumulate near the ceiling, while

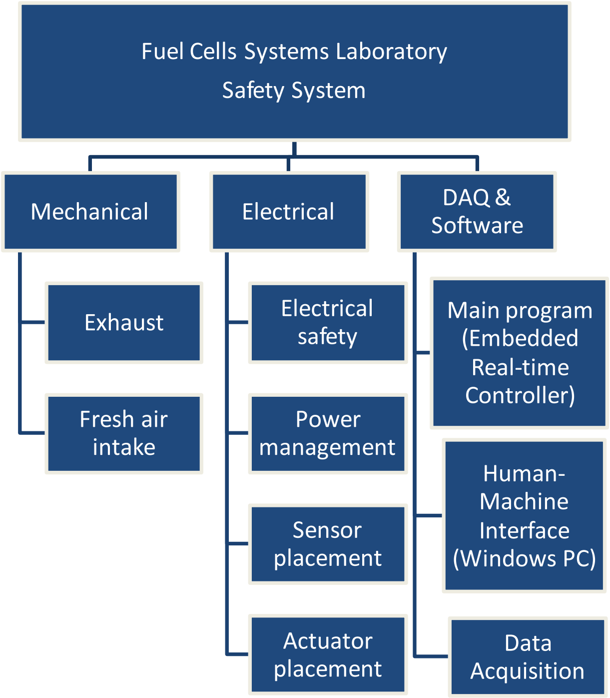

Fig. 1 – **Components of the safety system reflect the multidisciplinary approach to design.**