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Accident modelling and safety measure design of a hydrogen station

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ABSTRACT

An accident modelling approach is used to assess the safety of a hydrogen station as part of a ground transportation network. The method incorporates prevention barriers associated to human factors, management and organizational failures in a risk assessment framework. Failure probabilities of these barriers and end-states events are predicted using Fault Tree Analysis and Event Tree Analysis respectively. Results from the case study considered revealed the capability of the proposed method in estimating the likelihood of various outcomes as well as predicting their future probabilities. In addition, the scheme offers an opportunity to provide dynamic adjustment by updating the failure probability with actual plant data. Results from the analysis can be used to plan maintenance and management of change as required by the plant condition.

Introduction

Hydrogen is a promising energy for the future as it is available in abundance, renewable and sustainable [1]. It is also an efficient source that offers higher combustion energy with 142 MJ/kg compared to 45 MJ/kg for the case of gasoline. Recent estimation shows that by the year of 2050 there will be a hydrogen demand of over 42 million metric tons gasoline equivalent (GGE) in the United States of America alone, which can fuel up 342 million light-duty vehicles 8.2×10^{12} km travel per year [2]. This is however, not without challenges, and safety remains as one of the main concerns.

To realize hydrogen as the future source of energy and the subsequent hydrogen economy, safety issues must be thoroughly addressed. While hydrogen is not toxic, it has a wide flammability range and can easily be ignited to cause fire and explosion when combined with oxygen. Although safety records of hydrogen processing in the process industry are generally good, the combined risks associated with production, storage, transportation and use on the widespread scale to replace hydrocarbons will undoubtedly bring incidents [3]. To reduce the risk, reliable risk analysis methodology is required so that appropriate control measures can be planned and required safety standards can be established. This is particularly important especially when the population at large is involved such as in the case of hydrogen stations [4].

This concern has initiated works on the safety of hydrogen stations. In particular, a number of reports have been published recently focussing on the risk assessment. Duijm and Markert [5] applied a graphical tool known as safety–barrier

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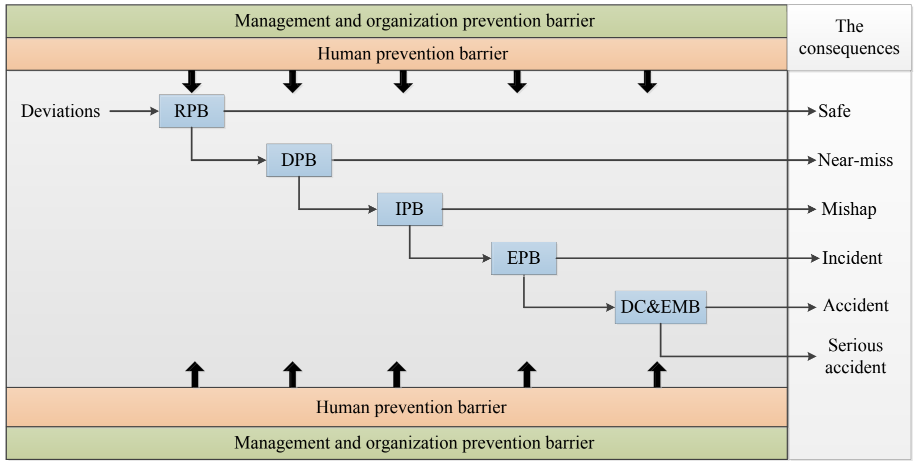

Fig. 1 – SHIPP methodology [9].

diagram to represents possible accident scenario and to assess the safety for an offsite hydrogen station. The method can be effectively used along with other hazard identification methods such as HAZOP and FMEA as it provides complementary technique for documenting accident scenarios and safety measures. Kikukawa and co-workers applied quantitative risk assessment (QRA) methodology to hydrogen stations [6,7] and based on the outcome of these studies, they proposed typical safety measures needed for the stations including some general guidelines as well as specific features for protecting the liquid hydrogen storage tank, hydrogen dispenser and the vent line. Zhiyong et al. [8] also used QRA to assess risks associated with gaseous hydrogen station and concluded that a compressor leak would be the most contributing factor in increasing risk of the three parties considered, i.e., workers, customers, and third party.

While the use of QRA has been generally accepted as a standard for risk assessment in process industries, it is a static methodology and the results are therefore valid based on the conditions used and information incorporated during the assessment. Furthermore, since it is an elaborate procedure and time consuming, it is perhaps a better strategy to include some mechanisms to accommodate changes in process conditions so that updates of the assessment can be generated without the need to repeat the full-blown QRA. This approach falls in the realm of dynamic sequential accident modelling approach, and the application of one of the techniques within this category to a hydrogen station is the focus of this paper.

Accident modelling and risk assessment framework

The model used is based on SHIPP methodology developed by Rathnayaka et al. [9]. SHIPP represents accidents as a propagation of material and/or energy releases through prevention and mitigation barriers that include process (operational, maintenance, and technical), human, as well as management and organizational barriers. As shown in Fig. 1, the framework is founded upon a series of prevention barriers, which are release (RPB), dispersion (DPB), ignition (IPB), escalation (EPB), and damage control and emergency management (DC&EMB) prevention barriers. These are typical layers of protection normally employed in process industries, in addition to plant operation facilities such as process control, alarm, interlocks and relief. A release that is triggered due to the failure of the RPB will be protected by the DPB, which will then be protected by the IPB, EPB and DC&EMB in which six different consequences are obtained depending on the failures or successes of the prevention barriers. The final consequences are safe, near-miss, mishap, incident, accident, and serious accident. The failure of these prevention barriers is causally modelled using Fault Tree (FT) models as top events, whereas the propagation of deviation through the prevention barriers is modelled using Event Tree (ET) model. In addition to all possible failures of equipment or components in each individual prevention barriers, the barriers are also affected by human errors and weaknesses resulting from management and organization factors. These are incorporated within the FT's.

Application of the methodology to hydrogen station

Generally, there are two types of hydrogen stations, i.e., offsite and onsite stations. In the offsite station, hydrogen is transported using trucks, whereas in the onsite station, it is produced adjacent to the station or as part of the station itself [5]. Within the station, hydrogen is either stored as pressurized gas or in liquefied cryogenic form. The liquid H_2 station is simpler in construction and requires less number of equipment compared to the pressurized counterpart. However, the handlings of liquefied H_2 at cryogenic temperature requires additional safety measures such as a storage tanks with vacuum double-wall configuration, along with its associated piping and dispensing hoses. In this work, an off-site liquid H_2 station is considered. The process flow diagram is the same as in Ref. [5] and consists of unloading facility, H_2 storage tank, evaporator, compressor, small high-pressure storage tank, and the refuelling facility.