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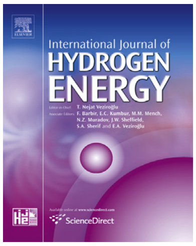

Predictive modeling of hazard radius for refinery hydrogen releases using regression technique

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ABSTRACT

Fundamental safety principle of hazardous area classification study is to avoid ignition of those releases that may occur during the operation of facilities handling flammable fluids. One of the methods for this study is the point source approach. Regarding this approach one can estimate hazard radius due to a release by having hole size and release pressure. However, till now no reference represents hazard radii for the wide range of possible hole sizes and release pressures. The aim of the present study is to propose a predictive model for estimation of hazard radii due to releases of typical refinery hydrogen gas based on hole size and release pressure. In this study, a complete database of hazard radii due to a broad range of hole sizes and release pressures is provided using available discharge and dispersion models. A regression-based model for estimation of hazard radii is developed based on the provided database. Performance investigation of the proposed model shows that the results are reliable with an acceptable standard error.

Introduction

Safety related standards introduced the concept of hazardous area classification in response to the possibility of leakage in process equipment during their operation [1]. In this regard, the probability of ignition must be controlled in classified areas. Codes and standards such as NFPA 497 [2], IEC 60079-10 [3], API-505 [4], and EI model code of safe practice, part 15: Area classification code for installations handling flammable fluids (EI 15) [5] have introduced some methods for carrying out hazardous area classification [6,7]. Two UK-based codes which are generally recognized to be adequate for the purpose of area classification are IEC 60079-10 (2009) [3] and EI 15 (2005) [5].

EI 15 have introduced the most popular method for hazardous area classification that is point source approach. This method considers each release source of flammable fluids as a point source and estimates the hazard radius (the largest horizontal extent of hazardous area, independent of ground effect) of each point source having its hole size and release pressure [8].

Table C9(a) of EI 15 code represents the hazard radii of some set of hole sizes and release pressures with the utilization of discharge and dispersion models, but this table just covered the limited set of hole sizes and release pressures due to so many variations of these two parameters in the process industries. Therefore, process safety experts have to model discharge and dispersion of fluids for estimation of hazard radius that is not in that table. Unfortunately, setting up of

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these models regarding standard requirement is time-consuming and may cause miscalculation in the case of lack of modeling experience.

Hydrogen can be widely found in refineries and chemical plants in many processes such as Hydrodesulphurization (HDS), hydrotreaters and synthesis gas unit. Several studies have been performed on hydrogen hazards [9–11].

Hydrogen and hydrogen-containing streams present special problems for hazardous area classification and selection of electrical equipment because of very low ignition energy of hydrogen. EI predictions of minimum spark ignition energy and quenching distances for CH_4/H_2 and C_3H_8/H_2 mixtures with air (2002) [12] has shown that mixtures containing more than 30% volume hydrogen should be regarded as hydrogen.

For the aim of simplicity in the estimation of hazard radii due to typical refinery hydrogen releases, the thrust of the present study is to make a complete database of hazard radii for various hole sizes and release pressures using discharge and dispersion models to propose a simple and reliable regression-based model over it.

Data gathering

The required database of hazard radii (the ground effect radius is not discussed in this study) is prepared using discharge and dispersion models. There are several models such as SLAB, ALOHA, HGSYSTEM and PHAST to determine consequences of flammable material releases. PHAST [13] is one of the best software programs with acceptable results for discharge and dispersion modeling [14–17]. PHAST model validation for hydrogen gas was performed in Mousavi et al. (2016) [18] study by comparing the results with experimental data obtained from Ganci et al. (2011) [19]. PHAST is also adopted in the present study.

Discharge

For pressurized equipment after the establishment of initial storage conditions, discharge calculation is carrying out based on the energy conservation equation. Due to the low probability of gas detection for small leaks which are in the scope of hazardous area classification, steady state discharge model can be used. This model calculates the initial expansion from stagnation to orifice conditions as well as the secondary expansion from orifice conditions to the atmospheric condition [20]. The expansion model is assumed to be Isentropic. The discharge flow rate is derived as follows [21]:

$$\dot{m} = C_D \cdot AP_1 \sqrt{\frac{2g_c}{R_g} \cdot \frac{M}{T_1} \cdot \frac{K}{K-1} \left(\left(\frac{P_2}{P_1} \right)^{\frac{2}{K}} - \left(\frac{P_2}{P_1} \right)^{\frac{K-1}{K}} \right)} \qquad (1)$$

where $\dot{m}$, P_1 and P_2, T_1, A, R_g, g_c, M, C_D and K stand for the flow rate (kg/s), pressure before and after discharge (kPa), temperature before discharge (K), rupture area (m^2), gas constant (Pa m^3/mole K), gravity constant (N s2/kg m), gas molecular mass (kg/mol), discharge coefficient and specific heat ratio of fixed pressure to fixed volume, respectively.

Dispersion

The dispersion process includes some phases, in the first of which it is assumed that if the fluid is under pressurized conditions, then to have some momentum that carries the cloud forward. As a result of air entrainment into the cloud and drag from the ground, the momentum will gradually dissipate. Air entrainment causes the cloud to move with the wind [14]. Hydrogen gas has a density lower than the air with positive buoyancy, so the Gaussian model is adopted for modeling dispersion. Gaussian model defines the distribution of concentration for continuous hydrogen gas release as follows [21]:

$$[C](x,y,z) = \frac{\dot{m}}{2\pi \cdot \sigma_y \cdot \sigma_z \cdot u} \cdot exp\left[-\frac{u}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \cdot \left(exp\left[-\frac{1}{2} \left(\frac{z-H}{\sigma_z} \right)^2 \right] + exp\left[-\frac{1}{2} \left(\frac{z+H}{\sigma_z} \right)^2 \right] \right) \qquad (2)$$

where $\dot{m}$, u, H, σ_z, σ_y, z, and y denote the discharged flow rate (kg/s), wind speed (m/s), release area height (m), dispersion coefficients in different directions (m), distance in perpendicular direction to earth (m), and distance in perpendicular direction to wind direction (m), respectively.

Modeling results

Discharge and dispersion modeling was carried out for typical refinery hydrogen gas. The composition of the gas is represented in Table 1. This gas can be identified as G(ii) fluid category based on EI 15 code.

The physical parameters used in modeling according to EI 15 code requirements are shown in Table 2 for modeling setup [22]. Hazard radius is an area that has a higher concentration than lower flammability limit of hydrogen. Hazard radii for nine different hole sizes in ten different release pressures is calculated using discharge and dispersion model of PHAST software. The resultant data formed a complete database that can provide a regression-based model over it.

Effective factors analysis

Effective factors on hazard radius are in two categories: meteorological parameters and process parameters [23]. Effective factors in hydrogen dispersion and ignition were studied by Mousavi et al. (2016) [18]. The results of Mousavi et al. show that leakage hole size, release pressure, and wind speed have the highest impact on maximum flammable vapor cloud distance.

The area classification process is NOT a full hazard assessment which takes account of the range of meteorological and process conditions and release events [22]. Accordingly Values for meteorological parameters and process parameters such as fluid temperature and release height was chosen to be fixed for calculating hazard radius (Table 2), and these are the same as those used in EI 15. Considering these effective factors fixed, release pressure and hole size are only effective factors on hazard radius.