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Gas leakage consequence modeling for buried gas pipelines

Mehdi Parvini*, Elmira Gharagouzlou

Faculty of Chemical Engineering, Gas and Petroleum, Semnan University, Semnan, Iran

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ABSTRACT

One of conservation transfer methods for such widely-used gases as natural gas and hydrogen is buried pipelines. Safety of these pipelines is of great importance due to potential risks posed by inefficiencies of the pipelines. Therefore, an accurate understanding of release and movement characteristics of the leaked gas, i.e. distribution and speed within soil, the release to the ground surface, the movement of hydrogen gas through the ground, gas underground diffusion, gas dispersion in atmosphere, and following consequences, are very important in order to determine underground dispersion risks. In the present study, consequences of gas leakage within soil were evaluated in two sub-models, i.e. near-field and far-field, and a comprehensive model was proposed in order to ensure safety of buried gas supply pipelines. Near-field model which is related to soil and ground and its output is the gas released at different points and times from ground surface and it was adopted as input of far-field sub-model which is dispersion model in atmosphere or an open space under the surface. Validation of near-field sub-model was performed by the experimental data obtained by Okamoto et al. (2014) on full-scale hydrogen leakage and then, possible scenarios for far-field sub-model were determined.

1. Introduction

Pipeline is a commonly-used method for transporting gas. Several risks threaten pipelines in terms of characteristics and process properties of the gas inside the pipelines and pipeline spread. Therefore, process risk determination and consequence modeling are very important.

If gas supply pipelines are buried in the ground, any leakage might result in gas diffusion and movement in soil. Such dispersion may reach residential underground spaces leading to loss of life and property by approaching explosion and combustion threshold. It may also damage underground plants and animals. If the leaked gas reaches ground surface, it might cause catastrophic accidents. Explosion, combustion, and toxicity are probable incidents caused by gas dispersion in soil.

Leakage consequence modeling is one of important principles of risk determination which consists of such stages as estimation of release rate and specification of material characteristics and evaluation of dispersion consequence, in other words, spatial and temporal profile or distribution of material concentration in the field followed by effects of the scenarios for such accidents as toxicity, fire, and explosion.

Several studies have been performed on flow rates of released material (Waller, 2000; Brag, 1960; Witlox and Holt, 1999, 2000; and 2001; Van den Akker et al., 1983; and Britter, 1995). Investigations on dispersion models have mostly focused on gas dispersion whether indoor or outdoor and few studies have been done on underground gas dispersion. Some studies have focused on underground fluid behavior, e.g. studies on underground water flow in saturated and unsaturated situations with pressure difference power (Hwang et al., 2004; Saito and Kawatani, 2003; Hibi, 2007; Ewing et al., 1999; Faust, 1985) where gas–liquid and liquid behavior for pollution transporting in different situations were evaluated. In a study on water vapor behavior in terms of soil temperature and moisture, Gerson et al. (2003) revealed that when a water vapor two-phase system is expressed by specific heat, thermal conductivity, and dispersion coefficient, its behavior is defined in terms of soil moisture and temperature. Nagai (2004) and Kumagai (1998) evaluated formation and movement of CO_2, N_2, and etc. in the natural world of soil-plant-air and confirmed vertical and macroscopic formation and circulation behavior in one dimension. In a study on gas dispersion in terms of particle movement and fluid behavior, Weerts et al. (2001) revealed behavior a fluid as a complex of regular particles motion (Stefan–Boltzmann Law). Gas dispersion has been scrutinized according to gas molecular diffusion as a result of concentration difference

* Corresponding author.
E-mail address: m.parvini@semnan.ac.ir (M. Parvini).

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power. In some studies, gas movement has been examined with regard to differences in concentration, pressure, and specific gravity (Senger et al., 2007; Wilson et al., 1987; Fujinawa et al., 2001; Akatsuka and Matsuda, 1988; Kobayashi et al., 2007; Slough et al., 1999; Cheng and Wang, 1996; Abriola and Pinder, 1985; Falta et al., 1992; and Sleep and Sykes, 1993). These theoretical studies are mainly on gas movement because of advection by using Darcy's and Fick's laws. Nevertheless, some validation and analytic studies using town gas have considered differences in pressure, specific gravity and concentration; for instance, Okamoto et al. (2014) attempted to propose a suitable solution for ensuring safety of hydrogen pipelines by determination of leaked hydrogen from buried supply pipelines.

Due to higher applicability or potential risks, some materials, e.g. hydrogen (Jafari et al., 2012), CO_2 (Witlox et al., 2009), and methane (Vianello &Maschio, 2014), have gained more attention in modeling dangerous material leakage.

Risks in gas transporting are usually comprised of fire and explosion. For instance, Rusin and Stolecka (2015)worked on hydrogen leakage and its consequences. Fig. 1 depicts an example of incident tree for hydrogen pipeline rupture which estimates probability of hydrogen pipeline rupture. In general, accidental dispersion may occur from small to big holes in pipes, from high pressure vessels, flanges, and washers of equipment such as compressors, electrolysis systems, and etc.

Taken together, it seems necessary to perform experiments on underground hydrogen dispersion and preparation of key data in order to make suitable decisions to cope with emergencies. Several field investigations on different gases have been performed (e.g. Hanna et al., 2012).

Several studies on mathematical modeling of material dispersion have been performed in recent years, such as investigations on CFD models for different kinds of hydrogen dispersion (Schmidt et al., 1999; Venetsanos et al., 2003; Wilkening and Baraldi, 2007; Venetsanos et al., 2008; Olvera and Choudhuri, 2006; Venetsanos et al., 2009; Middha et al., 2009); it should be noted that none of these studies considered buried pipelines.

By dividing the pipes into four parts (Fig. 2), Vianello and Maschio (2014) proposed a method for all directions of gas leakage: estimation of normal release flow no matter the pipes are buried or not and gas leakage remodeling with very low pipeline pressure (1 bar for the operational pressure exceeding 10 bar and 0.1 bar for operational pressure lower than 10 bar) for simulation of diffusion in soil with corrected hole sizes to achieve identical rate. It is noteworthy that consequence estimation for catastrophic gas leakage and average and big holes. Therefore, small holes are not considered. Okamoto et al. (2014) simulated hydrogen dispersion in soil numerically by using Darcy's and Fick's laws.

The present study aimed at determination of the consequences related to gas leakage and dispersion from buried supply pipeline holes. For this aim, modeling was performed in two models; near-field model which is related to soil and ground and its output is the gas released at different points and times from ground surface and it was adopted as input of far-field sub-model which is dispersion

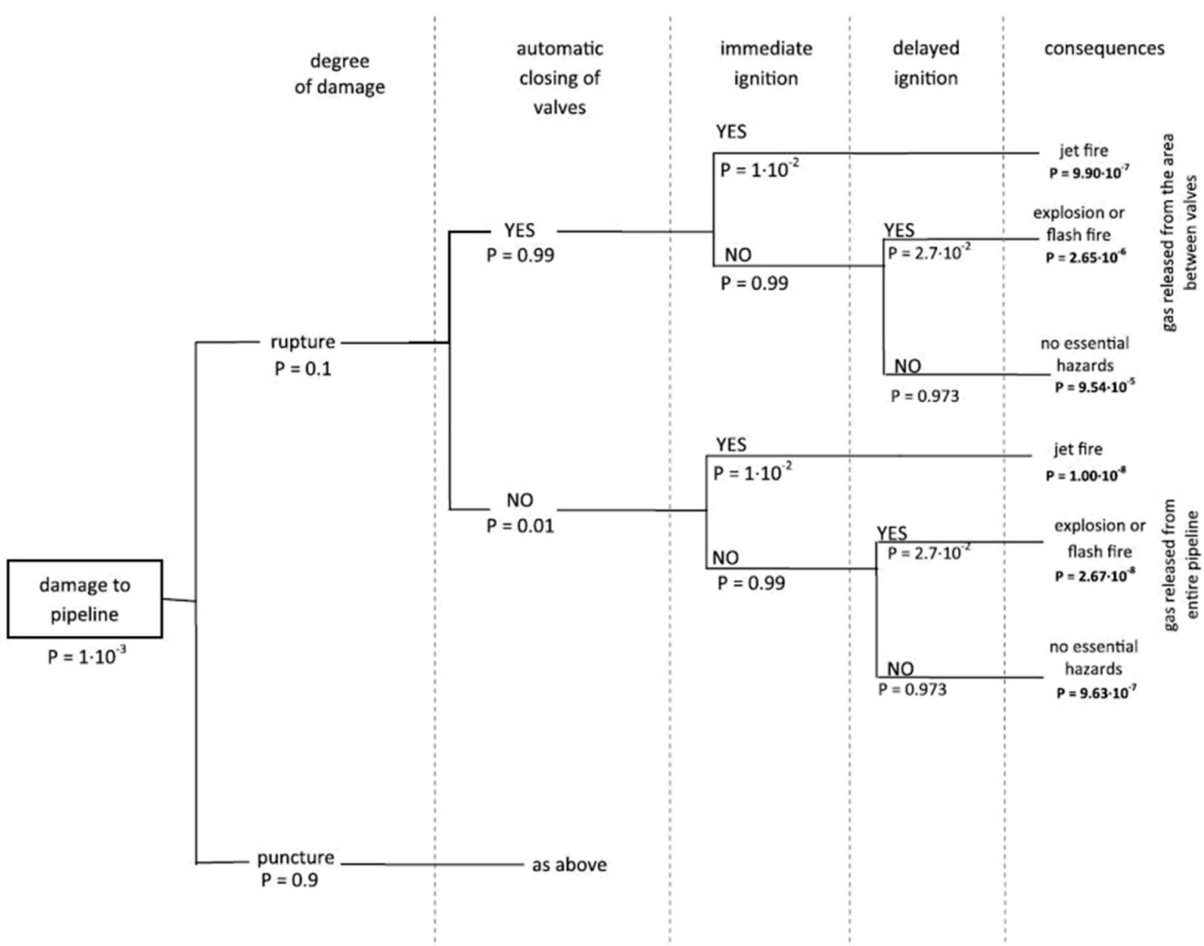

Fig. 1. An event tree for rupture of hydrogen supply pipeline (Rusin and Stolecka, 2015).