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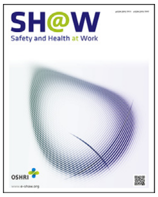

Original Article

Simulation and Damage Analysis of an Accidental Jet Fire in a High-Pressure Compressed Pump Shelter

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A B S T R A C T

Background: As one of the most frequently occurring accidents in a chemical plant, a fire accident may occur at any place where transfer or handling of combustible materials is routinely performed.
Methods: In particular, a jet fire incident in a chemical plant operated under high pressure may bring severe damage. To review this event numerically, Computational Fluid Dynamics methodology was used to simulate a jet fire at a pipe of a compressor under high pressure.
Results: For jet fire simulation, the Kemeleon FireEx Code was used, and results of this simulation showed that a structure and installations located within the shelter of a compressor received serious damage.
Conclusion: The results confirmed that a jet fire may create a domino effect that could cause an accident aside from the secondary chemical accident.

1. Introduction

Most chemical plants have and operate a significant number of compressors as installations to transfer raw materials, products, and waste gas from production. As the compressor is operated mainly under a high pressure, vibration generated from a pump operation may increase the time-dependent fatigue in a pump and nodes connected to surrounding devices, and thus an area with such issues is categorized as an area with a high risk of leakage of internal fluid.

Gómez-Mares et al [1] and Darbra et al [2] analyzed past cases of chemical accidents based on the MHIDAS (Major Hazard Incident Data Service) database, and their results showed that, for causes of major accidents in a chemical plant, fires accounted for 54% of events whereas explosions accounted for 30% [1–3]. This led to an evaluation that more interest and study are required to help reduce/eliminate fire hazards in chemical plants.

Moreover, recent studies involving numerical analysis of jet fires [4–7] only analyzed these fire incidents from the context of simple geometry, and there is not enough study about a simulation of jet fire in a complex structure such as a chemical plant [3].

Therefore, an analysis of a jet fire from a pipe connected to a compressor under high pressure with a simulation methodology was conducted with respect to a fire accident that frequently occur in a chemical plant, and various variables such as forms of installations and tools, positional density, turbulence, atmospheric condition, obstacles, and wind effect were assessed for an analysis of the thermal effect using Computational Fluid Dynamics (CFD), which generates the virtually estimated result to be very similar to the actual result [3,7,8].

In this study, a jet fire from a high-pressure compressed pump shelter in a chemical plant is described using the CFD method, and its damage effect on structure and devices is analyzed.

2. Materials and methods

2.1. KFX governing equation for analysis of gas combustion

To analyze the consequences of a jet fire, the Kemeleon FireEx (KFX) Simulator developed by ComputIT (Norway, Trondheim) was used. The KFX Simulator prepares a Cartesian grid in a three-

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dimensional space and applies a finite volume technique to analyze a fluid behavior under a direction of each axis [3,9].

The governing equations of the KFX Code applied to analyze a combustion generated from a place with complicated spatial features because of the structures and devices in a plant are a mass fraction budget equation of chemical species [Eq. (1)], continuity equation for mass conservation [Eq. (2)], momentum equation to compute a momentum in the coordinate direction with Navier–Stokes equation [Eq. (3)], and energy transmission equation for a flow of compressed gas [Eq. (4)] as follows [3,9]:

$$\frac{\partial\bar{\rho}\tilde{Y}_l}{\partial t}+\frac{\partial\bar{\rho}\tilde{u}_j\tilde{Y}_l}{\partial x_j}=-\frac{\partial}{\partial x_j}\left(\overline{\rho Y_l V_{lj}}\right)-\frac{\partial}{\partial x_j}\left(\overline{\rho u_j'' Y_l''}\right)+\bar{\rho}\tilde{R}_l+\bar{\rho}\tilde{R}_{liq,l} \tag{1}$$

$$\frac{\partial\bar{\rho}}{\partial t}+\frac{\partial\bar{\rho}\tilde{u}_j}{\partial x_j}=\bar{\rho}\tilde{R}_{liq} \tag{2}$$

$$\frac{\partial\bar{\rho}\tilde{u}_i}{\partial t}+\frac{\partial\bar{\rho}\tilde{u}_j\tilde{u}_i}{\partial x_j}=-\frac{\partial\bar{p}}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\overline{\tau_{ij}}-\overline{\rho u_j'' u_i''}\right)+\overline{\rho f_i}+\bar{\rho}\tilde{F}_{liq,i} \tag{3}$$

$$\frac{\partial}{\partial t}\left(\bar{\rho}\tilde{e}_T\right)+\frac{\partial}{\partial x_j}\left(\bar{\rho}\tilde{u}_j\tilde{e}_T\right)=\frac{\partial}{\partial x_j}\left(\overline{(\tau_{ij}-P)u_j}\right)+\frac{\partial}{\partial x_j}\left(\overline{k_l\frac{\partial T}{\partial x_j}}-\bar{\rho}\widetilde{u_j''e_T''}\right)+\overline{Q}_{gs}+\overline{Q}_{Rad}+\bar{\rho}\tilde{S}_{liq}, \tag{4}$$

where

$$R_{liq}=\sum_l R_{liq,\,l}$$

$$\overline{\tau_{ij}}=\mu\left(\frac{\partial\tilde{u}_i}{\partial x_j}+\frac{\partial\tilde{u}_j}{\partial x_i}\right)+\left(\kappa-\frac{2}{3}\mu\right)\left(\frac{\partial\tilde{u}_\kappa}{\partial x_\kappa}\right)\delta_{ij}$$

$$e_T=e+\frac{1}{2}u_iu_j$$

$$e=\sum_l Y_l e_l(T)$$

Comparing the KFX involves a CFD analytical methodology of the Reynolds averaged Navier–Stokes (RANS) technique with the equation of analytic methodology of Large Eddy Simulation and

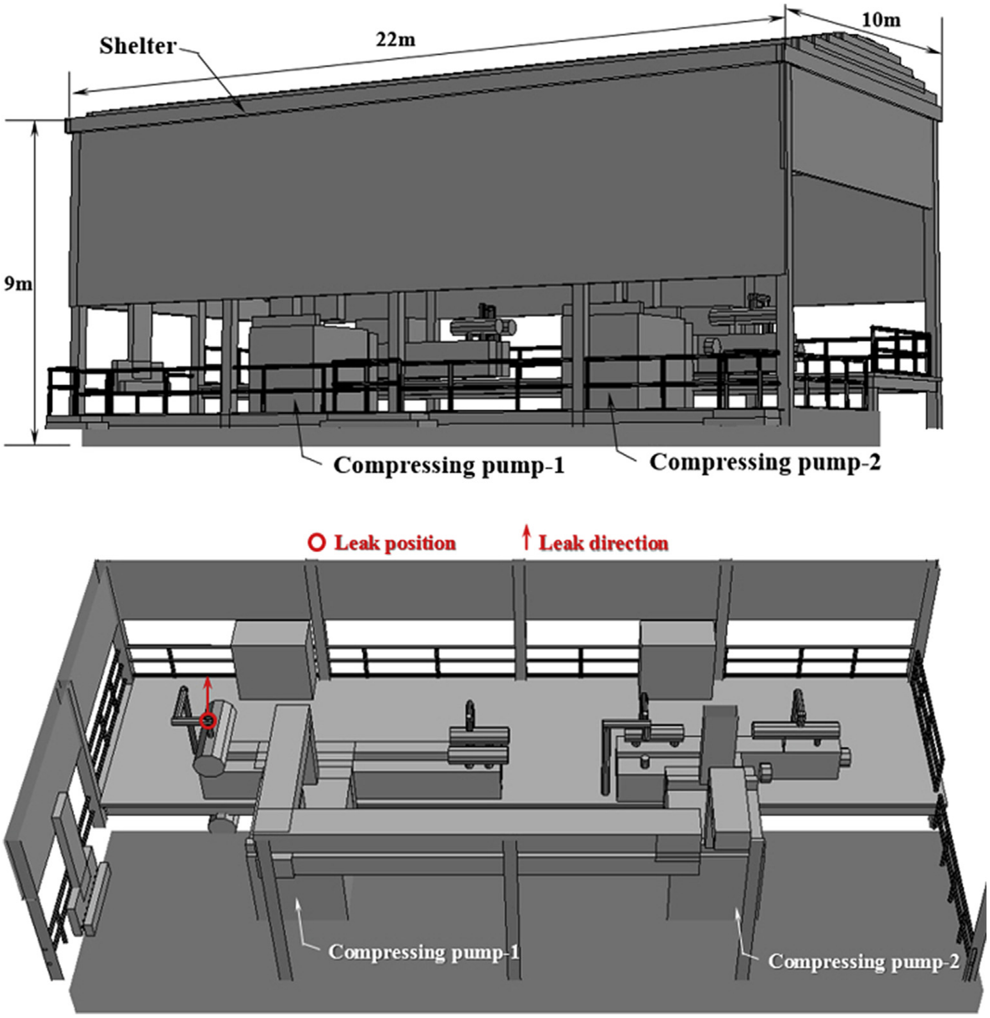

Fig. 1. 3-D geometry of the compressor pump shelter (top) and description for leak position and direction (down).

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