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Consequence Analysis of Catastrophic Release of Diesel and Fuel Oil from their Storage Tanks Using SCIA Software

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Catastrophic release of diesel and fuel oil from their storage tanks can lead disasters to human, property and the environment. Thus consequences analysis of the accident has significant importance to human communities living in the surrounding area and the authorities involved in land planning. Consequence analysis is normally carried out using mathematical models for predicting the impacts of chemical accidents. This paper presents result of the consequence analysis from study cases namely catastrophic release of diesel and fuel oil from their storage tanks using Simulation of Chemical Industrial Accident (SCIA) software. The software is a user-friendly and effective tool for evaluating the consequences of major chemical accidents, process decision making for land-use planning, namely locating suitable hazardous installations, hazardous waste disposal areas and emergency response plan. Release of diesel and fuel oil might escalate to pool fires and thus require evaluating their characteristics and the posed hazard. It is recommended for future land planning and development, a town must be located at least half kilometre away from the storage tanks to minimize the disaster impacts.

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1. INTRODUCTION

In the past few decades, oil and gas industries have suffered from number of major accidents. Operational mistakes (such as elevated pressure and temperature beyond critical limits) in oil and gas industries can cause catastrophic accidents. Cost of these accidents including fatalities, economic losses, and damage to the environment.

Major industrial hazards are generally associated with the potential for fire, explosion or dispersion of toxic chemicals. These usually involve the release of material from containment that is, in case of volatile materials, followed by its vaporization and dispersion [1]. Consequences or impacts of the accidents depend on the properties of the substances involved and their physical states (gas, liquid, solid, temperature, pressure, etc.), the equipment used (vessels, piping, valves, etc.) and the operations involved (storage, transport, chemical reaction, etc.) [2].

Examples of the worst accidents in the oil and gas industries are; Mexico City in 1984 [3-6], Piper Alpha in 1988 [5,7,8], Texas City in 2005 [7, 9-11].

Catastrophic release of flammable materials such diesel and fuel oil is regarded as potential of major accident. This is due a large quantity of the hazardous substances exist on site and thus, if catastrophic failure to their tank or piping systems or either overfills events, can potentially be escalated to pool fire or bund fire. From past incidents, it is reasonable to consider that all of tank content is released and flowed over the dikes or bund area.

There are several ways to evaluate the risk in oil and gas industries. The traditional way works via using mathematical models. The Mathematical models are extremely useful tools to simulate the consequences of industrial accidents [12]. However, it is difficult to be implemented manually and therefore, the complex development of the accidents scenarios can be achieved by using the consequences modelling combined with various computer software [2]. Several computer programs and software tools have been developed over the past decades and utilized for different case studies. For example PHAST (Process Hazard Analysis Software Tool) by Det Norske Veritas (DNV) is designed for fire, explosion and dispersion accidents. FRED (Fire, Release, Explosion and Dispersion) software created by Shell company, it is used to calculate effects such as blast waves from high-pressure-vessel failure, blowdown of two-phase pipelines and subsea gas releases. The SAFETI package (Safety Abroad First-Educational Travel Information) was developed by Technica for the risk assessment of chemical process industry facilities. The WHAZAN (World Bank Hazard Analysis) consequence analysis package developed by Technica to calculates the consequences and hazard zones resulting from incidents involving toxic and flammable chemicals. For more detailed information regarding these software/tools, readers are directed to work of Lewis [13] and Al-shanini et al. [14].

In this work, SCIA software (which was developed by El-Harbawi et al. [2]) has been used to study the potential consequences of pool fire which could be happen due to release of the stored materials. The accidents scenarios were based on estimated amounts of 50 tonnes of diesel and 150 tonnes of fuel oil respectively.

2. METHODOLOGY

SCIA (Simulation of Chemical Industrial Accidents) software is a hazard simulation tool for assessing the consequences from rapid risk occurring in chemical industries. SCIA simulates several mathematical models for hazardous events such fire, explosion and toxic release of hazardous installations. These models are often difficult to apply because they require competent users, therefore computer aided can be of a great help. The software combines several mathematical models sharing graphical user interfaces (GUIs) that include a comprehensive chemical database containing over 130 chemical substances. If the required data unavailable in the system there is a facility that the user can add himself the information by keying in the data into the database. Furthermore, the SCIA can easily be linked to geographical information system (GIS) for better visualisations [2].

Pool fires model are composed of several component submodels which are briefly reviewed as followed [15]:

- Burning rate
- Pool size and flame height

- Flame tilt and flame drag
- Flame surface emitted power
- Geometric view factor
- Atmospheric transmissivity
- Heat transfer

Large pool fires burn at a constant vertical rate, characteristic for the materials. Knowledge of the burning rate allows the heat output per unit area and the duration of the fire to be estimated [16]. The mass-burning rate is dependent on the diameter of the pool and the specific fuel type. For pool below 0.03 *m* in diameter, the flames are laminar, and the rate of burning decreases with increase in diameter. For large diameter (>1 *m*) pools, the burning rate becomes independent of diameter; the flames are now fully turbulent [16]. The mass burning rate for a particular fuel has been reported by following correlation (Eq. 1) based on work to relate the actual burning rate to the maximum burning rate for a fuel [17]:

$$\bar{m}'' = \bar{m}''_{\infty}\left[1 - \exp\left(-k_c D_p\right)\right] \tag{1}$$

where,

$\bar{m}''$ is the mass burning rate of fuel $\left(kg/m^2.s\right)$,

$\bar{m}''_{\infty}$ is the maximum mass burning of fuel $\left(kg/m^2.s\right)$,

k_c is the mean beam length corrector extinction coefficient product $\left(m^{-1}\right)$, and

D_p is the pool fire (m).

The maximum mass burning rate can be calculated from the correlation given by Eq. [2] [18]:

$$\bar{m}''_{\infty} = \frac{0.001\Delta H_c}{\Delta H_{v*}} \tag{2}$$

where,

ΔH_c is the net heat of combustion of the fuel at its boiling point (*kJ/kg*), and

ΔH_{v*} is the modified heat of vaporisation of the fuel (*kJ/kg*).

The modified heat of vaporisation is given by Eq. (3) [18]:

$$\Delta H_{v*} = \Delta H_v + H_c\left(T_b - T_0\right) \tag{3}$$

where:

ΔH_v is the heat of vaporisation of the fuel at its boiling point (*kJ/kg*),

H_c is the heat capacity of the liquid $\left(kJ/kg.K\right)$,

T_b is the liquid boiling temperature (*K*), and

T_a is the initial temperature of the liquid (*K*).

For unconfined continuous releases, it can be assumed that the pool increases in diameter until the release rate is balanced by the burning rate [19]:

$$D_p = \sqrt{\frac{\dot{m}}{\pi\,\bar{m}''}} \tag{4}$$

where,

m is the mass release rate of fuel (*kg/s*).

The area of pool fire can be calculated using Eq. (5):

$$A_p = \frac{\pi D_p^2}{4} \tag{5}$$

where,

A_p is the pool fire area $\left(m^2\right)$

The flame length can be calculated using correlation developed by Thomas (Eq. 6) [20]:

$$L_p = 42\left[\bar{m}^*\right]^{0.61} \times D_p \tag{6}$$

where,

L_p is the flame length (*m*),

$\bar{m}^*$ is the dimensionless mass burning rate of fuel,

ρ_a is the density of air at ambient conditions $\left(kg/m^3\right)$, and

g is the acceleration due to gravity (*m/s*^{2}).

The dimensionless mass burning rate of fuel can be determined using Eq. (7) [20]:

$$\bar{m}^* = \frac{\bar{m}''}{\rho_a \left(g * D_p\right)^{0.5}} \tag{7}$$

Thermal radiation is considered one of the more dramatic hazards related to hydrocarbon pool fires. There are two basic types of thermal radiation models, namely, the point source model and the plume fire model [21]. The radiative heat flux to a target, Q, may be expressed according to the source model by Eq. (8):

$$Q = \frac{q}{4\pi x^2} \tag{8}$$

$$q = f\,\bar{m}''\Delta H_c \tag{9}$$

where,

q is the energy released by radiation $\left(kW\right)$,
x is the distance from the flame centre $\left(m\right)$,
f is the fraction of the heat released as radiation, and
ΔH_c is the heat of combustion of the fuel $\left(kJ/kg\right)$.

The solid flame model is the most usual method used and which yields the most accurate results, both in the near and far field of any fire. The incident radiative heat flux onto a target is given by Eq. (10) [21]:

$$Q = E\,F\,\tau \tag{10}$$

where,

E is the surface emissive power $\left(kW/m^2\right)$,
F is the view factor, and
τ is the atmospheric transmissivity.

The surface emissive power depends on the fuel type and the pool diameter. The correlation of the following form is given by Eq. (11) [21,22]:

$$E = E_{\max}\exp\left(-sD_p\right) + E_g\left[1-\exp\left(-sD_p\right)\right] \tag{11}$$

where,

$E_{\max}$ is the maximum emissive power of luminous spots (approximately 140 kW/m^2),
E_g is the emissive power of smoke [approximately 20 kW/m^2, and
$s = 0.12\,m^{-1}$ = experimentally determined parameter.

Fig. 1 shows the logic diagram for the pool fire radiation effect calculations.

3. RESULTS AND DISCUSSION

3.1 Failure Rate and Hazard Analysis

The diesel and fuel oil are not easily ignited because they do not vaporize easily at ambient temperatures. The ignition probabilities of pool fire for both materials are assumed to be 0.30. This will result an annual frequency of a tank pool fire as 1.8×10^{-7} /year. The frequency is much lower than the frequency with related to fires and burn that is 3×10^{-5}/year [23]. As can be seen in Table 1, the failure rate of all tanks (4×10^{-6} /year) is slightly lower than the failure rate of a single tank. Furthermore, the frequency of major release (9×10^{-6} /year) is significantly lower than the catastrophic failure.

Table 1. Catastrophic failure frequencies of atmospheric storage tanks

Type of failure	Failure frequency (per tank-year)	Reference
Catastrophic rupture	6×10^{-6}	[24]
Catastrophic rupture (all tanks)	4×10^{-6}	[25]
Major release	9×10^{-6}	[26]

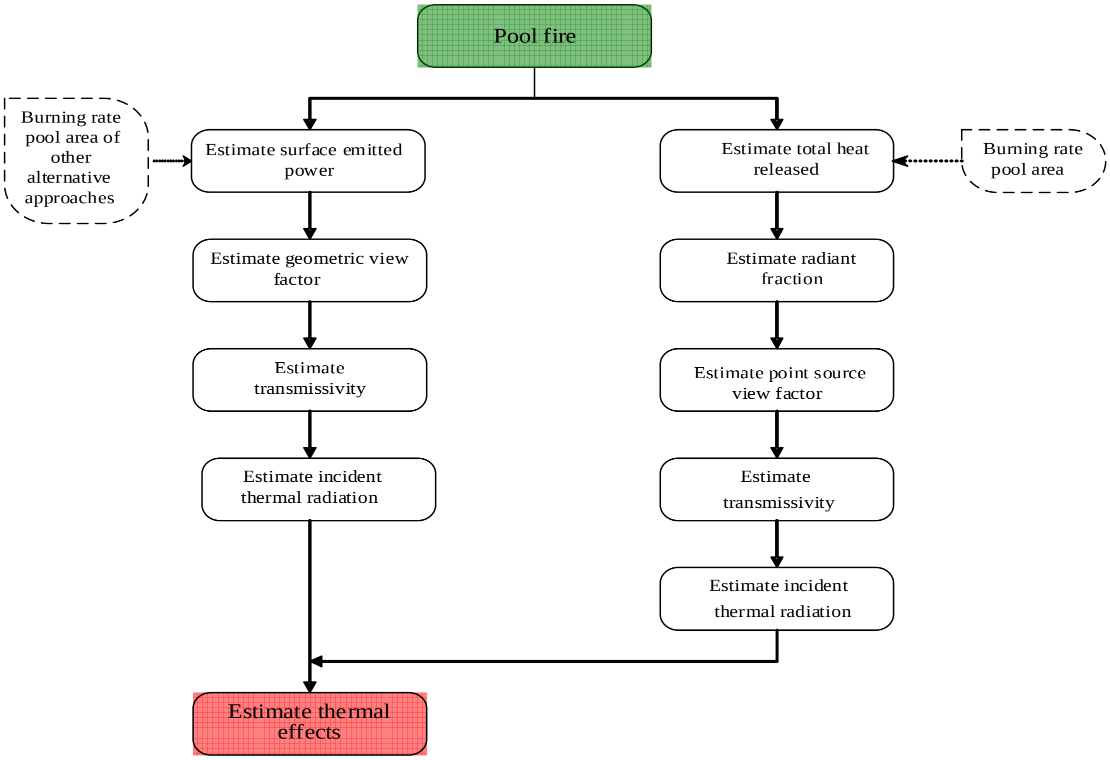

Fig. 1. Logic diagram for calculation of pool fire radiation effect

3.2 Consequence Analysis

By applying an input of release rate (0.04 *kg/s*) in the pool fire assessment using the SCIA software, it will estimate the free spill diameters around the rupture location of combustible liquids are 62 *m* for the diesel and 103 *m* fuel oil. The calculation asserts that the products spread out until it is about 2 cm depth. The correlation preferable for unconfined spills rather than relying on calculated diameter. The heights of pool fire due combustion of diesel and fuel oil are 69 *m* and 81 *m* respectively. Thermal radiation heat from burning of 50 tonnes of diesel gives 9.9×10^5 *kW*, while the radiation heat for burning of 150 tonnes fuel oil generates 2.2×10^6 *kW* of heat. The department of Housing and Urban Development (HUD) [27] has criteria or guideline for the radiation flux levels in determining Acceptable Separation Distance (ASD) between fire consuming combustible liquids or gases and nearby structures and people which are 31.5 kW/m^2 for building and 1.4 kW/m^2 for people respectively [28].

For the scenarios involving diesel, part of the structures or buildings in an area of diameter 48 *m* from the source may be affected by radiation flux of 31.5 kW/m^2.

Fire of a tank of fuel oil gives larger impact. Radiation flux of 31.5 kW/m^2 may covers in area of 73 *m* of diameter, whereas radiation flux of 1.4 kW/m^2 can reach a maximum 346 *m* diameter. The impact is mainly due the large quantity of fuel oil being stored in the tank (*i.e.* 150 tonnes). Part of buildings or on-site facilities will be affected by the incident. However, if there are no workers or visitors in the vicinity of 50 *m* radius from the tank, the impact to the people would be remote.

To minimise risk, the future development and land use planning, for development of commercial and residential areas as well as other facilities like school, mosque, public hall and recreation area in the surrounding area must be planned outside cycle area of 229 *m* diameter from the diesel storage and 346 *m* diameter from the fuel oil storage.

Table 2 shows the result summary of mass burning, *M*, flame height, L_p , and heat of radiation, Q, of pool fire events from catastrophic release of diesel and fuel oil.

Table 2. Estimation of the pool fire and thermal radiation

M (tonnes)	D (m)	L_p (m)	A_p (m^2)	Q (kW)	Distance (m) for flux 31.5 kW/m^2	Distance (m) for flux 1.5 kW/m^2
Diesel						
50	62	69	3018	9.9×10^5	48	229
Fuel oil						
150	103	81	8328	2.2×10^6	73	346

4. CONCLUSION

SCIA software has been used to study the potential consequences of pool fire which could be happened due to the release of diesel and fuel oil. The incident scenario shows that if an accident happened, it can affect part of the structures and buildings on-site and also on the surrounding residential and commercial areas. For future land planning, it is strongly recommended that development must be located half kilometre away from the location of the storage tanks to minimize the risk. Provision implementation of safe operating procedures and mitigation measures would further minimize the risk and its impact.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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