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Quantitative risk assessment on large-scale oil depots of opencast coal mine

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ABSTRACT
In recent years, many large-scale oil depots have been built in the opencast coal mine in China. In order to prevent and control major accidents of the opencast mine, it is important to assess the risk of large-scale oil depots. This paper aims to bring about a quantitative risk assessment (QRA) method to assess the fire risk of opencast coal mines. Firstly, risk analysis of large-scale oil depots for coal mine are made, the hazardous characters of gasoline and diesel are described, and the risk consequences are discussed. It is found that pool fire is the most typical and serious consequence, therefore, a mathematical model of pool fire is introduced. Furthermore, the quantitative risk assessment (QRA) method is developed to assess the fire risk of the large-scale oil depots. The QRA method is applied to assess the risk of a selected large-scale oil depot in a large opencast coal mine in China based on the QRA software CASSTQRA. For the gasoline tank of 1×104 m^3, the death, serious injury, and light injury affected radius of a pool fire are 64.75 m, 75.66 m, and 106.86 m and the individual risk was acceptable. Finally, some suggestions are proposed to improve the safety of the large-scale oil depots. The study is useful for the safety management and prevention of major accidents in opencast coal mines.
KEYWORDS: opencast mine; oil depot; risk assessment; QRA

1. INTRODUCTION

With the development of the economy and society, China's coal industry has made remarkable achievements in recent years. The production safety of coal mines has greatly improved. However, many major accidents have happened in the last decades. Many large-scale oil depot have been built in the opencast mine in China in order to meet the demands of the production of opencast coal mines. The emergence of those large-scale oil depots have brought new challenges to the safety of the opencast coal mine. In order to prevent or control major accidents of the opencast mine, it is important to assess the risk of the large-scale oil depots.

Risk is the sum of accident consequence and its probability caused by the risk. It has been shown that the main accidents associated with large-scale oil depots are fires and explosion of the oil tanks. Further, as a flammable liquid, pool fire is the most frequent and has more serious consequences than explosion once the gasoline and diesel oil leak in the fire dike. Based on the quantitative risk assessment, the mathematic model of pool fire consequences is introduced in this paper. A large-scale oil depot in an opencast coal mine in China is assessed based on the QRA method. Pool fire consequences such as death radius, serious injury, and light injury radius of the large-scale oil depot are also calculated by the QRA software CASSTQRA developed by the China academy of safety science and technology. The acceptable individual risk of the large-scale oil depot can be drawn. Finally, some conclusions and suggestions are proposed to improve the safety of the large-scale oil depots for opencast coal mines. The results can provide a theoretical basis and management guidance for government departments to manage opencast coal mines.

2. PROCEDURE OF QUANTITATIVE RISK ASSESSMENT

Quantitative risk assessment (QRA) is a complex and technical risk assessment method, which not only analyzing the causes of accidents qualitatively, but also calculates the frequency and consequence of accidents quantitatively. The risk result is compared with the existing acceptable risk standard to put forward measures to reduce or mitigate risk. The general procedure of QRA is shown in Figure 1.

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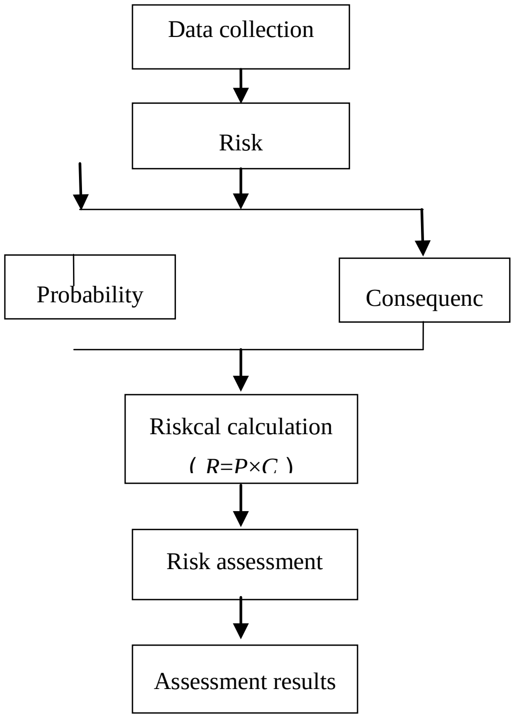

Figure 1: Procedure of quantitative risk assessment.

Individual risk is the key quantitative index of the quantitative risk assessment. The so-called individual risk refers to the risk of a variety of potential fire, explosion, and toxic gas leakage accidents caused by a fixed position in the region of a fixed position of the individual probability of death, which is the individual mortality. It is usually shown as a risk contour line (as shown in Figure 2), which can measure the size of an individual risk via a comparison with an acceptable risk criteria.

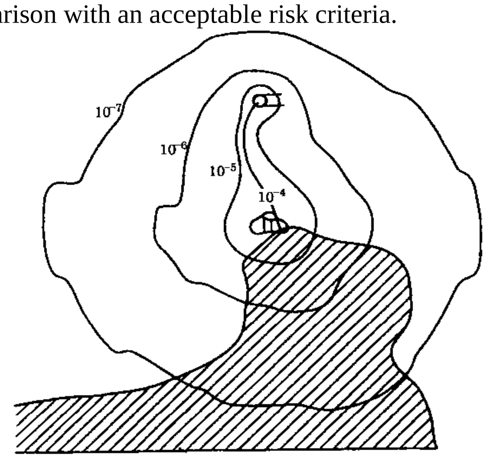

Figure 2: Sketch map of individual risk contour line.

In viewing of the risk to the surrounding people, facilities and environment, the acceptable individual risk criterion of the newly-built and existing facilities with hazardous chemical materials are defined in 2014 in China (as shown in Table 1).

Table 1: Acceptable individual risk criteria of China.

Protection target	Individual acceptable risk criteria (probability)	
	Newly-built facilities （per year）≤	In-service facilities （per year）≤
Low density areas（person number <30）: Single or a small amount of exposure persons.	1×10^{-5}	3×10^{-5}
High density residential places (30 ≤ person number < 100): residential areas, hotels, resorts etc. **Public gathering places with high density** (30 ≤ person number < 100): office, shopping malls, restaurants, entertainment etc.	3×10^{-6}	1×10^{-5}
High sensitive places: schools, hospitals, kindergartens, nursing homes, prisons, etc. **Important goals:** military forbidden zone, military management area, cultural relics protection unit, etc. **Special high density sites** (person number ≥ 100): large stadiums, transportation hub, open-air market, living district, hotels, resorts, offices, shopping malls, hotels, entertainment venues.	3×10^{-7}	3×10^{-6}

Seen from the Table 1, for the existing facilities, the acceptable individual risk cannot exceed 3×10^{-5}/year in the low density areas, 1×10^{-5}/year in high density residential places and public gathering places with high density, and 3×10^{-6}/year in high sensitive places, important goals and special high density sites. For the newly-built facilities, the acceptable individual risk cannot exceed 1×10^{-5}/year in the low density areas, 3×10^{-6}/year in high density residential places and public gathering places with high density, and 3×10^{-7}/year in high sensitive places, important goals and special high density sites.

3. MATHEMATICAL MODEL OF POOL FIRE FOR OIL DEPOTS

3.1 Mathematical Model of pool fire

When the boiling point of the combustible liquid in the liquid pool is higher than the temperature of the surrounding environment, the velocity of combustion of the unit area on the surface of the liquid pool can be expressed by equation (1).

$$\frac{dm}{dt} = \frac{0.001H_c}{C_p(T_b - T_0) + H} \quad (1)$$

When the boiling point of the flammable liquid in the liquid pool is lower than that of the ambient temperature, the velocity of combustion of the unit area on the surface of the liquid pool can be expressed by equation (2).

$$\frac{dm}{dt} = \frac{0.001H_c}{H} \quad (2)$$

Where,

H_c ——Combustion heat of combustible liquid, j/kg；

C_p ——Constant pressure specific heat of liquid, j/kg·°K;

T_b ——Boiling point of liquid, °K;

T ——Ambient temperature, °K;

H ——Liquid steam heating, j/kg.

For analysis, it is assumed that the liquid pool is round. If the liquid has reached the artificial boundary, the liquid pool area is the area of the artificial boundary, and the radius of the liquid pool can be expressed by equation (3).

$$r = \sqrt{\frac{S}{\pi}} \quad (3)$$

Because of the dangerous goods transportation accidents occurring in the road and the leakage of liquid usually without an artificial boundary, it is assumed that liquid to leaks as a cylindrical flat smooth surface toward the outer edge of the diffusion. At this time, the area of the liquid pool is changed with time, and the radius of the liquid pool can be calculated according to the following method.

For instant leaks, the pool radius can be expressed by equation (4).

$$r = \sqrt{\frac{t}{\left(\frac{\pi\rho}{8gQ}\right)^{\frac{1}{2}}}} \quad (4)$$

For continuous leakage, the liquid pool radius can be expressed by equation (5).

$$r = \left(\frac{t}{\sqrt[3]{\frac{9\pi\rho}{32gQ_0}}}\right)^{\frac{3}{4}} \quad (5)$$

Where,

r ——radius of liquid pool, m;

S ——Area of fire dike, m^2;

ρ ——Density, kg/m^3;

g ——Acceleration of gravity, $9.8m/s^2$;

Q ——leakage amount, kg;

Q_0 ——leakage velocity, kg/s.

And then, the total heat flux from the liquid pool can be expressed as Eq(6).

$$E = (\pi r^2 + 2\pi rh)\frac{dm}{dt}\eta H_c[(\frac{dm}{dt})^{0.61} + 1] \quad (6)$$

Where,

η ——efficiency factor, 0.13～0.35；

h ——flame height, m;

Assuming that all the radiation heat is emitted from a small spherical surface of the center of the liquid pool, the heat radiation intensity at a distance from the center of the liquid pool can be expressed by equation (7).

$$I = \frac{Et_c}{4\pi x^2} \quad (7)$$

Where,

E ——total heat radiation flux, w;

t_c ——air coefficient of thermal conductivity;

x ——object point to the center distance of the liquid pool, m.

Therefore, for the pool fire situation, personnel and equipment under the influence of different damage effects can be expressed by equation (8).

$$x = \sqrt{\frac{Et_c}{4\pi I}} \quad (8)$$

Where,

x ——Pool fire damage distance, m;

I ——the criteria for judging the damage, w/m^2.

3.2 Influence Area Analysis

Generally, the affected area can be divided into the death radius, serious injury, and light injury radius. The influence radius is the threshold distance of the oil fire accident, which experiences the consequences of death, environmental pollution, property loss, etc. Therefore, the influence area of large-scale oil depots is a certain threshold distance from the surrounding. The closer to the oil tank or depot, the higher the risk of the impact of an accident.

4. CASE STUDY

In this paper, a large-scale oil depot of a large opencast coal mine is taken as a case to study the risk assessment. There are 9 oil tanks in the large-scale oil depot, two gasoline tanks (each 1×10^4 m^3) and seven diesel oil tanks (each 2×10^4 m^3). Aiding with the QRA software CASSTQRA, the affected area and individual risk are shown as the following figures.

Figure 3: Influence area of pool fire of gasoline tank (each 1×10^4 m^3).

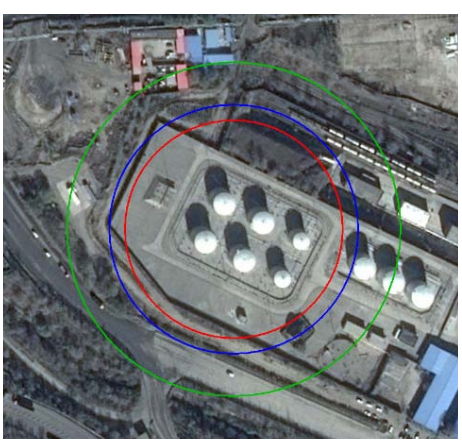

Figure 4.1: Influence area of pool fire of diesel oil tank (each 2×10^4 m^3).

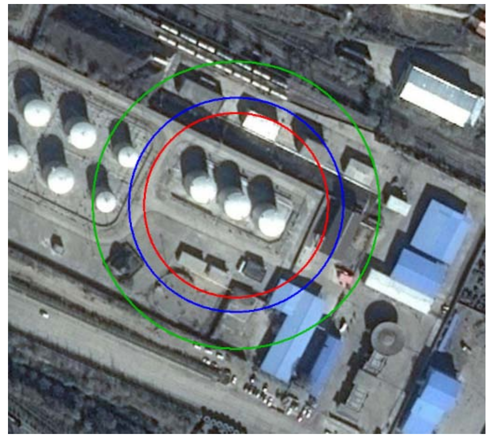

Figure 4.2: Influence area of pool fire of diesel oil tank (each 2×10^4 m^3).

The individual risk contour line of the large-scale oil depot can be drawn as Figure 5.

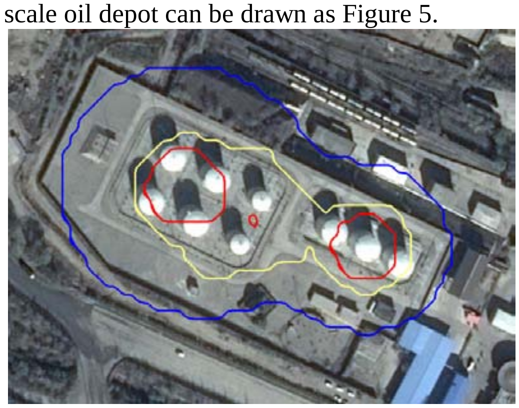

Figure 5: Individual risk contour line of the large-scale oil depot.

For the influence area (Figures 3-5), the red line is the death area, the blue line is the serious injury area and the green line is the light injury area. For the individual risk (Figure 5), the red line is 3×10^{-5}, the yellow line is 1×10^{-5}, and the blue line is 3×10^{-6}.

5. CONCLUSIONS

Quantitative risk assessment (QRA) is a complex and technical risk assessment method to assess the risk of large-scale oil depots for opencast coal mines. The pool fire is the most frequent and serious consequence, followed by explosion once the oil has leaked in the fire dike.

For the gasoline tank of 1×10^4 m^3, the death, serious injury and light injury affected radius of a pool fire were 64.75 m, 75.66 m, and 106.86 m, respectively. For the diesel oil tank of 2×10^4 m^3

gasoline, the death, serious injury, and light injury affected radius of a pool fire were 78.61 m, 88.72 m, and 120.13 m, respectively. For the diesel oil tank of $1 \times 10^4\,m^3$, the death, serious injury, and light injury affected radius of a pool fire were 53.43 m, 63.75 m, and 85.59 m, respectively.

All the individual risks were acceptable. However, some of the facilities may be affected by the pool fire of the large-scale oil depots, therefore, the opencast coal mine should take effective measures to avoid the risk of pool fire.

6. ACKNOWLEDGEMENT

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