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Leakage risk quantitative calculation model and its application for anaerobic reactor

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ABSTRACT

Anaerobic reactor is one of the most important reaction devices for biogas engineering. Fire, explosion and toxic incidents will be triggered if the biogas leaks, and severe serial explosion accidents will be easily caused if the leakage cannot be identified, monitored and warned early in the process of production and operation. Therefore, this paper aims to establish a leakage risk monitoring and early-warning model for anaerobic reactor. First of all, this paper collects the data from the simulation results of biogas leakage and diffusion, fire, explosion and other accidents, analyses the mechanism correlation that causes accidents of such multi-factor coupling as leakage calibers, elevation of leakage source, weather conditions and environments based on accident information, and finds major reasons that cause the anaerobic reactor accidents and their coupling relationships; second, a multi-parameter coupled model is established in this paper, which can be used to calculate the risk of all kinds of common leakage situations and obtain the information of accident consequences under various scenarios according to parametric variation; finally, this paper develops a quantitative calculation software aiming at the leakage hazards of anaerobic reactor in accordance with this monitoring early-warning model. This software can be employed to evaluate the safety distance and operation area by importing the data of actual production and operation. It can be calculated by the developed software that there shall be at least 9.5 m between anaerobic reactors, and the recommendation on the point location of the gas leakage detector is that the ground leakage source is from0.864 m (LFL) to 2.432 m (1/2 LFL). Besides, the distance of thermal radiation area in the emergency plan is planned.

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1. Introduction

Anaerobic reactor is a kind of special reactor designed for anaerobic processing technology. After waste water enters the reactor and mixes with the sludge bed in the reactor, anaerobic reaction will be triggered and a quantity of biogas will be generated. CH_4 and H_2S, the two important components of the biogas, are combustible materials. An accident with fire, explosion and poisoning will be caused if the biogas leaks and exposes to fire source, which will bring a great threat to people's lives and severity of surrounding buildings and equipment [1]. Therefore, it is necessary to accurately calculate the leakage hazard area and monitor, early-warning and control the leakage risk of hazardous chemical for the anaerobic reactor. Currently, solutions for quantitative risk calculation of hazardous chemical leakage are generally based on experimental study and numerical simulation. Swain and Swain [2] conducted an experimental study about the leakage rate of hydrogen and methane for various leaks. Zhang [3] developed a large-scale experimental device to conduct pipeline leakage experiments of CO_2. Luo [4] established a leakage and gas diffusion test experiment system to calculate the leak rate. However, it is difficult to carry out field experiment due to the field safety problems, long period and expensive cost. There are several companies, such as Gexcon and DNV GL, conducting a huge number of experiments, establishing calculation models and developing simulation software. PHAST, FLACS and ALOHA are the most widely used and recognized software to conduct leakage quantitative risk calculation [5–6]. Gant et al. [7,8] use PHAST and FLACS to simulate the diffusion of CO_2, respectively, and find that the simulation result is identical to the experimental result. The simulation result of the PHAST, which adopts the UDM model to describe gas leakage and diffusion, is close to the on-site scene, so American Petroleum Institute also regards this result as the basis for setting relevant standards [9]. However, this kind of software mainly makes offline calculation and performs offline simulation, which can only successively calculate the leakage risk under some specified circumstances. If not processed and analyzed, the output data of acci-

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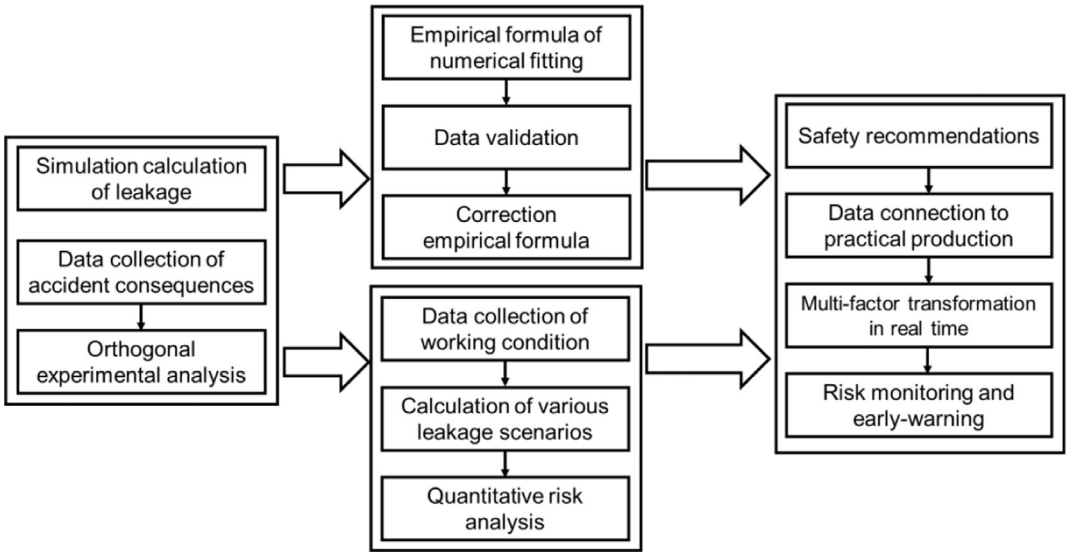

Fig. 1. Flow chart of the method for the monitoring and early-warning model of the leakage risk.

dent consequences cannot be applied to emergency rescue in the first time. In addition, it cannot monitor, warn early and provide emergency response for the real-time leakage of relevant equipment [10–12].

Taking anaerobic reactor as the research object, on the basis of the mechanism model of the leakage, diffusion, fire and explosion of hazardous chemical substance, this paper will model, carry out data processing for accident simulation results, put forward the monitoring and early-warning model for the leakage risk of the anaerobic reactor, and program relevant software applied to practical projects. This method, combined with the orthogonal experimental design, can conduct mining analysis on a large number of accident data. Meanwhile, this paper will establish various working conditions during the leakage and diffusion of the anaerobic reactor, and set up corresponding calculation procedures. Among them, the calculation model takes the influence of multi-factor coupling in the diffusion process of hazardous chemical substance into consideration, and provides relevant empirical formula and computational methods. Finally, on the basis of research content, this paper will develop a set of quantitative calculation software for the leakage hazard of the anaerobic reactor, which cannot only calculate the multi-factor coupling accident consequences, but also change the parameters according to practical circumstances in order to forecast the scope of influence in real time. What's more, this software can also provide the guidance of emergency plan, accident prevention and dynamic monitoring and early warning for all kinds of biogas projects.

Less attention has been paid to the risk identification of specific equipment in the current study, and most scholars use the software to calculate the quantitative risk of specific equipment, but they do not take the risk that equipment is under different conditions into consideration and also neglect combining with relevant laws and regulations. This paper discusses the construction, analysis and application of the monitoring and early-warning model of the leakage risk of the anaerobic reactor in detail, and puts forward a kind of calculation method applicable to petrochemical equipment and the accident consequences of equipment leakage. The flow chart of the method is shown in Fig. 1. This method mainly includes the following four steps:

(1) Data collection of accident consequences. The UDM model raised on the basis of DNV is mainly used to implement the simulation calculation of leakage accidents, and then the data of all kinds of accident consequences is collected.
(2) Data mining analysis. The orthogonal experimental design is carried out, a large number of accident data is mined in depth, and the major influence factor of the complicated process and the worst case scenario are determined.
(3) Empirical formula of numerical fitting. The numerical analysis method is mainly used to implement regression and fit to obtain the empirical formula, PHAST is used to verify the data, and the empirical formula is corrected.
(4) Practical application of software programing. The empirical formula is mainly combined with various leakage situations, and then the calculation results are applied to safety recommendations. Meanwhile, multi-parameter input can be changed in real time in accordance with the on-site environment, in order to monitor the leakage risk.

2. Construction and analysis of the monitoring and early-warning model of the reactor's leakage risk

2.1. Data collection of accident consequences

This paper adopts the UDM model to describe the gas leakage and diffusion process and its influence. The scope and degree of the influence of possible fire and explosion accident of the petrochemical plant can be calculated. Take the practical working condition of a device's anaerobic reactor as an example. The parameters of the anaerobic reactor is shown in Table 1. The model of the anaerobic reactor is shown in Fig. 2.

Followings are several leakage calibers of anaerobic reactor: ①10 mm is a small leakage caliber, such as flange gasket; ②25 mm is a common thinning leakage caliber of carbon steel; ③50 mm and 100 mm are large leakage calibers; ④150 mm is the worst leakage caliber, such as broken pipe.

2.2. Determine the major influence factors based on DM (data mining)

It is found that there are plenty of factors affecting the diffusion distance of gas leakage by using the UDM model to collect and calculate data, such as methane concentration inside the anaerobic reactor, the diameter of the leakage orifice, the height of the leakage orifice, wind speed, temperature, the stability of atmosphere,

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