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Estimation of corrosion failure likelihood of oil and gas pipeline based on fuzzy logic approach

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ABSTRACT

Oil and gas pipeline is likely to leak and rupture due to corrosion problems, which seriously impacts the safety operation of pipe systems. Corrosion phenomenon has the nature of uncertainty, which makes the estimation of corrosion failure likelihood (CFL) very difficult. In order to overcome this difficulty, an analytic model for assessing CFL of oil and gas pipelines has been developed by means of fuzzy logic approach. In this model, corrosion failure modes are divided into two types: corrosion thinning and corrosion cracking. Corrosion thinning factor, corrosion cracking factor, inspection effectiveness, and inspection times are introduced as the key influencing factors that affect the CFL of pipelines. The fuzzy rules between the factors and CFL were determined according to the influence degrees of the factors. The model was applied to a natural gas pipeline to assess the CFL. The assessment results can be used as effective reference for working out pipeline inspection and maintenance plans.

1. Introduction

Oil and gas pipeline is an efficient way to transport energy sources due to its advantages of low cost and large transmission capacity. The operating pressure of the pipeline is relatively high and the transmission medium is inflammable and explosive. Therefore, once the pipeline failures take place, some severe incidents, such as leakage, fire and explosion, may occur. One of the major reasons for failure is corrosion which can lead to the thinning or the cracking of the pipe wall. In order to mitigate corrosion and reduce economic loss, it is necessary to assess the failure risk of the pipeline and then take an effective inspection plan according to the risk ranking. Estimating the corrosion failure likelihood (CFL) of a pipeline is a crucial step in failure risk assessment.

In general, estimating the CFL requires the accurate data of corrosion thinning rates or crack growth rates of a pipeline. These data are generally derived from experiments, field inspections or physical models [1]. In practice, the service environment of pipelines is changing with time since it is influenced by the changes of the operating temperature, medium constituents and soil properties, which makes the corrosion problems of pipelines very complex. That means it is difficult to accurately estimate the CFL according to the physical models used to describe the evolution of the corrosion process. Another approach to estimate the CFL is the Fault Tree Analysis (FTA) [2]. FTA requires firstly to construct the fault tree describing the logical relationship between different level events, and then calculate the failure probability of the top event from the probabilities of the basic events (P_{be}s) by Boolean logic operations [3]. P_{be}s are derived from large numbers of failure data, but the data are inadequate in practice. To solve this problem, a fuzzy FTA (fFTA) was developed, in which P_{be}s are estimated by using fuzzy set theory [4–10]. However, since the

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influencing factors of corrosion are various and complicated, constructing the corrosion-related fault tree of the oil and gas pipeline is still a difficult task.

Some researchers have attempted to introduce the fuzzy mathematics concept into safety assessment methods of process industries in order to effectively deal with uncertainty (i.e. incomplete and imprecise data). Markowski et al. [11,12] introduced fuzzy logic system into the process industry to estimate the frequency and the consequences of the incident scenarios of process systems. Guo et al. [13] proposed a model to evaluate the criticality of petrochemical equipment based on fuzzy synthetic evaluation. The model considered four aspects (i.e. production loss, safety effect, environment effect, and maintenance costs) as the influencing factors of the criticality. Singh & Markeset [14] proposed a fuzzy logic-based prediction model for estimating the rate of CO_2 corrosion in carbon steel pipes. The model takes the plant operation parameters (i.e. temperature, gas and liquid flow rates, total pressure, CO_2 partial pressure and pH), the inspected rate of corrosion and the efficiency of inspection as fuzzy variables. Jamshidi et al. [15] developed a new fuzzy inference system for pipeline risk assessment.

Above-mentioned studies provided many valuable references for dealing with uncertainty in engineering safety analysis. However, there are few researches reported on how to handle uncertainty and complexity in the estimation of the CFL of an oil and gas pipeline. This work attempts to develop a new model for estimating the CFL of the pipeline. Considering the complexity and uncertainty of corrosion problems, the model uses fuzzy logic method to establish a fuzzy graph for describing the relationship between the CFL index and influencing parameters, which can be used to analyze the CFL of a pipe.

This paper is organized as follows. Section 2 introduces the framework of fuzzy logic. Section 3 describes the model for estimating corrosion failure likelihood of oil and gas pipeline. In Section 4, an application example is carried out. Finally, some conclusions are presented in Section 5.

2. Framework of fuzzy logic

Fuzzy logic is an effective mathematical tool for handling imprecise and uncertain information in the real world. It starts with the concept of a fuzzy set which is an extension of a classical set. In classical sets, an element is either a member of certain set or not, while in fuzzy sets the element is allowed to belong partially to a set.

Formally, if X is the universe of discourse and its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pairs: $A=\{x,\mu_A(x)|x\in X\}$, where $\mu_A(x)$ is called the membership function of x in A. The membership function maps each element of X to a membership value from zero to one. When the element belongs completely to the set A, the function has a value of one ($\mu_A(x)=1$); when the element does not belong to the set, a value of zero ($\mu_A(x)=0$); and if the element belongs partially to the fuzzy set, some value between zero and one ($0<\mu_A(x)<1$).

Fuzzy logic is one of applications of fuzzy set theory. This is achieved by the implementation of fuzzy logic system (FLS). The basic structure of FLS consists of three parts: fuzzification of the input variables, fuzzy inference process and defuzzification (see Fig. 1). The inference process is based on fuzzy logic operations which are the implication in each single rule and the aggregation from all rules. All output functions returned by the implication process for each rule are combined into a single output fuzzy set [16]. The specific inference process is as follows [1,17–19].

2.1. Step 1: determination of fuzzy rules and fuzzy sets

Fuzzy rules and fuzzy sets are crucial for establishing a fuzzy logic system. The rules are used to describe the heuristic knowledge about the behavior of a complex system. Fuzzy rules of a system can be generally expressed in the following form:

$$R^i: \ \text{If } X_1 \text{ is } A_1{}^i \text{ and } X_2 \text{ is } A_2{}^i \text{ and} \cdots X_m \text{ is } A_m{}^i \ \text{ Then } Y \text{ is } B^i, \ \ i=1,2,\dots n. \tag{1}$$

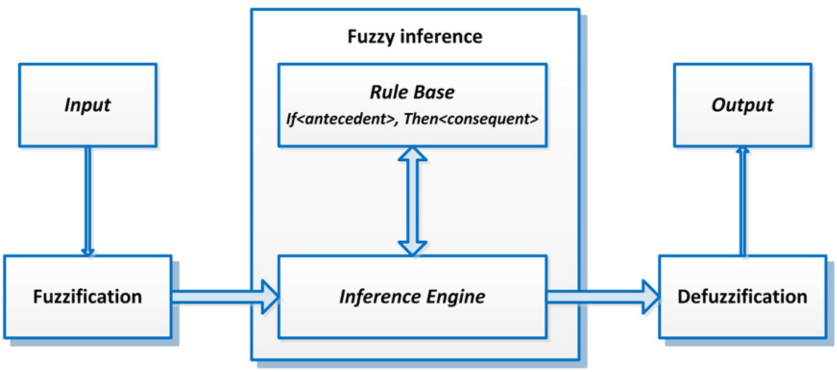

Fig. 1. The basic structure of fuzzy logic system.