Modeling Based on Markov Chains, for the Evolution Pitting Corrosion in Buried Pipelines Carrying Gas

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A stochastic model based on Markov Chains is presented for predicting the time evolution of the pit depth distributions, as manifestation of the corrosion experienced by pipelines carrying gas. The results obtained allow estimating the lifetime of pipelines in service, thereby achieving optimize time and maintenance costs.

Introduction

The pipelines for transport of hydrocarbons are perform strategic national importance and as consequence them, the phenomena associated with this infrastructure have a transcendental meaning, that is the case of the alternative transport costs, opportunity in the arrival of products, risks of loss of them and specially, harm to the population in the catchment area of the pipelines and facilities personnel operating there them.

Importantly, the pipeline system plays a prominent role for private and industrial sector, but also a latent risk represents for the civil population, since it is demonstrated by the disasters of diverse magnitudes happened, that have generated economic losses and human lives.

From this, it is very important to protect people and assets, considering all the necessary measures to avoid the most regrettable events because it constitutes the present of ducts for this use, one of the most economical way whit regard to other alternative fuel transportation.

The pipelines currently represent the most important and efficient transportation of hydrocarbons from the production areas, refining and petrochemical plants, to area of end use or distribution of products, or sometimes as a source for shipment going abroad.

The strategic significance of the pipeline lies in the nature of the products that transport, Fuel is essential today for the daily life of families, as raw material for processing a variety of products, as well as an energy source for the implementation of a large part of industrial processes.

Hence the need for a network of pipelines according of the needs of transport of hydrocarbons, operated by highly trained personnel, subject to modern surveillance systems, maintenance and troubleshooting.

Systematic monitoring of the operating conditions of a pipeline that carries fuel in different environments (water, soil and air) keeps the system in optimum condition. Inspection tools allow to achieve the objective before raised, sometimes it can not be oversight often enough, this implies the need to rely on estimates from the depths of defects based on previous inspections. (1)

It is common to make erroneous predictions of the severity of these defects, which lead to inappropriate development of the maintenance program.

The pipelines can suffer pitting corrosion, which is highly localized type, and occurs through anodic reaction that occur in small pits in the metal surface, by local anodic dissolution process where metal loss is accelerated by presence of a small anode and cathode larger.

Most metals suffer this type of corrosion. The carbon and stainless steels are affected by pitting corrosion, depending of the aggressive agents (environment) in contact with them. (2)

The pit depth estimation caused by corrosion in soils, difficultly can be quantified electrochemically. Due to in this phenomenon there are many variables involved, which links avoid the modeling by this approach. One element that makes possible to develop a stochastic model for growth of pits in pipelines is the possibility to consider a discrete variable the thickness of a tube. In order to, other characteristic is the fact that the corrosion process by pit does not present memory of the past. (3)

From this, it is necessary to use protection for corrosion to control this phenomenon in the pipelines used for this applications, usually in Mexico, based protection use tar and asphalt, because it provides sufficient adhesion to the metal surface, provides ductility to resist cracking, resistance to withstand damage the pipe and management efforts in the field, in addition to be compatible with any supplemental cathodic protection.

Cathodic protection is to require the pipe to function as a cathode in a corrosion cell, through the manipulation and modification of electrochemical factors.

Method and Material

It is estimated the state of a buried pipeline in clayey soils with relatively high resistivity (about 50 Ω-m) and potential between soil and tube (natural or imposed) about -0.85 V, this value close to optimum protection level. (4)

The pipeline's material is steel API X-70 (steel of low level of carbon, weight of, 0.08 a 0.12 %, and low alloy). The duct is in operation since 1981, in a region in Mexico center, and it has a length of 100 Km approximately, which is covered with coal tar, cathodically, whose outer diameter 355.6 mm and a wall thickness of 9.52 mm is using the information obtained through inspection in-line maked at the years 2002 and 2007.

If we consider that the wall thickness can be divided into N states and pit depth in a time *t*, can be represented by a discrete random variable D(t) with $P\{D(t) = i\} = p_i(t)$; i = 1,2,…, N. In addition, it can to assume of which the depth in the condition *i* advances one state during a short interval of time δt can be written as $\lambda_i(t)\delta t + o(\delta t)$. The probability that, for a time *t*, the damage progress from state i to state j (j ≥ i) in an interval Δt, can be obtained if Kolmogorov's differential equations system is solved. (5)

Results and Comments

To apply Markovian model the distribution of depths of the defects observed in 2002 was used as initial distribution. In this way $t_0 = 21$ years, $\Delta t = 5.5$ years and p_m $(t_0 = 21) = N_m/N_{02}$; N_m is the number of defects found in the state m. It was assumed that the soil's characteristics along the pipeline were similar. Using mathematics expresions. (5)

The probability that, for a time t, the damage progress from state i to state j (j ≥ i) in an interval Δt, can be obtained if that solves the system of Kolmogorov differential equations shown in the expressions [1]

$$\frac{dp_{ij}(t)}{dt} = -\lambda_j(t)\,p_{ij}(t) + \lambda_{j-1}(t)\,p_{ij-1}(t)$$
$$\frac{dp_{ij}(t)}{dt} = -\lambda_i(t)\,p_{ii}(t) \qquad [1]$$

For a Markov process defined by the expressions (1), is the interest to find the probability of transition from state m to state n (n ≥ m) in the interval (t_0,t), i.e. $p_{mn}(t_0,t) = P\{D(t) = n | D(t_0) = m\}$. The solution $p_{mn}(t,t_0)$ of the system (1) is shown bellow and its existence is shown in reference (5):

$$p_{mn}(t_0,t) = \binom{n-1}{n-m} ps^m (1-ps)^{n-m} \qquad [2]$$

Where:

$$ps = e^{-\{\rho(t)-\rho(t_s)\}} \qquad [3]$$

And

$$\rho(t) = \int_0^t \lambda(\tau)d\tau \qquad [4]$$

Analyzing the equation [2] it can be said that the increase in pit depth (*m* – *n*) in a interval of time $t\text{-}t_0$ corresponds to a NegBin(r,p), with parameters r = m y p = *ps*. When for $t = t_i$ the initial state is n_i, $d(t_i) = n_i$, the stochastic average of the process $\overline{M}(t) = E[d(t)]$), is defined by the next expression:

$$\overline{M}(t) = n_i e^{\rho(t-t_i)} \qquad [5]$$

Authors Cox and Millar (6) show the deterministic average in some events can match the stochastic average damage of the processes. In this research the law determines that expresses the growth of pits is as following:

$$\overline{D}(t) = k(t - t_{sd})^{\nu} \qquad [6]$$

Where t_{sd} is the average time of initiation of pits and k and ν are the parameters of proportionality and the exponent of the law of growth of defects, respectively.

In the present research assumes that deterministic average experimentally for the pith depth $\overline{D}(t)$ is equal stochastic average of the process:

$$\overline{D}(t) = \overline{M}(t) \qquad [7]$$

If in the expression (5) is $n_i = 1$; and the time the system spends in this initial state is significantly small compared with the time of the experiment, it can be show that the value of the function ρ(t) can be approximated as follows:

$$\rho(t) = \ln\left(k\left(t - t_{sd}\right)\right)^{\nu} \qquad [8]$$

And the probability *ps* can be expressed as follows

$$ps = \left(\frac{t_0 - t_{sd}}{t - t_{sd}} \right)^{\nu} \qquad [9]$$

Then, the transition probability from state m to a state n, in an interval of time ranging t to t_0, can be determined by:

$$p_{mn}(t_0, t) = \binom{n-1}{n-m} \left(\frac{t_0 - t_{sd}}{t - t_{sd}} \right) \left(1 - \left(\frac{t_0 - t_{sd}}{t - t_{sd}} \right)^{\nu} \right)^{n-m} \qquad [10]$$

The solution of the system of Kolmogorov differential equations only depends of the parameter ν and of the initiation time of pitting t_{sd}. It is assumed that the depth distribution in a time t_0, $P\{D(t_0) = m\} = p_m(t_0)$, is known. For example, this distribution can be obtained by instrumented equipment. In this case, t_0 is the time when the inspection took place and the probabilities value p_m would be determined by the relationship of the number of defects found in every state of the total number of defects. If the function of transition probability $p_{mn}(t_0,t)$ is known, then it is possible to determine the distribution depth of defects for any future time using the next expression:

$$p_n(t) = \sum_{m=1}^{n} p_m(t_0)\, p_{mn}(t_0, t) \qquad [11]$$

Analyzing the above expression, one can say that the probability distribution of the depth of defects in a time t is function of the probability distribution of depth of defects in a time t_0 and the transition probability between states. The latter can be completely determined if we know $\rho(t)$, which is direct function of the parameters ν and t_{sd} in the expression (5).

Then, it is possible to obtain the depth distribution of defects produced by Markov chains modelation. The result of this modeling is presented in the figure by a continue line. Figure 1 shows the similarity betwen the observed distribution in 2007 and the results obtained by simulation.

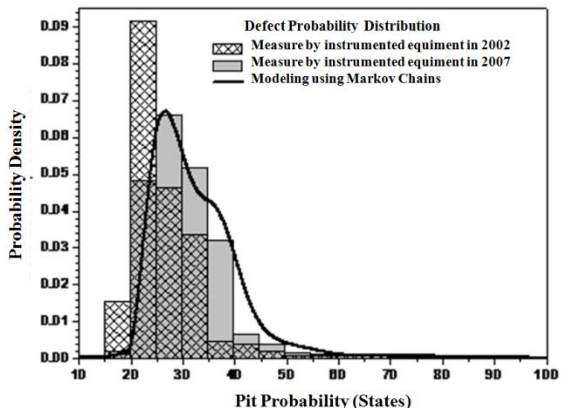

Figure 1. Results of the Markov chain modeling in a pipeline.

Conclusions

It is possible to find a model for determining the pit depth in buried pipelines using Markov chains. Using a non-homogeneous Markov process, of pure birth, to model the growth of pit corrosion is attractive due to the existence of an analytical solution of the Kolmogorov’s differential equations system. Using this solution avoids a reduction number of states, which increase the mathematical simplicity.

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