

An Alternative Approach To Evaluate Internal Pipeline Condition

The full-length paper details an uncertainty-based probabilistic approach to determine the internal corrosion condition of a pipeline under varying operating conditions. This approach allows the risks associated with future maintenance options to be quantified.

Introduction

Pipeline-integrity management is becoming increasingly important to the oil- and gas-production sector. Tiebacks from marginal fields into existing pipelines result in aging pipelines being operated well beyond their original design life. New pipelines also are being constructed in increasingly challenging environments. All of these factors introduce greater uncertainty into prediction of future pipeline integrity. In-line pipeline inspection is expensive, but modeling of pipeline operating conditions can provide an estimate of metal loss when no detailed inspection data exist.

Historically, engineers have used conservative values when there were uncertainties about parameter values. These assumptions result in a worst-case output that may result in the pipeline being condemned. Developing a means to incorporate these uncertainties into corrosion-prediction tools allows a more accurate determination of risk and a better selection of control programs.

This article, written by Assistant Technology Editor Karen Bybee, contains highlights of paper SPE 100727, "Alternative Approach to Internal-Pipeline-Condition Assessment," by K.E. Oliver, D.G. John, and A. Crossland, CAPCIS Ltd., prepared for the 2006 SPE International Oilfield Corrosion Symposium, Aberdeen, 30 May.

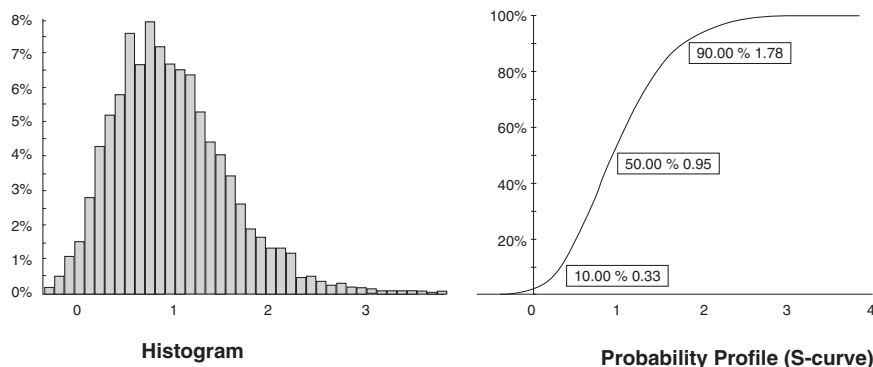


Fig. 1—Typical graphical output.

Uncertainty Modeling

A distribution of values is constructed for each uncertain variable used to calculate likelihood of failure. A number of different results can be compared for different operating scenarios. The risk of failure can be described in terms of probability of pipeline failure on a year-by-year basis for the scenarios.

Input-data uncertainties are described by a statistical distribution that is defined on the basis of operating data collected from the field. Current conditions can be assigned a distribution on the basis of the range of defects measured during an intelligent-pig or other inspection. Laboratory-test data can be used to assign corrosion-inhibitor efficiencies. Where there are no data, field knowledge can be used to assign a credible value range.

The distribution shape is based on the conditions surrounding the variable and therefore specific to the parameter in question. Typical distributions used include the following.

- Truncated normal distribution used for general-corrosion distribution.
- Log normal distribution used for pitting-corrosion defects.

- Triangular distributions used for inhibitor effectiveness and availability.
- Uniform distributions used for pressure.
- Minimum extreme distributions used for temperature under rapid-cooling conditions.

The distribution can be embedded in a standard corrosion-rate or metal-loss calculation by use of a Monte Carlo simulation that randomly generates values for the uncertain variable.

The simulation calculates multiple scenarios by repeatedly sampling values from the probability distributions for the uncertain variables. During a single trial, a randomly selected value from each of the defined ranges is used to produce an output. Multiple passes are carried out that produce a range of possible outcomes that are represented in a histogram or in a probability profile, also known as a cumulative probability curve (**Fig. 1**).

The histogram displays all of the outcomes along the x-axis and the probability of occurrence along the y-axis. This plot allows the shape of the outcome range to be visualized and the symmetry and peaks in the distribution to be seen. The cumulative probability curve shows the

For a limited time, the full-length paper is available free to SPE members at www.spe.org/jpt. The paper has not been peer reviewed.

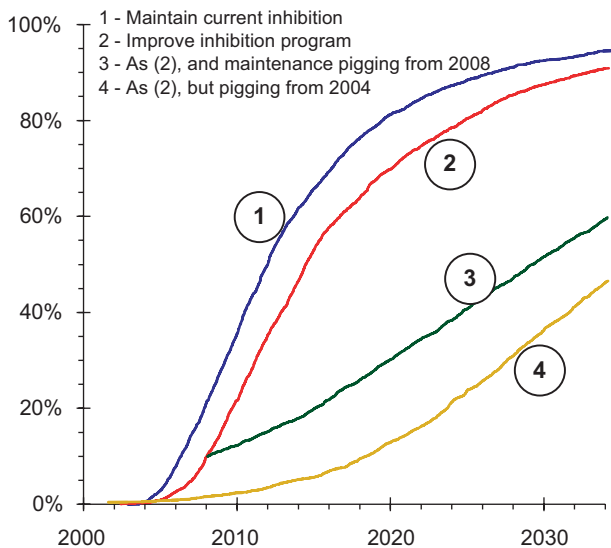


Fig. 2—Probability of failure vs. time.

likelihood or probability of reaching certain values. The cumulative frequency is plotted along the y-axis as a function of the output values plotted along the x-axis. A steep and narrow cumulative probability curve indicates less uncertainty, and a wide and long cumulative probability curve indicates more uncertainty.

Case Study 1

An internal-corrosion analysis was performed for a pipeline carrying crude oil from an offshore platform in the Middle East. The 18-in. 220-km-long pipeline was commissioned in 1999 and carries the total production from relatively small unmanned offshore production platforms to onshore processing facilities. Initially, the pipeline was operated without corrosion inhibitor. Following the identification of corrosion by a wellhead inspection and intelligent pigging, an inhibition program was begun. The objective of the analysis was to determine the effect on the 20-year design life of the initial period without corrosion inhibitor, partial inhibition, and the delay of routine maintenance pigging. The operator wanted to compare the effects of deferring the costs of preventive maintenance to the risk of failure.

Corrosion Threat. A review of the operating conditions, fluid chemistry, inspection reports, and pulled-tubing

surveys confirmed the main corrosion threat to be pitting corrosion caused by dissolved CO₂ and sulfides. Inhibitor-dosage records revealed historical underdosing, although there was a good correlation that the inhibitor was effective when correct dosages were used. Inspection data taken from manifold pipework at the pipeline inlet were used to generate a statistical distribution of likely corrosion rates.

Operating History. Two distinct periods of historical operation were considered. The first period was from the time of commissioning (September 1999) to December 2001, during which time the line was operating with no corrosion inhibition. The second period was from December 2001 to January 2004, during which time partial inhibition was in place.

From January 2004 onward, the effect of four operating scenarios was considered. In the first, operations are continued with no pigging and with the current corrosion-inhibitor program. In the second, there would be no pigging, but an improved corrosion-inhibitor program would begin. In the third, pigging would begin in 2008, followed by an improved corrosion-inhibitor program. In the fourth, pigging would begin in 2004, followed by an improved inhibitor program.

In this study, pipeline failure was defined as the time at which the

wall thickness reached the minimum-allowable wall thickness. The effect of each scenario on time to failure was evaluated by use of Monte Carlo uncertainty modeling and a decision- and risk-analysis software package. **Fig. 2** shows the results of the analysis. There is a clear difference in the likelihood of failure, and therefore in the risk associated with the different operating scenarios. In mitigating pitting corrosion, the additional inhibitor efficiency to be gained from pigging has a significant effect in deferring the likelihood of failure.

Improving the inhibition program alone without addressing the buildup of deposits in the line by pigging has only a marginal benefit on pipeline lifetime. The greatest effect is gained by pigging and improving the inhibitor performance. It is clear that in a system where pipeline degradation is driven by localized corrosion, maximizing inhibitor efficiency has significant benefits in deferring time to failure.

The time to 10% probability of failure (POF) is deferred by only 3 years by improved inhibition alone, but by 13 years by beginning routine pigging immediately. Deferral of 50% POF is again only 3 years for improved inhibition alone but increases to 17 years with routine pigging beginning in 2008. By starting routine pigging immediately, 50% POF is deferred for 22 years. Simple inhibition without incorporating regular cleaning almost certainly will result in pipeline failure long before the 20-year design life of the pipeline.

The additional cost for the improved inhibitor program (higher dosage rates) alone is an estimated U.S. \$60,000; the cost of implementing a regular pigging operation is an estimated U.S. \$100,000. The cost of a pipeline failure is an estimated U.S. \$9 million. Examination of net present value and relative costs over a 20-year design life reveals that there is little benefit in adopting only an improved inhibitor program, but there is a significant benefit in beginning routine pigging as soon as practical.

Case Study 2

Over a 2-year period, a North Sea field experienced extended shut-ins caused by startup problems and

blockages caused by hydrate formation. The original 10-year design life of the pipeline was in question because of uncertainty in corrosion-inhibitor dosing and effectiveness, and it was necessary to determine the effect of the shut-in periods on future risk. The main corrosion threats were identified as general sweet corrosion and preferential weld corrosion caused by the use of nickel-rich weld filler metals.

Six distinct periods of operational history were considered where significant changes in pressure, temperature, or inhibition regime occurred because of shut-ins or blockages. These were normal operations with and without inhibitor, pipeline blocked with inhibitor present and high and low pressures, normal operations with inhibitor, and pipeline shut-in with inhibitor. A simulation was performed to determine the range of metal loss during each period. The probable metal loss during each period then was summed to find a probability of total-cumulative-metal-loss profile.

Laboratory testing was performed on weld coupons to evaluate inhibitor performance on precorroded surfaces of both the parent metal and the weld region. A Monte Carlo simulation with a spreadsheet and risk-analysis software was used in the wall-loss predictions. A triangular distribution was used for the CO₂ content and bicarbonate concentration. A uniform distribution was used for pressure, and a minimum extreme distribution was used for the temperature.

Use of a probability-based approach resulted in a 0.61- to 0.82-mm wall loss for the parent metal. This indicated a relatively low range of potential damage to the parent metal resulting from shut-in. Greater metal loss was possible for the welds because of uncertainty of inhibitor performance on weld metal. Metal-loss range for the welds was 0.76 to 1.6 mm.

The analysis revealed that future inhibition must focus on weld-metal protection rather than parent-metal protection. Therefore, inspection and corrosion-monitoring programs should focus on the weld metal and

achieving inhibitor concentrations necessary to control weld corrosion.

Discussion

By use of probabilistic modeling, backed by experimental results, inspection data, and best estimates, it is possible to obtain a clear understanding of not only the potential range of metal loss but also the probability associated with that loss. As illustrated in Case Study 1, running parallel assessments enables key parameters to be varied to determine their effect and identify those that have the greatest effect on the particular system.

When using conventional approaches, there is a tendency to assume worst-case corrosion rates or consider a single inhibitor performance. By use of a probabilistic approach, it is possible to examine a range of potential conditions. The economic effect of deferring maintenance or rehabilitation costs also can be determined in terms of future risk to assets, and the real financial value of short-term cost savings can be evaluated. **JPT**