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An Approach To Optimize the Wall Thickness of In-Service Pipelines

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ABSTRACT

This paper presents a case study of a hypothetical pipeline that operated without coatings or Cathodic Protection (CP) for nearly the first 20 years of its service. Metal loss anomalies with depths greater than 50% of nominal wall thickness will require excavation according to federal regulations. To reduce the number of unnecessary excavations, laboratory testing data combined with methodology from both API 579 and ASME B31.4 was applied to determine an optimized wall thickness (t').

Based on hypothetical anomaly data considered in this paper, the optimized wall thickness resulted in a 70% reduction in the number of anomalies that required excavation, while still maintaining a safety factor of 1.39 (corresponding to 100% SMYS). This ensured that the anomalies that posed an imminent threat were targeted, excavated and repaired.

Following the good engineering practices specified in ASME and API codes, tempered by engineering judgement and some conservative assumptions, the optimized wall thickness will result not just in cost savings, but also in repairing anomalies that constitute a substantial risk to public safety.

INTRODUCTION

Pipeline systems are designed to withstand various loading conditions such as internal pressure, external pressure, cyclic loadings, temperature differentials, axial force and bending moments. Reasonable tolerances are provided for unusual external conditions the pipeline may encounter in river crossings, areas of heavy traffic, long self-supported spans, unstable ground, vibration or forces from abnormal operating conditions. Some of the protective measures may include;

installing casings, adding concrete protective coating, increasing the wall thickness, lowering the line to a greater depth or adding more line markers.

Wall thickness established during the design phase of a new pipeline includes tolerances such as mill tolerances, defect tolerances and time-dependent threats that compromise the pipeline's integrity. However, after a pipeline has been in operation for several years or decades and with regular monitoring and maintenance, some of the uncertainties associated during the design phase, specifically external corrosion threat to the pipeline will be well understood. The increased wall thickness due to additional tolerances generally results in pipe operating at a lower operating stress while the remaining strength of the material is underutilized. This presents opportunity for determining a new optimized nominal thickness (t') for a given set of operating conditions without reduction in safety and satisfying the ASME and API code requirements. As will be discussed in this paper, the optimized wall thickness will satisfy the mechanical integrity requirements and result in enormous cost savings by excavating anomalies that are truly necessary.

For the purpose of this case study, it is assumed that the pipeline was built in the 1950's. The design philosophy of pressure equipment's designed in the 1950's was that the wall thickness of the pipe or pressure vessel should be such that the maximum hoop stress does not exceed the allowable stresses. However, modern assessment methods for design as well as evaluation of anomalies are now based on the well-established fracture mechanics principles, which permits use of higher allowable stresses without reduction in safety. The case study presented in this paper utilizes principles from API and ASME code to demonstrate the acceptability of a new optimized wall thickness for an in-service pipeline.

The primary objective of this work is to carry out a Fitness-For-Service (FFS) assessment based on the existing wall thickness, establish the new nominal thickness (t') and to perform mechanical integrity / remaining strength calculations based on the new nominal wall thickness.

PIPELINE BACKGROUND

The hypothetical pipeline considered in this paper has two different wall thicknesses and operated bare, without coatings or Cathodic Protection (CP), for nearly the first 20 years of its service.

NEW NOMINAL THICKNESS – METHODOLOGY

In addition to utilizing laboratory testing data, the below two (2) approaches were also utilized in determining a new nominal thickness.

1. Top Down Approach - Thickness Averaging
2. Bottom Up Approach - ASME B31.4

It is assumed that the material exhibits a ductile behavior and external corrosion is the predominant threat. In a pipe, away from any structural discontinuities, the longitudinal length of the corroded area is the most important parameter which affects the burst pressure in a pipe. Since the axial stress is half the hoop stress (in the case of end capped pressure vessel) when subjected to internal pressure, the circumferential length of corrosion has a small influence on the burst pressure. The failure of corrosion flaws is controlled by their size and the yield stress of the material.

Top Down Approach – Thickness Averaging

The top down approach is based on thickness averaging. This method is similar to a level 1 assessment per API 579. This approach is extensively used in the refinery and petrochemical sectors to analyze smaller segments of pressure components. The procedure was extended to analyze data from the ILI runs. The thickness averaging approach was used to calculate the

average remaining thickness in the pipeline segment. Modified B31G criteria was later utilized to evaluate the remaining strength based on the new nominal thickness (t') and therefore, a conservative general metal loss was determined and applied.

Average measured thickness (t_{am}) is calculated as:

$$t_{am} = \frac{1}{N} \sum_{i=1}^N t_{rd,i} \quad (1)$$

where:

t_{rd} is the thickness readings
 N is the number of thickness readings

COV was defined as the standard deviation divided by the average thickness and is calculated using the following equation:

$$COV = \frac{1}{t_{am}} \left[\frac{S}{N-1} \right]^{0.5} \quad (2)$$

where S is extent of metal loss given by:

$$S = \sum_{i=1}^N (t_{rd,i} - t_{am})^2 \quad (3)$$

COV was found to be less than 10%, suggesting that the use of ILI data for thickness averaging is valid.

Bottom Up Approach - ASME B31.4

The bottom up approach utilizes ASME B31.4 which is the design code for the mechanical design of liquid pipeline systems.

The internal pressure design wall thickness (t) of steel pipe shall be calculated by the following equation.

$$t = \frac{P_i D}{2S} \quad (4)$$

where:

S is the allowable stress, psi ($S = 0.72 \times \text{Weld Joint Factor} (E) \times \text{minimum specified minimum yield strength}$)

P_i is the internal design pressure, psi (Assumed MAOP in this case)

D is the outside diameter of the pipe, in

The pipe material is API 5L Gr B with a minimum yield strength of 35,000 psi. Weld Joint Factor for ERW and Seamless pipe is 1 based on B31.4.

CORROSION GROWTH ASSESSMENT

Defects in a pipeline may grow to an unacceptable depth and cause failure due to active corrosion. Therefore, to evaluate the condition of the pipeline in future it is prudent to estimate the time it will take the defect to grow to an unacceptable depth and/or failure. This can be achieved by modelling the growth of defect using a predicted corrosion rate.

Traditionally, when multiple sets of ILI data are available, a corrosion growth rate can be determined using the comparison of the tool runs. In this case, based on data collected from multiple excavations, thickness measurements performed in the lab and utilizing Uhlig's data for freely corroding steels and cathodically protected steels based on soil drainage, a conservative corrosion growth rate was estimated. Figure 1 illustrates the approach to estimate the corrosion growth rate. By utilizing data from excavations, thickness measurements performed in the lab and Uhlig's data for freely corroding steels / cathodically protected steels based on soil drainage, a conservative corrosion growth rate was established.

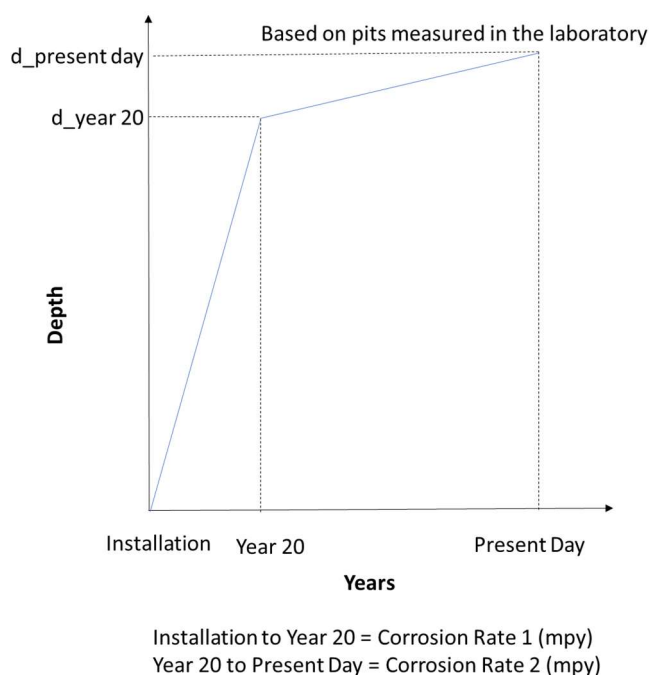


Figure 1 – Approach to estimating corrosion growth rate

DEFECT ASSESSMENT METHODOLOGY

Assessment of corrosion features

Failure pressure calculations for metal loss anomalies have been performed according to Modified B31G based on both the new nominal thickness as well as the current (original) nominal thickness. The input dimensions used for the evaluation of anomalies as per modified B31G assessment is illustrated in figure 2. The parameters used in the new thickness calculation is shown in the figure 3 below.