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America's Evolving Oil and Natural Gas Transportation Infrastructure
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Topic Paper #4-6

INSPECTION TECHNOLOGIES TO CHARACTERIZE MATERIAL PROPERTIES

Prepared for the

Technology Advancement and Deployment Task Group

On December 12, 2019 the National Petroleum Council (NPC) in approving its report, *Dynamic Delivery – America's Evolving Oil and Natural Gas Transportation Infrastructure*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Permitting, Siting, and Community Engagement for Infrastructure Development Task Group. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 26 such working documents used in the study analyses. Appendix C of the final NPC report provides a complete list of the 26 Topic Papers. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

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Topic Paper

(Prepared for the National Petroleum Council Study on Oil and Natural Gas Transportation Infrastructure)

4-6	**Use of Inspection Technology to Characterize Material Properties**
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SUMMARY

Pipeline operators sometimes do not have complete records of the pipeline material properties for each joint of pipe due to the age of the asset or available records. This information is important for validation of operator records, integrity decision making, and optimization of in-service welding procedures. In-line and in-the-ditch inspection techniques allow gathering of data for sufficient characterization of these properties while minimizing costly destructive testing. Standards and recommended practices facilitate inclusion of these tests into industry best practices but there remain regulatory barriers for the use of these test results. This topic paper addresses continued research and development underway to enhance the capabilities and accuracy of these techniques as a means of continuous improvement.

I. INTRODUCTION

Design and construction documentation record pipeline data such as manufacturing specification, dimensions, grade, and hydrostatic test pressures of each of the pipe joints making up the asset. These records will often include mill test reports generated by the manufacturer, which contain detailed information about measured chemical composition, results of qualification testing (including destructive testing performed to validate lot mechanical properties), seam weld type, and other information as prescribed in the applicable manufacturing specifications[1]. Assets obtained during subsequent commercial acquisitions and/or constructed prior to the era of digital recordkeeping are less likely to have the depth and granularity associated with current industry best practices. Development of in-line and field non-destructive examination inspection tools with the capability to characterize the pipeline material properties in-situ would permit post-

[1] American Petroleum Institute Specification 5L: Specification for Line Pipe.

construction validation of operator records, assist in integrity decisions as the asset ages, and allow for better optimization of in-service welding procedures.

This paper describes some of the techniques available for identifying baseline pipe data using both in-line inspection and field measurements with multiple technologies, including a case study, a discussion of industry experience, and references to relevant industry research projects in this field.

II. IN-LINE INSPECTION TECHNIQUES FOR DETERMINING SEAM WELD TYPES

Most common in-line-inspections are able to distinguish between different weld types such as long seam double submerged arc welded (DSAW) pipe, spiral DSAW pipe, and electric resistance welded pipe by virtue of the pronounced weld caps inherent in any double submerged arc welded pipe. However, vintage electric resistance weld seams have a characteristic geometry that can be mistaken for DSAW seams. Distinguishing between electric resistance weld seams and seamless pipe can usually be inferred by the local wall thickening and artifacts from the weld upset trim operation inherent in the electric resistance welding process.

Despite the available techniques for distinguishing weld types using in-line inspections, reliability metrics for seam type identification are not established by the ILI vendors. Also, differences in metallurgical properties within a particular seam weld type (toughness, hardness, microstructure, etc.) are not detectable with these or any other commercially available in-line inspection tools. These limitations warrant further technology development related to seam weld determination, as gathering this information with available methods requires additional field inspections which can be costly and only provides information regarding the excavated areas.

III. IN-LINE INSPECTION TECHNIQUES FOR DETERMINING MATERIAL PROPERTIES

Commercial in-line inspection products on the market today can assist in determining relative differences in strength along the length of the pipeline. Different combinations of inspection technologies can be used to determine the material properties using proprietary techniques unique to each vendor. Some methods use a variety of magnetic flux leakage and high-resolution caliper tools while others use eddy-current tools along with pipe magnetization. Analysis is performed based on the available data to group similar pipe joints and identify the different populations of pipe present across the pipeline segments. These populations can then be validated and further assessed using available material test records and results from in-ditch verifications. The locations for verification are selected by considering the populations and any discrepancies or locations of specific concern.

In a 2011 case study, an operator's natural gas service pipeline was inspected using a commercial material properties inspection technique. The in-line inspection tool reported that the magnetic flux leakage signature differences between the primary tool module (performing the corrosion assessment of the pipeline) and the residual module (used to degauss the magnetism from the pipeline post inspection). When assessing the tool data, the analysts used the inspection results to characterize the material density along the pipeline, comparing the material density signals to known grade changes along the pipeline from prior in-ditch inspections to identify areas of signal differences as shown schematically in Figure 1. At the time, the vendor could not quantify the grade or changes, only that a change was occurring, as shown in the schematic below, where the color of the horizontal line (green, orange, and purple), represent different groupings of pipe with similar material properties. Through this analysis method, the number of in-ditch assessments required to validate the material properties was minimized to those areas of the pipeline that exhibited differences in signal as called by the analyst and identified as Grade Digs 1 through 7. In addition, four joints were identified as having different metallurgical patterns and were determined to be associated with prior repair sites. Following the assessment, the pipeline operator performed destructive testing for the in-ditch assessments to support the validation of material properties.

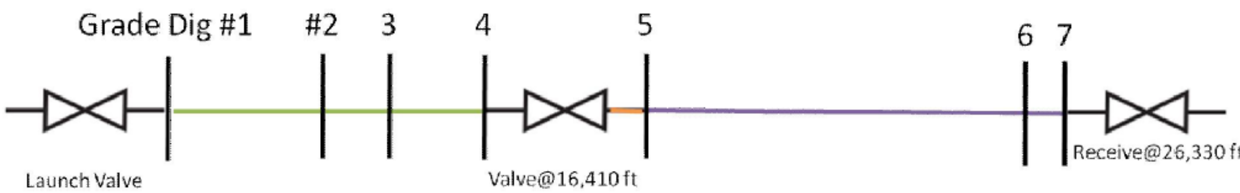

Figure 1: Example Method to Determine Pipeline Material Property Change Locations

Although not widely used in the industry at present, in-line inspection techniques have been shown to provide a beneficial technology to assist in determining material properties.

IV. FIELD NON-DESTRUCTIVE TESTING TECHNIQUES FOR DETERMINING MATERIAL PROPERTIES

In order to validate the in-line inspection results for mechanical properties or simply to gather more information about the material properties of a given pipeline, significant costs have historically been incurred by operators to perform destructive testing at select joints. In doing so the pipeline would be excavated, taken out of service, and cleaned; so that the pipe material could be sent to a lab to compare the destructively tested mechanical properties to those required by the American Petroleum Institute[2]. In addition to the high cost, this approach is susceptible to sampling errors due to the limited number of areas tested. Recently, through multiple joint industry projects between operators, manufacturers, private engineering firms, and research groups such as Pipeline Research Council International (PRCI), industry now has the ability to perform in-ditch non-destructive testing of the pipeline materials rather than cutting out coupons for destructive testing. These methodologies are not currently recognized in regulations, but use of these methodologies has been allowed in some cases.

While field testing for chemical composition is insufficient to establish grade or mechanical properties in isolation, it can be employed as positive material identification to verify expec-

[2] American Petroleum Institute Specification 5L: Specification for Line Pipe.

tations, identify probable ranges, and/or ensure that in-service weld procedures are optimal and compliant with applicable codes and regulations. API Recommended Practice 578[3] describes a number of technologies suitable for this purpose, including portable X-ray fluorescence and optical emission spectrometry (such as shown in Figure 2). Both technologies work by exciting atoms on the surface of the pipe which causes them to emit a characteristic electromagnetic spectrum for subsequent analysis. Recent advances in the portability and precision of these units have led to their displacing laboratory chemical analysis, which was slow to produce results and required the removal of significant amounts of material from the pipeline.

Figure 2: Portable Optical Emission Spectrometer[4]

Non-destructive portable field hardness testing[5] is a well-established technology that utilizes a standardized load and indenter to measure material hardness and make inferences about strength. More recently, a number of field-equipped non-destructive examination technologies capable of completing in-situ material property assessments have emerged out of research and development efforts targeted at providing immediate in-ditch local yield strength, longitudinal weld seam type, and weld/heat affected zone toughness measurements. In addition, some methods are capable of assessing the longitudinal seam weld area to obtain toughness albeit with a degree of error.

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[3] American Petroleum Institute Recommended Practice 578: Guidelines for a Material Verification Program for New and Existing Assets.

[4] Image from Hitachi High-Tech Analytical Science website, https://hha.hitachi-hightech.com, accessed May 23, 2019. Intended as an example of a practical application of the technology and does not represent an endorsement or review of any particular measurement device.

[5] ASTM E110 Standard Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers.

Those technologies/methodologies that are currently commercially available were recently tested by PRCI[6]. The goal of the PRCI study was to validate the reliability and accuracy of several different NDE methodologies for predicting material properties as well as to establish a consistent field-testing protocol. As part of this study four methodologies were tested and results suggested that there has been a measurable improvement in the area of in-situ materials characterization since 2014.

Additional development is still needed particularly in the area of microstructural analysis where the variability between the field and lab assessment results are the greatest. Additional research and development efforts are currently underway to improve the accuracy and reliability of seam weld toughness assessments.

V. CONCLUSION

Well established technologies are capable of distinguishing weld seam types via in-line inspection and in-field hardness testing. Improvements in the portability of optical emission spectrometers has led to more widespread use as a valuable tool for verifying mill test report information in the field and selecting appropriate in-service welding procedures. More recent technological advances have expanded operator abilities to characterize the pipe yield strength along the length of a pipeline via in-line inspection when supported by an in-field technical test program based on destructive test sampling and/or inferences of strength from non-destructive field hardness testing. These approaches have not yet received regulatory acceptance, although they have been accepted in specific cases as a means of confirming pipe properties in the absence of reliable records. Broader validation and continual improvement of these approaches is ongoing.

[6] PRCI project NDE-4-8: Validation of In-Ditch Material Characterization Technologies, project PR-335-173816, report released May 8, 2018.