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To refurbish or replace steel water pipelines, that is the question

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Abstract

Underground steel water pipelines that are not suitably coated and lined will corrode after a certain period of time, externally where the steel is in contact with the soil and internally where the steel is in contact with water. Such corrosion results in the thinning of the pipeline walls, reduction in the mechanical strength due to this thinning and finally possible failure of the pipeline. The integrity of older pipelines can be investigated by conducting a series of tests on the pipeline, both destructive and non-destructive, to determine the condition of coating and lining of the line pipe, the mechanical properties, and the extent of the thinning of the pipe walls. The results of these tests are used to determine whether refurbishment or replacement of the pipeline is the most viable option. This paper reports one such case study. © 2001 Published by Elsevier Science Ltd.

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1. Introduction

Many steel pipelines that have no corrosion protection leak due to damage caused by corrosion. Corrosion will occur in areas where environmental differences create galvanic cells in the presence of oxygen and moisture. This happens in a number of ways where steel pipelines are in contact with soil externally and water internally. Such corrosion damage results in product loss, costly repair procedures and eventually it becomes necessary to replace the pipeline at a great cost.

Testing procedures have been developed to detect potential corrosion problem areas, so that the required corrosion protection techniques can be applied before the damage necessitates replacement of the pipeline. On older pipelines, however, it becomes necessary to analyse the cost to repair a pipeline

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and the subsequent service life of the pipe, versus the cost of replacing the pipeline. This paper will report one such case study.

2. Background

Due to the high incidence of leaks and the associated increased maintenance costs of a 450 mm diameter steel pipeline, an internal and external corrosion assessment of the pipeline was carried out. This was done to determine whether refurbishment or replacement was the most viable option.

The 400 mm diameter pipeline has been in operation since 1974. It has a bitumen internal lining and a bitumen fibre-glass external coating. The pipe sections are joined via Viking Johnson (VJ) couplings. No cathodic protection was in place on the pipeline. The increase in the frequency of leaks prompted the owner of the pipeline to investigate the refurbishment and replacement options. The corrosion investigation was carried out in two phases:

Phase 1 Line pipe characterisation and assessment of internal corrosion on six cut out pipe sections and three VJ couplings. Line pipe characterisation is done by means of mechanical tests on a section of pipeline, chemically analysing the content of steel and non-destructive testing on the coating, lining and wall thicknesses and measuring corrosion pit depths. The results are used to predict remaining service life of the pipeline based on environment and operating pressures.

Phase 2 A DC voltage gradient (DCVG) survey and visual inspection of defects to assess the external corrosion conditions. A DCVG survey is an overland technique used to pinpoint coating defects from the soil surface with a high degree of accuracy. This is done by measuring the voltage gradient that is established in the ground by applying direct current to the pipeline via an external source. The cathodic protection system on the pipeline is used to supply the current. In addition, the technique allows for the ranking of defects in terms of severity, as well as an approximate indication of the corrosion status (anodic or cathodic), both with the cathodic protection turned on and off.

3. Phase 1: metallurgical analysis

3.1. Visual examination

Six cut out pipe sections of approximately 200 mm width and three VJ couplings were examined. Lining and coating on the pipe sections and VJ couplings and the metal surface of the pipeline, once the coating and lining had been removed were examined.

3.1.1. Results and discussion of visual examination

The visual examination of the six pipe sections revealed that the lining and coating of most of the samples received were in poor condition. On some of the samples the coating and lining had completely degraded and no coating or lining was present. On the remaining samples only remnants of the coating and lining remained. Removal of the coating and lining showed metal loss in the form of numerous evenly distributed pits externally and isolated pitting internally. Since, tubercular deposits were found internally on some of the pipe sections, the localised internal pitting occurred, perhaps, due to sulphate reducing bacterial (SRB) attack. This was confirmed by energy dispersive X-ray spectroscopy (EDS) of tubercular deposits showing high sulphur content. Thinning of the walls of the pipe section cut out at joints was also noted. This was due to a combination of crevice corrosion and SRB attack.

As with the pipe sections examined, the coating of the VJ couplings was seen to be in poor condition resulting in evenly distributed pitting. Extensive pitting internally on the VJ couplings was noted, this probably being due to a combination of crevice corrosion and SRB attack. The localised nature of the internal pitting is a further indication of SRB attack.

3.2. Mechanical testing and chemical analysis

Transverse tensile testing was carried out according to ASTM A370 on all pipe sections and VJ couplings. Hardness tests were also carried out on the samples received using the Wolpert test machine with indentation load of 10 kg. Bulk hardnesses were determined on transverse cross sections that had been mounted and prepared to a 1 μm finish.

Spark chemical analysis was done on all the samples received.

3.2.1. Results and discussion of mechanical testing and chemical analysis

The mechanical tests and chemical analysis were done to confirm conformance of the steel grade used to manufacture the pipe sections and the VJ couplings. The steel grade was found to be API 5L Grade B, this observation was made based on the results obtained from the hardness measurements and tensile test results. The sulphur content of both the pipe sections and the VJ couplings was found to be high, but both the pipe samples and couplings conformed to the API 5L Grade B specifications.

3.3. Metallographic examination

The mounted and prepared transverse sections of pipeline and VJ couplings were etched in 2% Nital to reveal the microstructures. The microstructures were then examined under the microscope.

3.3.1. Results and discussion of metallographic examinations

The micrographs for the six pipe samples showed relatively fine grained microstructures, predominantly of ferrite with some areas of pearlite which would add to the ductility of the material and would lead to the acceptable elongation values. The micrographs of the VJ couplings showed coarse microstructures. The layered appearance was indicative of a rolling operation being performed.

3.4. EDS

The EDS facility of the scanning electron microscope (SEM) was used to determine the nature of internal tubercular deposits found on pipe sections 3 and 4.

3.4.1. Results and discussion on EDS

EDS was carried out to find out the nature of the tubercular deposits found on the inside of the pipeline sections. The aluminium and silicon peaks indicated water borne deposits such as silicates and aluminium hydroxides. The prominent iron peaks were clearly related to iron rich corrosion products including iron hydroxide and haematite. The sulphur peaks indicated the presence of sulphate reducing bacteria which correlate with the extensive pit formation internally on the pipeline.

3.5. Non-destructive testing (NDT)

A wall thickness survey was conducted using the ultrasonic pulse-echo contact technique and the Stresstell Gridnite Gauge (digital thickness gauge) calibrated using the steel step wedge. Pit depth measurements using the mechanical techniques and the Elcometer 123 clock instrumentation were also carried out on all the pipe and VJ coupling samples.

3.5.1. Results and discussion on NDT

The wall thickness survey, in conjunction with the pit depth measurements that were carried out, indicated that the smallest detected wall thickness was 2.02 mm. The following formula was used to calculate the maximum permissible pressures so that relevant information could be obtained with regard to the refurbishment or replacement options:

$$P = \frac{2St}{D}E, \quad [1]$$

where P is the maximum permissible pressure (bar); S is the maximum yield strength (MPa); t is the smallest wall thickness (m); D is the outside diameter (m); and E is the quality factor determined to account for the likelihood of stress raisers in the pipe wall (values tabulated in Ref. [1]).

The maximum permissible pressure was calculated to 20.5 bar using this formula and the operating pressure of the pipeline was given to be 6.0 bar. It should be borne in mind, however, that the sections that were sent in for analysis may not represent the worst case condition.

3.6. Phase 1: conclusions

The material used for the manufacture of the pipeline and VJ couplings was found to be API 5 L Grade B. The visual examination of the submitted samples showed that the lining and coating of the pipeline and couplings was considered unacceptable. Extensive pitting was apparent both externally and internally on all the pipe sections and couplings received. The pitting was found to be a combination of SRB attack and crevice corrosion. The NDT results showed that the minimum wall thickness found was 2.02 mm. Subsequent to the calculations carried out using the minimum wall thickness measurement, it was found that cement mortar lining of the pipeline was a viable option. It was, however, recommended that the external condition of the coating and the extent of external corrosion along the entire length of the pipeline be assessed prior to any final decision on refurbishment or replacement of the pipeline.

4. Phase 2: DCVG survey

4.1. Introduction and background

The DCVG survey was conducted based on the Phase 1 recommendations. The DCVG technique was designed to detect coating faults on underground steel pipelines. This is done by the application of DC in the same manner as cathodic protection. A voltage gradient is established in the ground due to the passage of current through the soil to the coating defect. The voltage gradient concentrates at the coating defect, and, in general, the larger the coating defect, the greater the current flow and hence the voltage gradient. The out of balance between two $Cu/CuSO_4$ half cells, created by the voltage gradient is measured on a sensitive millivoltmeter. Interference originating from other DC sources is eliminated by installing a switch which switches the DC 1 cycle per second in the ratio of 2/3 OFF and 1/3 ON. Once the voltage gradient has been established and the interrupter switch installed in the system, the coating defects are located and ranked according to a severity/size percentage measurement (%IR). After all the defects have been located and ranked, a number of these are selected for excavation and visual inspection. This is done to correlate the severity rankings with the visual inspection and hence gives a better overall picture of the coating condition of the pipeline.

4.2. Methodology

Two isolated sections of the pipeline were surveyed due to the fact that the pipeline traversed under tarred roads, which made contact between the $CU/CuSO_4$ electrodes and the soil impossible. In addition to this, the presence of VJ couplings could severely limit the length of pipeline to be surveyed due to the resistance, and the insulation effect that VJ couplings sometimes cause between pipe sections. This problem was overcome by measuring the DC signal at frequent intervals along the length of the pipeline.

The pipeline in question does not have a cathodic protection system. A temporary portable CP system was used to conduct the DCVG survey. This temporary CP system was set up at two locations such that the two isolated sections of pipeline could be surveyed.

4.3. Phase 2: results

During the DCVG survey of Section 1 a total of 30 defects over a distance of 567 m were located and ranked. A total of 33 defects over a distance of 263 m were located in Section 2. Table 1 shows the defect size/severity distribution of these defects. The results presented above in Table 1 are plotted graphically below in Fig. 1 in comparison to a typical distribution of a pipeline coating in relatively good condition. It is evident from Fig. 1 that the severity distributions of both Sections 1 and 2 deviate substantially from that of a typically well-coated pipeline.

Eleven of the 63 coating defects located were excavated and visually examined. At two locations in Section 1, leaks were found. At the 11 defects excavated, the coating condition and adhesion was found to be generally poor.

4.4. Discussion

The DCVG survey results showed that a relatively large number of defects per meter were found (one defect every 8 m for Section 2 and every 19 m for Section 1). This in conjunction with the comparison to the defect distribution data of a relatively well-coated pipeline, is indicative of an external coating in poor condition. The excavation and examination of 11 defects further confirmed this finding.

Table 1
Defect severity/size distribution for the two sections of pipeline

%IR size/severity rankings	Number of defects	
	Section 1	Section 2
0–15% (Small)	7	2
16–35% (Medium)	7	10
36–70% (Medium/large)	10	20
70–100% (Extra large)	6	1
Total	30	33

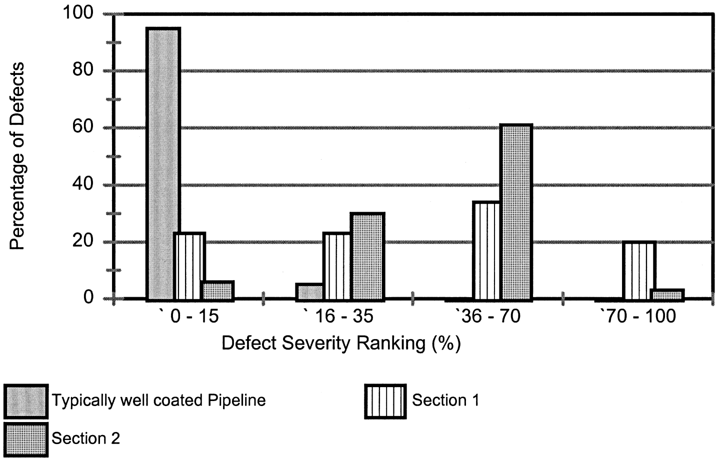

Fig. 1. Severity distributions of Sections 1 and 2, shown in comparison to the severity distribution of a relatively well coated pipeline.

4.5. Phase 2: conclusions

A total of 63 defects over a distance of 830 m were located and ranked according to the DCVG survey technique. The high number of defects over a relatively short distance is indicative of a coating in generally poor condition. This fact is further compounded by the findings of generally poor adhesion and damaged coating during the visual inspections done at the excavations. In view of these findings, it is likely that the poor condition of the coating would prevail along the entire length of the pipeline.

5. Overall discussions and conclusions

Based on the findings of the Phase 1 and Phase 2 operations, the condition of both lining and coating of the entire length of the pipeline was considered to be poor.

Refurbishment of the pipeline is a viable option for continued use of the line, but this would include the excavation and re-coating of the entire pipeline, the continuity bonding of all VJ couplings, as well as the removal of the lining before re-lining the pipe. The associated costs of such an exercise would be large. The decision to either refurbish the pipeline or replace it would be heavily dependent on the associated costs versus expected life of the pipeline.

References

[1] ASME Standard B31.1. Chemical plant and petroleum refinery piping. New York.