International Journal of
Science and Engineering Investigations
vol. 6, issue 65, June 2017
ISSN: 2251-8843

Failure Analysis of a Natural Gas Pipeline-Case Study

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Abstract- This paper discusses the failure of a natural gas pipeline due to stress corrosion cracking (SCC). It was diagnosed that the SSC was magnified by coating disbondment. High-density polyethylene coatings are vulnerable to disbonding. Disbonding can be initiated by either cathodic protection systems and osmotic conditions or a combination of these. External soil stress accompanied by the diffusion of moisture, oxygen, and carbon dioxide under the pipeline coating created a corrosive environment, initiating cracks into the pipe structure. The paper addresses how altering cathodic protection criteria, repairing coatings on weld joints or the welds themselves, and using coatings less sensitive to disbonding can reduce stress corrosion cracking-induced pipeline failures.

Keywords- *Stress Cracking Corrosion, Pipeline, External Corrosion, Cathodic Protection*

I. INTRODUCTION

Hydrocarbon is the main source of world's energy [1]. Transportation via pipeline is popular means in oil industry. Oil and gas pipelines suffer from a wide range of corrosion attacks [2]–[9]. Disbonded coatings leading to external pipe corrosion is one of the serious problems that oil & gas industry has been facing in pipeline management. Steel pipes protecting with organic coatings should stand sources of stress like transportation, embedment operation and soil pressures. In all of these procedures, defect emerging is very possible in the coating structure[10], [11]. To make sure that pipes are perfectly protected from corrosion, cathodic protection (CP) is applied as a complimentary method along with organic coating on steel pipes [12]. Developing corrosion under the fully disbonded coatings, external surface of the pipes, that are under CP is a serious problem. In fact, this dangerous phenomenon may lead to a disaster. This matter should be deeply considered when the CP system is not able to convey electric potential into the disbonded area of the pipe [11], [13]. When a coating is disbonded, the status of pipe and soil potential on the surface may be vague. This misty status can lead to damage in the pipelines. This is a matter of notice especially for old used coating that does not have non-shielding properties. This work addresses main the reasons of occurred damages in the pipelines of an Iranian gas gathering field. The pipeline network is well protected with CP system. The main reason for the occurred damages was found to be cathodic shielding phenomenon in heat shrinkable sleeve applied in weld joints which led to stress corrosion cracking (SCC) and consequent damages. External corrosion direct assessment and securing the pipe network considered for safety of both personnel and production. Some measures applied to prevent or mitigate cathodic shielding phenomenon.

II. CATHODIC SHIELDING

Cathodic Protection (CP) systems applied on pipe can cause coating to be disbonded from the pipe surface. This usually happens due to peripheral conditions and forming chemical reactions. This phenomenon, disbonded coating, is due to CP current and is called cathodic disbonding. Usually, cathodic disbonding is initiated from the location of damages into the coating and develops axially around the defects. The main reason for existence of defects in coating is the increase of electrolyte PH in the common surface of the pipe and coating. Often, the value of pH at the edge of disbonded coating is higher. This is related to factors like the speeds of cathodic reactions, cathion diffusion speed and the shape of disbonded area.

Hydrogen reduction reactions in acidic circumference include oxygen and hydrolyze reaction in cathodic or neutral comprise oxygen. All of these reactions increase PH and accumulation of hydroxide ions under the coating. PH value can be above 12 in the edge of disbonded area of coatings. In caustic cathions, the value of PH for solution can reach to 9.2 and then is limited by iron hydroxide saturation.

In the presence of CP system, hydroxide ions near to the holes can move to contact surface of metal and coating. Such immigrations can intensify the cathodic disbonding process. There many factors that help, lonely and together, speeding up the coating disbonding. From all these factors some are mentioned here; weakness in foundation preparation of the pipe external surface, defects in pipe construction, weak performance of supervisory organizations and quality control units in accurate controlling of the pipe construction from A to Z, miss electing of material, remaining of stress in coating layers, effect of mechanical stress on coating due to hydrostatic test, variation in temperature during pipe operation, soil stress, diffusion of humidity under the coating either in construction or pipe operation stages and etc.

Existence of holes and lack of adhesiveness are the main defects of coating. Such defects can expose pipe surface to electrolytes. Emerging holes in coatings and disbonding can be occurred via different conditions. Surface impurities due to remaining of corrosion products under coating and captivation of hydrophilic solvents, existing in structure of some coatings, under coating may lead to osmosis phenomenon, physically and chemically. In osmosis condition, the absorbing force of water can move to the pipe surface via coating. Existence of a water film and forming corrosion products under the disbonded coating lead to lowering the adhesiveness of coating on the pipes.

In some cases that the coating has no holes, including needle defects and holidays, the rate of ion diffusion can be ignored in contrast with the rate of cathodic current. It is difficult to determine if a coating remain virgin, with no holes, or not. There are ways for penetrating vapor, oxygen and carbon dioxide through the coating and reaching pipe surface. These ways may be such as; locations that coating is scratched by rock, overlap coating, local damages during coating repairmen and via connection points of cables, from scarifying anode underground, which are cad welded to the pipe. All of these conditions have negative impact on CP system and lead to losing its efficiency for protecting certain areas of the pipe. Therefore, the consequence is the activation of corroding centers under the coating in disbonded points. In general, corrosion rate is highly associated with oxygen diffusion. This matter can be intensified by an increase in temperature and lead to cause defect in coating; therefore, CP system would not efficiently protect the pipe because of cathodic shielding.

The definition of cathodic shielding covers conditions which lower cathodic current to the metal surface. This is a matter of notice when current intensity is lesser than the least required current for protecting pipe surface from corrosion (polarization). Cathodic shielding occurs when a CP system, designed and installed appropriately, cannot protect the pipe due to incontinuity in the electrolyte path between anode and pipe or the long gap between them. The consequence is that pipe potential does not meet the protective potential. This weakness however is not recognizable in regular inspections.

Likewise disbonding phenomenon, emerging blisters into the coating can lead to electric shielding. In such conditions, the CP system would not be effective under the blisters and the pipe is exposed to the corrosion risk. Cathodic current reach disbonding area through the formed solution layer under the coating. Indeed, CP current should overcome both ohmic resistance of the solution layer and polar resistance between the existing gap of solution and pipe. In this condition, as the distance from the holes location increases, the current potential under the layer becomes less negative.

When the cathions reach the disbonded location, by means of CP system, anions like chloride would be confined. Thus, pitting corrosion can be occurred.

III. DISCERNMENT OF SCC

Any coating system has a limited life. Upon the decadence of coating, water, oxygen and other chemical factors can reach the pipe surface via coating. In such circumstances, increasing CP current is often the only proper solution for preventing the pipe being corroded. Increasing cathodic current can’t be always effective; therefore, the pipe may keep the corrosion process, unless the defective coating be repaired or replaced. Although firms that manufacture coating, play an important role in providing standard defect less coatings, much of the deficiencies in coatings are because of weakness in pipe foundation, construction techniques, soil and other stresses, lack of harmony in coating material and the environment conditions, operating temperature and etc. lack of necessary experience with executive contractors, supervisory organization and quality control have been intensifying the coating issues.

If adhesiveness of coating fails, pipe will force with cathodic shielding. Question is that what happens in this status. Acidic environment and PH near to neutral which develop under the disbonded coating, showing shielding behavior, have direct impact on emerging cracks and fragments in pipe. In general, changes in the properties of pipe can be considered as a defect. Principally, CP shielding comprises risks for pipeline such as pitting and general corrosion, microbial corrosion and SCC in PH near to neutral. If defective coating is not a hinder to transferring cathodic current then ordinary monitoring can be applied for CP system to be sure of the quality and wholesome of the pipe. If weakness in coating adhesiveness coincide with water penetration under the coating, two status will be possible; first, possibility is that of shielding a portion of cathodic current. Second, cathodic current may be shielded entirely. Both of these status lead to corrosion, but the latter involve more aggressive corrosion and thus considerable damages. In most of the cases, severity and type of corrosion depend on the electrolyte that is in existence under the coating. Likewise pitting and general corrosion, microbial, SCC in caustic and acidic PH and corrosion around the longitudinal and peripheral filler wire of the pipe.

IV. FAILURE ANALYSIS

An 8-inch pipeline, transferring natural gas from well to gas gathering unit, southern Iran, experienced an explosion which was due to SCC. Corrosive environment under the disbonded coating and also stresses from soil around the pipe caused slight cracks into the pipe. Stresses from flowing fluid into the pipe helped development and growth of formed cracks and led to SCC and then explosion as shown in Figure 1.

Figure 1. The failed natural gas pipeline due to SCC

V. DIRECT CURRENT VOLTAGE GRADIENT & CLOSE INTERNAL POTENTIAL SYSTEM

Considering an underground pipe which is protected by cathodic system, in the location of ruined coating, the pipe would be connected to the earth. It is obvious that protective current will enter into the pipe, from soil, through the ruined coating. The amount of protective current can be ignored when coating has good quality with no damages. Entering current into the pipe via soil, considering soil resistance, cause voltage loss of soil around the damaged coating. The consequence of this is forming concentric circles with different potential. Voltage loss (gradient), is proportional to severity of the damaged coating. Sever damages in coatings lead to higher gradient of voltage. Voltage gradfient is also a function of special resistance of the soil around the damaged coating. At the current work, we applied CIPS and DCVG procedures and detailed describing these two monitoring approaches, for CP system, is out of this issue.

CIPS includes measuring potential in close intervals of pipe. The following trends are the results of the two mentioned tests which signify that the pipes are under CP.

VI. CONCLUSIONS

Based on the occurred explosions in the natural gas transmission pipeline, a procedure provided for pipe excavation and external corrosion direct assessment. Such measures are taken to secure the safety of personnel and production. A distance of 200 meter from both wellhead sites and gas gathering units were excavated. The results of investigation and comparison with standards like ASME B31.8 and ASME B31G 2009 are shown below. After ECDA and then sand blasting, tape wrapping was performed with inner layer, 3ply PE CO extrude, and outer layer with 50% overlapping. Next, after Holiday Detector Testing, pipe backfilling was performed according to NACE RP0188. In order to avoid disbonding phenomenon, according to NACE standards, 100 mv polarization shift criterion was regulated.

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