Stress corrosion cracking in pipelines

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Abstract. Stress corrosion is viewed as cracking of a pipe metal in cathodic protection regions of gas transmission pipelines, which are simultaneously affected by various unrelated, at first glance, factors. Stress corrosion is otherwise referred to as stress corrosion cracking or SCC. Stress corrosion cracking of pipelines is the main cause of emergencies in gas transmission pipelines. Currently, this type of corrosion is widespread and very dangerous. The reliability and safety of modern pipelines is of great national importance. Despite being significant, multiple efforts to address this problem have not yet identified the causes and algorithms for handling stress corrosion.

1. Introduction

There are many different considerations and theories to understand the nature of this phenomenon. They are followed by all sorts of implications and recommendations. Some experts recommend individual steel grade for major pipelines, others recommend more highly efficient insulating materials, while others recommend that pipeline construction should be revised and updated. There are even proposals to treat the soil with special compounds entirely throughout the pipeline. However, in fact, none of them will completely address stress corrosion algorithm at large, since they “extract” only one or several involuntary components from the whole gamut of factors and bonds. Meanwhile, the very phenomenon of this type of corrosion still remains unknown. In the fight against stress corrosion, one can hardly rely on success without clarifying such a physical (mechanical, chemical) model [1–4].

Stress corrosion mechanism should explain all facts available and respond to a number of questions, including the following:
- in what way does electrochemical protection (ECP) affect stress corrosion?
- what properties need to be developed to effectively inhibit stress corrosion?
- what is the role of insulation coating in stress corrosion (bitumen, film, factory-made)?
- why does stress corrosion often occur over gas transmission pipelines and does not do at all over oil transmission pipelines, over pipelines of gas supply systems, over field pipelines?

2. Materials and methods

The research plan is composed of the following:
- addressing the relevance of this problem and streamlining the evolution of stress corrosion over
major pipelines;
  - evaluating all results available and shaping the main prerequisites for stress corrosion cracking of pipelines;
  - developing and building up a physical model of pipe stress corrosion, establishing the foundations of this type of corrosion;
  - comparing specimens of pipe metals taken from the fracture zone.

3. Results and Discussion
Stress corrosion cracking differs from other types of corrosion. Stress corrosion in pipe walls causes parallel axial cracks. Stress-corrosion cracks in an annular direction occur in those sections of pipelines where there is an elastic bending, and, as a consequence, there are significant bending stresses that are in the longitudinal direction. The outer surface of the metal actually cracks in a stress corroded area and advances deep into the pipe wall, with structural changes of the metal to occur simultaneously. However, the inner surface of the metal still remains plastic.

The elements, including hydrogen, carbon, nitrogen, etc., that can enter from the outer surface, cause the embrittlement of metal, which is possible at high temperatures alone. One of the main elements to induce stress corrosion is hydrogen (H+).

The pipe surfaces are negatively charged and therefore a positively charged hydrogen cation will be attracted to the metal. After that, the hydrogen cation is neutralized in the metal surface. Then, the only electron, a hydrogen atom, becomes a part of the electron cloud of metal, and the remaining core is like a proton, i.e. an elementary particle. Further, the proton can easily enter the metal and retain great mobility and activity there. In addition, increased concentrations of the proton in the metal entails an increased internal stress. In turn, the internal stress is combined with external stresses, and such formations cause cracking of the pipeline. Therefore, the stress-corrosion mechanism comprises several stages:
  1) incubation period is related to the intrusion of hydrogen atoms deep into the metal;
  2) initiation and growth of microcracks, further accumulation of gases, assembling of microcracks, expansion of cracks to the sizes observed through diagnosis methods;
  3) crack propagation under internal and external forces;
  4) destruction of the major gas pipeline.

Currently, it is believed that many factors influence this type of corrosion: chemical composition and soil moisture, weather conditions, temperature interval, vibrations, residual stresses in the major pipeline, stresses induced by many types of loads, deployment of a pipeline region close to the compressor station, terrain, steel grade, the presence of certain microbes in the soil and many others. Most likely, this is all true. However, all these factors alone will not be able to trigger the stress corrosion mechanism. They only have the ability to enhance or weaken the effects of the main factors: hydrogen and stress [5–7].

Several external factors affect the rate of the first stage, namely the release of atomic hydrogen in the metal surface. The external factors embrace the status of the insulation coating (defect, lack of adhesion), the “ground-pipe” potential difference, the state of metal surface, the chemical composition and saturation of substances in ground water, the pH of the medium (acidity), humidity, vibrations, weather conditions, environmental temperature (soil).

The rate of the second and third stages, namely the propagation of hydrogen into the metal and the processes occurring inside the metal is affected by some internal factors. These include the chemical composition and structure of the metal, the temperature of the metal, the stress state. Moreover, stresses induced by working pressure, as well as external and internal impacts play a crucial role. The latter involves those acting on the crystals and dislocations.

Thus, some factors, like temperature and vibration, fall within both internal and external factors, since they affect all processes that occur both outside and inside the metal.

Unlike other types of corrosion (for example, chloride), corrosion cracking of steels can start and develop not only in the surface, but also inside the metal as such.
A very important conclusion can be derived from this assumption, which may become crucial in ensuring the protection of gas pipelines from stress corrosion. In fact, given that atomic hydrogen is prevented from occurring in the metal surface, all other processes to entail stress corrosion cracking will be stopped as well. These processes will lack a single and principal participant in the process, otherwise known as hydrogen (similar to the fact that if oxygen is excluded, there will be no oxidation) [8, 9].

This assumption is not yet a physical stress corrosion model, but, subject to the outcomes of some further studies in line with the tasks assigned, claims to be.

A comparative analysis shows that gas transmission pipelines (in those sections where stress corrosion is detected) have large diameters and are exploited under high pressures. This means that mechanical stresses in the wall of major gas pipelines are much higher than in all other pipelines. Accordingly, high tensile stresses in the pipeline wall are considered to be the main factor determining the conditions favourable for stress corrosion.

The main stages of the physical model for stress corrosion in major pipelines are:
- Atomic hydrogen is generated in the pipe surface and accumulated in the metal.
- Atomic hydrogen enters the metal in the form of a proton gas (proton).
- Increased tensile stresses result in faster hydrogen propagation into the metal.
- Currently it is proposed to introduce a new concept of “stress corrosion strength”. Each metal has stress corrosion strength that characterizes the threshold at which stress corrosion is noticeably accelerated. Below this level, there is almost no stress corrosion.
- Based on this physical model, it was found that the intensity of atomic hydrogen generation in the surface of the pipe metal depends on the quality state of the insulation coating and the operation mode of the electrochemical protection system.

Each individual crack tends to reduce the stress intensity factor about all other cracks. Therefore, a line of parallel cracks is less dangerous than a single crack of the same size. Based on the findings, strength criteria are stated as applied to a stress-corrosion defect [10].

Insulation materials need to be selected properly when it comes to the repairs of existing gas pipelines affected by stress corrosion. In almost all cases, a stress-corrosion defect accompanies the unsatisfactory state of a film insulation coating. In some regions, the adhesion completely disappears, and the film easily moves away from the pipe. In fact, the film coating turns into a kind of shell that contains a pipe within, whereas ground water accumulates between the pipe and the shell. In this case, the pipe does not only have protection against stress corrosion, but partially loses its protection against general and pit corrosion despite the “protection” capacity.

A method is proposed to stop stress corrosion in gas pipelines by restoring the insulation coating through new materials with chemical activity and inhibitory properties.

Being aware of stress corrosion algorithm in major pipelines explains all the above mentioned features and patterns of this phenomenon, and provides the possibility to justify stress corrosion in certain sections of pipelines.

This phenomenon implies that the development of local stress corrosion is possible in oil pipelines in the regions where two conditions appear simultaneously: 1) there is a stress concentration in the form of defects or welded joints; 2) in this region the insulation coating is missing or worn. Stress corrosion is among the deterioration mechanisms (embrittlement and cracking) to affect the metal during long-term operation of pipelines.

4. Conclusion
Thus, hydrogen-induced cracking of a metal of pipelines goes through several stages:
1) generation of active (atomic) hydrogen in a metal surface;
2) atomic hydrogen propagation into a metal;
3) hydrogen-related processes occurring at the level of the microstructure of the metal.
Actually, these three points are the main elements constituting the physical model of pipeline stress corrosion. Provided that the mechanism proposed is correct, the protection of the pipeline from stress corrosion cracking should rely on the attempts to remove the source of atomic hydrogen off the surface of the pipeline. Since the insulation coating and ECP cannot be removed, it is worth selecting more effective insulation coatings. Thus, coatings must be highly adaptable so that the insulation of existing gas pipelines can be restored.

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