Construction of pipes resistant to stress-corrosion.

Main author

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Russia
ABSTRACTS

Introduction

Within the recent 10 years among the risk factors relevant to trunk pipelines destruction the most crucial becomes pipe metal corrosion cracking under stress or otherwise stress-corrosion.

In JSC "GAZPROM" underway are the works and managing measures dedicated to fight this fault. Involved in these activities are the leading experts of Russian industrial, academic institutes and universities and E.ON Ruhrgas AG.

Aim of the Study

JSC "GAZPROM" strategy of fighting stress-corrosion is prophylactics of its early signs, diagnostics and monitoring of less dangerous faults, repair of critical cracks or pipeline as a whole.

One of the prospective in our opinion working directions to provide prophylactics against stress-corrosion is to create pipes with higher resistance to stress-corrosion.

Methods

With this objective JSC "GAZPROM" now carries out the studies aimed at defining parameters of metal and technological processes of pipes manufacturing responsible for pipes resistance against stress-corrosion damages.

These works are based on successfully approbated method for pipe metal laboratory testing, maximally reproducing pipeline operation conditions.

Metal is tested under loadings in terms of its scale and nature comparative with stressed-deformation status of operating gas pipeline. As active medium are used actual soil electrolytes. Methods are elaborated to significantly reduce the time of sample exposure before stress corrosion cracking appears.

Results

Use of this method will allow to find out factors which if put together result in pipe metal stress-corrosion cracking and determine their critical parameters:

- Pipe steels chemical break-down and manufacturing technology defining steel susceptibility to stress-corrosion;
- Pipes forming and welding parameters defining the level and character of residual mechanical stress distribution over the pipe body;
- Threshold mechanical stress for starting stress-corrosion;
- Soils and soil electrolytes parameters;

Conclusion

As a result of these works will be defined the level of requirements to sheet products, process diagram of pipes moulding and welding, surface condition providing for higher pipe resistance to stress-corrosion cracking.
TABLE OF CONTENTS

Introduction

Aim of the Study

Methods

Results

Conclusion
Construction of pipes resistant to stress-corrosion

Recent years the tendency to geographical expansion of SCC revealments, also called stress-corrosion, appeared in the world gas industry. In the 1950s of last century refusals on main gas pipelines, caused by SCC, were observed in the USA. Since 1970s up to present time this phenomena reveals itself on Canadian and Russian gas pipelines.

Recently in connection with the development of pigging methods, the stress-corrosion damages of pipe metal were detected on the other gas supply systems, i.e. in Argentina, Germany, Ukraine.

Refusal caused by SCC of pipe metal might be followed by pipeline breaks (picture 1 at the bottom), gas losses and transportation interruption. This leads to huge losses for gas-transportation companies.

Considering the above, the main strategy of fighting SCC for branch scientists and maintenance crew is searching for methods of early diagnostics, prophylactics and preliminary
inspections of main gas pipelines that were subjected to SCC and trying to eliminate reasons for SCC on newly built gas lines.

Main directions of strategy for struggling with SCC in three parts of Complex Program of researching SCC, making up tools of technical diagnostic and also tools for saving and methods of inspection of main gas pipelines, liable to SCC:

- Researching of reasons for initiation and development of processes of SCC.
- Development of tools of in-line inspections.
- Making up tools and methods of diagnostic and repairing of gas pipelines, subjected to SCC.

Let's pay special attention to the parts of the Program.

Works of the first part aim to make up the technical demands to the pipes, firmness to SCC. In the same time it's necessary to detect the conditions of environment and stress-strain state of pipe's metal, led to SCC damage of the metal.

Detecting the aims of the first part of the Program we have collected all knowledge about the subject of the research.

SCC phenomenon is known for a long time. It appears on various metal and non-metal materials. Most common signs of SCC are groups of parallel cracks, orthogonal to main mechanical stresses and growing deeply perpendicular to the product's surface.

SCC appears to be the synergic process so the obligatory condition for it's running is the collection of following reasons (picture 2):

- Exceeding limit of threshold mechanical stress for the given material
- Existence of a certain environment that is special for each given material and that directly contacts surface of the material and causes cracking of the material in given stress-strain state.

![Picture 2. Groups of reasons for initiation and development of SCC](image-url)
Some types of SCC depend on temperature (carbonate-bicarbonate steel cracking; SCC of austenite steels in chlorides, etc) or on air moisture (“season” cracking of projectile cartridges during World War I).

There is an interesting natural phenomenon for SCC processes. Environments, active for SCC, are always passive for pitting and total corrosion for the same materials in unstressed condition (i.e. chlorides for austenite stainless steels). This also refers to stress corrosion on main gas pipelines:

- Groups of cracks, parallel to pipe axis can be seen on pipes of gas lines, if main stresses on this piece of pipeline are hoop exploitation stresses (picture 1 left at the top) for longitudinal-welded pipes and on picture 2 for spiral-seamed thermally improved pipes. If longitudinal stresses are higher than hoop stresses, as can be seen in case of bending stresses, cracking direction is perpendicular to pipe axis (picture 1 right at the top).

- Mineralization of environments, contacting with pipe metal is mainly the same as of drinking water and they are not active for pitting and total corrosion (picture 3).

- Potential signs of SCC on main gas pipelines usually are:
  - Diameter of pipes liable to SCC, mainly 1020, 1220, 1420 mm
  - Usage of cold coating for anti-corrosion isolation of pipes
  - Working pressure in pipelines and at compressor stations exit points – 5.4 and 7.4 MPa
  - Hydrogen index of soil electrolytes in SCC areas between pH = 5-7 (weak acidic or neutral environment)

<table>
<thead>
<tr>
<th>Komponenty</th>
<th>МГ Ужур-Енисей 1, 1383 км</th>
<th>МГ Красноярск-Куту- Серовский 2, 15 км</th>
<th>МГ Примош-Углов- Грандич, 530 км</th>
</tr>
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<tr>
<td>Калий</td>
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<td>16,16</td>
<td>2,48</td>
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<td>0,54</td>
<td>2,92</td>
<td>5,31</td>
</tr>
<tr>
<td>Фосфор</td>
<td>1,55</td>
<td>15,03</td>
<td>29,62</td>
</tr>
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<td>Хлориды</td>
<td>1,1</td>
<td>135,49</td>
<td>35,60</td>
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<td>Сульфаты</td>
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<td>2,34</td>
<td>207,45</td>
</tr>
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<td>19,27</td>
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<td>0,45</td>
<td>7,5</td>
<td>8,30</td>
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<td>Натрий</td>
<td>0,49</td>
<td>23,9</td>
<td>13,40</td>
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<td>0,32</td>
<td>0,73</td>
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<td>Миним. 1,0</td>
<td>6,09</td>
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<td>Нитраты</td>
<td>0,49</td>
<td>805,1</td>
<td>29,87</td>
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<td>Алюминий</td>
<td>0,074</td>
<td>1,17</td>
<td>1,04</td>
</tr>
<tr>
<td>Сернистый (S²⁻)</td>
<td>нет</td>
<td>нет</td>
<td>10,8</td>
</tr>
<tr>
<td>Сернистый (S³⁻)</td>
<td>нет</td>
<td>нет</td>
<td>4,97</td>
</tr>
<tr>
<td>Магний (Mg²⁺)</td>
<td>нет</td>
<td>нет</td>
<td>0,004</td>
</tr>
<tr>
<td>Кремневая кислота</td>
<td>413,0</td>
<td>нет</td>
<td>4219</td>
</tr>
<tr>
<td>Медная кислота</td>
<td>0,144</td>
<td>нет</td>
<td>1,24</td>
</tr>
<tr>
<td>Молочная + Уксусная кислоты</td>
<td>1,44</td>
<td>нет</td>
<td>нет</td>
</tr>
</tbody>
</table>

**PICTURE 3. Chemical composition of ground electrolytes, mkg/g.**

We should add that pH value of soils is the same on Canadian gas lines where SCC takes place. And on US gas pipelines SCC failures took place in soils with pH value greater than 12 (alkali environment).
SCC mechanism at low pH is not determined yet. Russian and Canadian scientists perform active research on this problem. They rely on the following hypotheses in their research:

- Cracks appear and grow according to the mechanism of anode dissolving of metal
- Cracks appear and grow according to the mechanism of strength reduction with adsorption (so called Rebinder effect)
- Cracks grow because of “hydrogen embrittlement” of steel with hydrogen that appears as a result of electrolysis of soil electrolyte at high potentials of electrochemical protection of pipe metal from corrosion

The author agrees with the second mechanism, one or several component of soil electrolyte that is surface active in reference to pipe metal, including hydrogen can cause strength reduction. Any significant dissolving is not necessary, surface adsorption is enough to reduce strength.

The analysis of gathered information allowed finding connections between project and construction parameters, main gas pipelines exploitation regimes and conditions of SCC appearance.

Today we can be sure in the following facts:

- Regimes of active electrochemical protection of gas pipelines do not influence appearance and development of SCC
- Values of potentials reached with electro-chemical protection on Russian gas lines do not cause metal saturation with hydrogen and hydrogen embrittlement, according to plastic deformation on the tip of stress corrosion crack (picture 4).

SCC on Russian gas lines appears at points where:

- Anti-corrosion coatings in form of short-term film were used, because effectiveness of such isolation is lost after 5-10 years of exploitation, after what metal begins to contact soil electrolyte directly.
- Construction team didn’t completely follow construction design, or design didn’t include local geo-technical peculiarities of the area (landslides, etc), possibly leading to change of stress-strained state of pipeline. For example, distribution of stresses at section of pipe, that is bended because of landslide not counted during making gas line draft. Such stress-strained state of pipe can lead to destruction. (picture 1 right at the bottom).

A long study of SCC problem on main gas pipelines shows that after degradation of isolation, when electrolyte begins to contact metal surface directly, metallurgical factor becomes dominating. Beginning from this moment, the following parameters of metallurgical technology become one of the groups of factors influencing development of stress corrosion processes in metal of large-diameter pipes:

- Internal metal stresses, acquired during pipe making process
- SCC susceptibility, depending on the technology of thermal-deformational processing of metal

Chemical composition of steels in our opinion influences SCC less. It can be seen on table at picture 5 where term of service of gas line before appearance of dangerous stress corrosion cracks and chemical composition of pipe metal are not correlated.
JSC “Gazprom” realizes a “Complex program of SCC research, creating tools for technical diagnostics of SCC, means for protecting gas pipelines and methods of repairing gas lines that suffer from stress corrosion.

This program’s goal is solution of stress corrosion problem on gas pipelines.

For detecting deterministic dependences between properties of the pipe’s metal, parameters near-pipe environment and stress-strain state was made up and in 2005 year is going to be realized special strategy of accelerated tests of model full-sized samples of pipe’s metal (picture 6).

The particularity of this strategy is that during the operation test metal is subjected to load which character is close to stress-strain state of applied gas pipeline. Real and simulated ground electrolytes are used as the conditions of environment.

**PICTURE 5. Chemical composition of pipe steel**

<table>
<thead>
<tr>
<th>Brand of steel</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Al</th>
<th>V</th>
<th>Nb</th>
<th>Ti</th>
<th>N</th>
<th>Term of operation</th>
</tr>
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<tbody>
<tr>
<td>17Г1С</td>
<td>0.180</td>
<td>0.290</td>
<td>1.470</td>
<td>0.020</td>
<td>0.026</td>
<td>0.190</td>
<td>-</td>
<td>0.008</td>
<td>0.005</td>
<td>-</td>
<td>0.009</td>
<td>0.0</td>
<td>18</td>
</tr>
<tr>
<td>14Г2СФб</td>
<td>0.170</td>
<td>0.450</td>
<td>1.650</td>
<td>0.015</td>
<td>-</td>
<td>0.100</td>
<td>0.050</td>
<td>0.020</td>
<td>0.100</td>
<td>0.035</td>
<td>-</td>
<td>0.0</td>
<td>18</td>
</tr>
<tr>
<td>14Г2САФ</td>
<td>0.150</td>
<td>0.350</td>
<td>1.500</td>
<td>0.020</td>
<td>0.017</td>
<td>0.060</td>
<td>0.080</td>
<td>-</td>
<td>0.070</td>
<td>-</td>
<td>-</td>
<td>0.0</td>
<td>20</td>
</tr>
<tr>
<td>X 70</td>
<td>0.092</td>
<td>0.180</td>
<td>1.800</td>
<td>0.027</td>
<td>0.005</td>
<td>0.050</td>
<td>0.020</td>
<td>0.020</td>
<td>0.010</td>
<td>0.040</td>
<td>0.020</td>
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<tr>
<td>X 70</td>
<td>0.097</td>
<td>0.280</td>
<td>1.600</td>
<td>0.018</td>
<td>0.003</td>
<td>0.030</td>
<td>0.020</td>
<td>0.050</td>
<td>0.040</td>
<td>0.040</td>
<td>0.020</td>
<td>0.0</td>
<td>20</td>
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<tr>
<td>X 70</td>
<td>0.106</td>
<td>0.240</td>
<td>1.750</td>
<td>0.026</td>
<td>0.004</td>
<td>0.200</td>
<td>-</td>
<td>-</td>
<td>0.050</td>
<td>0.030</td>
<td>-</td>
<td>0.010</td>
<td>0.013</td>
</tr>
<tr>
<td>X 70</td>
<td>0.074</td>
<td>0.180</td>
<td>1.750</td>
<td>0.017</td>
<td>0.002</td>
<td>0.040</td>
<td>-</td>
<td>-</td>
<td>0.050</td>
<td>0.040</td>
<td>-</td>
<td>0.009</td>
<td>0.008</td>
</tr>
<tr>
<td>X 70</td>
<td>0.109</td>
<td>0.240</td>
<td>1.750</td>
<td>0.019</td>
<td>0.002</td>
<td>0.040</td>
<td>-</td>
<td>-</td>
<td>0.030</td>
<td>0.050</td>
<td>-</td>
<td>-</td>
<td>0.008</td>
</tr>
<tr>
<td>X 70</td>
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<td>0.180</td>
<td>1.650</td>
<td>0.020</td>
<td>0.013</td>
<td>0.030</td>
<td>-</td>
<td>0.030</td>
<td>0.050</td>
<td>-</td>
<td>-</td>
<td>0.008</td>
<td>0.008</td>
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<tr>
<td>X 70</td>
<td>0.070</td>
<td>0.180</td>
<td>1.670</td>
<td>0.019</td>
<td>0.013</td>
<td>0.030</td>
<td>-</td>
<td>0.030</td>
<td>0.050</td>
<td>-</td>
<td>-</td>
<td>0.008</td>
<td>0.008</td>
</tr>
<tr>
<td>X 70</td>
<td>0.100</td>
<td>0.200</td>
<td>1.550</td>
<td>0.022</td>
<td>0.003</td>
<td>0.210</td>
<td>0.010</td>
<td>0.010</td>
<td>0.060</td>
<td>0.010</td>
<td>0.0</td>
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<tr>
<td>X 70</td>
<td>0.120</td>
<td>0.280</td>
<td>1.590</td>
<td>0.018</td>
<td>-</td>
<td>0.300</td>
<td>-</td>
<td>0.070</td>
<td>-</td>
<td>0.00</td>
<td>0.0</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>
Application of this strategy allows us to detect the main factors, which cause SCC on gas pipelines and to determine their critical parameter:

- the particularities of steel chemical composition and of technologies of steel production, which determine steel SCC inclination;

- the parameters of forming operations and welding of pipes, which determine the level and character of dispersion of remaining mechanical stresses on the pipe body;

- threshold mechanical stress, below which SCC doesn’t occur;

- the parameters of grounds and electrolytes, responsible for occurrence of SCC.

This research will determine the level of requirements to plate steel, to forming and welding of pipes, to the surface stain, providing the stability of pipes to SCC.

Practical solution of the SCC’s problem has become possible at the expense of development of measures, allowing us either to raise the stability to SCC, or to determine the pipe remaining resource, being in operation in conditions of SCC. These measures were developed during the realization of the second and the third part of Program, aimed at making means and methods of diagnostics and repair of gas pipelines, subjected to SCC.

At present the number of measures is worked out to detecting and efficient preventive repairing of SCC damages of Russian pipelines on their early and not dangerous stages.

The most important result in this area is the creation and introduction in practice the equipment and technologies of in-line magnetic inspections, grounded on the principle of transverse magnetization. On the pictures 7 and 8 represented intelligent pigs, intended for SCC’s inspection of pipelines with diameter 1420 mm., and also the example of processing of the results.
For the successful diagnostic of damages caused by SCC in-line inspections of pipelines should be used in combination with designed and developing at present time other methods.

- strategy of detecting potentially dangerous areas in accordance with sign of crossing of pipeline by the level of underground water (on the assumption of design, executive documentation and field researches);
- detecting of areas and sequence of in-line inspection;
- post-examination of the most dangerous defects;
- revision of the calculation of dangerous defects;
- determination of terms and methods of repairing;
- determination of terms of next in-line inspection’s undertaking.

By the results, received in the course of diagnostic, is carried out the assessment of remaining safe operation life of pipeline with using of the designed strategy, defined methods of repairing.

For the repairing of pipelines liable to SCC was designed and applying great variety of methods:

- polishing of not deep cracks (picture 9);
- reinforcement of defective areas by steel sleeve;
- welding of deep cracks.
### CONCLUSION

The represented analysis of SCC on main gas pipelines shows, that in result of complex measures, provided by JSC «Gazprom», preconditions for development of pipes with increased level of stability to SCC and prolonged lifetime of gas pipelines, used in conditions of SCC.

The designed strategy of pipe metal laboratory tests reproduces nearly real conditions of pipeline usage. The application of this strategy allows us to determine critical factors, initiating SCC of pipe metal.

The following methods were established:

- rehabilitation of carrier ability on pipes, subjected to SCC;
- increase of stability level of pipes to SCC;
- determination of remaining safe operation life of pipelines with SCC defects.

<table>
<thead>
<tr>
<th>External diameter of pipe, mm</th>
<th>Maximum area of sample for welding, mm²</th>
<th>Maximum length of sample for welding, mm</th>
<th>Maximum depth of sample for welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1420</td>
<td>35000</td>
<td>500</td>
<td>About 65% of thickness of pipe, but not lesser than 5 mm of remaining thickness of the pipe</td>
</tr>
</tbody>
</table>

*PICTURE 9. Development of fitness criteria for repair and technology of SCC defects repair with application of welding*