1 Introduction

Stress-corrosion is a factor that shapes the operational status of the trunk pipelines. Being a complex and ambiguous phenomenon underlain by various environmental conditions, stress state, structure and metal-specific properties, stress-corrosion is known as one of the most dangerous types of damages affecting pipes (Figure 1).

According to recent findings, apart from linear part of trunk pipelines, underground flowlines (compressor stations process pipelines) are also affected by stress-corrosion. In-pipe inspection is somewhat difficult to conduct on compressor station flowlines as soon as the pigs can not be run, therefore specific corrosion control and pipeline maintenance methods need to be developed.

These days, OAO Gazprom is implementing a plan package to mitigate risks of failures due to stress-corrosion. The root causes of stress-corrosion have been detected; a pipeline maintenance methods have been adopted (including methods of inspection, evaluation of strength properties and scope of repair); a pipeline re-insulation program has been launched (under this program a large variety of coatings have been developed to ensure reliable corrosion-proof operation of pipelines).

2 Focus Areas

Due to the efforts of OAO Gazprom, its subsidiaries, specialised and research organisations, operating reliability of gas transport objects is managed to maintain at the
stable level and prevent avalanche increase of failures. The distinctive progress has been made in the lots of organisational and engineering issues associated with mitigation of stress-corrosion risk. At the moment, the major causes and conditions of stress-corrosion are identified and the strategy of maintenance service is developed for gas pipelines which are the subject of corrosion. This technique includes different diagnostic methods and technologies, strength assessment and repair of trunk pipelines exposed to SCC (Figure 2). Number of identified and repaired SCC defects is growing with the increase of maintenance overhaul; the production models of scanners able to detect SCC defects during re-insulation are developed along with the methods of SCC defects welding-up and maintenance of pipes with SCC defects by couplings.

Figure 2. Maintenance of trunk gas pipelines exposed to SCC

Evolution of the gas mains failure occurrences caused by SCC (Figure 3) in OAO Gazprom shows that the number of them tends to decrease due to the package plan implemented by OAO Gazpom, its subsidiaries, specialised and research organisations. The stable trend of reducing the pipelines accidents caused by SCC has emerged during the last 10 years, for the first time after the year 2004.
The positive trends are observed in the dynamics of the amount of SCC defects, which are registered in the sections of the repeated in-line inspections (Figure 4). On the Figure 4 one can clearly see the decrease of SCC defects number registered by the repeated in-line inspections (ILI). This goes to prove that it is not a significant growth of existing SCC defects in the most sections of gas mains. A similar trend is generally observed in the overall dynamics (of primary and repeated inspections) to identify SCC defects.

Pipeline protection projects may focus on the following areas:
- regular inspections of trunk pipelines by running “Spetsneftegaz” magnetic flaw detectors that are capable of detecting the longitudinal cracks;
- development of production models of scanners to detect flaws during re-insulation;
- development of regulations for inspecting and evaluating severity of stress-corrosion defects;
- research projects focusing on analysis of stress-corrosion in compressor stations flowlines;
- development of repair methods involving welding, application of pipe couplings, or removal of damaged sections.

**Evaluation of stress-corrosion on the compressor station flowlines**

Started in 2005-2008, re-insulation activities showed the high relevance of SCC challenge on the process pipelines of the compressor stations (CS). Opposite to assumptions, the pipelines of I and B classes occurred to be exposed to stress-corrosion among the others (Figure 5). The situation is worse in comparison with the linear trunk pipeline portions because the CS flowlines are still not available for in-line inspection whilst the consequences of the CS accidents may be incomparably greater. What is more, the existing regulations don't consider the possibility of pipes repair on the sections of I and B classes. The issue of SCC on the process pipelines of CS should be expanded.

![Figure 5. State of SCC issue on the process pipelines of CS](image)

During 2006-2008 and till now the comprehensive repair of the process communications has been conducted on 75 CS compressor sections with total length of more than 90 km of flowlines. The examples of detected defects are presented along with their parameters on Figure 6.
One may state that processes evident now due to SCC on the CS processing communications are the same as on the linear trunk pipeline portions 10-15 years ago. The SCC defects were detected as a result of examination in the pipes with diameter 720, 1020, 1220 and 1420 mm. For the listed pipes SCC defects occurs at wall thickness from 9 to 23.3 mm, it confirms that SCC process can occur on the heavy walled pipes of I and B classes. So, it is evident today that that SCC defects occurrence on the CS flowline is not a random event. Obviously, the fact of detection of SCC defects on the CS flowline shows that the extent of SCC on the gas transportation facilities is really much more considerable than it was previously expected.

### 3. Research Methods

#### 3.1 Comprehensive research

Pipeline sections potentially vulnerable to stress-corrosion are detected by implementing a set of services that identify favorable stress-corrosion conditions and drivers stimulating its propagation. The set of services includes analysis of design and operation documentation, field studies, and data processing. The algorithm of services is shown on the following flowchart (Figure 7). The flow chart includes design stage measures that help mitigate stress-corrosion risks by selecting the appropriate route sections. During the operation stage the in-pipe inspection and coating inspection data is used.
Based on the result of research general drivers are identified – a stress state, insulation status, soil corrosion activity, ground water occurrence, that are evaluated by using weight metrics.

On the next stage a severity level is evaluated, and the framework for the next inspection is provided.

3.2. Detecting potentially vulnerable sections of compressor station flowlines.

As soon as inspection of process flowlines provides certain challenges, an individual method was required for detecting potentially vulnerable sections and ranging compressor stations based on the priority of inspection and technical maintenance. The method suggests doing the following:

- detect potentially vulnerable sections;
- evaluate stress-corrosion defects in sampling pits;
- evaluate operational reliability of the flowlines;
- provide forecast of the stress-corrosion state.

This methodology is shown on the following flow chart, fig. 8. The main challenge with the compressor station flowlines is that its underground sections need to be uncovered first.
(the pits should be made) so that the inspection could be carried out. Then the workflow follows the research algorithm specified under para 3.1.

Figure 8 The workflow of identification of potentially vulnerable sections and inspection of compressors process flowlines in pits.

3.3. Repair methods

Based on the inspection results, the following repair methods to remove stress-corrosion defects were developed:

* crack grinding and a follow-up welding repair technique;
* application of pipe couplings;
* removal of a damaged section.

The applicable technique is selected based on the flaw severity and the priority status of a pipeline. Fig. 9 shows the repair technique selection algorithm for process flowlines of a compressor station that are deemed to be top priority facilities of a trunk pipeline. The flow
chart shows a number of selection scenarios that vary depending on the crack depth and length, physical properties of a pipe metal, and the degree of stress-state.

### Setting initial metrics:
- Category of compressor station process flowline;
- Pipe metrics (diameter $D_n$, wall thickness $\delta_i$ and pressure $p$);
- Physical material properties ($K_{IC}$, $\sigma_v$, $\sigma_t$);
- Real defect size ($L_r$, $W_r$);
- Coupling workload, $\Delta p$.

### Repair method applicability check:
- Controlled grinding for I & B pipelines.

\[
R_k \leq \left[R_k\right] \\
d_r \leq \left[d\right] \\
\text{yes} \quad \text{Controlled grinding repair method}
\]

### Repair method applicability check: pipeline couplings

\[
R_s \leq \left[R_s\right] \\
L_p \leq \left[L_p\right] \\
R_{\text{m}} \leq 1 \\
\text{no}
\]

### Repair method applicability check: controlled grinding and application of pipeline couplings for I pipelines.

\[
R_m \leq \left[R_m\right] \\
L_p \leq \left[L_p\right] \\
R_i \leq 1 \\
\text{yes} \quad \text{Controlled grinding and application of pipeline couplings}
\]

### Removal of sections in I & B pipelines

\[
R_m \leq \left[R_m\right] \\
L_p \leq \left[L_p\right] \\
R_i \leq 1 \\
\text{no}
\]

Figure 9 Selection of a method to repair pipes with crack-like defects

### 4. Providing a stress state forecast for a pipeline sections

During the last years the significant amount of researches was carried out to develop the new methodological approaches of detection of pipeline sections, which are potentially vulnerable to stress-corrosion; pipes of gas mains were ranked by their vulnerability to SCC etc. Figure 10 presents the methodological approach for scheduling the next in-line inspection on the trunk gas pipelines sections exposed to SCC. This approach is implemented in the Gazprom 2-2.3-095-2007 «Guidelines for diagnostic examination of linear portion of the trunk gas pipelines» standard statement document. Timing for the next in-line inspection of trunk gas pipelines is defined on the base of evaluation of the expected increase of detected defects number; statistic processing of ILI results are used for this
Figure 10 The stress-state forecast for a trunk pipeline section provided on the basis of in-pipe inspection results and definition of the scope of repair.

The surface technique for stress-corrosion diagnostics has got a practical application. It is based on the design and as-built documentation and was developed in “Giprogaztsentr” research institute. The prediction methodology for identification of potentially vulnerable stress-corrosion sections was developed on the base of this technique (see Figure 11). Scheme shows that it is possible to detect the sections with the probable stress-corrosion on the base of soil conditions analysis, hydrogeological data, design and construction solutions and take appropriate actions on the design stage.

Figure 11. Prediction technique for identification of potentially vulnerable stress-corrosion sections
The new technology recently developed in VNIIGAZ Ltd. is rather prospective for identification of pipe steels vulnerability to SCC. This technology is based on the laboratory tests of the model x-shaped samples and allow to simulate cracking process in the short time (Figure 12). The technology implemented in Gazprom 2-5.1-148-2007 «Test methods for steel and welded joints for stress-corrosion cracking” document allows to estimate the influence of forces of metallurgic and engineering nature that are responsible for SCC occurrence. According to this technique the vulnerability to SCC of number of Russian and imported pipes is evaluated. Figure 13 presents the results of stress cracking resistance examination of 6 pipe types that was conducted together with «JFE STEEL CORPORATION» (Japan). Figure 13 shows that the examination allowed to rank the pipes by their vulnerability to stress-corrosion and detect the correlation between structure and strength of the steel and vulnerability to cracking.

Figure 12. The new techniques of pipe steels examination for resistivity to SCC
At present, the most part of scientific and engineering problems related to the applied components of the SCC challenge are solved as a part of yearly R&D Programs of OAO Gazprom.

For the last three years VNIIGAZ Ltd. has developed five regulatory documents (Figure 14) relating to SCC effect in diagnostics, strength calculation, testing and improvement of repair methods.
5. Conclusion

In Russia a well-established comprehensive system is implemented that enables detect, repair and provide forecast for stress-state defects propagation and applicable methods of repair.

The scope of stress-corrosion field research is required to include the following:
- the study of impact of pipe structure and factory defects on physical properties of the pipes, stress cracking resistance, and operational reliability.
- development of methodical framework and tools enabling control of physical and chemical environment metrics that stimulate stress-corrosion, general, and sub-coating corrosion during pipeline construction and operation.