IV International Scientific and Practical Seminar

IMPROVEMENT OF RELIABILITY OF MAIN GAS PIPELINES SUBJECT TO STRESS CORROSION CRACKING

June 6–8, 2018

SCC 2018

CONFERENCE PROGRAM. ABSTRACTS

Gazprom VNIIGAZ,
Moscow

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DEAR COLLEAGUES!

We are happy to welcome you in Gazprom VNIIGAZ, LLC at the 4-th Workshop dedicated to increase of reliability of Gazprom, PJSC main gas lines that are exposed to stress corrosion cracking.

The workshop proved to be a unique platform for exchange of knowledge in the field of stress-corrosion between administration employees, directors and specialists of production divisions from Gazprom, PJSC affiliated companies and organizations, scientific workers from HEIs (Higher Educational Institutions), research institutes, heads of diagnostic and repair organizations, producers of innovative products and technologies. Therefore, with support of Gazprom, PJSC, our event takes place annually and in 2018 it acquired the international status: specialists from Germany, China, Korea and Poland will take part in the Workshop operation.

The applicable System for MGL Gazprom, PJSC technical condition and integrity control ensures proper monitoring of its stress-corrosion condition. However, alongside with Gazprom, PJSC main gas line lifetime extension in conditions of their protective coating properties degradation, the tasks for planning and rational distribution of resources for technical diagnostics and repair of pipes with SCC defects gain more and more importance.

The system investigation and field tests of pipes with stress-corrosion damages implemented by Gazprom VNIIGAZ, LLC prove by experiment that it is possible to stop (preserve) MGL SCC for a long term if there is no access of corrosive environment to the steel damaged surface. The pipes with stress-corrosive damages of the base metal up to 10 % depth of pipe wall thickness possess significant strength reserve, and, consequently, the specified damages do not represent any hazard in relation to MGL reliability in the medium term (till next inspection). The obtained results allow for review of requirements to MGL operation and repair right now.

In support of the above named task, at the beginning of 2018 Gazprom, PJSC approved innovative protective coatings containing inhibiting compositions in MGL. Their application in field conditions minimizes the risks for development of SCC defects.

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Gazprom, PJSC management pays special attention to improve the quality of MGL technical diagnostics and implementation of innovative technologies in non-destructive testing of tubes and welded joints. In the immediate future, use of innovative diagnostic complexes in MGL will result in significant increase of registered anomalies, including different depth stress-corrosive damages. Development of the process calculation and experimental and kinetic models providing reliable prediction of life time for damaged pipes for targeted planning of the overhaul repair and well-grounded assignment of inter-diagnostic intervals appears to be probable key area of activity in investigation of MGL SCC area processes. Association of Russian and foreign laboratories for performance of system investigation works in the area of corrosion and mechanical strength and durability of steel tubes with account of their wide nomenclature and regional conditions of MGL operation is a promising factor.

With respect to development of computer technologies, the algorithms of artificial intelligence, machine learning and data analysis are used more frequently in the applied sciences for solution of complicated multi-factor problems. It is worth using the international experience and adapt the existing computer technologies for prediction of multiple-factor process of corrosive-mechanical destruction of steels within the frame of GTS of SCTCI (Gas transportation system of the System for control of technical condition and integrity) in conditions of incomplete and noisy initial data of technical diagnostics.

With account of prospective lines of investigation in the area MGL SCC the Workshop program provides for reports on the following main topics:

– – simulation of MGL SCC processes with account of test results and development of technical diagnostics intelligent system elements;

– – development of non-destructive testing facilities for detection and identification of SCC sizes of defects ;

– – implementation of the program for log-term tests of pipes with SCC defects operated at Gazprom, PJSC facilities including experimental works on SCC process investigation;

– – selection of MGL long sections for re-insulation in 2019–2020 in accordance with “Procedure of works during field re-insulation of MGL long sections with the depth of metal surface damages up to 10 % of wall thickness”;

– – development and implementation of technical diagnostics data intelligent analysis elements in Gazprom, PJSC for prediction of MGL corrosive and stress-corrosive condition;

– – development cost-effective technologies for repair of pipes with SCC defects using protective coatings with inhibiting compositions during MGL field repair;

– – implementation of methods for estimation of aggressiveness of soils and classification of MGL by the degree of hazard in relation to under-film corrosion and SCC;

– – analysis methods for calculation of strength and operability of gas pipelines with SCC type defects;

– – development of the program of technical and scientific events aimed at prevention of formation and development of corrosive processes under MGL protective coating delamination.

I emphasize that, following the current Workshop, publishing of dedicated issue (collection of documents) of publications on the topic of stress corrosion cracking of pipelines is planned in 2019 in the journal “Vesti gazovoi nauki”, included in HAC list. The publications shall be addressed to the Workshop official address **SCC@vniigaz.gazprom.ru** before the end of 2018.

In conclusion, I would like to wish successful work to all Workshop participants. I am sure that, by joint efforts, we can achieve significant progress both in understanding SCC mechanism and its individual aspects, and in normative and technical regulation in the operation process of MGL exposed to stress-corrosion, in development of requirements to new types of pipe products and protective coatings, as well as in implementation of modern equipment and technologies for diagnostics and repair of pipelines.

PROGRAM

IV International Scientific and Technical Seminar

IMPROVEMENT OF RELIABILITY OF MAIN GAS PIPELINES SUBJECT TO STRESS CORROSION CRACKING

Razvilka **Gazprom VNIIGAZ LLC**

June 5, 2018, Tuesday

Meeting of seminar participants. Accommodation

June 6, 2018, Wednesday

8.30–9.00	**Transfer from Milan Hotel to Gazprom VNIIGAZ**
9.00–9.30	**Registration of participants** **Collection of presentations** **Morning coffee** **(1st floor, Conference Hall)**
9.30–9.35	**OPENING OF THE SEMINAR** **Sergey Nefedov,** Deputy General Director for Science, Gazprom VNIIGAZ LLC
9.35–10.00	Scientific and technical aspects for prevention of stress corrosion cracking on Gazprom gas lines. Problem status and prospects for solution **Andrey Arabey** *(Gazprom PJSC)*
10.00–10.30	Regularities of pipe steel stress corrosion cracking **Ilya Ryakhovskikh** *(Gazprom VNIIGAZ LLC)*
10.30–11.00	Stress-corrosion as manifestation of pipeline metal delayed fracture phenomenon **Taymuraz Esiev** *(Gazprom VNIIGAZ LLC)*

11.00–11.30	Effect of small-amplitude stress fluctuation and residual stress on stress corrosion cracking behavior of high grade pipeline steel **Anqing Fu** *(CNPC Tubular Goods Research Institute)*
11.30–12.00	Improvement of corrosion development models for tasks of main gas lines technical condition prediction **Dmitry Zapevalov** *(Gazprom VNIIGAZ LLC)*
12.00–12.30	Unified approaches to estimated assessment of strength of pipeline structures with crack-like defects **Viktor Silkin** *(Gazprom VNIIGAZ LLC)*
12.30–13.30	**Group photo of SCC-2019 participants.** **Dinner (Restaurant of hotel Gazprom VNIIGAZ)**
13.30–14.00	Experience in operation and planning repair of gas pipelines subject to SCC **Vladimir Kozliakov** *(Gazprom transgaz Yugorsk LLC)*
14.00–14.30	Features of detecting SCC defects using different diagnostic tools and non-destructive testing methods **Vladimir Lazarev** *(Gazprom VNIIGAZ LLC)*
14.30–15.00	Gas pipeline inspections using ultrasonic technology: practices **Christina Günther** *(Open Grid Europe GmbH)*
15.00–15.30	Monitoring of stressed-deformed state of gas lines as the element of their corrosion cracking prevention system **Dmitriy Lyapichev** *(Gazprom Orgenergogaz JSC)*
15.30–16.00	**Coffee break**

16.00–16.30	Evolution of requirements to improved corrosion resistance steels operated in neutral water environments including in contact with soil electrolyte **Irina Rodionova** *(Central Research Institute for Ferrous Metallurgy)*
16.30–17.00	Development factors and possibilities for monitoring SCC defects in company Gazprom transgaz Samara pipelines **Aleksei Afanasev** *(Gazprom Transgaz Samara LLC)*
17.00–17.30	Propositions on development of procedure for classification of operated main gas line sections according to proneness to SCC **Sergey Kovalenko** *(Gazprom gaznadzor LLC)*
17.30–18.00	Prediction of pipe replacement volume during overhaul repair of gas lines subject to SCC **Vera Podolskaia** *(Gazprom transgaz Ekaterinburg LLC)*
18.00–20.00	**SCC-2018 Official Gala Dinner (1st floor, Conference Hall)**
20.00	**Transfer to Milan Hotel**

June 7, 2018, Thursday

8.30–9.30	**Transfer from Milan Hotel to Gazprom VNIIGAZ** **Morning coffee**
9.30-10.00	Gazprom VNIIGAZ testing complex concept of development. Prospective areas of modern fundamental and applied investigations in the field of corrosive-mechanical destruction of pipe steels **Roman Bogdanov** *(Gazprom VNIIGAZ LLC)*
10.00–10.30	Evaluation of carrying capacity and residual service life of pipes with SCC cracks according to the results of field tests in Gazprom transgaz Ukhta **Stepan Poguliaev** *(Gazprom transgaz Ukhta LLC)*
10.30–11.00	Implementation of technology for preservation of stress corrosion cracking in main gas pipelines **Artem Shkapenko** *(Gazprom transgaz Tchaikovsky LLC)*
11.00–11.30	Evaluation of structural steels tendency to brittle fracture **Aleksandr Kudrya** *(National University of Science and Technology «MISIS»)*
11.30–12.00	Creation of specimens with set distribution of residual stresses for investigation of materials corrosive properties **Sergey Tikhonov** *(Bauman Moscow State Technical University)*
12.00–12.30	Influence of crystallographic texture and residual stresses on SCC crack development in main gas pipelines **Olga Krymskaya** *(National Research Nuclear University MEPhI)*
12.30–13.30	**Dinner (Restaurant of hotel Gazprom VNIIGAZ)**
13.30–14.00	Evaluation procedure for aggressiveness of soils causing SCC **Vasili Ignatenko** *(Institute of Physical chemistry and Electrochemistry RAS)*

14.00–14.30	Evaluation of residual stresses in welded joints in relation to their influence on stress corrosion cracking of gas pipelines **Victor Brovko** *(«Welding and Testing» of Bauman MSTU)*
14.30–15.00	Features of corrosion destruction of main gas lines under delaminated insulation coating **Roman Kashkovskiy** *(Gazprom VNIIGAZ LLC)*
15.00–15.30	Experimental determination of local corrosion damage development rate on the surface of pipe steels in solutions simulating soil electrolyte **Alevtina Rybkina** *(Institute of Physical chemistry and Electrochemistry RAS)*
15.30–15.45	**Coffee break**
15.45–16.15	Creation of ultra-strong composite couplings for restoration and maintaining operating reliability of high pressure main pipelines **Mikhail Smirnov** *(RME CENTROTECH)*
16.15–16.40	Evaluation of reliability indicators for pipeline structures with crack-like defects **Evgeniy Ovsyannikov** *(Gazprom VNIIGAZ LLC)*
16.40–17.05	Hybrid metal-composite pipes for gas pipelines subject to stress cracking **Vladimir Khomenko** *(Russian Union Of Oil And Gas-Builders)*
17.05–17.30	Assessment of natural factors of stress corrosion accidents on the basis of the geospatial modeling and analysis **Lada Vlasova** *(Gazprom VNIIGAZ LLC)*
17.30–18.00	**Dinner (Restaurant of hotel Gazprom VNIIGAZ)**
18.30	**Transfer to Milan Hotel**

June 8, 2018, Friday

8.30–9.30	**Transfer from Milan Hotel to Gazprom VNIIGAZ** **Morning coffee**
9.30–9.50	Information system for analysis of in-pipe diagnostics data of «IntroScan» as an element of the system for increasing the efficiency of technical diagnostics of technological pipelines of compressor stations **Stanislav Voronchikhin** *(IntroScan Technology JCC)*
9.50–10.10	Status for implementation of system for identification of stress corrosion cracking at Gazprom transgaz Moscow facilities **Aleksandr Izmaylov** *(Gazprom transgaz Moscow LLC)*
10.10–10.30	Comparative analysis of contractors work results on the detection and identification stress-corrosion defects in the gas pipelines **Viktor Zaznobin** *(Gazprom transgaz Nizhny Novgorod LLC)*
10.30–10.50	Inspection of stress-corrosion sections of pipelines using «IntroScan» robot-based diagnostic complex **Alexei Miturkin** *(ENTE LLC)*
10.50–11.10	Prediction of stress-corrosion damaging of main gas line sections based on non-linear methods of optimization and algorithms of neural networks **Dmitriy Misharin** *(Gazprom VNIIGAZ LLC)*
11.10–11.30	Features of stress corrosion cracking in hydro-sulphuric environments. Pipe products for gas fields containing hydrogen sulphide **Konstantin Konishchev** *(Gazprom VNIIGAZ LLC)*

11.30–11.50	Extension of service life for reinforced fittings (weldolets) based on their fatigue strength computer modelling **Mikhail Ponomarev** *(Bauman Moscow State Technical University)*
11.50–12.10	Monitoring of “lithosphere-atmosphere-ionosphere-magnetosphere” supersystem transient activity for prediction of earthquakes in the areas of main gas lines **Evgeny Loginov** *(Institute for Market Problems RAS)*
12.10–12.30	Perspectives of mechanochemical concept for understanding and preventing stress corrosion cracking of main gas pipelines **Emmanuel Gutman** *(Ben-Gurion University of the Negev, Israel)*
12.30–14.00	**Dinner (Restaurant of hotel Gazprom VNIIGAZ)**
14.30	**Transfer to Milan Hotel**
SEMINAR WRAP UP	

ABSTRACTS

Scientific and technical aspects for prevention of stress corrosion cracking on Gazprom gas lines. Problem status and prospects for solution

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SCC of pipe metal is one of the main factors, which determine technical condition, technology-related risk and reliability of MGL Gazprom, PJSC with long terms of operation (25-30 years and longer). SCC is determined by the complex of technical, process reasons and external natural conditions. It features for complexity and non-linearity of process development and has wide geographical coverage.

For solution of a complex of tasks on improvement of reliability of MGL exposed to SCC, during the period from 1996 to 2004 JSC Gazprom has formed the Coordination Council operating with support of VNIIGAZ, LLC. Coordination Council performance resulted in a number of system solutions (organization of maintenance, monitoring, development of technical diagnostics facilities, industrial prototypes of equipment and technologies for repair of pipelines, new types of protective coatings), allowing for significant reduction of the annual number of failures (failure rate) of MGL due to SCC.

In 2005 by decision of Gazprom, LLC Production and Scientific and Technical Departments the special-purpose laboratory for monitoring and prediction of stress-corrosion processes was organized on the basis of VNIIGAZ, LLC. In elaboration of works performed earlier, its specialists developed general approaches to solution of a challenge for prevention and protection of main gas lines from SCC; they developed the basic standard documentation of Gazprom, PJSC standardization system in the area of MGL operation and organization of dedicated corrosion and mechanical tests for pipe steels.

Since 2013, in Gazprom VNIIGAZ, LLC there runs the laboratory for investigation of SCC processes with its key task for development of scientifically grounded effective activities of the System for Gazprom, PJSC GTS technical condition and integrity control aimed at ensuring long-term operability of MGL with corrosive and mechanical damages, at that, optimizing operational costs for technical diagnostics and repair. In the shortest terms, jointly with the largest gas transportation companies Gazprom, PJSC performed integral laboratory and field tests of pipes with stress-corrosion damages. Following their results the criteria for ranging of damages by the hazard degree and permissibility for operation were developed; possibility for operation of gas pipelines with available non-hazardous stress-corrosion defects was grounded scientifically. Technical solutions for improvement of performance features of field-applied protective coatings due to using SCC inhibiting compositions were developed.

At present, taking into account the scientific and technical stock accumulated during the problem investigation period, Gazprom, PJSC with Gazprom VNIIGAZ, LLC immediate participation, the substantial grounds appear for implementation of efficient methods and technologies in prevention of MGL by means of:

– Gazprom VNIIGAZ, LLC and affiliated companies' experimental complex for evaluation of corrosive and mechanical strength of pipes and MGL durability under exposure to corrosive environment;

– calculation and experimental simulation of SCC process kinetics both for new and for pipelines operated for a long-term by results of serial hydraulic and laboratory tests of pipes, including the dame exposure to corrosive environment, cathodic and anodic polarization;

– technologies of repair of pipelines with application of innovative insulating coatings and materials, including those, which contain SCC inhibiting compositions;

– methods of computer simulation and implementation of intelligent systems providing integrated accounting of “environment-metal-stress” factors during prediction of SCC processes.

Regularities of pipe steel stress corrosion cracking

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Unified Gas Supply System (UGS) is a unique process complex, the key element of which is the largest in the world Gas Transportation System (GTS) of Gazprom, PJSC. By now about 80% of large diameter main gas lines (MGL) in GTS composition is operated beyond the limits of protective coatings standard service life. As a result, upon access of corrosion environment to the pipe surface, formation and gradual development of corrosion processes, the most hazardous of which is stress corrosion cracking (SCC), occurs in the locations of insulating coating delamination.

SCC-specific scenarios for pipe steels MGL in composition describing main stages of the process, rate and their implementation conditions. For pipes different in terms of design with 1420 mm in diameter, manufactured at Mannesmann and KhTZ plants and made of low-carbon steels, X70 strength grade, after prolonged operation in MGL composition, the complex of electrochemical, corrosion, corrosion and mechanical, mechanical, operational-life tests, as well as X-ray tests of layer-by-layer texture non-uniformity and residual stresses, metal and physical tests of micro structure and dislocational substructure of pipe fragments was implemented. The share of tested pipes takes about half of accidents in MGL for SCC reason and approximately 83 % accidents with 1420 mm diameter pipes, which ensures significant conservatism of obtained results during construction of kinetic model.

The process of crack formation in steels predominantly occurs in locations of local corrosion damages formation, with accumulations of non-metallic inclusions exiting on steel surface as their hot points. Growth kinetics of newly formed cracks is determined by the level of residual process stresses on the steel surface and by the aspect ratio of cracks. It was demonstrated that the level of texture non-uniformity of material and residual process stresses in the pipe wall outer layers are the parameters featuring potential for growth or slowdown of cracks at the process initial stages . The plastic deformation zone on the crack top is the factor enabling relaxation of stresses in the tip of the crack. After cyclic tests of pipes simulating MGL operation, no indicators of fatigue increment and significant changes of dislocational substructure was identified nearby the tips of corrosion mechanical cracks with up to 3 mm depth. However, by results of fractographic investigation of fractures for the majority of investigated fractures after cyclic tests, violation of the oxidic film integrity is observed, which may stimulate growth of cracks according to local anodic dissolution (LAD) mechanism during access of the corrosion environment. It was demonstrated that during static and low-amplitude cyclic loads the crack growth rate in the test media with pH 5.5 and 7.0 accelerates with available soil component (sulfide, carbonate and phosphate ions) stimulating the metal anodic dissolution rate.

By results of performed investigations it was identified that insignificant SCC damages up to 10% deep of pipe wall thickness do not present immediate hazard in relation to MGL operational reliability, and, under exposure to corrosion environment, the predicted development rates of such damages do not exceed 0.3-0.4 mm/year. Therefore, in case the specified damages persist in service or they are not detected during technical diagnostics of MGL LP and CS PP using ILI facilities, their dimensions will not reach the emergency values during standard inter-diagnostic period of up to 5 years. The obtained result lets leaving the pipes with defects in operation till overhaul repair on scientifically grounded basis. Prevention of corrosion environment access to the surface of pipes damaged by SCC defects with up to 15% of pipe wall thickness, for example, by means of their re-insulation, will ensure full stop (preservation) of this process. The corrosive-mechanical cracks of any dimensions located in the welded joints and along the weld-fusion line, which should be always considered as potentially hazardous and subjected to removal after their detection, is an exception.

Stress-corrosion as manifestation of pipeline metal delayed fracture phenomenon

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The concept was introduced, according to which the stress-corrosion damaging of pipeline metal is a special case for manifestation of a more common phenomenon called “metal delayed fracture”. According to known principles of mechanics of materials the delayed fracture is referred to as destruction of a part (sample) occurring during long-term action of continuous load with stresses below the rated ones (i.e. lower than yield point). In addition to stress-corrosion, manifestation of the pipeline metal delayed fracture should be attributed to cases with destruction of pipes due to mechanical damages – burrs and notches, as well as destruction of pipeline welded joints observed after long-term operation. It is demonstrated that, despite significant differences of the listed types of the pipeline metal damaging, their common case consists in dependence on stresses and deformations due to time, as well as factors controlling the destruction process, which are acting inside the metal.

It is noted that the distinctive feature of delayed fracture is its kinetic nature, namely, it includes consequent incubation period, the stage of sub-critical crack growth (group of cracks) and the final stage of unstable destructive crack growth.

The existing classical models of stress corrosion cracking are not able to explain the nature of pipeline stress-corrosion to the full extent. Firstly, in most cases ground water compositions do not contain required concentrations of aggressive components causing cracking. Secondly, as opposed to known forms of corrosive cracking, to simulate the stress-corrosion process during static loads is still a failure under laboratory conditions. At present, there is also no full understanding for mechanism of development of cracks from burrs and in the pipe welded joints. They appeal to fatigue mechanism (corrosion fatigue mechanism) quite often to explain the crack development mechanism (including stress-corrosion cracks) in pipes. Without denying the role of variable (or, rather repeated-statical) stresses, it is noted that this mechanism does not cover the whole variety of pipeline delayed fracture cases, for which the variable stresses are not obligatory.

Based on analysis of pipe destruction materials with the listed types of damages, the model of delayed fracture for pipe steels of high elasticity and viscosity was proposed. The model feature consists in consideration that the crack emergence and growth from defect is controlled by the process of continuous plastic deformation (cold creep) in the local areas of pipe metal differing by increased stressed state. At that, the driver force of creep process (and, consequently, the delayed fracture) are non-uniformities of stress fields caused by different reasons in the stressed body.

According to the model, the creep kinetics depends on structure (including the thin one), phase composition and physical-mechanical properties of pipe

metal, but the main point, on the level and rate of stress change in the locally non-uniform zone. Under usual conditions the creep has rapidly damped character subjected to logarithmic law: $\varepsilon_{\text{п}} \sim lnt$, where $\varepsilon_{\text{п}}$ - creep deformations, t - time. However under influence of corrosion-active (or surface-active) environments, the low-temperature creep may proceed for longer lasting time subjected to other expression $\varepsilon_{\text{п}} \sim t$. As a result of continuously proceeding plastic deformation, the plasticity exhaustion occurs in the metal local volumes, and starting, when critical value ($\varepsilon_{\text{пл}} = \varepsilon_{\text{кр}}$) is reached by the accumulated plastic deformation and completing with formation of cracks. The presented model provides for implementation of several possible scenarios of the process development: 1) proceeding growth of a single crack completing with formation of a through damage - blowhole, 2) proceeding growth of a group of closely located cracks completing with their spontaneous association and rupture of metal jumper under defects (pipe burst), 3) gradual stabilization of cracks and termination of their further development. The last scenario assumes the creep rate damping occurring both due to growth of resistance to dislocation displacements in the metal lattice (metal strain strengthening), and in relation to reduction (relaxation) of local stresses in crack vicinity (crack field).

It is also noted that continuous plastic deformation (creep) and subsequent crack formation of pipe metal present the united relaxation process, during which the system (pipe under pressure), so to speak, “adapts” to originally unfavourable local stressed state.

It was shown that, among other things, (operating pressure in the pipeline, diameter and pipe wall thickness) the metal creep kinetics depends on of elastic energy accumulated in the pipeline. Thus, maintaining of required rate for performance of plastic shears in the pipe metal of the pipelines is provided due to increased reserve of elastic energy concentrated both in the metal of pipes and in the compressed gas. Therefore, delayed fracture of pipes in the main gas pipelines represents higher hazard, than in the liquid pipelines (oil- and product pipelines).

Effect of small-amplitude stress fluctuation and residual stress on stress corrosion cracking behavior of high grade pipeline steel

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X-80 pipeline was successfully used in the West-East Pipeline Project in China. It is well known that high grade pipeline steel is more susceptible to stress corrosion cracking (SCC) than low grade pipeline steel. Electrochemical measurements, constant strain rate testing and corrosion fatigue techniques were employed to investigate the SCC behavior of X-80 pipeline steel.

For estimation of the influence of small-amplitude stress fluctuation, cracking rates were studied at two stress ratio values (R-value). It was found that cracking rate is directly related to R-value and applied stress, cracking rate increased with the decreasing of R-value and the increasing of applied stress level in NS4 solution. The cracking rates were $2.23 \cdot 10^{-5}$ mm/cycle and $8.3 \cdot 10^{-6}$ mm/cycle at R-value of 0.85, applied stress $100\%\delta_s$ and $85\%\delta_s$, and fluctuation frequency of 0.02Hz. The cracking rates are $1.98 \cdot 10^{-4}$ mm/cycle and $1.27 \cdot 10^{-4}$ mm/cycle at R-value of 0.75, applied stress $100\%\delta_s$ and $85\%\delta_s$, and fluctuation frequency of 0.02Hz.

Moreover, the tests without stress fluctuation carried out at the same applied stress levels shown that small-amplitude stress fluctuation had an enhanced effect on crack propagation. For estimation of the influence of residual stress, SCC susceptibility of X-80 pipeline base metal and weld joint was studied in NS4 and H_2S containing solution under constant applied stress and residual stress. No SCC occurred in base metal and weld joint in NS4 solution with only constant applied stress of $50\%\delta_s$ and $90\%\delta_s$, no SCC was observed in base metal and weld joint even with the combined effects of residual stress (104MPa~303MPa) and constant applied stress ($50\%\delta_s$~$90\%\delta_s$), while corrosion was enhanced by the combined effects of residual stress and constant applied stress.

SCC behavior was also studied in H_2S containing solution, no SCC occurred in base metal and weld joint when the constant stress level is less than $70\%\delta_s$ without residual stress, SCC was observed when the residual stress is bigger than 104MPa without constant applied stress. While SCC always occurred with the combined effects of residual stress (104MPa~303MPa) and constant applied stress ($50\%\delta_s$~$90\%\delta_s$), the SCC susceptibility is reduced in orders of weld joint, heat affected zone, base metal. Results from this work will provide an insight into the small-amplitude stress fluctuation and residual stress driven mechanism of high grade pipeline SCC.

Improvement of corrosion development models for tasks of main gas lines technical condition prediction

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The main types of corrosion impacts, which can effect technical condition of main gas lines, were considered.

The results of inspection of the main gas lines, control of external impacts and corrosion protective facilities are the basis for corrosion hazard evaluation.

For corrosion prediction task, the rate of the corrosion process development is taken as the key indicator. Parameters of corrosion defects and their location depend essentially on the type of corrosion impact, which shall be taken into account during prediction.

It was demonstrated that, for ensuring of reliable prediction of the main gas line corrosion state, under external corrosion impact, it is necessary to determine the type of priority corrosion process (in “protective coating – corrosion conditions” system).

Evaluation of a number of factor influencing the development rate and geometrical characteristics of corrosion defects, and parameters for evaluation of such impacts were presented. The methods for control of parameters of protective coatings condition at the construction and operation stages were considered.

Based on the complex of experimental (field and laboratory) investigations performed by Gazprom, LLC, the results of improvement of models for several types of corrosion processes were demonstrated.

Unified approaches to estimated assessment of strength of pipeline structures with crack-like defects

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The approaches to estimated assessment of strength of pipeline structures with surface crack-like defects based on using calculation models and non-linear fracture mechanics were discussed. For these goals, two-parameter interpolation-type criteria have come into common use.

The interpolation-type criteria allow taking into account the impact of two alternative in form destruction mechanisms (brittle and ductile) in coordinated mode, but interrelated on the physical level. In each particular case the dominant type of destruction depends on the type and loading conditions, the defect parameters and the metal basic mechanical properties determined by results of laboratory tests, including crack testing. Subject to particular combination of parameters, some kind of mixed destruction type depending on proportion between strength characteristics upon brittle and ductile types of destruction may be implemented. The existing adapted variants of interpolation criteria allow taking into account the impact of additional factors, such as the impact of residual stresses, available yield strength, different restrictions on the value of limit stresses and deformations, more accurately.

The considered calculation models and criteria were used in full within the frame of the system for provision of welded joints safety developed and used in Gazprom, PJSC. The uniform hierarchical structure of calculation models and criteria for strength of welded joints with defects, adapted to composition of original data on properties of structural materials, the results of non-destructive inspection and the data on loads and their impacts with subsequent formation of multi-level system for evaluation of the circular welded joints on its basis is used in the system. During switching to higher level, the system provides successive lowering of conservatism in evaluations due to expansion of composition of reference data and using more accurate and complicated calculation criteria and methods. The substantial volume of laboratory tests to determine the required characteristics of the basic metal and the metal of welded joints was fulfilled. The corresponding test and results processing procedures were developed. The accumulated experience can be used for evaluation of strength for the pipeline structures with surface crack-like defects.

The examples on evaluation of strength based on the considered models within the frame of the unified approach are given.

Experience in operation and planning repair of gas pipelines subject to SCC

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– The analysis and dynamics of change of stress-corrosive condition of MGL linear part sections and CS process pipelines;

– analysis of MGLLP ILI results reliability and CS PP according to the data of performed inspections of pipes at MGL KR by a contractor or using own resources;

– results of diagnostics of pipes with SCC defects in test drilled holes and on temporary sites for pipes repair (TSPR) by non-destructive methods of control MGL LP sections;

– planning methods for repair of MGL LP exposed to, stress corrosion cracking;

– experience in operation, diagnostics and repair of pipes with SCC defects in MGL in Sos'vinsky and Komsomol'sky MGL LOMD (local operations & maintenance department of main gas lines).

Features of detecting SCC defects using different diagnostic tools and non-destructive testing methods

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At present the vast majority of fault detectors included in composition of complexes for in-line pipe technical diagnostics (ILI) of linear part of main gas lines (LP MG) is based on using magnetic non-destructive testing (NDT). Among NDT hand-held instruments, the magnetic particle and eddy current fault detectors are widely used. Using of magnetic particle and eddy current inspection imposes a number of restrictions and features on possibility for detecting the crack-like defects and, in particular, SCC defects.

As the main restrictions associated with detection of cracks the following can be noted:

– significant impact of crack geometrical parameters on probability for their detection by hand-held and automated tools of non-destructive testing;

– substantial impact of automated control main parameters on probability and identification of SCC defects: the fault detector travel speed, capacity of magnetic system, hardware dynamic range, uniformity of stray magnetic fields in the inter-polar interval;

– restrictions associated with impact of interfering factors during detection of SCC defects in the zones of common corrosion, fabricated and mounting welded joints.

The Report is prepared based on results of NDT in test drilled holes performed during verification of ILI complexes in MGL LP.

This Report includes:

– physical features of magnetic, eddy current and acoustic non-destructive testing related to detection of crack-like defects.

– main tasks faced by the specialists of gas transportation companies Gazprom, PJSC and NDT inspectors of diagnostic organizations;

– promising areas for development of MGL Gazprom, PJSC LP in-line pipe technical diagnostics.

Gas pipeline inspections using ultrasonic technology: practices

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As cracks and crack growth are a fundamental integrity risk, their reliable detection and sizing have a great importance for the integrity assessment of pipelines containing cracks. As an inspection technique, the ultrasonic transducer inspection is presented here. The focus of this presentation is based on the practices and execution, including the inspection procedure and planning challenges.

Monitoring of stressed-deformed state of gas lines as the element of their corrosion cracking prevention system

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Stress corrosion cracking (SCC) is one of the main causes for accidents in the nail gas line linear part and process pipelines of the compressor stations. So, for example, on August 23, 2017 due to development of SCC defect the accident has occurred in the main gas line Yamburg-Tula 1 resulting in destruction of the gas line section 33 m long, outbreak of 4 fragments and heavy gas inflammation. Economic damage from that accident exceeded 38 million, apart from reputational loss caused by significant public resonance.

As the crack growth kinetics investigations showed, one of the factors determining accelerated growth of SCC defects is an increased level of mechanical stresses in the wall metal of the gas line, including the stresses of the gas line transverse axis.

At present, for evaluation of the level of stresses calculation, experimental and calculation-experimental methods are used. Due to substantial contribution of residual process stresses - welding, installation, etc. - in actual stressed state of the metal, using of calculation-experimental method in the continuous monitoring mode allow for reaching maximum accuracy.

Feasibility of using the facilities for monitoring of stressed-deformed state as the elements for systematic solution on prevention of accident failure due to accelerated development of SCC process is justified in the publication.

Evolution of requirements to improved corrosion resistance steels operated in neutral water environments including in contact with soil electrolyte

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Improvement of corrosion resistance for steel metal products in neutral water environments is important not only for structures, working in atmospheric conditions, in seawater, for infield pipelines, but also for main gas lines (MGL). This results in extension of incubation period for appearance of corrosion spots during contact of MGL pipe surface with the soil electrolyte and in reduction anodic metal dissolution rate in the crack mouth at subsequent stages of SCC development.

For evaluation of pipe steels resistance to corrosion in water environments the new electrochemical procedure was developed, in accordance with which the corrosion resistance criterion is saturation current density recorded during tests in the simulative environment under certain potential. This indicator depends on chemical composition, structural condition of steel, its contamination with different type non-metallic inclusions. The test results according to this procedure correlates well with actual terms of oilfield pipelines operation.

The procedure tests of MGL pipe samples with SCC defects after their operation, as well as after additional hydraulic field tests demonstrated that saturation current density increment after hydraulic field tests may be the criterion for predicting the rate of further SCC defect development and possibility for further use of such pipes. With this indicator value below 0.3 mA/cm^2, probability for further SCC defect development is minimal and such MGL pipes may be recommended for further use in MGL system.

Development factors and possibilities for monitoring SCC defects in company Gazprom transgaz Samara pipelines

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According to VNIIGAZ investigations, SCC defects with the depth up to 10% of pipe wall thickness do not effect the gas line reliability, if the measures have been taken for prevention of the development. During implementation of standard documentation, which allows for leaving the pipes with SCC small depth defects in composition of UGS (Unified Gas Supply System) during overhaul repair, the diagnostic information quality will become critically important.

The results of work carried out in Gazprom Transgaz Samara, LLC since 2012 are presented in this report. The results of SCC sample investigations using fractographic, metal micrographic and microscopic methods were summarized. The results of quantitative evaluation of MGL linear part cyclic operating loads for 11 years were given. The test results simulating the gas line operation under similar loads during 20 years were given. The results of mechanical and fatigue tests of pipes damaged by SCC were shown. The statistic analysis of SCC propagation on pipes from different manufacturers based on MGL overhaul repair real section is given. The results of numerical modelling using the method of finite elements and functions crack depth dependence on its geometrical parameters on pipes under pressure are given. Use of these functions during inspections, in addition to instrumentation methods will allow for evaluation of crack depth during diagnostics and will become the basis for monitoring facilities of SCC defects.

Propositions on development of procedure for classification of operated main gas line sections according to proneness to SCC

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The approach to making preliminary prediction of potential failures in the main gas line linear part due to stress corrosion cracking (SCC) for 3-4 years based on accumulated retrospective data about accidents with account of a trend for stress-corrosion accidents is proposed in the Report.

The method for distribution of predicted number of accidents according to enterprises, structural elements and causes of accidents is shown.

The algorithm for primary determination of potentially hazardous MGL sections from the point of view of accident possibility due to SCC using the equipment for pattern recognition the database on accidents and results of test drilling.

Propositions on classification of sections referred to as potentially hazardous from the point of view of the accident possibility due to SCC were formulated.

Prediction of pipe replacement volume during overhaul repair of gas lines subject to SCC

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Insufficient reliability in detection and identification of stress corrosion cracking (SCC) defects according to in-line inspection (ILI) data determines the necessity to use “predicted number of elements with SCC defects not detected by ILI” parameter during calculation of indicators for technical condition and planning repair of gas line sections exposed to SCC.

In Report:

1. The experience in use for calculation of a number of pipes subjected to replacement, procedures for determination of predicted number of pipes with stress-corrosive cracks specified in Gazprom, PJSC TSD was considered;

2. The alternative procedure for determination of predicted number of elements exposed to SCC was proposed. It allows for:

a) optimization of scope for additional diagnostic inspection at the stage preceding calculation of indicators for section technical condition and selection of repair technology;

b) improvement of accuracy for determination of replacement volume at the stage of planning of overhaul repair of gas line sections exposed to SCC due to use of geoinformation prediction technologies;

3. The experience of using the presented procedure during planning of overhaul repair of gas line sections exposed to SCC and operated by Gazprom Transgaz Yekaterinburg, LLC was set forth.

Gazprom VNIIGAZ testing complex concept of development. Prospective areas of modern fundamental and applied investigations in the field of corrosive-mechanical destruction of pipe steels

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Operation problem for tubes with stress corrosion cracking (SCC) defects is among the most relevant in the countries having extended system of underground main gas lines (MGL).

The accumulated experience in operation of MGL exposed to stress-corrosion and generalized analysis of modern experimental investigations of pipes with defects allow using kinetic models for predicting the rates of SCC defects development upon available complex of empirical factor determining corrosive-mechanical strength and durability of pipes in the soil electrolytes.

It is known that Gazprom, PJSC gas transportation system consists of pipes made of different grades of steels and according to different technical specifications. Therefore, for verified prediction of SCC process, it is required to organize systematic testing pipes of different type-dimension (including the new strength grade X80-X100 pipes) with account of conditions and terms of their operation based on unified testing procedures and criteria corrosive-mechanical strength.

Solution of the specified task is possible owing to organization of serial tests of a wide nomenclature on the basis of Gazprom, PJSC unified test complex. The test complex shall include:

– experimental sections in composition of MGL in service;

– full-size test benches for performing hydraulic tests of pipes and pipe strings with possibility for simulation of MGL operation modes, for applying the bending loads, feeding the corrosion environment and imposing the potential;

– dedicated laboratory test benches and equipment for performance of serial corrosive-mechanical tests and metallographical tests of pipe fragments and steel structures with operational defects;

– auxiliary laboratory equipment for investigation of standard-compliant mechanical properties, chemical composition of steel, evaluation of residual stress level and preparation of specimens for metallographical tests;

– research laboratories for performing specialized corrosive-mechanical tests of steels, studying of underground corrosion, metal-physical, X-ray structural and sub-structural investigation of steels.

Evaluation of carrying capacity and residual service life of pipes with SCC cracks according to the results of field tests in Gazprom transgaz Ukhta

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Evaluation of carrying capacity and residual service life within the framework of the field tests was performed for confirmation of strength redundancy and durability of pipes with stress corrosion cracking (SCC) cracks. The program of field tests comprised selection of defective pipes, laboratory testing, installation of different sensors, devices and other measuring instruments on the pipe string for studying behaviour of SCC defects.

For field tests, from the sections of active main gas lines the pipes Ø1420 mm with SCC cracks of Khartsyzsk tube-rolling mill and Mannesmann manufacture were selected. The pipe string loading consisted of stepped rise to operating pressure with 1 MPa pitch and multiple loading in 0-7.4 MPa-0 mode with the pipe string subsequent destruction. Prior to commencement of field tests, the mechanical properties and element-by-element composition of metal in the specimens made of defective pipes were determined in the laboratory conditions. In the course of field tests, the monitoring of SCC crack growth was performed periodically using non-destructive inspection methods. In addition, the observation of pipe metal deformations with the use of strain-gauge measurement methods in the zones with different local surface curvature was conducted.

Conclusion on actual carrying capacity and real residual service life of SCC pipes with cracks is based on the analysis of results of crack depth monitoring, strength calculations and pipe destruction nature.

Implementation of technology for preservation of stress corrosion cracking in main gas pipelines

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Total length of Gazprom Transgaz Chaikovsky, LLC MGLs is above 10 000 km; most of them were built in 70-80s of the last century and have a film protective coating. Gradual degradation of the specified protective coatings, their delamination and penetration of soil electrolyte on the pipe steel surface resulted in the fact that by now the Company has to operate the gas lines under conditions of exposure to stress-corrosion.

Despite the fact that TSD applicable in Gazprom, PJSC does not allow operation of pipes with stress-corrosive damages, for a long time most of them remain running, because the small cracks available in them are not detected during scheduled in-line inspection (ILI). At that, the stress-corrosion cracks below the sensitivity threshold of ILI facilities do not effect the strength and service life characteristics of pipes, which was proved many times during experimental works on the basis of the Company Engineering and Technical Center. The analysis of results of experimental works jointly with Gazprom VNIIGAZ, LLC allowed to come over to implementation of field technology for preservation of stress corrosion cracking on the Company MGL in service.

During 3 years the Company successfully operates MGL section containing the pipes with stress-corrosive damages of about 10% depth of the wall thickness. The section is re-insulated with innovative coating reducing the risk for formation of new damages in case of its failure. The technology efficiency is confirmed by successful implementation of Gazprom VNIIGAZ, LLC 2-year Program of tests, by results of field inspections and ILI data.

Evaluation of structural steels tendency to brittle fracture

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Usually evaluation of structural steels tendency to brittle fracture includes determination of their crack resistance (using fracture mechanics criteria) and cold brittleness. At that, it is important to assess the role of the metal structural non-uniformity unavoidable practically for any industrial technology for manufacture of metal products.

Successful solution of this task is inextricably linked with development of methods for observation and measurement of non-uniformity of structures and destruction.

In this connection, in particular, the procedures for plotting of serial curves according to N.N. Davidenkov were tried out (including cases with limited number of samples and natural scattering of measurement results) - for objective evaluation of small differences in position of serial curves based on maximum-likelihood principle. For referencing of cold brittleness parameters to the structure, the local method for evaluation of ductile-to-brittle-transition-temperature by acoustical emission (AE) was tried out, during fracture in micro samples with the overall dimensions commensurable with the scale of structure non-uniformity.

Determination of crack resistance for materials with high plasticity was carried out according to the value of the critical crack opening displacement δ_c (*CTOD*), with evaluation procedure based on measurement of crack opening geometry, its propagation kinetics and structure of fractures.

It was demonstrated that in combination with quantitative measurements of structure morphology the proposed methods for determination of tendency to brittle fracture allow for obtaining objective estimation of metal product quality, prediction of its reliable operation in the structure.

Creation of specimens with set distribution of residual stresses for investigation of materials corrosive properties

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Experimental procedures of materials tests for stress corrosion cracking (SCC) require dedicated loading facilities for maintaining necessary level of stresses in the specimens exposed to corrosive environments during the whole testing period. This reduces availability of test procedures in conditions of plant laboratories and an option for obtaining necessary volume of data for statistic processing, as well as increases the cost and labour intensity of investigations.

Potential for manufacturing of model specimens with set process stressed state (including biaxial), which do not require loading in the course of tests, allows for significant simplifying of procedure of material testing for SCC. Such specimen can be obtained by means of different methods for processing of blank edges: reeling by rollers or forging, as well as local heating and build-up welding of material differing according to properties from the specimen basic material.

The choice based on computer modelling of combination of these techniques allows for creating any set stressed state on the surface area in the specimen centre (in the place of contact with corrosive environment). It is important that the specimen investigated area is not exposed and retains its original properties. The procedure is used both for flat specimens and for pipe segments.

Influence of crystallographic texture and residual stresses on SCC crack development in main gas pipelines

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The preliminary investigation of main gas line (MGL) pipe fragments performed previously demonstrated the available relation between the pipe crystallographic texture inhomogeneity and their tendency to stress corrosion cracking (SCC). It was demonstrated that significant reduction of SCC crack development rate upon reaching the layer with markedly different crystallographic grain orientation, within which limits the texture parameters change significantly.

The other factor having a significant effect on formation and initial development of SCC cracks is the level of residual (process) stresses in the pipe near-surface layer, which can increase the level of working stresses determined by the gas operating pressure. At that, calculation of pipes residual service life at present is made without account of changes in stresses along the pipe wall thickness, although it is known that, with the distance from the external surface, the value of tensile residual stresses reduces.

In this publication, the quantitative texture parameters and its non-uniformities along the pipe wall thickness having impact on their tendency to SCC are determined based on X-ray data obtained for ∅1420×16.5 mm pipes made of X70 steel strength grade after their long-term operation in MGL composition. The procedure for evaluation of distribution of residual tangential (circumferential) stresses along the pipe wall thickness by X-ray $\sin^2\psi$ method was also proposed.

Propositions for consideration of influence of texture quantitative parameters and residual stresses during prediction of expected stress-corrosion crack development rates were prepared based on the obtained data analysis results.

Evaluation procedure for aggressiveness of soils causing SCC

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Stress corrosion cracking (SCC) of pipe steels relates to a number of the most urgent problems of main gas line operation. Among other factors, the nature of pipe steels SCC under gas line operation conditions is determined by composition of corrosion environment. The soil electrolyte main components are anions of sulphate, chloride, carbonate (bicarbonate), nitrate and cations of calcium, magnesium, alkali metals, humic acids, hydrogen sulphide and other compounds.

Taking into account the soil electrolyte diverse composition, classification of its components according to their action on the rates of electrical and chemical reactions occurring in the crack was made. The effect of soil electrolyte components on the metal anodic dissolution rate, its hydro-treatment and the crack growth rate in pipe steel X70 were studied. The citric buffer solution with pH 5.5 and NS-4 solution with pH 7.0 modelling the under-film electrolyte made the background environment.

It was demonstrated that the crack growth accelerates in solutions with addition of components, which are activators of the metal anodic dissolution and it decelerates, when the anodic dissolution inhibitors are present. The soil electrolyte components and parameters having most effect on SCC were allocated.

The evaluation procedure for aggressiveness of soils causing SCC of pipe steels was developed. In accordance with this procedure, the soil inspections in the gas line sections in are carried out in shot-holes using diagnostic probes. The electrochemical characteristics of pipe steel, the soil degree of aeration, the soil hydro-treatment capacity and the soil electrolyte chemical composition are measured.

In accordance with developed criteria, each measured parameter is subject to evaluation for its degree of impact on SCC process. SCC development probability score evaluation is carried out in each point for diagnostics. Ranking of gas line sections according to SCC occurrence probability is performed by inspection results.

Evaluation of residual stresses in welded joints in relation to their influence on stress corrosion cracking of gas pipelines

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The main feature of welded joint residual stresses, which effect stress corrosion cracking (SCC) fundamentally, is their non-uniformity and multi-directionality. This is manifested practically in all directions of the welded joint section, which, with account of the welded joints location in relation to the main directions of working stresses, is able both to stimulate SCC in the zone of tensile residual stresses, and, on the contrary, result in SCC development slow-down upon the crack reaching the metal layers (zone) with compressive residual stresses.

In this report, some calculation and experimental assessments proving the need for consideration of welded joint residual stresses during studying SCC on the pipeline surface are given. The prediction according to types and sections of pipeline welded joints in relation to potential effect of residual stresses on SCC is presented.

Features of corrosion destruction of main gas lines under delaminated insulation coating

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According to official data about 80 % of MGL Gazprom are run overtime standard life service terms of protective coatings. In this relation, degradation processes occurring under delaminated protective coating, in locations of under-film electrolyte access to the naked pipe surface render more and more impact on MGL reliability. The specified processes include total and local corrosion under potential of free corrosion or under insufficient protection potential, stress corrosion cracking and microbiological corrosion, at that, the latter may lower the efficiency of electrochemical protection of gas lines and enhance total corrosive aggressiveness of the soil electrolytes.

The main mechanisms and regularities of MGL corrosion destruction under delaminated coating, the results of own investigations of bio-corrosive impact of the environment on steel and the methods for its reduction, as well as promising areas of activities in the field of MGL under-film corrosion are presented for discussion following the results of conducted studies it is proposed to organize the complex of measures aimed at predicting and preventing of MLG corrosion destruction processes, including performance of required investigations, development of new technical solutions and improvement of regulatory management in the sphere of ensuring gas transportation safety.

Experimental determination of local corrosion damage development rate on the surface of pipe steels in solutions simulating soil electrolyte

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It is known that formation of local corrosion damages (pitting, pits, etc.), which are concentrators of stresses on the pipe surface, may be the initial stage pipe steel SCC. The work objective was experimental determination of local corrosion damage development rate on the surface of samples of pipe steels, X70 strength grade of KhTZ and Mannesman manufacture, in synthetic soil electrolytes NS4, C2, NOVATW with pH close to neutral.

Microscopic investigations demonstrated that the initial stage for occurrence of local corrosion defects on the steel surface with free corrosion potential is formation of a narrow groove around non-metallic inclusion. The groove expansion and deepening in parallel with inclusion gradual destruction occurs in the course of time. This was most pronounced in NS4 and C2 solutions, where the maximum size defects were observed on cementite inclusions. It should be noted that for NOVATW solution the available inclusions is not the obligatory condition for pitting occurrence.

In all solutions, increase of a number of defects on the piece of metal surface occurs during the first 2-4 days; further on the number of defects stabilizes and growth of their geometrical dimensions is observed.

The size of the local defect mean diameter was assessed during different test periods. Maximal defects are observed on KhTZ steel samples in NOVATW solution – 35 μm. The depth of pittings during initial period of tests similar for both steels under inspection and it makes ≈ ½ of inclusion height. Rate of pitting growth reduces in the course of time and after 24 days it makes from 0.16 to 0.33 mm/year depending on steel and electrolyte composition.

It was demonstrated that, with potentials for corrosion, the size of corrosion defect generated on the steel surface is determined by the superposition of two factors – nature of non-metallic inclusions and composition of corrosion environment.

The obtained data on the pitting growth rates on X70 pipe steel of KhTZ and Mannesman manufacture were used during development of stress corrosion cracking calculation model for steel gas pipelines.

Creation of ultra-strong composite couplings for restoration and maintaining operating reliability of high pressure main pipelines

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The integrated composite system based on ultra-strong carbon-fibre and epoxiurethane bonding agent required for repair and extension of terms of operation for main gas lines up to 1420 mm diameter (inclusive) is proposed in the publication.

RME CENTROTECH has developed the special system “КСУМТ-ВВК-01/02” for restoration of corroded and worn main and field pipelines in operation under pressure of transported medium, as well as in the other facilities permitting use of system for integrated hardening, for process pipelines of compressor stations regardless of their operation term. It is reasonable to use “КСУМТ-ВВК-01/02” for repair in those cases, when the product transportation full stop is impossible or technologically impermissible during certain period, or when other methods of repair impossible for different reasons (water-flooded locality, low temperatures down to -50 ^{o}C, deficiency of new pipes, fire works cannot be carried out, it is impossible or hard to deliver metal-composite coupling, at present there no for sufficient properties in materials used for polymer composite hardening.

Evaluation of reliability indicators for pipeline structures with crack-like defects

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The most important condition for efficient operation of the main gas line linear part is ensuring reliability. The linear part reliability problems covers a wide range of questions, including analysis of conditions for occurrence of damages and development of constructive activities for their prevention, statistical analysis of reliability indicators and methods of calculation and prediction of indicators for reliability of sections and their component elements. At present, both deterministic and probabilistic approaches are used in Gazprom, PJSC for planning the linear part diagnostics and repair terms. The probabilistic approaches based on evaluation and rating of event risk associated with violation of tightness and structural integrity allow for taking into account the accidental factors for more justifiable evaluation of its technical condition.

Based on physical-statistical approach, the model of predictive evaluation of reliability indicators for the local defective sections located within the limits of the main gas line linear part is considered in the Report.

The specific feature of the developed procedure is complexity of approach to evaluation and justification of permissible level of defects in the operated main gas line sections. The proposed approach provides for joint use of deterministic physical-mathematical models for evaluation of carrying capacity with account of impact of different type defects, and the probabilistic model “load – resistance” for current reliability level (probability of failure-free operation) evaluation, based on which the optimal strategy of subsequent operation and maintenance of the inspected section is selected.

Within the framework of joint use of basic principles of mechanics of fracture and mechanics of damaged environment, the new engineering model for evaluation of carrying capacity of large diameter pipes with longitudinal cracks is proposed. The results of comparisons with known experimental data confirming the developed model adequacy are given.

Hybrid metal-composite pipes for gas pipelines subject to stress cracking

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Modern high-pressure gas pipelines (10 - 25 MPa), as a rule, are constructed using high-strength pipe steels and are rather metal intensive and expensive structures, and their failure results in significant ecological and economical loss. Therefore, with huge volume of construction and necessity in performing large-scale overhaul repair of the old large diameter main gas lines, including those, which are exposed to stress cracking (SCC), the extension of pipeline accident-free operation becomes a critical task.

It is known that the pipe metal stressed state, to a great extent, effects its corrosion resistance and its SCC, in particular. In this relation, reduction of maximal stresses in the pipe body under growing operating pressures becomes a critical task. One of solutions for this task consists in changing pipe design.

In the pipe under internal pressure, the axial and circular stresses differ approximately by 2 times, and, therefore, it is feasible to have the material with the circus-bound strength more intensive (the stress is higher there), than in the axial direction.

Hence, it feels feasible to use the pipe design consisting of metal base, taking up the axial loads, and the surface layer, made of composite materials, ensuring taking up the circular loads and creating hardening and the pipe corrosion protection (hybrid metal-composite pipes). Such pipe design results in the pipeline metal consumption reduction by 35 -40% and significant decrease of circular stresses (below the threshold values) in the pipeline metal part, which ensures high corrosion resistance, including SCC resistance.

In the Report, the composite materials, providing creation of such pipe design, the composite coating and metal pipe thickness parameters, depending on the operating pressure in the pipeline, are given, technology for composite material application on the pipe surface is shown, and the results of preliminary economical effect from using such pipes are presented.

Assessment of natural factors of stress corrosion accidents on the basis of the geospatial modeling and analysis

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Natural factors (environment factors) are considered in various methods of assessment and the forecast a stress corrosion condition for the trunk pipelines along with factors of technical state and material of tubes. A wide variety of natural factors, poor study of their contribution to stress corrosion accidents are determine reasonability of natural factors model.

Methodical approaches of identification of sites, potentially dangerous on natural factors for stress corrosion accidents, on the basis of cartographical model and the geospatial analysis (on the example of a responsibility zone of LLC Gazprom transgaz Yugorsk) will be presented in the report. The model includes the set of geospatial data: trunk pipelines (are executed on high spatial resolution imagery), location of stress corrosion accidents (1990-2017) and natural factors digital layers (more than 40).

Realization of an analysis algorithm is presented in the report:

– the analysis of interrelations between an arrangement of accidents and natural factors (maps, tables, histograms);

– the selection of the most significant indications and their criterias, assessment of weights, proceeding from model of the dangerous site (statistical and expert assessment);

– creation of a series of the maps reflecting distribution of each indications according to their weights;

– addition of the reclassified factor maps (on a cell-by-cell basis) and creation of forecast maps;

– determination of criteria for a decision making, classification, detection of potentially dangerous sites.

Information system for analysis of in-pipe diagnostics data of «IntroScan» as an element of the system for increasing the efficiency of technical diagnostics of technological pipelines of compressor stations

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Alongside with extension of operation terms, running of process pipelines (PP) for compressor stations (CS) requires development of a system of special activities on ensuring set level of technical condition and reliability. The important component of such system is available reliable information on the current technical condition of the facility under operation, including one obtained from the results of in-line (technical) inspection (ILI).

Information system, which allows improvement of efficiency for the applicable evaluation system of CS PP technical condition, provides:

– collection, storage, archiving and primary processing of CS PP technical diagnostics data with the use of automated diagnostic complexes;

– automatic recognition and determination of geometric dimensions of the anomalies and construction elements of compressor station process pipelines according to ILI data;

– verification, assessment of quality of technical diagnostics data performed by the automated diagnostic complexes;

– search and visualization of information using the object multi-layer information model, where each layer is a set of certain type data (design and as-built documentation, results of diagnostics, results of technical condition evaluation, etc.), and the object is presented in the form of spatial model.

Status for implementation of system for identification of stress corrosion cracking at Gazprom transgaz Moscow facilities

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Responsiveness and timeliness in taking immediate management decisions during detection of crack-like defects in main gas lines and process pipelines of compressor stations mainly depends on quality of performed works in key areas:

- identification of crack-like defects as SCC defects;
- hazard evaluation of detected defects;
- assign necessary additional diagnostic inspections.
- assign repair method;
- performance of bench and field tests of pipes;

For this task solution Gazprom Transgaz Moscow, LLC (hereinafter – The Company) performs works on implementation and support of “System for identification of stress corrosion cracking in main gas line linear part and process pipelines of compressor stations” (hereinafter – The System). The System optimizes the process of GTS technical condition and integrity control.

The System relevance, implementation in the Company, structure and its functional are considered in the publication. Summary of main stages implementation results is given.

Comparative analysis of contractors work results on the detection and identification stress-corrosion defects in the gas pipelines

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5953 km main of gas lines, in which ILI is performed on a permanent basis, is operated in Gazprom Transgaz Nizhniy Novgorod, LLC.

The presentation includes the results of analysis of three contractor's reports: CJSC Gazpriboravtomatikaservis, JSC Gazprom orgenergogaz and NPC VTD, which performed inspections in Gazprom Transgaz Nizhniy Novgorod, LLC gas pipelines in 2012-2018. According to ILI reports of different contractors during diagnostics, the confidence evaluation of stress-corrosion defects detection was performed.

The summary of results of comparative tests performed for Gazprom, PJSC main gas in-line pipe technical diagnostics equipment is given. The results of ILI facilities compliance with requirements of standard documentation evaluation carried out by ETC specialists on the dedicated test bench in Bogorodsk city in 2018 were considered.

The data of test bench and field tests conforms with the results of analysis and evaluation of convergence of ILI reports made by different contractors and of external inspections in the test drilled holes of stress-corrosion defects.

Inspection of stress-corrosion sections of pipelines using «IntroScan» robot-based diagnostic complex

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Alongside with extension of operation terms and steady ageing of the natural gas pipeline transportation system, probability of its failure due to development of pipe operational defects grows: corrosion, stress-corrosion, etc. Available relevant and objective information on actual technical condition of system elements (pipes, components) is necessary to ensure safe operation of process pipelines in the oil&gas facilities and for improvement of efficiency in creation of strategic programs for control of pipeline transport on the whole. This task can be solved using modern facilities of in-line inspection (ILI).

For solution of in-line inspection task in relation to pipeline systems with complicated configuration without their integrity violation and with minimal preparatory activities for cleaning the pipeline inner cavity from contaminations, company CJSC IntroScan Technology developed the in-line robot-based diagnostic complex A2072 IntroScan (Scanner) for control of process pipelines of compressor stations containing a set of devices, tools and equipment.

By results of pilot industrial operation, it was identified that detectability of defects, with the depth above 10% of the wall thickness of the part examined using the Scanner, made 91 %, including the stress-corrosion defects, which complies with Gazprom, PJSC standard requirements.

High level of ILI automation processes, as well as high level of inspection results information content allows for taking reasonable solutions on the examined object further operation in the shortest terms, as well as to ensure the set level of reliability and safe operation of the controlled object.

Prediction of stress-corrosion damaging of main gas line sections based on non-linear methods of optimization and algorithms of neural networks

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The global scientific experience of pipe metal SCC investigation indicates multi-stage and multi-factor parameters of this phenomenon, as well as it substantial selectiveness both in relation to damaging individual pipes and the kinetics process in different pipeline section, due to which prediction of MGL section stress-corrosion damaging appears to be a promising task. The existing prediction procedures based on expert and marking and factorial methods of data analysis have high level of subjectiveness and do not ensure the required accuracy of prediction result reproducibility.

With respect to development of computer technologies, the technologies of artificial intelligence, machine learning and data analysis are used more frequently in the applied sciences for solution of complicated multi-factor problems. It was demonstrated that multi-layer neural network (perceptron) trained by the principle of back propagation of error using the stochastic gradient descent method according to Adam modification, is able to make prediction of MGL section stress-corrosion damaging with up to 90% accuracy due to consideration of up to 25 different factors with account of pipeline parameters, soil characteristics and geotechnical features of MGL route line.

The report offers optimal architecture of neural network model and the best non-linear algorithm for calculation of weight coefficients for network neurons from the point for maximization of task solution rate and obtaining accuracy of prediction. Prediction of MGL stress-corrosive condition with account of ILI (in-line inspection) data and of newly developed model will ensure accurate planning of material and technical resource volumes required for MGL selective and overhaul repair.

Features of stress corrosion cracking in hydro-sulphuric environments. Pipe products for gas fields containing hydrogen sulphide

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Simultaneous impact of hydrogen sulphide and stresses on pipe metal results in formation of cracks. Such type of corrosion is called sulphide stress corrosion cracking (SSCC). SSCC mechanism is associated with available ferrous sulphide film in the crack mouth. Depending on conditions for its formation it can fulfil both protective role, and SSCC. In the course of corrosion in hydro-sulphuric environments, the atomic hydrogen may be adsorbed on the pipe metal surface, which penetrates depthwards and expedites destruction of the pipe wall with formation of cracks under stresses less than the yield point. Such type of corrosive impact relates to hydrogen embrittlement. The main gas field, containing hydrogen sulphide, and specification of temperature-and-pressure conditions are presented. The methodology for testing of pipe metal for resistance to sulphide stress corrosion cracking using different method was grounded. Within the framework of scientific and technical cooperation between Gazprom, PJSC and domestic plants-manufacturers of pipe products for the fields, containing corrosive-aggressive components (hydrogen sulphide and carbon dioxide) production of TBG made of 110CrNi corrosion resistant alloy was mastered. Utilized pipe products of domestic manufacture demonstrated a number of competitive advantages as regards the foreign analogues.

Extension of service life for reinforced fittings (weldolets) based on their fatigue strength computer modelling

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T-connections are the most loaded sections of pipeline networks due to concentration of stresses along the outline of main pipe mouth. The promising means for T-connection reinforcing is using of reinforced fittings (weldolets). The existing methods for selection of parameters of weldolet constructions are based on rather coarse analytical dependencies, which do not consider important features of constructions behaviour. Finally, this results in ill choice of design parameters, which is expressed in their service life reduction.

Using of computer modelling allows for evaluation of general regularities of construction deformation under action of operating loads. Identification of deformation general regularities requires generalized computer model of T-connection. As a result of such analysis, the most significant factors of stress concentration were identified for different proportion of the main pipe diameters and pipe branch diameter. Based on identified factors, recommendations on reinforcing of weldolet designs were given. The obtained procedure allowed for significant reducing of stress concentration in weldolets, minimizing of construction weight and justifying of reasonable shape of fillet weld connecting the weldolet and the main pipe.

Computer modelling was performed on ANSYS Workbench 18.2 software complex in elastic-plastic position. The investigation results are: identified mechanisms of weldolet deformation, recommendations on reinforcing of weldolets based on proportion of branch pipe and main pipe diameters, recommended model line-up of weldolet type-dimensions.

Monitoring of “lithosphere-atmosphere-ionosphere-magnetosphere” supersystem transient activity for prediction of earthquakes in the areas of main gas lines

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Dynamics of geological medium metastable states monitoring within detection of integrated structure of factors determining seismic activity in the zones of main gas lines allows for allocation of a set of characteristics for coherent-resonant ensembles of vibrational modes as a part of a sort of “lithosphere-atmosphere-ionosphere-magnitosphere” super system transient activity. Depending on non-uniformity of oscillation parameters with their certain spatial configuration in the main gas line zones, possibility for prediction of geological medium exit beyond the limits of quasi-stable conditions. At that, the chaotic peak manifestations of seismic activity may be presented as external manifestations of integrated synchronization of quasi-harmonic oscillations. Evaluation of geological medium dynamics probability can be implemented based on the analysis of dynamics of functional interrelations of different geophysical factors based on the data integrated analysis, including vertical and horizontal profiles of temperature and humidity, electronic concentration, local parameters of ionospheric plasma, infra-red radiation flows, etc. The novelty of declared approach consists in consideration of earthquakes, when the chaotic peak manifestations of seismic activity are presented as external manifestations of synchronization of quasi-harmonic oscillations. It provides for modelling the results of integrated monitoring of aggregated territories in the zones of main gas lines.

Perspectives of mechanochemical concept for understanding and preventing stress corrosion cracking of main gas pipelines

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The aim of the every theoretical stress corrosion study is to develop a theoretical basis for quantitative prediction and qualitative diagnostics of the incidence of cracking and failure under the impact of stresses and environments. However, as it was shown in our recent analysis, even ‘‘old’’, well-established concepts, such as film-rupture mechanism (Parkins, Ford and Andresen), can contain contradictions and inconsistencies. Experimental evidence and theoretical fundamentals suggest that a single mechanism cannot explain the entire range of stress corrosion processes, and creating new mechanisms is an endless process of their development and rejection, etc. However, this does not say that a particular theory is necessarily wrong. It seems that the more realistic way today is to subdivide stress corrosion into separate significant phenomena and to study these phenomena in the hope to use the results for stress corrosion prevention. Such significant phenomena are mechanochemical and chemomechanical effects developing in the tip of corrosion cracks with a synergetic interaction between them. On this basis, we proposed the autocatalytic mechanism of the failure in the crack tip during stress corrosion cracking and corrosion fatigue.

As so called near-neutral-pH stress corrosion cracking on natural gas pipelines was observed de-facto with the transgranular form of cracks and corrosion products are detected inside of cracks, such type of corrosion cracking seems to be just suitable for our mechanochemical concept. It therefore seems relevant systematic study of mechanochemical effects at the tip of the crack when cracking of pipe steels, as well as the development of methodical complex on their experimental study.

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