Slovak Republic

Assessment of the condition of underground collector lines situated inside the technological complexes of underground storage facilities

1. Introduction

The assessment and diagnostics of the condition of underground gas lines, kept in operation for several decades, is the critical factor for the decision-making about their further safe and reliable operation. The assessment is especially important if parts of the pipeline are situated inside the UGS facilities, not protected by the cathodic protection. The gas collector lines represent the equipment, which is often buried under the surface facilities. Although there is a number of non-destructive and diagnostics methods and instruments designed for this purpose, they are usually designed for natural gas pipelines equipped with pig traps.

However, the assessment and diagnostics of underground gas collector lines requires a specific “custom-made” approach tailored to individual collector types. The specific nature of the collector lines means that they represent pipes of various diameters, tens of meters long and sometimes exceeding one hundred meters, with lots of off-takes. The collector lines are usually not equipped with any pig traps allowing the use of internal diagnostics as in-line inspection. Also, the fact that the gas collector lines are placed underground prevents a simple access from outside for visual checks or measurement of wall thickness. Because the collector lines represent the central part of the pipeline infrastructure, where the natural gas flows is commingled or re-distributed, the time of the work limiting the operation of underground gas storage has to be minimized.

In view of the aforementioned facts, in 2003 NAFTA Company commenced an extensive program oriented on the evaluation and assessment of the condition of underground gas collector lines. The program was divided into several stages. The non-destructive testing, chosen for both the inside and outside assessment, of the collectors’ condition were complemented with the collecting of samples from the collectors’ bodies and subsequent laboratory tests oriented on the determination of the nature of materials exposed to the effects of many years’ operation. Because the diagnostics methods and non-destructive testing require a specific know-how, the program was implemented in close cooperation with the company NS a.s., which provided further subcontractors. The scope of works included evaluation of results, setting of proposals and implementation of measures ensuring further operation reliable and safe operation.

This article describes the diagnostics method for the most important gas collector lines situated at the Central Station of the Lab underground natural gas storage complex, which was implemented 2005. The project has been run during standard operation of underground storage whereby specific works were carried out in the course of regular shut down periods.
2. **The Lab complex of underground gas storage**

NAFTA Company operates the Lab complex of underground storage located in the south-west area of the Slovak Republic, near the Austrian border.

The UGS Lab complex was built gradually, in stages since 1973. The main part of this complex is the Central Station, originally serving as the place of treatment of the gas withdrawn from or injected into the first storage structures became the core of the entire storage complex.

During the following development, the Central Station was significantly expanded with more facilities. Four gathering centers serving for the primary treatment of the withdrawn gas or for re-distribution of the injected gas into individual wells were constructed approximately 12 km away from the Central Station. The gathering centers are connected to the Central Station by connecting gas pipelines and the Central Station thus became the place of installation of compressors, entry/exit metering and related equipment, including a number of surface and underground pipe interconnections and collectors. The Central Station then expanded from the original gathering center into an important junction, which represents the supporting part of the technical infrastructure of the UGS Lab complex.

3. **Program of evaluation and assessment of the condition of collector lines**

The gas collector lines installed at Central Station of UGS Lab complex are part of the pipeline system connecting or re-distributing the gas flows within the technology. They also allow an efficient re-direction of the gas flow within the Central Station according to the current technological needs or clients’ requirements.

As the Central Station shows a relatively high density of pipelines and technological equipment, all the collector lines were built underground, including some off-takes, which are also located underground. Although such arrangement allows decreasing the density of surface pipelines, on the other hand, it does not allow their periodical checks and causes complications whenever they need to be diagnosed.

With respect to the aforementioned conditions, until 2003 all diagnostics of the collector lines was limited only to pressure integrity tests. Although these tests showed the collectors’ ability to safely fulfill their role, they said nothing of their actual condition or whether they needed to be repaired or reconstructed. In addition, the pressure tests, as a standard conducted with water, cause subsequent problems with the collectors’ drying. Also, the pressure test adds undesirable tension to the pipe material, in particular at the places where the pipe walls are weakened e.g. by corrosion, or at the places with hidden material defects, although the operation is absolutely safe under the standard conditions.

With regard the aforementioned facts and to the fact that the age of all the gas collector lines exceeds 20 years, it was decided in 2003 to change the method of the collectors’ diagnostics. The objective of this diagnostics is to detect possible defects of the basic material, to ascertain the consequences of degradation mechanisms, potential corrosion affecting the collector walls, the general assessment of their present condition, and to determine of their remaining useful life. For such objective it is of course necessary to have an additional database, which can be created only by a number of measurements.
According to the possible method of their diagnostics, the gas collector lines were divided into those that can be diagnosed only from the outside and those that can be modified for inside inspection conducted by pipeline inspection tools. A time schedule of their diagnostics, spread over several years, was then prepared.

The time schedule planned spreading the collector diagnostics over four years, in particular to maintain full operation of the underground storage except from regular shutdowns without a negative impact on the continuity of operation. These conditions represented great demands on the projection and organizational preparation of the diagnostics, as well as on the reliable and safe work of individual parts of the underground storage.

With the outside diagnostics it was most important to secure the stability of the dug-out gas collector lines and, with the inside diagnostics conducted by pipeline inspection tools, it was necessary to accurately observe the time schedule of the test preparation and performance with respect to the limited time of the storage’s shutdown.

To offer a better understanding of the outside diagnostics, we would like to note that it was necessary to manually move approximately 900 m$^3$ of soil at the K 102 and K 103 collector lines (Picture No. 1), both from the collector lines to the dumpsites, and back. Due to the high concentration of underground lines it was not possible to deploy any mechanisms for the work.

The preparatory works were usually carried out during the normal operation of the storage and special works, requiring partial or complete shutdowns of the storage were carried out during the regular shutdowns of the underground storage.

Of the total number of 9 collector lines, 7 collector lines were gradually diagnosed by 2005. All the gas collector lines were diagnosed from the outside but inside diagnostics by pipeline inspection tools were also conducted on two gas collector lines. Of course, the time schedule also considered the necessity of potential repairs of the collector lines to ensure the continuity of operation, which eventually proved to be a pragmatic solution. The diagnostics of the last two collector lines are planned for 2007; their technical and projection preparation is now under way.

4. Methodology and course of the collectors’ diagnostics

From the viewpoint of operation safety and continuity, we first commenced the collectors’ diagnostics on the oldest and most exposed gas collector lines. Because the surface collector lines are periodically checked, we focused on the underground pipelines that had never been diagnostically checked during their life.

Before the beginning of the diagnostics, we tested the projection documents and material certificates of individual pipeline parts. With respect to the importance of this equipment from the viewpoint of operational safety – we used mechanical tests to ascertain the quality of the material over the time of its exposure to operational conditions. Whenever it was possible to shut down the given line from operation, we collected samples for the tests directly from the pipes, together with perimeter welds, and laboratory tests were subsequently conducted.

The following tests of these materials were conducted:

1) Mechanical tests:
   - Tensile test – basic material, welding metal
• Impact tests in the bend (KV) at various temperatures for the basic material in perimeter and longitudinal directions and for the welding metal and areas affected by heat
• Measurement of the welds' hardness

2) Accompanying tests:
• Chemical analysis of the material
• Micro-structure of the basic material and welds
• Macro-structure of the welds

Where the operational conditions did not allow shutting down the operation and where the thickness of the wall was sufficient and the homogeneity of the material verified, we collected the samples in the form of spherical caps from the pipe surface during full operation. These samples were chemically analyzed and the penetration method was used to ascertain the yield and strength values and extensibility. The test results served as part of the data for the general evaluation of the diagnostics and the pipeline’s useful life.

Before selecting the diagnostic methods to detect the inside defects of the pipeline, we considered the following viewpoints:

- Possibility to conduct the diagnostics during an operation shutdown or under the full operation pressure in the pipeline,
- Possibility to conduct the diagnostic from the inside of outside of the pipeline
- Length of the collector lines
- Admissibility and efficiency of individual diagnostic methods to be used

On short collector lines we conducted the diagnostics during full operation from the outside surface of the pipeline. After measuring the pipeline’s geometry and wall thickness, we measured the hardness of the welds and of the areas affected by heat. The pipeline surface was tested by the magnetic method. This method allows, depending on the surface’s harshness, to ascertain indications already from the length of from 1 mm under the surface to the depth of 2-3 mm. The welds and the pipe material were tested by ultrasound, using the following methods:

- TOFD / Time of Flight Diffraction/ - an ultrasound method identifying internal locations of non-compact character such as breaks, fissures, debris impressions, gas hollows or lacks of fusion from 0.5 mm up, and determining the size of the non-compactness with the accuracy of ±0.2 mm.
- MAPSCANE – ultrasound checking with the mapping of critical places – corrosion losses and internal locations of non-compactness, lamination type. This method catches defects of 1 mm substitute size at the depths from 1.5 to 14 mm and defects of 2 mm substitute size at the depths of 0.5 to 40 mm.
- Wherever pitting occurred, the remaining thickness of the wall was measured by the classical Krautkrämer UT device with a special pencil-shaped probe, accuracy ± 0.2 mm.
5. **Diagnostics of the K 100 and K 101 collector lines.**

The diagnostic of the K 100 and K 101 collectors was divided into several logical steps, namely:

(a) Digging out and exactly locating the entry and exit parts of the collector lines, which provided the data for the shop preparation and for the inlet flange connections. Part of this step was also the exact locating of the welding places for the entry and exit valves, to secure the suitable basic material for the weld fusion.

(b) Digging out all the connecting pipelines leading to the collector lines and their diagnostics, which provided more data for the complex assessment of the collectors’ reliability and safety.

(c) Shop preparation of the material for the modification of the collectors’ entry and exit parts, necessary from the viewpoint of the selected diagnostic technology. The preparations basically represented the manufacture of the start-up inlet connections with bends, and capping both sides of the collector line with removable blinding flanges.

(d) Shutting down the collector lines during the shutdown of the underground storage and modification of their end parts by welding on them the prepared flange joints and bends (see Picture No. 2). This solution allowed the entry of the pipeline inspection tools from the surface flange joint without the necessity to build an underground shaft. For the surface entry it was only necessary to prepare a disassembling work platform.

(e) Filling the collector lines with water and conducting the inside diagnostics by pipeline inspection tools.

We conducted the diagnostics of pipeline off-takes from the outside surface using the methods described in Part 4. On straight sections we used the more efficient diagnostics by ultrasound checking by the pipeline inspection tool (PIT). An advantage of this device is that, contrary to the classical inspection equipment, it needs no pig receivers or launchers as it is a self-moving device which moves inside the pipeline using its own drive. The general view of the device during its mobilization and when entering into the pipeline is depicted in Pictures Nos. 3 and 4.

The PIT consists of three parts interconnected by an optical cable.

- Drive unit with a carrier of 64 ultrasound probes. This unit allows the device’s movement inside the pipeline at speeds from 360 to 540 m/hr.
- Unit with UT electronics
- Unit containing an electronic control system

When the PIT is used, the collector line is filled with water, which allows the transmission of the signal from the 64 ultrasound probes placed on the inside perimeter of the pipeline into the pipeline wall. The results of the scans from individual probes are transmitted through the optical cable to a separate evaluating PC unit. The device provides a comprehensive digital record from the continuous scanning of the wall thickness and defects inside the pipeline’s material and welds. Part of the record is shown in Picture No. 5. We have these records filed in an archive in the digital form and, in addition to using them when evaluating the diagnostics we file them in the data matrix. In the future, the data matrix will serve during repeated diagnostic checks for comparisons with the measurement results.
6. Evaluation of the diagnostics results and proposed measures

The final stage of the diagnostics was the evaluation of the acquired results from individual measurements and material analyses, when we performed:

- Analyses of the off-takes tension using the method of end elements
- Evaluation of the tests of materials after long-time operation
- Judging the admissibility of fissures
- Judging the admissibility of corrosion defects
- Judging the found inside material defects
- Judging the useful life and operational reliability of the collector lines
- Proposals of potential repairs of the collector lines

The probability calculation method was used for the calculation of the useful life. The result of the calculation is the probability of formation of new fissures (limit condition) during the further operation.

First, the probability of formation of fissures at individual exposed places is determined and then the dependence of the probability of fissure formation in the whole collector line is determined. The collector’s reliability is judged as the reliability of a system consisting of a number of elements (exposed localities). Each of the elements, depending on the tension and fatigue of the material, contributes with a certain probability fissure formation to the general probability of fissure formation in the entire system.

For the calculation of elements with basic material the curve according to the ASME CODE Section III was used. For weld joints, the BSI PD 6493 calculation curve was used. Residual stress was considered according to the API 579 regulation. The properties of the material and wall thickness were considered random values.

To the exposed places of the collector lines where we can expect short useful life belong the locations with high tension (edges of the openings of the off-takes of connecting pipelines, places where material defects occur, places weakened by corrosion) and places with the occurrence of material of worse nature (weld joints).

From the probability viewpoint, the probability that fissures will form in the collector lines is now lower than $10^{-4} (0.01\%)$. The probability of fissure formation will grow during the further operation and will reach the still acceptable value of $10^{-3} (0.1\%)$ at the defined number of working cycles when further measures concerning the useful life will be proposed.

The useful life of the collector lines was determined with recommendation of potential repairs and with setting the period of repeated diagnostic and defectoscopic checks, complemented with calculations.

Diagnostic checks confirmed good conditions of inspected gas collector lines. No serious defects were discovered. Small defects, originating from manufacturing process included mainly laminations; however, they did not impose a serious hazard for current operation. Nevertheless, in order to maintain the standard of long-term operational safety, we have covered the place of the greatest dislocation of defects of the collector pipes’ material with longitudinally divided collars.
7. Conclusion

The collector lines’ diagnostics confirmed the correctness of the approach to addressing the operational safety of the old pipelines. Non-destructive measurements found some internal material defects that could represent the source of a decreased long-term operational safety. Therefore, to ensure the long-term operational safety, their effects have been effectively eliminated by the implemented measures. It is necessary to emphasize that these diagnostics methods are used on the pipelines whose design and arrangement do not allow using the standard diagnostic methods. Described methods can provide a sufficient volume of data, which allow creating a perfect depiction of the pipeline’s technical condition. With the database acquired during the process it is possible to calculate the remaining useful life and later, during repeated measurements, to verify the correctness of the prediction. In future, further diagnostic checks are planned in order to verify envisaged trends and provide additional data for thorough investigation.
Picture No. 2

Picture No. 3  The PIT device during mobilization before entering the pipeline
Picture No. 4  Head of the PIT device entering the inlet flange of the diagnosed collector line

Picture No. 5  Digital record from the diagnostics of the K 100 collector line by the PIT device
Explanation of picture No. 5:
The red color in the top part of the picture shows the laminations in the basic material of the body whose evaluated section was manufactured as a ring from bent sheet metal. The picture shows that the defect begins at the length of 92.37 m; at the perimeter it is located at the clock hands’ angle from 2:27 o’clock to 8:16 o’clock – the length is 368 mm and width 1,165 mm.

The bottom part of the picture shows the profile of the wall thickness, from which it is possible to ascertain that the found laminations are located at the depths from 10 to 13 mm.