NOVEL BOREHOLE- AND TEST PROCEDURES FOR UNDERGROUND GAS STORAGE ASSETS BY USING AN INTELLIGENT PIG FOR DOWNHOLE INSPECTIONS

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Defects both within the base material and within areas of casing connections (screwed / welded) can particularly affect the integrity of boreholes apart from numerous other operational demands/stresses as well as material and environment characteristics. The weld condition is vitally important for the evaluation of welded installed casings.

For this reason on behalf of the VNG - Verbundnetz Gas AG by the UGS - Untergrundspeicher- und Geotechnologie-Systeme GmbH 2004 a comprehensive research regarding an appropriate inspection method/inspection tool that offers improvements to previously used methods/tools was done. Since in the pipeline industry integrity evaluations of pipelines based on the inspections results of intelligent pigging systems are successfully performed, in connection with the research also the possibility of the application of an adapted standard pigging system of the pipeline industry for downhole inspections was investigated (figure).

The research tied in with former investigations of the UGS GmbH. On the basis of the study “The application of intelligent pigging systems in the field of downhole inspections” and after the consideration/evaluation of different tool concepts, it could be estimated that the umbilical operated inspection system offered by GE Oil & Gas Pipeline Solutions, PII - Pipetronix in partnership with the company AGR - PipeTech AS basically achieves the main requirements for an underground application.

The inspection tool is based on the conventional ultrasonic inspection principle combined with the TOFD-principle (time of flight diffraction). It offers a tool-cable-connection by default and therefore also an online data communication / data transfer.

With the inspection tool of PII / AGR the acquisition of the casing condition (production casing / last cemented casing), viz the measurement of geometry, wall thickness, corrosion and crack detection, shall be realized. Therefore the special emphasis is the investigation of welded casing connections with their specific flaw indications (corrosion-/ crack features, manufacturing defects), which is not possible with the present used inspection technique.

Within the project progression PII as the case may be AGR rebuilt the inspection tool from the formerly flexible to the currently rigid tool configuration. In addition a tool-cable-adaptor for the connection to a standard Wireline-Service for downhole applications was developed.

The results of the witnessed trial (testing casing) and first downhole experience in storage well will be reported in the presentation. Statements regarding the tool-movement within vertical casings as well as statements in terms of the measuring ability of the inspection tool during the tests will be demonstrated. In the context of the analysis/evaluation of the inspection data collected during the various tests a comparison between the results of the inspection campaigns and the results of the inspection tool used so far will be likewise led.

On the basis of the increase in information possibilities for extending the present evaluation standards with respect to the quantifiable reliable evaluation of casing conditions will be explained. Within the presentation the possible evaluation of girth welds as well as potential statements in terms of the production period/technical risks will be prioritized. Additional analyses/research programs, such as fracture mechanical analyses, for the establishment of updated evaluation directives will be introduced.
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1 PRELIMINARY REMARKS

During the last 20 years the UGS - Untergrundspeicher- und Geotechnologie-Systeme GmbH (UGS) has developed a method for evaluation of downhole equipment for underground storage facilities.

Right now there is no official legislation regarding the evaluation of mining safety of downhole equipment available. For this reason on behalf of the VNG - Verbundnetz Gas AG (VNG) standard evaluation rules concerning all storage facilities of VNG were developed. Those rules had been approved by the mining authorities as standard procedures. Associated with that, continuous revisions have to be specified.

A very special issue of the evaluation of downhole equipment is the identification of the casing geometry by using modern geophysical logging services. There exists an extensive evaluation routine by the use of the finite elements method based on survey logging data. For further developments the key aspects of activity are the advancement of the methodology as well as the use of new tools which can achieve more logging data, higher resolution and higher accuracy of measurement.

On behalf of the VNG the UGS did a comprehensive research regarding an appropriate inspection method / inspection tool that offers improvements to previously used methods / tools. Therein also the possibility of the adaption of standard pipeline-pigging systems for downhole inspections and therewith possible test-procedures were investigated.

The umbilical operated inspection system offered by GE Energy, PII – Pipetronix (PII) in partnership with the company AGR - PipeTech AS (AGR) turned out to be most suitable for underground applications. Using this tool the investigation of the casing condition (production casing / last cemented casing), viz the measurement of geometry, wall thickness, corrosion and crack detection, was essential. The special emphasis was the investigation of girth welds with their specific flaw indications (corrosion-/ crack features, manufacturing defects).

2 DOWNHOLE INSPECTIONS

2.1 RELEVANT FLAWS

The integrity of casings can be particularly affected by relevant flaws within the base material as well as flaws within the casing connections (girth welds). Possible flaws can be:
- Corrosion-dependent areal defects (metal loss, wall thickness thinning),
- Cracks within the base material and in girth welds,
- Fabrication defects or
- Defects due to mechanical loads/operational demands.

During the project progression the main focus was the detection of metal loss and cracks.

2.2 TECHNICAL REQUIREMENTS FOR INSPECTION-TOOLS

The new inspection tool should be preliminary used within an 11 3/4” last cemented casing over a gas filled storage cavern. Thereby the casing was totally filled with saturated brine and backed up by different packer systems.
In order to be applied the tool configuration had to meet the main following requirements:
- It must be a stiff tool configuration,
- The system must be adapted to a standard wire line-system considering standard rated breaking points,
- The tool must insure online data communication and
- The tool must be pressure-resistant for a maximum inspection depth of 600 m.

Within in certain tests the tool had:
- To prove the ability of bi-directional moving through a vertical casing,
- To investigate the present casing condition, like
  - Wall thickness and
  - Casing geometry and possible ovalities;
- To prove the ability to measure/investigate existing defects within the base material and girth welds while meeting the set requirements, such as
  - The detection and sizing of defects and
  - The differentiation into different defect types;
- To document, interpret and evaluate all measured defects,
- To reveal measurement and tool restrictions respectively.

2.3 EQUIPMENT CONFIGURATION OF INSPECTION TOOL

The inspection tool is based on the conventional ultrasonic inspection principle combined with the TOFD-principle (time of flight diffraction).

The tool provider rebuilt the inspection tool from a formerly flexible to the currently rigid tool configuration. During the project the inspection tool consisted of two modules, one for the wall thickness measurement and the other for the circumferential crack detection.

![Figure 1: Tool modules for crack detection (left) and wall thickness measurement (right)](image)

The standard pigging system offers a tool-cable-connection by default and therefore also an online data communication/data transfer. However due to its technical specification and material condition the existing cable system could not be used for downhole inspections. For this reason a tool-cable-adaptor for the connection to a standard Wireline-service was developed.
Figure 2: Tool-cable-connection including adaptor piece and standard cable head

For all adaptation procedures, functional tool tests as well as the Wireline service during the field test the project parties worked in close collaboration with the company Schlumberger (SLB). For the field test a Cable Interface Service (CIS), viz the supply of sufficient wire line equipment and the recording of the depths and loads during the inspection campaign was provided by SLB.

3 TOOL TESTS 2005

3.1 WORKSHOP TEST

For the performance of the workshop test a testing casing containing 3 girth welds and artificial defects were manufactured. By applying mechanical methods as well as sparks erosion artificial defects (root defects, pores, pitting, fabrication defects and slag) were placed in/on the testing casing. All defects were documented in order to insure the subsequent comparison between the actual and measured defects.

The results of the workshop test can be summarized as follows:
- Bi-directional moving through a vertical casing was successful,
- The tool was able to pass changes in wall thickness, offsets and eccentricity and
- Online presentation of the inspection data was possible.

Wall thickness measurement:
- Clearly identification of all girth welds,
- Detection, localization and sizing of defects (wall thickness thinning, areal defects, pitting),
- Differentiation into different defect types,
- Documentation, interpretation / evaluation of defects and
- Comparison between actual and measured defects.

Crack detection:
- Inspection of all three girth welds,
- Detection, localization and sizing of flaws within the welding areas,
- Sporadically differentiation into different defect types and
- Number of placed defects ≠ number of measured defects.

Based on the results of the workshop test the accomplishment of different functional tests and finally the realization of a field test were decided.

3.2 FUNCTIONAL TESTS

In order to meet all safety regulations and due to the fact that for the first time an adapted pipeline pigging system was used for downhole inspections several functional tests had to be performed prior to the actual field test.
The tests are as follows:
1. First adaptation test for the verification of the mechanical and electrical tool-cable-connection,
2. Pressure test of the adapted inspection tool at a test pressure of max. 85 bar,
3. Final functional test in order to prove the complete tool functionality after the pressure test and
4. Tool check at the test-site and final acceptance test.

The results of all four tests approved the use of the adapted pigging system for a casing inspection over a gas filled storage cavern.

3.3 FIELD TEST

For the field test the main goals were the initial mentioned requirements for downhole inspection tools. By using the adapted tool system the actual casing condition (production casing / last cemented casing) should be analyzed, viz the measurement of geometry, wall thickness, corrosion and crack detection.

The special emphasis was the investigation of girth welds with their specific flaw indications (corrosion-/crack features, manufacturing defects).

The results of the field test can be summarized as follows:
- Bi-directional moving through a vertical casing, maximum depth was 540 m,
- Appearance of few restrictions in movement due to the little tool-weight, interior casing roughness and the low operation-speed,
- The tool was able to pass changes in wall thickness, offsets and eccentricity,
- Tool-cable-connection mechanically and electronically functional,
- Selective data transfer, viz simplified online presentation of the inspection data was possible and
- Appearance of tool restrictions due to the increasing pressure.

Wall thickness measurement:
- Identification of all girth welds,
- Detection, localization (internal / external), sizing of selective and areal defects (wall thickness thinning, areal defects, pitting) and
- Documentation, interpretation / evaluation of defects.

Crack detection:
- Partly inspection of selected welding areas and
- Tool restrictions due to the increasing pressure.

In order to perform further field tests several optimizations are necessary. The optimizations regard:
- The inspection tool incl. fabrication of a tool housing,
- The tool-cable-connection,
- The online presentation of the inspection data, software optimization,
- The data recording,
- Repeatability of the inspection data,
- The sensor constancy and
- The amplification of the inspection intervals (temperature / pressure resistance).
4 CONCLUSIONS

With the field test the bi-directional movement through a vertical casing could be proved even though few restrictions appeared. By increasing the tool weight with the use of drill collars and by raising the operation-speed the bi-directional movement could be smoothed.

For further projects the inspection tool as well as the software has to be optimized. Furthermore the repeatability of the inspection data has to be proved (reference measurements).

A decision-making in terms of the usability of an adapted pigging system for downhole inspections can not only be based on the performed field test because only a partly comparison between different inspection tools but not the compensation against the actual defects were possible.

A realistic evaluation regarding the suitability of such adapted pigging system can only be given after accomplishing the inspection of a production casing. Thereby a real comparison between the measured and actually present defects can be made after the production casing was taken off and be analyzed.

For the upcoming years summarized the following steps have to be accomplished:
- Modification / optimization of the inspection tool and the software,
- Development of smaller tool dimensions,
- Development of the module for axial crack detection,
- Further field tests, viz inspection of production casings to assure the comparison between the measured and actually present defects and
- Update of existing evaluation standards on the basis of the increasing in information.