CONCEPT OF LEAK TIGHTNESS MONITORING AT UNDERGROUND GAS STORAGE

Markéta HORÁKOVÁ, Jakub RYBA, Erik ROČEK
Department of Geological Engineering, Faculty of Mining and Geology, VSB – Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava Poruba, Czech Republic
marketa.rubesova@vsb.cz; jakub.ryba@vsb.cz; erik.rocek@vsb.cz

ABSTRACT

The most important part of the operation of each underground gas storage facility is the implementation of a regular monitoring system for leak tightness monitoring. This article deals with the design of a proposal leak tightness monitoring concept in underground gas storage in porous reservoirs (depleted gas/oil reservoirs, aquifer reservoirs). This concept interconnects all commonly used and established leak tightness monitoring methodologies and evaluates them in time with comparison with historical results with reference to possible solutions or implementation of remedial measures.

Keywords: underground gas storage, leak tightness, well integrity

1 INTRODUCTION

Natural gas is an important energy source. It is used both for electricity generation and for remote and individual heating. The security and reliability of gas supplies depend on their stability, the well-developed gas transport system and the capacity of underground gas storage (thereinafter "UGS"). The importance of UGS is increasing in the event of a supply shortage. [1]

To determine field's suitability as natural-gas storage, its physical characteristics such as porosity, permeability, and retention capability should be examined along with the site preparation costs, deliverability rates and cycling capability [2].

For underground gas storage are primarily used depleted oil or gas reservoirs, aquifers and caverns. The advantage of converting a field (depleted oil or gas reservoirs) from production to storage duty is that one can use the existing wells, gathering systems and pipeline connections. Aquifers are suitable for gas storage if the water bearing sedimentary rock formation is overlain with an impermeable cap rock. Storage is created by injecting gas and displacing the water. This type of storage usually requires more cushion gas (the volume of gas intended as permanent inventory in a storage reservoir to maintain adequate pressure and deliverability rates throughout the withdrawal season) and greater monitoring of withdrawal and injection performance. Caverns (salt, mine, hard rock) provide very high withdrawal and injection rates relative to their working gas capacity (the maximum volume of gas that can be stored in UGS facility by design minus cushion gas, i.e., the volume of gas in the reservoir above the level of cushion gas). Cushion gas requirements are relatively low [2].

This article will further deal with the UGS facilities created in depleted oil or gas reservoirs and in aquifers.

The following terminology is used in connection with UGS facilities:

- Total gas storage capacity – the maximum volume of gas that can be stored in UGS by design. It is determined by the physical characteristics of the reservoir and installed equipment.
- Total gas volume in storage (Gas in place) – the volume of storage in the UGS at a particular time.
- Cushion gas – the volume of gas intended as permanent inventory in a storage reservoir to maintain adequate pressure and deliverability rates throughout the withdrawal season.
- Working gas capacity – the total gas storage capacity minus cushion gas, i.e. the volume of gas in the reservoir above the level of cushion gas.
- Injection/withdrawal volume – the volume of gas that can be injected/withdrawn into storage fields during a given period.
- Withdrawal rate/capacity – a measure of the amount of gas that can be withdrawn from a storage facility on a daily basis with MMCM/day.
- Injection rate/capacity – the amount of gas that can be injected into a storage facility on a daily basis with MMCM/day.

Volume LXV (2019), No. 2
p. 58 – 68, ISSN 1802-5420
DOI 10.35180/gse-2019-0012

- Maximum reservoir pressure – the maximum reservoir static pressure, which must not be exceeded at the end of the injection season.
- Minimum reservoir pressure – the minimum reservoir static pressure, which must not be exceeded at the end of the withdrawal season [2]

In order to ensure a reliable operation of the UGS, its tightness must be ensured as a priority. During the operation of UGS there are several risk factors, i.e. places of potential gas leakage:

- wells in UGS,
- spill point,
- tectonic closures - sealing faults in the upper parts,
- insulation properties of overburden rocks,
- surface plant technology of UGS.

In each UGS's facility, a leak tightness monitoring system must be in place. The monitoring system usually includes:

- measurement of reservoir pressure in reservoir (in gas and water part of reservoir),
- measurement of reservoir pressure in monitoring horizon (in overburden and underlying of UGS's reservoir),
- measurement of reservoir pressure, monitoring of gas chemistry behind structural, tectonic and other closure of UGS,
- measurement and checking of pressures on annulus production and surface casing and checking level of packer liquid at wells equipped with a packer,
- checking of dissolved gas and water chemistry (chromatographic and isotopic) in indication horizons,
- analysis of soil air (volume control CH4 in soil air),
- well logging in wells,
- periodic revisions of surface parts of wells, technology of wells and UGS. [3]

The implementation of individual methods into the leak tightness monitoring system is specific to individual UGS. The system must be configured to cover the most important parts of leak tightness monitoring, both primary (relative to the tightness of storage structures) and secondary (relates to well integrity). [3]

The past few years, UGS operators have been introducing a well integrity management system (thereinafter "WIMS"). Well integrity concept described in standards ISO-DIS-16530-1 [4], ISO-TS-16530-2 [5] and NORSOK Standard D-010 [6] is defined to be an application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well. As a minimum, the following elements shall be addressed in well integrity management system:

- well integrity policy and strategy,
- resources, roles, responsibilities and authority levels,
- risk assessment aspects of well integrity management,
- well barriers (WBE-Well Barrier Elements),
- well component performance standards,
- well operating limits,
- well monitoring and surveillance,
- annular pressure management,
- well handover,
- well maintenance,
- well integrity failure management,
- management of change,

- well records and well integrity reporting,
- performance monitoring of well integrity management systems,
- compliance audit. [5]

In the context of the integrity of the wells (WIMS) there is software (e.g. BOHRIS from ESK - Innogy) that allows for standardized visualization and documentation of the required well data (casings, well completion, well head and well barriers) regardless of the well's spud data and the quality of available documents. Technical details are usefully linked to the geological characteristics (e.g. layer boundaries). This software is able to calculate MAWOP (Maximum Allowable Wellhead Operating Pressure) / MAASP (Maximum Allowable Annulus Surface Pressure) for each well. [7]

An essential part of each leak tightness monitoring is its regular evaluation and the implementation of remedial measures in the event of its disturbance.

2 METHODOLOGY

The solution methodology was divided into two phases. In the first phase, the available literature was studied, dealing with various methods of investigating the tightness of UGS. The second phase focused on the evaluation of the results of the tightness monitoring at the UGS Uhřice (depleted gas reservoir), Uhřice-jih (oil-gas reservoir) in the Czech Republic [8] and UGS Stockstadt/UGS Hähnlein (aquifer type of reservoir) in Germany [9].

2.1 Methodology of leak tightness monitoring

Leak tightness monitoring could be divided into primary and secondary. Primary leak tightness monitoring refers to the tightness of reservoirs. It is proven by the existence of a primary deposit trap saturated with hydrocarbons (oil/gas reservoir) or water (aquifer). For the case of overpressure in the process of UGS, knowledge of the structural closure and the extent of gas accumulation after reservoir pressurization are necessary. These data are controlled and monitored by p/z curve monitoring (gas in place vs reservoir pressure reduced by compressibility factor) [3].

First, it is necessary to understand what the normal storage cycle (p/z curve) looks like after the end of the start-up period and conversion of the reservoir to the UGS. After cushion formation (residual original gas or additionally injected gas), further gas is injected, which represents the working gas to be subsequently withdrawn. The next season, more gas is injected, which is again withdrawn. This formula is repeated for further 2 or more years until the full capacity of the UGS is reached, i.e. 100% of the projected working gas.

Injection and withdrawal of gas from the reservoir cause pressure changes in the reservoir. In the case of the completed start-up period of the reservoir at the UGS, we can trace the operation mode of the reservoir and the course of season during the injection and withdrawal of gas. If, from a reciprocal comparison of the slope, the p/z curve of individual injection/withdrawal seasons, which follow each other during the cycle, indicates that the injection and withdrawal lines are identical from year to year, this means that there is not a gas leak from the reservoir. [10] If gas is lost, the curves move towards a larger gas volume at a given p/z. [2] Loss of gas from UGS can also be monitored by calculating the storage coefficient from the relation:

$$m = \frac{\Delta G}{\Delta p/z} \tag{1}$$

where:

m = curve slope

G = Gas in place (MMCM)

p/z = reservoir pressure reduced by compressibility factor (MPa)

If the resulting value is more or less constant, there is no loss of gas from the UGS. In the case of aquifers and water drive reservoirs, the storage coefficient is calculated at level 100% of working gas in UGS. [11]

Secondary leak tightness monitoring is related to the integrity of the operational, abandoned wells and is ensured by their equipping. In case of cementation of wells, the procedures and the highest quality types of cement are used, ensuring perfect contact of casing - cement - rock. The wellhead is equipped with a tight production cross designed for maximum operating pressure conditions, allowing the connection of the gas pipeline and the control of individual annulus [3]. Measuring the annular pressures is a basic and most effective control of the integrity of wells. The presence of a permanent pressure in the annulus may be caused by a leak in the well elements. Therefore, the wells on the underground gas storage facility are equipped with a remote-control system of data-pressure transfer from the wellhead and from annulus of surface and production casing. In the case of data transmission absence, the pressures are periodically physically transcribed from the manometer on the well. [12]

Volume LXV (2019), No. 2
p. 58 – 68, ISSN 1802-5420
DOI 10.35180/gse-2019-0012

To assess and control the annular pressures, UGS operators are introducing well integrity control systems. For this purpose, the American Petroleum Institute Recommended Practice 90 Annular Casing Pressure Management for Offshore Wells (thereinafter "API RP 90") is used. Although API RP 90 is targeted at offshore wells, the fixed platform drill section is fully applicable to onshore wells [13]. Well integrity is specified in standards ISO-DIS-16530-1 and ISO-TS-16530-2 [4], [5]. In API RP 90, it is referred to as the annulus A-annulus between tubing and production casing and the annulus B-annulus between the production casing and the next outer casing (mostly surface casing) [13]. The maximum allowable wellhead operating pressure (thereinafter “MAWOP”) according to API RP 90 [14] and the maximum allowable annulus surface pressure (thereinafter “MAASP”) according to ISO-TS-16530-2 [5] at the annulus A, B, is calculated on each well. MAWOP represents the maximum allowable operating pressure for a particular annulus, measured at the wellhead relative to ambient pressure [14]. MAASP represents greatest pressure that an annulus can contain, as measured at the wellhead, without compromising the integrity of any element of that annulus, including any exposed open-hole formations [5].

UGS wells have subsurface safety valves (thereinafter “SSSV”). SSSV systems are designed and installed to prevent uncontrolled well flow when actuated. The functionality of SSSV is checked on the basis of API RP 14B standard twice a year. The amount of gas that passes through the closed valve must be less than 0.43 CM/min so that the SSSV can be considered functional [15].

Well logging measurements are usually used to monitor the technical condition of the wells. The measurement is able to capture both the static state of the change in saturation and eventually a dynamic process of ongoing overflow in the affected horizons and monitoring of potential secondary accumulations that would result from gas migration outside the reservoir area. Furthermore, it can verify whether there is a gradual overflow and saturation in the overburden monitored reservoirs caused by the leakage of the reservoir wells, eventually by gradual saturation directly on the contact of the UGS structure with the overlying layer. Frequency of well logging depends partly on the well logging results on wells observed over time and on the legislation in the country [16].

Furthermore, sampling soil air is carried out in the built measured points and profile lines, including selected monitoring wells. It is based on the analysis of soil air transported by the field analyser. The aim of sampling soil air is to determine, at selected measured points, the degree of contamination of the geological environment by organic substances (contaminants). The method of field sampling soil air is used to verify the tightness of the overlying layers and the completion of the well. If the measured values range from 0.1 vol.% and more, thus it may indicate leakage. It must be verified by repeated measurement and then by sampling for chromatographic analysis to clarify the origin of hydrocarbons (C1-C5). In case of doubt about the origin, an isotopic survey is necessary [3].

3 CONCEPT PROPOSAL OF LEAK TIGHTNESS MONITORING AT UGS

The methods of leak tightness monitoring, which are commonly implemented in underground gas storage facilities, are well set with regard to their predictive capability. The proposed concept of leak tightness implements these methods into a single interconnected system, at the end of which a conclusion should be drawn on whether UGS is tight or not, and in the case of detecting a UGS integrity disturbance, which it actually deals with and the design of its solution.

The concept of leak tightness monitoring is based on the principle of dividing the individual components of leak tightness monitoring methods into diagrams and its annual evaluation compared to historical data. The methods of leak tightness monitoring are continuously evaluated during the year. After every injection and withdrawal season of UGS, a final analysis and evaluation report are compiled [8]. Each method of leak tightness monitoring is evaluated separately [9]. If a problem occurs, it is important to find a report from previous injection/withdrawal season and look for the certain situation. This concept proposal establishes rating sheets where after all sheets A-E have been gone through, the integrity after end of each injection/withdrawal season (from 1.4. to 31.3.) is assessed and this model would be stored in a comprehensive set of files indicating where the problem occurred under which conditions, the problem has been resolved. This means that the integrity of UGS would be captured in a simple way once a year, indicating the problem, its possible solution and when the problem occurred. In the case of a new or similar problem, in the past, it is about a tedious search in the dates and news when this problem occurred and how it would be solved. Concept proposal is divided into 5 sheets (A-E). It includes both primary and secondary leak tightness. The design of the concept is illustrated in Figure 1, Figures 3-6, and Tables 1-3.

Volume LXV (2019), No. 2
p. 58 – 68, ISSN 1802-5420
DOI 10.35180/gse-2019-0012

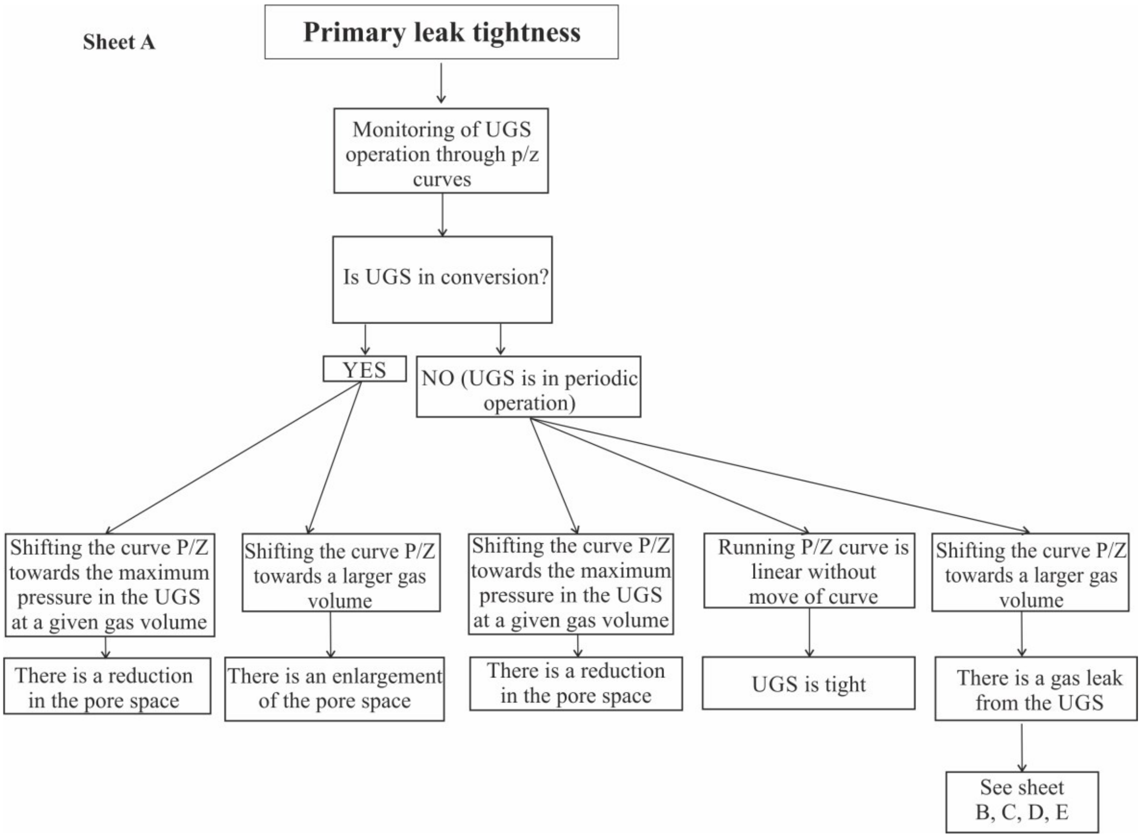

Figure 1. Primary leak tightness – Sheet A

Sheet A (Figure 1) deals with the primary leak tightness that relates to the tightness of the reservoir structure used for underground storage of gas. Primary leak tightness is monitored using the so-called p/z analysis. This represents the dependence of the reduced reservoir pressure on the gas in place (thereinafter “GIP”) in reservoir [3]. The slope of the curve is monitored for all UGS withdrawal and injection periods. And depending on how the curve deviates from the so-called "normal waveform", it is determined whether it may be a gas leakage from the storage structure or a decrease / enlargement of the pore space. When the curve is shifted towards a larger gas volume in the UGS it means a gas leakage from UGS or enlargement of the pore space, mainly in case of development/conversion of UGS. When the curve is shifted towards the maximum pressure in the UGS it means a decrease in the pore space [2]. Example of gas leakage from UGS is given in Figure 2. Gas leakage is represented by curve – Year i+2. The difference between curves Year i+1 and Year i+ 2 is the loss of gas [2].

Volume LXV (2019), No. 2
p. 58 – 68, ISSN 1802-5420
DOI 10.35180/gse-2019-0012

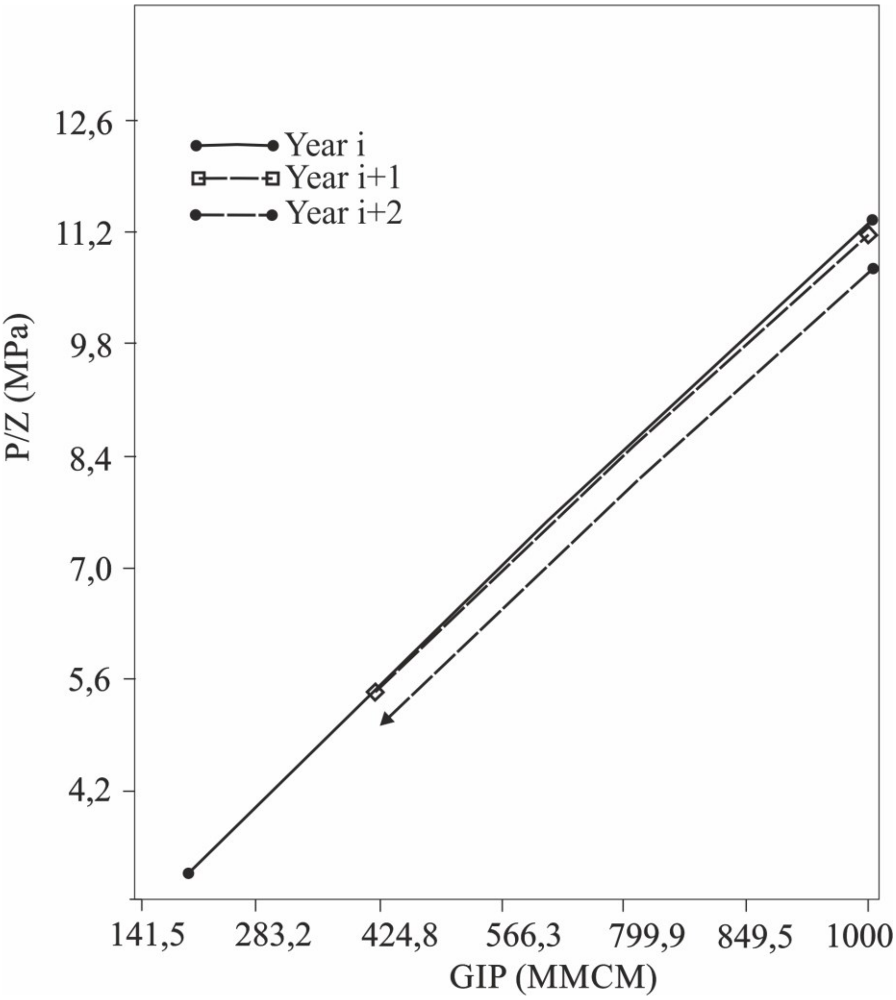

Figure 2. Curve P/Z vs Gas in place (GIP) [2]

The source of primary data - p/z vs GIP - will serve as the basis for the primary gas leak evaluation. The sheet A (Figure 1) is used to evaluate the injection-withdrawal season.

Sheet B (Figure 3) deals with secondary leak tightness, represented by the measurement of reservoir pressures in the reservoir layer.

Volume LXV (2019), No. 2
p. 58 – 68, ISSN 1802-5420
DOI 10.35180/gse-2019-0012

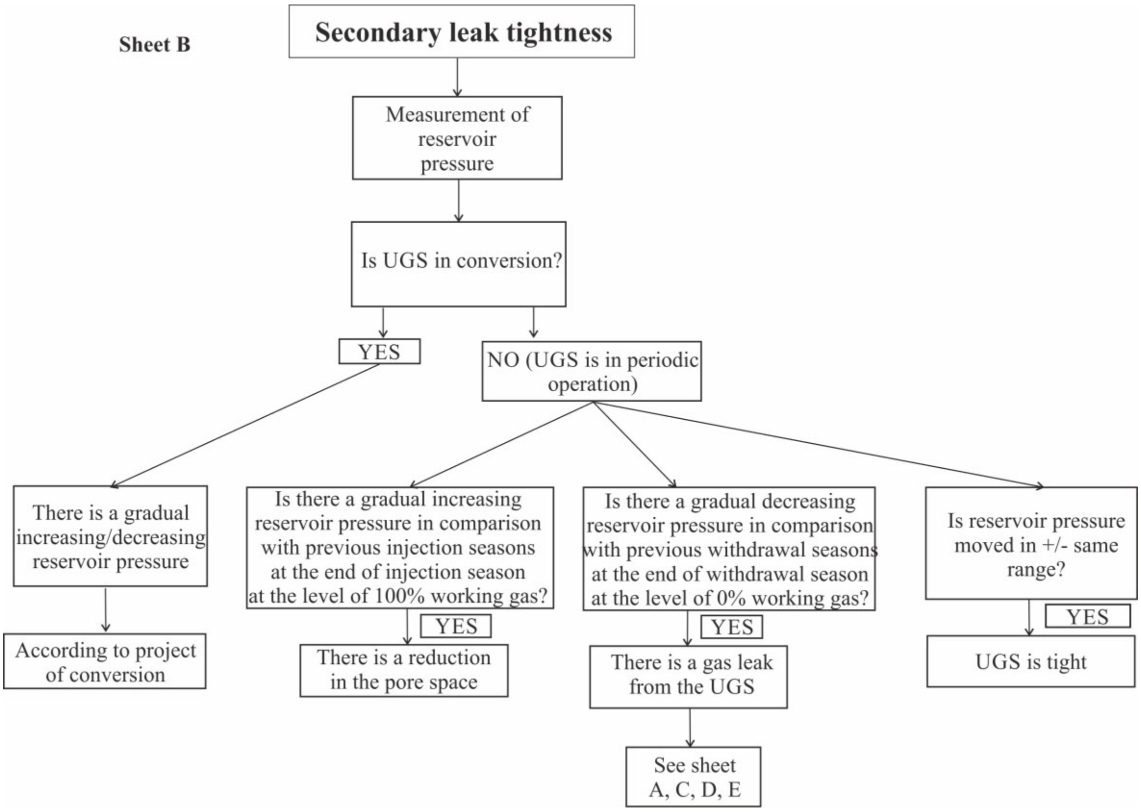

Figure 3. Secondary leak tightness – Sheet B

Storage reservoirs usually have their pressure checked twice a year. This usually occurs at the end of the injection period and at the end of the withdrawal period. The pressure check on storage reservoirs is to make an inventory assessment and to determine the general health of the reservoir. When pressure measurements are made, the reservoir is usually shut in for a period of time to allow the pressure to stabilize. The period may be as long as 30 days. The pressure is then measured with a dead-weight tester. After this measurement the storage well is returned to the operation. The reason for shutting in the reservoirs before the pressure measurement is to allow the pressures in the reservoir to stabilize and equalize throughout the reservoir [10]. If there is a reservoir pressure drop at the level of 0% working gas in comparison to previous withdrawal seasons, there may be a gas leak from UGS. This pressure drop can be already from 3% of the set primary minimum working pressure [2].

Sheet C (Figure 4) deals with secondary leak tightness related to reservoir pressure measurement at the control horizon, mostly in wells located in the overburden of the storage structure.

Volume LXV (2019), No. 2
p. 58 – 68, ISSN 1802-5420
DOI 10.35180/gse-2019-0012

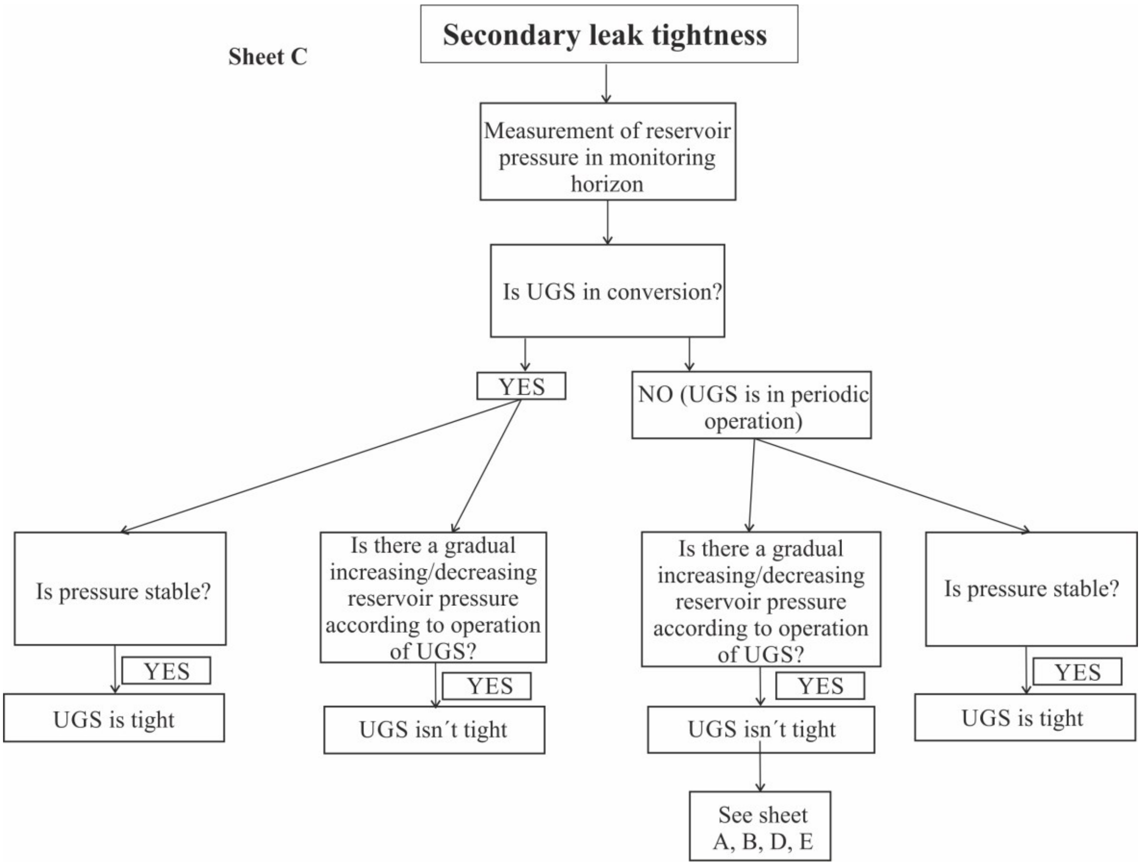

Figure 4. Secondary leak tightness – Sheet C

From the reservoir pressure monitoring, it can be ascertained whether the reservoir pressure measured in the control well reacts to the movement of the gas in the storage structure. If there is an increase or decrease in the reservoir pressure in accordance with the UGS operation, there may be gas overflows between the storage space and the overburden and therefore partial communication, which has a negative effect on the UGS leak tightness and thus its safe operation [3].

Sheet D (Figure 5) is related to secondary leak tightness, dealing with reservoir pressure measurement, monitoring of gas chemistry under structural, tectonic and other closures.

Volume LXV (2019), No. 2
p. 58 – 68, ISSN 1802-5420
DOI 10.35180/gse-2019-0012

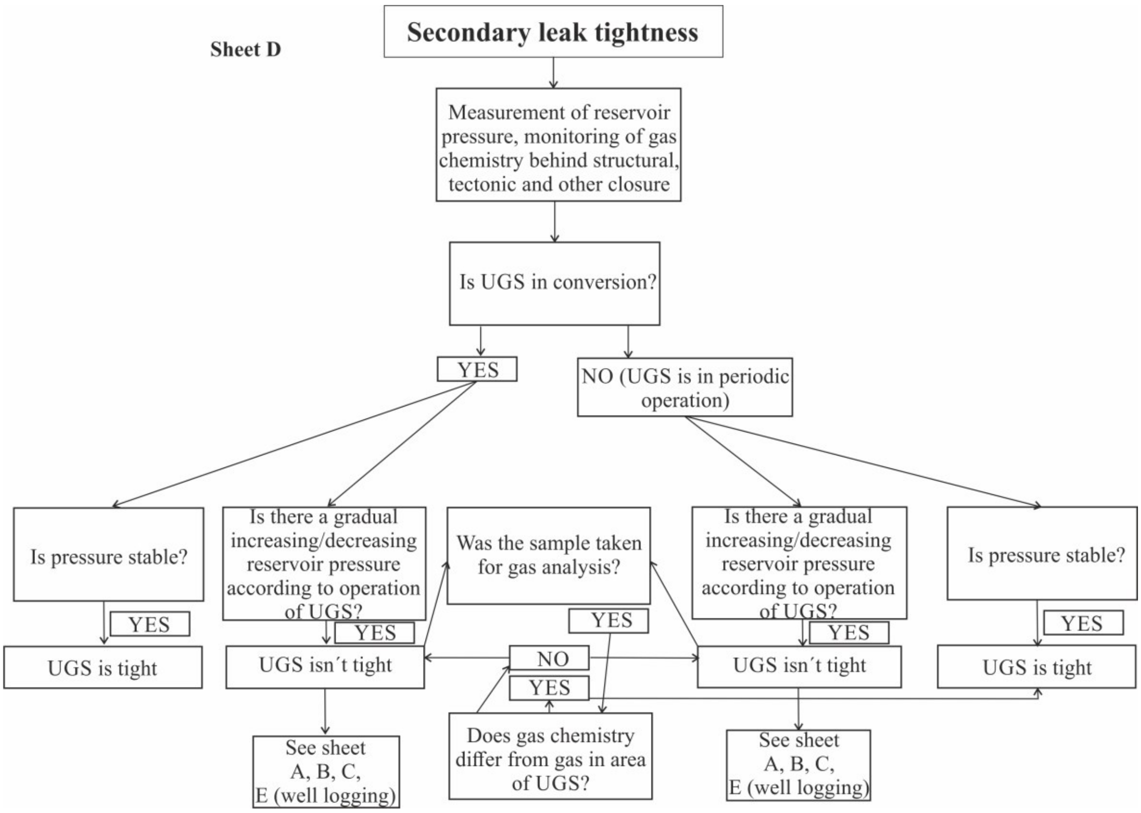

Figure 5. Secondary leak tightness – Sheet D

If the reservoir pressure behind the structural, tectonic and other closures moves in accordance with the UGS gas flow, there may be communication with the UGS storage structure. As a supportive means for this assertion, a sample of gas is taken from both the wells from the storage structure and from the wells located behind their closures. Depending on whether or not gas chemistry is the same, it is possible to consider well communication under structural, tectonic and other closures with a storage structure [3].

Sheet E (Figure 6) includes secondary leak tightness methods, namely, measuring and controlling the pressures on the annulus of the production and surface casing on wells equipped with a packer. It also deals with the control of the level of the packer liquid and its filling, well logging, the control of gas and water chemistry, the analysis of soil air and function test of subsurface safety valves.

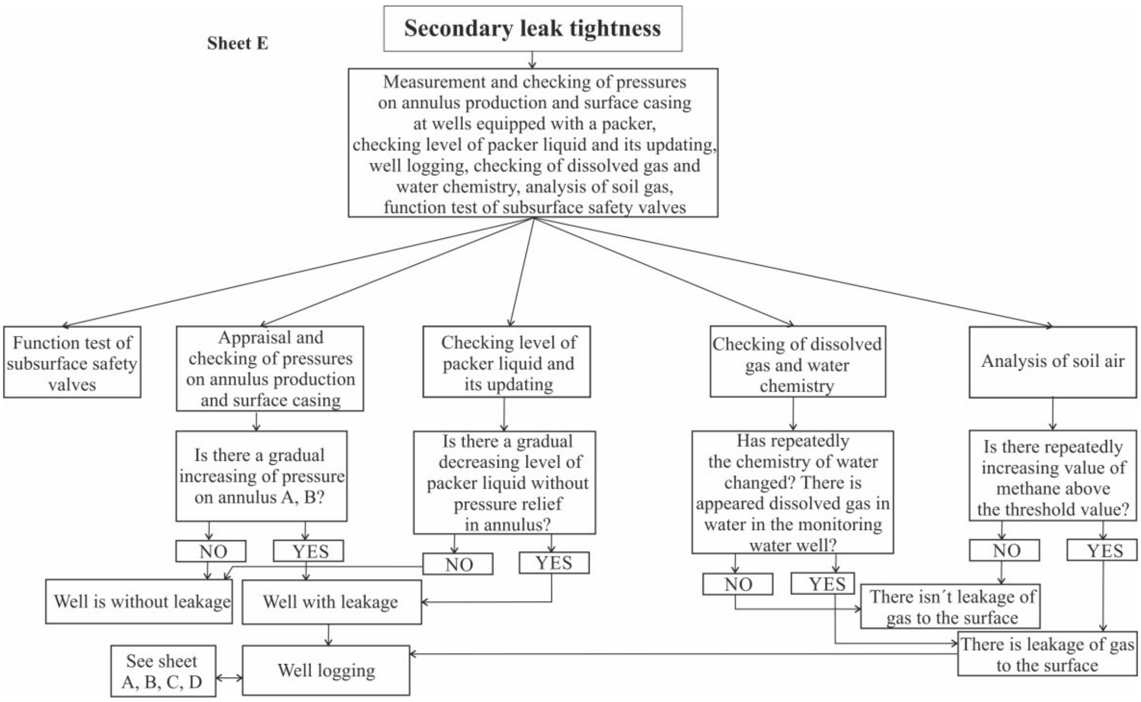

Figure 6. Secondary leak tightness – Sheet E

These methods predominantly relate to wells leak tightness monitoring. If pressure builds up on the annulus and cannot be released, it may be a signal that leakage may be present in the well completion [14]. Similarly, if the annulus is not released and the packer fluid is rapidly leaked, it may also indicate a leak in the well [3]. The technical condition of the wells and gas saturation is verified by carrying out well logging measurements. Additionally, samples of water wells are regularly taken. If there are any abnormalities in the composition of water or even a gas-charged liquid, it is a warning that the gas could leak out to the surface. The same is followed by gas wells where increased methane content in soil gas above the threshold can mean gas leakage to the surface [3].

Proposal of Sheets A-E is designed to easily link all methods of leak tightness monitoring to a single set. When all sheets A-E will be gone through, the summary results will be written into tables. An example of the table for writing of results is shown in Table 1 (for sheet A-D) and Table 2, 3 (for sheet E).

Table 1. Example of final report evaluation of the leak tightness of UGS after the end of every injection-withdrawal season for sheet A-D

Year / I/W season	Regime of UGS (I/W)	Storage ratio GIP/pz (MMCM)/MPa	Gas in place (GIP) after the end of season (MMCM)	Level of working gas (MMCM)	Value of GIP from the elongation curve slope after ending of withdrawal season (MMCM)	Value of BHP at maximum level of working gas (MPa)	Value of BHP at minimum level of working gas (MPa)	Summary results	Proposal of solution	Link to primary data store

Table 2. Example of final report evaluation of the leak tightness of UGS after the end of every injection-withdrawal season for sheet E

Date of performance of SSSV functionality	List of wells with non-functional (leaking) SSSV	List of wells with exceed limited value of MAWOP (MAASP) A	List of wells with exceed limited value of MAWOP (MAASP) B	List of wells with loss of packer liquid	List of monitoring wells with changed chemical composition of liquid	List of monitoring wells where was detected dissolved gas in water	List of monitoring wells with methane levels above the limit value in the soil air	Summary results	Proposal of solution	Link to primary data store

Table 3. Example of final report evaluation of the leak tightness of UGS after the end of every injection-withdrawal season for sheet E

List of wells with secondary saturation determined from well logging	List of wells with bad cementation determined from well logging	List of wells with thinned wall/corrosion of casing determined from well logging	Summary results	Proposal of solution	Link to primary data store

Main purpose of this concept of leak tightness monitoring is its use for annual evaluation of tightness of UGS after the end of every injection/withdrawal season. The concept will clearly state what problem occurred, when this happened and the proposal of its solution or the corrective action that was taken and whether the UGS is leak tightness with respect to the results.

4 CONCLUSION

Monitoring and annual evaluation of leak tightness storage structure and wells is an integral part of every UGS operation. Each operator of UGS should have implemented a system and methodology for leak tightness. Due to the fact that each methods of leak tightness monitoring is somehow connected and interconnected, the concept of leak tightness monitoring was designed. This system is designed to fully evaluate the leak tightness monitoring of UGS and its monitoring over time. This system is divided into 5 sheets that cover all commonly used leak tightness monitoring methods. So, it is fully applicable to a wide range of operated UGS. After all sheets will be gone through, the results will be set in the annual evaluation, which will provide clear information on the results of the leak tightness monitoring of each injection/withdrawal season, eventual occurrence of the problem, timing, and what solution or corrective action will be taken. The search for historical data in individual injection/withdrawal seasons does not need to take place in the event of a recurring problem in future operation of UGS. It may also be useful for a quick orientation on whether the integrity of UGS or wells deteriorates, or is good in the long-term.

ACKNOWLEDGMENT

This article was supported by the Moravian-Silesian region within the program "Support of science and research in Moravian-Silesian region 2017" (RRC/10/2017) and also by the project Institute of clean technologies for mining and utilization of raw materials for energy use - Sustainability program. Identification code: LO1406. The project is supported by the National Programme for Sustainability I (2013–2020) financed by the state budget of the Czech Republic.

REFERENCES

[1] MINISTERSTVO PRŮMYSLU A OBCHODU. Státní energetická koncepce České republiky (The National Energy Concept of the Czech Republic), Praha, Czech Republic, 2014.

[2] WANG, X. and M.J. ECONOMIDES. *Advanced natural gas engineering*. Houston, Tex.: Gulf Pub. Co., 2009. ISBN 1933762381

[3] BUJOK, P. *Vliv vrtného průzkumu, těžby a uskladňování kapalných a plynných uhlovodíků na životní prostředí (The environmental impact assessment of boring investigation, extraction and storage of liquid and gas hydrocarbons).* Ostrava: Vysoká škola báňská - Technická univerzita, 2003. Sborník vědeckých příruček. ISBN 80-248-0478-6.

[4] TECHNICAL SPECIFICATION ISO/TS 16530-1. Petroleum and natural gas industries – Well integrity – Part 1: Life cycle governance, Geneva, 2016.

[5] TECHNICAL SPECIFICATION ISO/TS 16530-2. Well integrity – Part 2: Well integrity for the operational phase, Geneva, 2014.

[6] NORSOK STANDARD D-010. Well integrity in drilling and well operations, Lysaker, Norway, 2013.

[7] INNOGY. Bohris, *Wellbore Software Solutions*, Freiberg, Germany, 2018.

[8] ZÁKOPČAN, M. *Geologické zhodnocení podzemní části PZP Uhřice-Vtlačně-odběrová sezóna 2016-2017 (Geological assessment of underground facility PZP Uhřice-Vtlačně - sampling season 2016-2017)*, MND a.s, Hodonín, 2017.

[9] RUBEŠOVÁ, M. *Zhodnocení vtlačně-odběrové sezóny 2017/2018 PZP Stockstadt a PZP Hähnlein (The assessment of sampling season 2017/2018 in PZP Stockstadt and PZP Hähnlein)*, MND a.s, Hodonín, 2018.

[10] FLANIGAN, O. *Underground gas storage facilities: design and implementation.* Houston: Gulf Pub. Co., 1995. ISBN 0884152049.

[11] BITTKOW, P. Erdgasspeicher Stockstadt Sand 7.2, Statusbericht zum Druck-Volumen Verhalten, Essen, Germany, 1991.

[12] RUBEŠOVÁ, M., P. BUJOK and M. KLEMPA. Assessment of integrity wells on the underground gas storage using measurement of annular casing pressure. In: *17th International Multidisciplinary Scientific GeoConference: SGEM 2017:* conference proceedings: 29 June-5 July, 2017, Albena, Bulgaria. Volume 17. Sofia: STEF92 Technology Ltd., 2017. pp. 547-554. ISBN 978-619-7105-00-1.

[13] SUCKO, A. Implementation of API Recommended Practice 90 for Annular Casing Pressure Management for Offshore Wells in the Onshore Underground Gas Storage Operatins. XVI. International scientific and technical conference "Nove poznatky v oblasti vrtania, tazby, dopravy a uskladnovania uhlovodikov", Podbanske, TU Košice, Slovak Republic, 2012, pp. 79-83.

[14] AMERICAN PETROLEUM INSTITUTE: Recommended practice 90 for Annular Casing Pressure Management for Offshore Wells, first edition, Washington, USA, 2006.

[15] AMERICAN PETROLEUM INSTITUTE: Recommended practice 14B Design, installation, operation, test and redress of subsurface safety valve systems, Washington, USA, 2016.

[16] RUBEŠOVÁ, M., P. BUJOK and M. KLEMPA. Application of production well logging for the monitoring of tightness underground gas storage. In: *17th International Multidisciplinary Scientific GeoConference: SGEM 2017*: conference proceedings: 29 June-5 July, 2017, Albena, Bulgaria. Volume 17. Sofia: STEF92 Technology Ltd., 2017. pp. 27-32. ISBN 978-619-7105-00-1.

Volume LXV (2019), No. 2
p. 58 – 68, ISSN 1802-5420
DOI 10.35180/gse-2019-0012