BS EN 1918-1:2016

BSI Standards Publication

Gas infrastructure — Underground gas storage

Part 1: Functional recommendations for storage in aquifers

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National foreword

This British Standard is the UK implementation of EN 1918-1:2016. It supersedes BS EN 1918-1:1998 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GSE/33, Gas supply.

A list of organizations represented on this committee can be obtained on request to its secretary.

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This European Standard was approved by CEN on 10 January 2016.

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European foreword

This document (EN 1918-1:2016) has been prepared by Technical Committee CEN/TC 234 “Gas infrastructure”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2016 and conflicting national standards shall be withdrawn at the latest by September 2016.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 1918-1:1998.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

For a list of significant technical changes between this European Standard and EN 1918-1:1998, see Annex B.

This document is Part 1 of a European Standard on “Gas infrastructure - Underground gas storage”, which includes the following five parts:

— *Part 1: Functional recommendations for storage in aquifers*;

— *Part 2: Functional recommendations for storage in oil and gas fields*;

— *Part 3: Functional recommendations for storage in solution-mined salt caverns*;

— *Part 4: Functional recommendations for storage in rock caverns*;

— *Part 5: Functional recommendations for surface facilities.*

Directive 2009/73/EC concerning common rules for the internal market in natural gas and the related Regulation (EC) No 715/2009 on conditions for access to the natural gas transmission networks also aim at technical safety including technical reliability of the European gas system. These aspects are also in the scope of CEN/TC 234 standardization. In this respect, CEN/TC 234 evaluated the indicated EU legislation and amended this technical standard accordingly, where required and appropriate.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This European Standard covers the functional recommendations for design, construction, testing, commissioning, operation, maintenance and abandonment of underground gas storage (UGS) facilities in aquifers up to and including the wellhead.

It specifies practices, which are safe and environmentally acceptable.

For necessary surface facilities for underground gas storage, EN 1918-5 applies.

In this context "gas" is any hydrocarbon fuel:

— which is in a gaseous state at a temperature of 15 °C and under a pressure of 0,1 MPa (this includes natural gas, compressed natural gas (CNG) and liquefied petroleum gas (LPG). The stored product is also named fluid);

— which meets specific quality requirements in order to maintain underground storage integrity, performance, environmental compatibility and fulfils contractual requirements.

This European Standard specifies common basic principles for underground gas storage facilities. Users of this European Standard should be aware that more detailed standards and/or codes of practice exist. A non-exhaustive list of relevant standards can be found in Annex A.

This European Standard is intended to be applied in association with these national standards and/or codes of practice and does not replace them.

In the event of conflicts in terms of more restrictive requirements in the national legislation/regulation with the requirements of this European Standard, the national legislation/regulation takes precedence as illustrated in CEN/TR 13737 (all parts).

NOTE CEN/TR 13737 (all parts) contains:

— clarification of relevant legislation/regulations applicable in a country;

— if appropriate, more restrictive national requirements;

— national contact point for the latest information.

This European Standard is not intended to be applied retrospectively to existing facilities.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1918-5, *Gas infrastructure - Underground gas storage - Part 5: Functional recommendations for surface facilities*

3 Terms and definitions

3.1 Terms and definitions common to parts 1 to 4 of EN 1918

For the purposes of this document, the following terms and definitions apply. They are common to parts 1 to 4 of EN 1918.

3.1.1
abandoned well
well permanently out of operation and permanently plugged including removed surface facilities

3.1.2
annulus
space between two strings of pipes or between the casing and the borehole

3.1.3
aquifer
reservoir, group of reservoirs, or a part thereof that is fully water-bearing and displaying differing permeability/porosity

3.1.4
auxiliary well
well completed for other purposes than gas injection/withdrawal, e.g. water disposal

3.1.5
casing
pipe or set of pipes that are screwed or welded together to form a string, which is placed in the borehole for the purpose of supporting the borehole and to act as a barrier preventing subsurface migration of fluids when the annulus between it and the borehole has been cemented and to connect the storage reservoir respectively cavern to surface

3.1.6
casing shoe
bottom end of a casing

3.1.7
cementing
operation whereby usually a cement slurry is pumped and circulated down a cementation string within the casing and then upwards into the annulus between the casing and the open or cased hole

3.1.8
completion
technical equipment inside the last cemented casing of a well

3.1.9
containment
capability of the storage reservoir or cavern and the storage wells to resist leakage or migration of the fluids contained therein

Note 1 to entry: This is also known as the integrity of a storage facility.

3.1.10
core sample
sample of rock taken during coring operation in order, e.g. to determine various parameters by laboratory testing and/or for a geological description

3.1.11
cushion gas volume
gas volume required in a storage for reservoir management purpose and to maintain an adequate minimum storage pressure for meeting working gas volume delivery with a required withdrawal profile and in addition in caverns also for stability reasons

Note 1 to entry: The cushion gas volume of storages in oil and gas fields may consist of recoverable and non-recoverable in-situ gas volumes and/or injected gas volumes.

3.1.12
drilling
all technical activities connected with the construction of a well

3.1.13
exploration
all technical activities connected with the investigation of potential storage locations for the assessment of storage feasibility and derivation of design parameters

3.1.14
formation
body of rock mass characterized by a degree of homogeneous lithology, which forms an identifiable geologic unit

3.1.15
gas injection
gas delivery from gas transport system into the reservoir/cavern through surface facilities and wells

3.1.16
gas inventory
total of working and cushion gas volumes contained in UGS

3.1.17
gas withdrawal
gas delivery from the reservoir or cavern through wells and surface facilities to a gas transport system

3.1.18
geological modelling
generating the image of a structure from the information gathered

3.1.19
indicator horizon
horizon overlying the caprock in the storage area and used for monitoring

3.1.20
landing nipple
device in a tubing string with an internal profile to provide for latching and sealing various types of plugs or valves

3.1.21
liner
casing installed within last cemented casing in the lowermost section of the well without extension to surface

3.1.22
lithology
characteristics of rocks based on description of colour, rock fabrics, mineral composition, grain characteristics and crystallization

3.1.23
logging
measurement of physical parameters versus depth in a well

3.1.24
master valve
valve at the wellhead designed to close off the well for operational reasons and in case of emergency or maintenance

3.1.25
maximum operating pressure
MOP
maximum pressure of the storage reservoir or cavern, normally at maximum inventory of gas in storage, which has not to be exceeded in order to ensure the integrity of the UGS and is based on the outcome of geological/technical engineering and is approved by authorities

Note 1 to entry: The maximum operating pressure is related to a datum depth and in caverns usually to the casing shoe of the last cemented casing.

3.1.26
minimum operating pressure
minimum pressure of the storage reservoir or cavern, normally reached at the end of the decline phase of the withdrawal profile and for caverns is based on geomechanical investigations to ensure stability and to limit the effect of subsidence and normally has to be approved by authorities and has not to be underrun

Note 1 to entry: The minimum pressure is related to a datum depth.

3.1.27
monitoring well
observation well
well for purposes of monitoring the storage horizon and/or overlying or underlying horizons for subsurface phenomena such as pressure fluctuation, fluid flow and qualities, temperature, etc.

3.1.28
operating well
well used for gas withdrawal and/or injection

3.1.29
overburden
all sediments or rock that overlie a geological formation

3.1.30
permeability
capacity of a rock to allow fluids to flow through its pores

Note 1 to entry: Permeability is usually expressed in Darcy. In the SI Unit system permeability is measured in m^2.

3.1.31
porosity
volume of the pore space (voids) within a rock formation expressed as a percentage of its total volume

3.1.32
reservoir
porous and permeable (in some cases naturally fractured) formation having area- and depth-related boundaries based on physical and geological factors

Note 1 to entry: It contains fluids which are internally in pressure communication.

3.1.33
saturation
percentages of pore space occupied by fluids

3.1.34
seismic technology
technology to characterize the subsurface image with respect to extent, geometry, fault pattern and fluid content applying acoustic waves, impressed by sources near to surface in the subsurface strata, which pass through strata with different seismic responses and filtering effects back to surface, where they are recorded and analysed

3.1.35
string
entity of casing or tubing plus additional equipment, screwed or welded together as parts of a well respectively completion

3.1.36
subsurface safety valve
valve installed in casing and/or tubing beneath the wellhead or the lower end of the tubing for the purpose of stopping the flow of gas in case of emergency

3.1.37
tubing
pipe or set of pipes that are screwed or welded together to form a string, through which fluids are injected or withdrawn or which can be used for monitoring

3.1.38
well
borehole and its technical equipment including the wellhead

3.1.39
well integrity
well condition without uncontrolled release of fluids throughout the life cycle

3.1.40
well integrity management
complete system necessary to ensure well integrity at all times throughout the life cycle of the well, which comprises dedicated personnel, assets including subsurface and surface installations, and processes provided by the operator to monitor and assess well integrity

3.1.41
wellhead
equipment supported by the top of the casing including tubing hanger, shut off and flow valves, flanges and auxiliary equipment, which provides the control and closing-off of the well at the upper end of the well at the surface

3.1.42
working gas volume
volume of gas in the storage above the designed level of cushion gas volume, which can be withdrawn/injected with installed subsurface and surface facilities (wells, flow lines, etc.) subject to legal and technical limitations (pressures, gas velocities, flow rates, etc.)

Note 1 to entry: Depending on local site conditions (injection/withdrawal rates, utilization hours, etc.) the working gas volume may be cycled more than once a year.

3.1.43
workover
well intervention to restore or increase production, repair or change the completion of a well or the leaching equipment of a cavern

3.2 Terms and definitions not common to parts 1 to 4 of EN 1918

For the purposes of this document, the following terms and definitions apply, which are common to part 1 of EN 1918 only.

3.2.1
capillary pressure
pressure difference between the non-wetting phase and the wetting phase in porous rock

3.2.2
capillary threshold pressure
pressure needed to overcome the property of a porous rock saturated with a wetting phase (water) to block the flow of a non-wetting phase (gas)

3.2.3
caprock
sealing barrier for fluids overlying the pore storage reservoir

3.2.4
closure
vertical distance between the top of the structure and the spill point

3.2.5
connected aquifer
aquifers, which are connected to the storage and thereby subject to changes of pressure caused by the storage operations (hydraulic communication)

3.2.6
gas water contact
interface between the gas and the water in a reservoir

3.2.7
hanger
device for supporting the weight of pipes and to assure the pressure tightness of the annulus

3.2.8
initial reservoir pressure
pressure existing in a reservoir before any change due to operation of the reservoir or due to operation in the surrounding area

Note 1 to entry: The initial reservoir pressure is related to a datum depth.

3.2.9
reservoir simulation
numerical modelling of a reservoir to predict or to monitor the behaviour and movement of the fluids in the formation and in general the reservoir behaviour with respect to rates, pressures and saturation distribution

3.2.10
sand screen
filters placed at the level of the storage formation in order to avoid the entrainment of sand particles and fines during withdrawal

3.2.11
spill point
structural point within a reservoir, where hydrocarbons could leak and migrate out of the storage structure

3.2.12
well testing
taking pressure and flow rate measurements during flowing and shut-in periods of operating wells to provide information about the characteristics of the storage reservoir and the capacity of the wells

4 Requirements for underground gas storage

4.1 General

This clause gives general requirements for underground gas storage. More specific requirements for underground gas storage in aquifers are given in Clauses 5, 6, 7, 8 and 9.

4.2 Underground gas storage

4.2.1 Overview and functionality of underground gas storage

The EN 1918 covers storage of natural gas, Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG). Because of the relevance of underground gas storage of CNG the major part of this introduction is related to this.

The underground gas storage (UGS) is an efficient proven common technology and is in use since 1915. UGS became an essential indispensable link in the gas supply chain for adjusting supply to meet short-term and seasonal changes in demand.

Natural gas produced from oil and gas fields is increasingly being used to supply energy requirements. As the gas supply from these fields does not match with the variable market demand natural gas is injected into subsurface storage reservoirs when market demand falls below the level of gas delivery or if there is an economic incentive for injection. Gas is withdrawn from storage facilities to supplement the supply if demand exceeds that supply or withdrawal is economically attractive.

The primary function of UGS is to ensure that supply is adjusted for peak and seasonal demand. Apart from this, the storage facilities can provide stand-by reserves in case of interruption of the planned supply. Increasingly UGS is applied for commercial storage services.

Thus in summary underground gas storage facilities can be used for:

— security of supply;

— providing flexibilities;

— balancing of seasonal demand variabilities;

— structuring of gas supply;

— provision of balancing energy for the optimization of transport grids;

— trading and arbitrage purpose;

— stand-by provisions and strategic reserves;

— structuring renewable energy sources – power to gas;

— storage of associated gas as service for production optimization and resultant environmental conservation.

4.2.2 Types of UGS

For storage of natural gas several types of underground gas storage facilities can be used, which differ by storage formation and storage mechanism (see Figure 1):

— pore storage:

  — storage in aquifers;

  — storage in former gas fields;

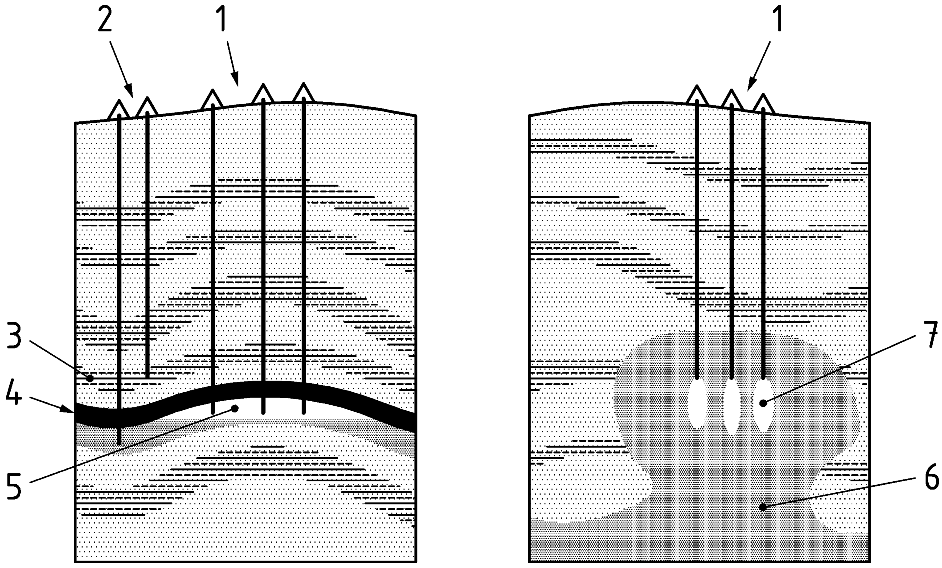
  — storage in former oil fields.

— caverns:

  — storage in salt caverns;

  — storage in rock caverns (including lined rock caverns);

  — storage in abandoned mines.



Key

1 operating wells

2 monitoring wells

3 indicator horizon

4 caprock

5 storage reservoir and stored gas

6 salt dome

7 cavern

Figure 1 — Storage in aquifers, oil and gas fields, solution mined salt caverns

For LPG storage only salt or rock caverns can be applied.

The UGS type applied, is dependent on the geological conditions and prerequisites as well as on the designed capacity layout.

4.2.3 General characterization of UGS

UGS are naturally or artificially developed reservoirs respectively artificially developed caverns in subsurface geological formations used for the storage of natural gas (or LPG). An UGS consists of all subsurface and surface facilities required for the storage and for the withdrawal and injection of natural gas (or storage of LPG). Several subsurface storage reservoirs or caverns may be connected to one or several common surface facilities.

The suitability of subsurface geological formations have to be investigated individually for each location, in order to operate the storage facilities in an efficient, safe and environmentally compatible manner.

In order to construct a storage facility wells are used to establish a controlled connection between the reservoir or cavern and the surface facilities at the well head. The wells used for cycling the storage gas are called operating wells. In addition to the operating wells, specially assigned observation wells may be used to monitor the storage performance with respect to pressures and saturations and the quality of reservoir water as well as to monitor any interference in adjacent formations.

For the handling of gas withdrawal and gas injection the surface facilities are the link between the subsurface facilities and the transport system, comprising facilities for gas dehydration/treatment, compression, process control and measurement.

Gas is injected via the operating wells into the pores of a reservoir or into a cavern, thus building up a reservoir of compressed natural gas (or LPG).

Gas is withdrawn using the operating wells. With progressing gas withdrawal, the reservoir or cavern pressure declines according to the storage characteristic. For withdrawal, re-compression may be needed.

The working gas volume can be withdrawn and injected within the pressure range between the maximum and minimum operating pressure. In order to maintain the minimum operating pressure it is inevitable that a significant quantity of gas, known as cushion gas volume, remains in the reservoir or cavern.

The storage facility comprises the following storage capacities:

— working gas volume;

— withdrawal rates;

— injection rates.

The technical storage performance is given by withdrawal and injection rate profiles versus working gas volume.

Recommendations for the design, construction, testing and commissioning, operation and abandonment of underground storage facilities are described in Clauses 5, 6, 7, 8 and 9.

Construction of a storage facility begins after the design and exploration phase and should be carried out in accordance with the storage design. It is based on proven experience from the oil and gas industry.

For specific elements of an underground gas storage facility, e.g. wells and surface installations, existing standards should be applied.

4.2.4 Storage in aquifers

Storage of gas in aquifers is a proven technology and is mainly used for the storage of large gas volumes.

UGS in aquifers (see Figure 2), in which gas reservoirs are built up artificially in originally water bearing structures, require an extended exploration phase in order to prove its ability for the storage of gas. As reservoir pressures above initial pressures have to be applied in UGS in aquifers, the containment of the originally water bearing structure under gas at anticipated operating pressures has to be demonstrated. The applied technologies for exploration, construction and operation are based on technologies in the oil and gas industry and are similar to technologies applied to UGS in oil and gas fields.

Special care has to be dedicated to the impact of the stored fluid on adjacent strata and the interference of injected fluids with reservoir water in contact.

Feasibility of pore gas storage structures require:

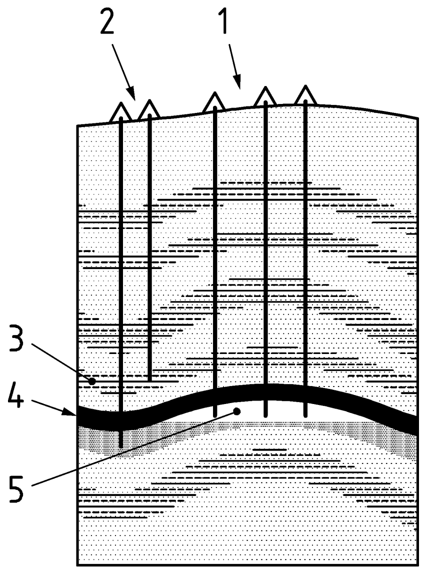
— dome-shaped structures, structural traps and/or lithological traps with an adequate closure to ensure satisfactory containment of the gas-filled zone;

— reservoirs with adequate porosity and permeability to provide the desired capacity and productivity;

— lithological, vertical and horizontal geological containment of the storage reservoir considering the structural shape, sealing caprock layers and faults, if any, in order to prevent gas leakage at anticipated operating pressures;

— especially proof of the caprock tightness at the anticipated operating pressures above initial reservoir pressure based on the capillary threshold concept;

— technical integrity of existing and abandoned wells in order to prevent gas leakage at anticipated operating pressures.



Key

1 storage wells

2 monitoring wells

3 indicator horizon

4 caprock

5 storage reservoir and stored gas

Figure 2 — Aquifer storage

4.3 Long-term containment of stored gas

The storage facility shall be designed, constructed and operated to ensure the continuing long-term containment of the stored gas.

This presupposes:

— adequate prior knowledge of the geological formation, in which the storage is to be developed and of its geological environment;

— acquisition of all relevant information needed for specifying parameter limits for construction and operation;

— demonstration that the storage is capable of ensuring long-term containment of the stored gas through its hydraulic and mechanical integrity.

All operations adjacent to a storage facility shall be compatible with the storage activity and shall not endanger its integrity.

All new storage projects shall take into account existing adjacent activities.

4.4 Environmental conservation

4.4.1 Subsurface

The storage facility shall be designed, constructed, operated and abandoned in order to have the lowest reasonably practicable impact on the environment.

This presupposes, that the surrounding formations have been identified and their relevant characteristics determined and that they are adequately protected.

4.4.2 Surface

The storage facility shall be designed, constructed, operated and abandoned so that it has the lowest reasonably practicable impact on ground movement at the surface and impact on the environment.

4.5 Safety

The storage facility shall be designed, constructed, operated, maintained and abandoned to get the lowest reasonably practicable risk to the safety of the staff, the public, the environment and the facilities.

In addition to the usual safety rules and recommendations applicable to all comparable industrial installations measures shall be taken to reduce the risk and consequences of blow-out and leakages. These measures shall at least include a surface safety valve and a subsurface safety valve for gas bearing wells if technically applicable.

A safety management system should be applied.

4.6 Monitoring

In order to limit the environmental impact of storages, adequate monitoring systems and procedures shall be implemented and applied.

5 Design

5.1 Design principles

Surface and subsurface installations shall be designed in an integrated way in order to achieve an environmentally, economically and technically optimized layout.

Surface and subsurface installations shall be designed to control the process and used fluids at any combination of pressure and temperature to which they may be subjected to within a determined range of operating conditions. They shall conform to existing standards for the individual part of a storage system. The key parameters and procedures at the connection with the gas transport system and the operative cooperation with the transport system operator shall be considered.

Proven technology shall be used for analysis and calculations. All relevant data should be documented.

Technology proven in the oil and gas industry should be used where possible.

The design shall be based on written procedures and shall be carried out by competent personnel and companies.

All relevant data concerning the design (such as equipment specification, operating procedures, quality assurance plan) shall be documented and made available to the owner and the operator of the storage facility.

Emergency procedures should be developed.

Adherence to the safety and environmental requirements shall be monitored.

During the design phase, the following activities and reviews related to safety will be carried out, including but not limited to:

— HAZOP review or equivalent;

— risk analysis and pre-construction safety study.

The design should be summarized in a report, which is sufficient for the purpose of demonstrating that adequate safety and reliability have been incorporated into the design, construction, operation and maintenance of the facility. The safety study will be updated at storage construction completion to take into account the actual facility to be operated.

5.2 Geological description

5.2.1 General

Design of UGS in aquifers is mainly concerned with the demonstration of the ability of a structure and formation to be used for gas storage.

The ability of a structure to ensure confinement of the stored gas shall be demonstrated. The impact of the underground storage on water contained in the storage aquifer and in connected aquifers shall be acceptable. This requires the spreading of the gas zone to be known, the maximum operating pressure to be predicted and the monitoring device to be designed. Consequently geologic and reservoir studies shall be undertaken.

These studies are essential and require special care because the behaviour of storage in the long term depends on this.

5.2.2 Geological description and modelling

The search for identification of and characterization of a geological structure suitable for conversion into an underground gas storage facility are based on the following main aspects:

— the presence of a reservoir with adequate geometric and petrophysical properties;

— the existence of a gastight caprock above this reservoir over the whole gasbearing area.

The model generated shall be based on a series of measures, tests or observations that are sufficient to ensure, in combination with the available location data, that all the elements of information necessary to be certain that the reservoir is gastight (e.g. presence of faults) are known.

The model should indicate clearly the following:

a) the structure of the reservoir's caprock, including:

    1) the areal distribution of depths;

    2) the spatial distribution of thicknesses;

3) fault patterns;

b) the main geometric and hydraulic parameters of the reservoir rock, including:

1) thickness;

2) depth;

3) permeability;

4) porosity;

5) capillary pressure;

c) the hydraulic characteristics of the surrounding aquifer and connected aquifers of the gas storage horizon;

d) the indicator horizon such as an aquifer or a gas bearing structure above the storage horizon.

The methods used to identify the features listed above are numerous and differ for each case. In general, they are as follows:

e) a general geological survey both at regional level and on particular points to spot potential structures;

f) seismic surveys to determine the structure of the geological layers concerned, and more particularly to assess the depth and thickness of the reservoir rock and of the caprock in conjunction with wells;

g) exploration drilling for:

1) further geological information;

2) coring in the caprock for tightness tests or in the reservoir material for geological and petrophysical survey;

3) control of seismic surveys;

4) well testing to assess the distribution in space of the hydraulic characteristics;

5) logging.

5.2.3 Evidence of the existence and the continuity of a tight caprock

5.2.3.1 Determination of the caprock sealing capacity

A study shall be carried out to prove the existence, the continuity and the leak tightness of the caprock.

This study should identify the following:

a) the nature (lithology, genesis) of the formation which forms the caprock;

b) the hydraulic characteristics of the caprock and, in particular:

1) its capillary threshold pressure;

2) its permeability, in order to estimate the water transfers that may permeate the caprock.

c) its geometrical characteristics, i.e.:

1) structure;

2) thicknesses;

3) horizontal extension;

4) faults.

5.2.3.2 Assessment of caprock discontinuities

If the caprock investigation reveals a fault in the planned storage area, its effects on the gas tightness of the caprock shall be investigated, given the nature of the faulted layers, their plasticity and the throw of the fault. In the absence of sufficient information a hydraulic test should be performed.

If the analysis of the caprock reveals discontinuities (extension limits, open faults) outside the planned storage area, such discontinuities shall be taken into consideration in the assessment of pressures in the storage aquifer and of those transmitted to the indicator horizon. The reservoir behaviour prediction shall incorporate such discontinuities. Operating conditions shall be defined to ensure that the gas-filled zone is remote from the discontinuities.

5.3 Determination of the maximum operating pressure

5.3.1 General

Based on the overall description of the caprock, the overburden, the structural situation, the sealing capacity of faults and the technical situation of all wells penetrating the storage formation, the maximum operating pressure for the storage facility shall be determined so that the following is avoided:

— mechanical failures;

— gas migration through the caprock;

— uncontrolled lateral spread of gas;

— jeopardizing the integrity of all existing wells that have penetrated the storage reservoir.

For the anticipated maximum operating pressure, the existence and the continuity of a gastight caprock shall be proved by detailed investigation. Consideration should be given to recovering cores from the caprock for gas tightness tests.

The characterization of the caprock should specify:

— the lithology;

— the petrophysical and hydraulical characteristics and, if applicable, the capillary threshold pressure and the permeability;

— the geometry with respect to structure, thickness and lateral extension;

— geological discontinuities or other features, which may affect the containment above initial reservoir pressure;

— fracture gradients.

Based on these investigations about the caprock, the overburden and the technical integrity the maximum operating pressure of the reservoir shall be evaluated at the following locations:

— the most sensitive position in the storage reservoir;

— structural locations which are in hydraulic communication with the storage.

This will enable the following to be avoided:

— mechanical failures of the caprock by fracturing;

— gas migration into the caprock by displacing water out of the caprock, via faults in the formations or due to leakages in wells.

5.3.2 Limit for avoidance of mechanical failures

It is essential that the changes in pressures and stresses do not cause mechanical failures in the layers or in the faults. The thrust developed by the gas beneath the caprock shall remain less than the weight of overburden. It is necessary to check, using modelling, that at every point the gas reaches, the petrostatic pressure corresponding to the overburden weight, to which a safety factor margin has been allocated to allow for potential compaction defects, remains in excess of the pressure applied by the reservoir fluids.

The safety factor margin shall make allowance for the embrittlement of rocks induced by the well casing cement job, and, more specifically, for the risk of failure liable to occur at steel-cement interfaces and cement-rock interfaces.

Effects should also be examined in the area remote from the gas zone where reservoir operation will generate appreciable pressure rises.

In practice, the maximum pressure gradient X, taking into account the safety factor margin, may vary between 0,013 MPa per meter and 0,017 MPa per meter depending on the specific geological situation. Then the maximum pressure limit $p_{\max,1}$ to avoid mechanical disturbance is given by:

$$p_{\max,1} = X \cdot H_{\min}$$

where

$p_{\max,1}$ is the maximum pressure limit, in MPa;

X is the maximum pressure gradient, in MPa per meter;

$H_{\min}$ is the minimum thickness of overburden calculated from the base of the caprock, in meter.

5.3.3 Limit for avoidance of the gas migration through the caprock

Gas shall not migrate through the caprock by displacing water. Gas migration occurs when the difference between the water pressure in the caprock and the gas pressure below the caprock exceeds the capillary threshold pressure.

Taking this risk into account, the maximum pressure $p_{max,2}$ is given by:

$$p_{max,2} = p_w + CTP$$

where

- $p_{max,2}$ is the maximum pressure, in MPa;
- p_w is the initial pressure of the water in the base of the caprock in the dome area of the storage formation, in MPa;
- CTP is the capillary threshold pressure of the caprock, in MPa.

The resulting maximum pressure should include a safety margin.

5.3.4 Maximum operating pressure (MOP)

The maximum operating pressure (MOP) of the reservoir is the lower of $p_{max,1}$ and $p_{max,2}$. taking into account:

— the fracture pressure of the caprock;

— the pressure at which the well integrity could be affected;

— the calculated pressure resulting from the pressure in the caprock plus the threshold capillary pressure of the caprock (if applicable).

5.4 Wells

5.4.1 General

For the operation of an underground storage facility in aquifers three types of wells are used:

— operating wells, used for the injection and withdrawal of the storage gas and also for monitoring purposes;

— monitoring wells in the storage formation and indicator horizon such as upper aquifers or oil and gas fields;

— auxiliary wells for water supply or for disposal of water.

The design of a well is focused on:

— the drilling platform, well site and wellhead area;

— the equipment of the well, especially the casing and the completion (see Figure 3);

and this design shall take into account:

— the integrity of the storage reservoir;

— the gas tightness of the subsurface installations;

— the flow rates, pressures and temperatures that will be applied to the well, especially for the cyclic operation of the storage facility;

— the composition of the gas, noting corrosive components;

— corrosion prevention, e.g. by inhibiting fluids in the casing/tubing annulus;

— protection of the formations (e.g. water aquifers, oil fields), which have been penetrated by the well;

— subsurface measurement requirements;

— the planned lifetime of the well;

— location of the well;

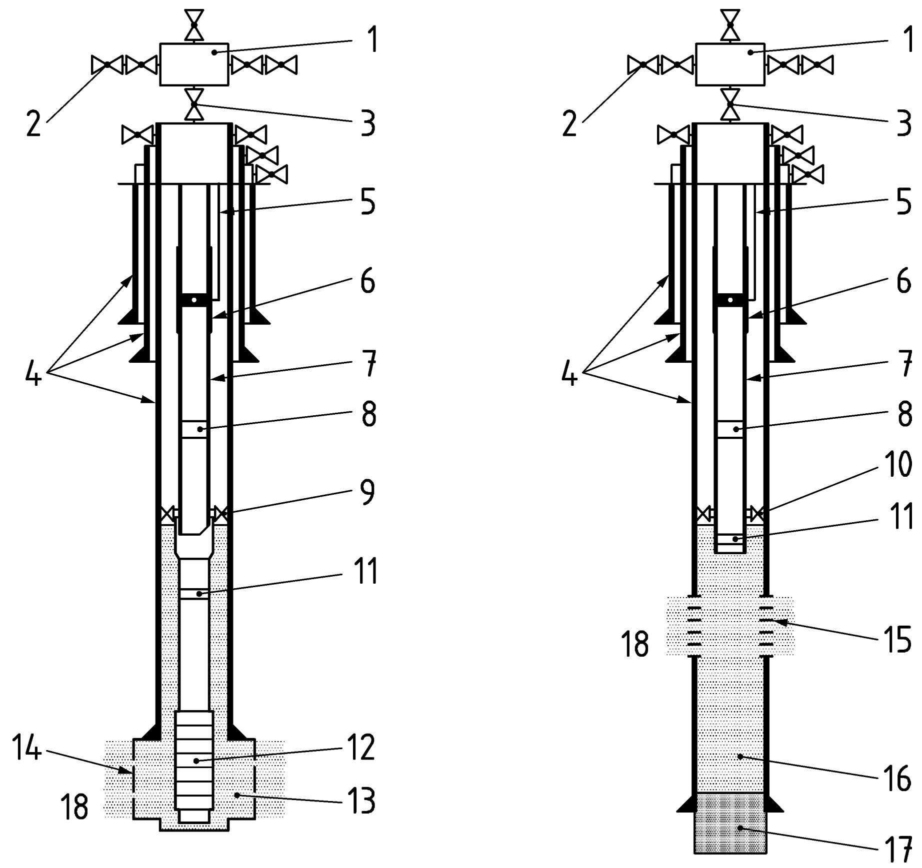
— applicable standards and recommendations (see list in informative Annex A).

To ensure the integrity of the system all information shall be used, which are necessary to evaluate the wellhead, casing, cement and the completion scheme for all operating conditions in all existing and abandoned wells penetrating the storage formation or the directly overlaying caprock. It shall be verified that the wellhead, tubing, liners and casing strings of the existing wells and abandoned wells meet these requirements. Wells shall be designed so that stimulations and perforating can be carried out without jeopardizing caprock, casing and cement integrity.

All equipment should conform to the product related standards in force. Most of the equipment necessary is related to the petroleum industry, e.g. valves, tubing strings, accessories, packers.

If the status of a well may jeopardize storage containment, remedial action shall be taken; if necessary such a well shall be plugged and abandoned.

Original design of the wells is recommended to include their plugging and abandonment process.



Key

1	wellhead	10	production packer with snap-latch seal assembly
2	wing valve	11	landing nipple
3	master valve	12	sand screen
4	casing	13	gravel pack
5	control line for subsurface safety valve	14	underreamed storage horizon
6	subsurface safety valve	15	perforation
7	tubing	16	sump
8	sliding side door	17	cement head
9	production gravel pack packer – safety joint	18	storage reservoir

Figure 3 — Examples for well completions - gravel pack completion (left) and perforated cased hole completion (right)

5.4.2 Location

The drilling platform, well site and wellhead area shall be selected so that any inadmissible impact on the environment is prevented. It shall be located in positions such that, if an emergency situation occurs, the risk of harm to people and neighbouring property will not exceed acceptable levels.

If applicable, wells should be concentrated on well platforms in well clusters.

Safety distances to housing zones or critical neighbouring points shall be based on normal operation and emergency according to applicable rules and regulations.

The wellhead area should be protected against unauthorized access.

The wellhead area shall be designed to avoid any flow of contaminating fluids to the environment during drilling and workover and as well as during storage operation.

The cellar and the foundation for the drilling and workover rig shall be designed to bear the static and dynamic loads resulting from drilling or workover.

Ambulances and safety equipment shall have access to the well site at any time.

5.4.3 Equipment

5.4.3.1 Casings

A well (see Figure 3) is built up by a set of casing strings cemented in the annulus between the casing and the formation. The last cemented inner casing string of wells likely to be in contact with gas should be provided with gastight connections.

By the installation of cemented casings sensitive formations such as fresh water horizons and unstable layers are protected and tightness is provided between water bearing horizons, hydrocarbon formations and the storage horizon. A sufficient number of casing strings shall be set to avoid uncontrolled fluid movements into the well during the drilling operation. A casing shall be installed and cemented on either the storage caprock or a leak tight formation separating the storage horizon from overlaying aquifers and/or oil and gas fields. In certain cases, a liner installation may has to be installed in the lowermost interval of the well without a surface casing.

The program for the casing scheme and the cementation shall be planned and carried out so that there is no impact on upper fresh water horizons.

The diameter of the casings shall be selected to meet withdrawal/injection requirements.

The grades of the casings shall be selected to ensure that pressure integrity is maintained under the permitted operating conditions. Design and safety factors for collapse, burst, tension and compression of casings should be applied according to relevant standards.

Casings should be manufactured, inspected and tested in accordance with relevant standards and recommendations. Casing strings shall be cemented to prevent fluid movements behind them. Particular attention should be paid to cementing techniques which minimize voids, channelling and micro annuli. Cement bonding to both the casing string and the strata should be investigated.

The design shall prepare for pressure testing of the casing and the casing shoe of the last cemented casing string, if applicable.

Suitable technical measures for preventing corrosion of the last cemented casing should be considered.

5.4.3.2 Completion

A well completion (see Figure 3) consists of installations that are necessary for safe operating or inspection purposes inside the casing strings and/or bottom hole, e.g. tubing strings and sand screens.

A storage well completion typically consists of:

— if applicable, a sand screen in front of the storage horizon;

— a tubing string completed with gastight joints (under the permitted operating conditions) installed inside the casing;

— a packer anchored to the casing above the storage formation and connected to the tubing to isolate the cemented casing from the fluid and pressure inside the tubing;

— a packer/tubing anchor seal assembly or a sliding seal assembly at the packer or a telescopic joint in the tubing may be used to cover the cyclic stresses caused by temperature and pressure fluctuations. To face the effect of elongation or shrinkage due to storage operation the tubing can be pre-stressed alternatively;

— one or more landing nipples at strategic positions in the tubing;

— a subsurface safety valve, which may if applicable be surface-controlled, located in the tubing string of operating wells and of wells, which penetrate gas-bearing intervals and are in pressure communication with the storage;

— a wellhead with at least one master valve and one wing valve.

Completion needs to be adapted for observation and auxiliary wells.

Gas storage wells are characterized by long-term use.

Unlike in gas or oil production the operation cycles in gas storages lead to large variations in pressure and temperature in the operation wells. This has to be taken into account in the design and installation of the completion.

The annulus between the last cemented casing and the tubing isolated at its bottom end by the packer and at its top end by the tubing hanger is filled with annulus fluid. This prevents the last cemented casing from coming into contact with flowing gas and so protects it against corrosion and undue pressure changes which might otherwise damage the surrounding cement. Above all it provides a double containment for enhanced safety. Leaks may be detected and monitored by measuring pressure and volume at the wellhead. Consequently, all wells likely to be gas filled shall use this double containment concept, providing greater safety in terms of leak tightness.

Landing nipples for plugs should be added to the system to ensure that the well can be totally sealed at the packer level.

Measures shall be taken to minimize blow-out hazards. Therefore in gas bearing wells or in wells in pressure communication with the storage reservoir at least one master valve shall be installed at the wellhead and, except for exceptional cases justified by technical considerations, a subsurface safety valve shall be installed in the tubing.

The subsurface safety valve is set into the upper part of the tubing several meters below the surface. It can be activated via a control line from the surface and/or by the subsurface pressure and/or flow rate conditions. Subsurface velocity safety valves operated without control lines, e.g. "storm chokes", can be installed as well in certain cases.

The subsurface safety valve shall shut down automatically in the event of unallowable operating conditions as excessive rates, abnormal low pressure or emergency or remote/local shut-down signal. Safety valves should only be re-opened after safe conditions have been re-established. Re-opening of the subsurface safety valve shall not be possible from the control room.

An access port shall be installed at the head of the annulus. As a minimum requirement, installations on the last cemented annulus for pressure measurement and on the casing-tubing annulus for pressure measurement and for injection of fluid shall be provided.

5.4.3.3 Wellhead

The wellhead shall control the flows into and out of the storage under normal and emergency operating conditions.

The wellhead shall have sufficient mechanical strength to withstand the maximum operating pressure of the storage facility.

The storage wellhead and the associated valves including actuators, flanges and ring type joints should be compliant with the standards and recommendations in force.

Wellheads shall be designed to be installed with the workover/drilling rig on site.

Storage wells shall have at least one master valve. This valve shall isolate the well for operational reasons and in case of emergency or maintenance.

On the major intakes and offtakes the wellhead should have a manual and/or an actuated valve. Actuated valves are usually controlled by a local wellhead panel with an option for remote operation from a central control room.

Wellheads shall be equipped with standardized fittings so that, in the event of an accident, the flanges and fittings which compose them can be used for the direct connection of emergency equipment.

The design shall allow each connection to be pressure tested.

The wellhead/flowline system has to be equipped with devices to automatically shut down the well in case of unallowable operation or emergency. Remote controlled shut off of the flowline may be used as an alternative.

At least one surface safety device shall be installed and shall close in the event of:

— flowline rupture, e.g. extra low wellhead pressure;

— failure of utility supply (e.g. power, electricity, instrument air);

— site emergency shutdown system actuated either remotely or at the wellhead.

Safety devices shall not allow for re-opening from the control room.

A system for hydrate inhibitor injection may be provided at the wellhead to inhibit and control hydrate formation.

5.5 Monitoring systems

5.5.1 General

The monitoring system shall be designed to verify gas containment and storage reservoir integrity while the storage facility is operating. The design should require the collection of data such as representative storage pressures and annuli pressures, injected and withdrawn volumes and gas qualities and, if applicable, saturation logging results.

Geological knowledge combined with modelling techniques (geological modelling and/or reservoir simulation) provide the most appropriate monitoring systems to ensure the following:

— vertical sealing;

— lateral gas confinement.

In cases where the gas containment is certain for geological reasons (depth, thickness or plastic characteristics of the caprock, high closure), the monitoring systems described in 5.5.2 and 5.5.3 can be significantly reduced.

The most appropriate monitoring system should be individually designed for each project.

5.5.2 Vertical confinement

Vertical tightness is generally monitored by a system of wells for checking that gas migration, if any, towards the aquifers located above the reservoir remains under control (indicator horizon). The requirement for observation wells has to be based on the site specific situation.

The following types of observation wells may be applied:

— wells in pressure communication with the indicator horizon level and used for the measurement of pressure or gas saturations (either in the storage formation or in the indicator horizon level);

— non-perforated wells (logging wells) exclusively devoted to neutron logging, which determines the gas saturation in the storage formation to detect and possibly assess the presence of gas in the monitored aquifers.

The observation wells opened to indicator horizon are designed to enable the detection of gas occurrence in particular by pressure monitoring. They should only be drilled as far as the base of the monitored layer. They should not reach the caprock, which separates the monitored aquifer from the one below. This is particularly applicable to the indicator horizon as it is essential to avoid connection with the storage aquifer.

The non-perforated logging wells are used to monitor the distribution of gas in the storage aquifer but they may be used to obtain similar information in indicator horizon. Typically one logging well is located in up dip position of the storage reservoir. It should be drilled as far as the reservoir base, lined without perforation and with a cement plug at the bottom. Gas logging, of limited range in the immediate vicinity of the monitored well, exhibits great sensitivity in revealing small accumulations of gas.

Where there are several aquifer horizons, usually the first continuous aquifer above the one used for storage can be selected as indicator horizon for monitoring because of its spread and its vicinity to the storage to be monitored. The choice of the indicator horizon should also take into account good transmissibility for easy understanding of any abnormal phenomena.

5.5.3 Lateral confinement

Lateral gas spreading is monitored by the required observation wells. Gas spreading in sensitive directions is monitored where the effects of the dip and permeability may contribute to a preferred development of the gas front. To identify these sensitive zones it is necessary to model the gas zone behaviour correctly. In zones where these sensitive directions need to be monitored, peripheral observation wells are installed. Each of these helps to control the injection by providing indications of the gas front position. The system of observation wells may utilize wells drilled within the scope of the reservoir exploration process.

For positioning of observation wells in the area of the main lateral gas spreading a preliminary definition of the discharge hazards is necessary. These can be classified as follows.

— gas migration towards zones where there is a likelihood of upward flow towards the surface or other operated aquifers capable of jeopardizing safety. Examples of such zones are non-leaktight lateral faults, caprock discontinuities, and spill points that are not definitely isolated from the most remote extensions of other aquifers. Observation wells, which aim to protect against this hazard, should be located so far from the critical zone that the gas cannot reach it, taking into account the effect of residual expansion, which remains active when the injections are stopped.

— gas trapping in an area, which is not involved in operation but which has been identified and located. The gas trap is then "stabilized" (either in a lateral structure or in a nearly horizontal extension of the structure, if any). Such events only concern the economic aspects of reservoir utilization.

5.6 Neighbouring subsurface activities

The design, construction and monitoring of any proposed storage facility shall take into account all neighbouring subsurface activities, past or present such as oil or gas reservoirs and fresh water aquifers, mining activities and other underground storage facilities.

The operations of any proposed storage facility and those of neighbouring subsurface activities shall be compatible with each other.

All available information necessary to evaluate the potential impact of a planned storage facility on neighbouring subsurface activities shall be used.

Gas storage operations cause changes in the reservoir pressure within the storage aquifer and in connected aquifers. Gas injection (or gas withdrawal) causes an increase (or decrease) in pressure in the storage aquifer in the vicinity of the gas zone. The connection between pressure changes in the aquifers and gas operation is less direct and more complicated distant from the gas zone. The amplitude of the changes decreases with distance. Within the reservoir engineering studies it should be demonstrated that the impact on water pressure in the storage aquifer and in connected aquifers is acceptable.

Furthermore, because gas remains in close contact with water contained in the storage aquifer, its components transfer into aquifers by molecular diffusion and are transported by the flow of the water within the aquifer. However, the diffused quantities are very small and the movement of water in aquifers is in general negligible. In special cases, if the storage aquifer or aquifers, which are in communication with the storage horizon, contain drinking water or water capable of being rendered potable after special treatment, reservoir engineering studies of impact on water quality should be carried out in order to demonstrate that the effects of the gas storage operation are acceptable.

Deciding whether the impact of the storage on water pressure and quality is acceptable depends on the regional environment and can only be discussed case by case.

6 Construction

6.1 General

Construction of a storage facility begins after the design and exploration phase and should be carried out in accordance with the storage design.

This phase covers the construction of surface facilities (see EN 1918-5) and the drilling and completion of wells. It is based on proven experience from the oil and gas industry.

Drilling, cementing and completion, as well as inspection and testing of all subsurface equipment and the wellhead, shall conform to relevant standards and recommendations in force.

Employees and contractors shall be informed about the local safety and environmental circumstances and instructed to comply with the safety rules and environmental requirements.

A reporting system shall be set up. All equipment installed and materials used shall be documented. Discharge of all wastes, solids and fluids shall be controlled and documented in a reporting system.

6.2 Wells

Drilling mud shall be compatible with the formations drilled through in order to ensure good resistance of the open hole walls and achieve a good open hole geometry, absence of damage to aquifers and from water contamination and quality of cementation.

The quality of the casing cement job, especially in the vicinity of the caprock/overburden, shall be monitored. The last cemented casing shall be constructed that it is gas tight and any unintended release of gas does not occur under the pressure conditions likely during storage operation.

If fluids are expected during drilling, measures shall be taken to avoid any risk of unintended release of these fluids. Such measures include, e.g. providing mud pumps with a large enough capacity, providing an adequate reserve of appropriate quality mud, providing emergency power supply, checking the anchorage and solidity of the casings and using blow-out preventers.

6.3 Completions

The length and diameter of casing, tubing and equipment should be measured and a complete tally should be made for the tubing string.

Joints shall be carefully cleaned, inspected and gauged before running into the well.

Joints shall be torqued up in accordance with the manufacturer's instructions.

Provision shall be made for pressure testing the casing/tubing during the installation.

If the setting depth of a special item of equipment is of relevance, it may be necessary to run a casing collar locator log or any other appropriate measure to identify and locate the equipment within the cased hole.

6.4 Wellheads

All flanged joints shall be pressure tested.

All the major casing/tubing seals shall be energized and tested to the supplier's recommended pressures and durations.

7 Testing and commissioning

Testing and commissioning shall be based on written procedures and shall be performed by skilled personnel. The safety of the first operational steps should be ensured by fully observing the recommendations on design and construction described in Clauses 5 and 6.

A complete knowledge of the storage behaviour and performance is only possible once the storage facility has been fully developed. Thus, for this type of storage facility, it may be impossible to carry out all testing and commissioning for the whole facility directly after construction. Some elements of the facility such as wells can be tested and commissioned both individually and combined in all relevant modes.

For every well logging and testing shall be performed to verify wellhead, casing and cement integrity. It shall be verified that the wellhead, tubing, liners and casing strings of the wells conform to the recommendations in Clauses 5 and 6.

After drilling the last cemented casing including the casing shoe may be pressure tested.

All parts of the wellhead shall be pressure tested before the well is commissioned.

Test pressures, test fluids and test duration may vary according to the specific requirements. They shall be chosen to check the operability of the tested installation.

Safety devices shall be functionally tested prior to operation.

8 Operation, monitoring and maintenance

8.1 Operating principles

The operation of any aquifer gas storage facility consists of several activities including the successive built up of cushion gas volume and the development of the working gas volume. The main part is the control of the injection and of the withdrawal of gas. The operation of an aquifer gas storage requires suitable monitoring of the surrounding aquifers. The control of operations shall ensure that the gas remains in the predetermined, recognized and controlled storage zone and that the impact of storage on the overburden remains acceptable.

Operation of these facilities shall conform to written operating instructions and safety procedures. These shall cover start-up, normal operations, emergency conditions, shut-down and maintenance operations.

The management should employ operating staff of suitable number, ability and experience. The management shall ensure that staff is trained to carry out their duties in a safe manner. Safety training shall be given and updated as necessary.

All safety devices shall be periodically checked to ensure that they function properly.

Monitoring results may require remedial action and/or limitation of gas inventory in case of unacceptable deviation from the planned gas spreading. Workover jobs shall be carried out as soon as possible, if there is evidence that operation of a well is no longer safe or that the well integrity is jeopardized.

8.2 Monitoring of the storage reservoir

8.2.1 Pressure monitoring

The pressure in the reservoir shall be monitored to ensure that it is kept below the maximum operating pressure.

The well should be equipped for measuring gas pressure at the wellhead as frequently as required by reservoir operation. From this measured wellhead pressure, the bottom hole pressure at the most sensitive point can be calculated, taking into account the possibility that water may be present in the well. An annual measurement of the bottom hole pressure is also recommended.

8.2.2 Monitoring of the gas zone

Observation wells and operating wells are used to derive the following information:

— downhole pressure;

— lateral gas spreading from the controlled area;

— gas saturation distribution inside the reservoir;

— position of gas water contact.

Using the information supplied by these wells and the information supplied by the operating wells, the gas log wells and the peripheral observation wells the conditions governing the development of gas distribution inside the reservoir can be checked (vertical and lateral extension and gas saturation).

Knowledge of the lateral extension is important to avoid lateral gas discharge in sensitive zones, for which there is a preferred gas migration path, and thus to control the gas extension.

During operation, the model of the storage shall be adjusted, taking into account all the measurements. The use of a well-adjusted model allows the analysis of any deviation from expected storage performance and the storage operation to be optimized, e.g. to obtain the maximum storage gas volume.

8.2.3 Monitoring of gas operation

Measuring the gas flow rate and pressure per well, together with the knowledge of the total volume of gas in the reservoir and the pressure in the gas bearing reservoir, is necessary for monitoring the reservoir performance and further development and improvement of reservoir simulation models.

This monitoring can help to predict, possibly using modelling, different operating scenarios. This, together with the measurement of gas/water ratio in the withdrawn gas per well, should enable the optimization of the strategy for injection and withdrawal.

The composition of injected and withdrawn gas shall be monitored.

To ascertain that in case of UGS in potable water aquifers the water contained in the reservoir has not undergone any unacceptable change in characteristics, representative water samples should be taken regularly from observation wells for analysis.

8.3 Monitoring of indicator horizon

8.3.1 General

Monitoring the indicator horizon is essential to ensure either that the storage facility is gastight or that any leakage is limited and controlled.

The objectives of monitoring the indicator horizon are as follows:

— to check whether their state is changed by reference to their initial conditions;

— to monitor the storage tightness, particularly at the points, where the wells penetrate the caprock.

The various possible indicator horizon monitoring operations are as follows:

— pressure measurements;

— water analyses;

— gas log recordings.

Each of these measurements requires accurate knowledge of the situation, which prevailed before the gas was introduced inside the aquifer, and of its possible evolution under the effect of the various external factors (for instance: third party operations). Appropriate representative measurements should be made prior to any gas injection until for each type of measurement a reference series has been drawn up to provide knowledge of the initial values of the monitored parameters along with their pre-storage variation or evolution.

8.3.2 Pressure measurements

Pressure evolution monitoring in the indicator horizon, is carried out by using routine pressure measurements inside the well, which opens into this horizon.

8.3.3 Water analyses

Wells used for pressure monitoring can be used for the sampling of water for analysis. Representative samples should be taken inside the wells; a good practice is to pump two times the well volume before.

Analyses made on samples taken in this manner are complementary to the pressure monitoring system.

8.3.4 Gas logging

Gas logs, of limited range in the immediate vicinity of the monitored well, exhibit greater sensitivity in revealing small accumulations of gas likely to escape detection by pressure monitoring and water analyses.

Their limited range and greater sensitivity call for appropriate interpretation by the operator.

8.4 Monitoring of connected aquifers

It may be necessary to monitor the pressure effects due to the storage operation in a connected aquifer.

The measurements taken may be useful in adjusting the model and determining revised operating conditions that will maintain acceptable pressure effects on connected aquifers.

8.5 Monitoring of wells

For all wells, an integrated analysis is required.

Wells are spread out over a large area and it is important that they are closely monitored. To this effect, periodic inspection runs shall be carried out on all the wells so as to detect any anomaly and to carry out any necessary measurement. Inspections to check that the annulus fluid is maintained in the annulus should be carried out at suitable intervals. The pressure on the casing/tubing annulus shall be monitored.

For monitoring the completion integrity the annuli pressures shall be regularly measured. The completion or wellhead should be designed so that any build-up of pressure in the annuli can be vented safely.

An annular casing pressure management concept should also be established defining in particular the Maximum Allowable Annular Surface Pressure (MAASP).

Any deviations should be recorded and assessed as to whether remedial action needs to be taken.

8.6 Injection and withdrawal operations

During the injection phase the operation design limits, especially the maximum operating pressure (see 5.3), shall be adhered to.

The operator shall ensure that corrosion and erosion of casing and tubing are minimized and that they do not affect the safe operation of the storage facilities.

8.7 Maintenance of wells

It is recommended to develop a preventive well integrity management system. This can be defined as the application of technical, operational and organizational solutions to reduce risk of uncontrolled release of fluids throughout the life cycle of a well.

As part of the well integrity plan, all equipment, such as wellheads, valves, plugs and especially safety equipment, such as subsurface safety valves, master valves and pressure control equipment, shall be regularly tested in situ (functional test) or in workshop.

Integrity of other well barrier elements such as tubing, production packer, last cemented casing and cementation should be regularly evaluated. In case the completion is removed, wall thickness measurements of the last cemented casing may be considered.

8.8 HSE

8.8.1 HSE management

The operator shall implement within a reasonable time prior to start-up of the facility a Health, Safety and Environmental (HSE) management system in accordance with applicable directives in force. It shall demonstrate that the operator takes all possible measures necessary to limit risks.

The HSE management system shall include operator’s Health, Safety, Security and Environmental (HSSE) requirements, rules, and regulations. It will provide a manual and procedures with the objective to accomplish operator’s HSSE performance standards. Subject manuals and procedures shall be auditable.

The HSE manual shall provide a structured collection of guidelines on HSE matters in all areas of underground gas storage by the storage facility operator. It covers but is not limited to the following topics: HSE management systems, HSE management in business and hazards and effects management tools & techniques.

8.8.2 Emergency procedures

The operator of the storage facility shall include emergency procedures in its HSE management system, which shall include but not be limited to:

— established emergency procedures, including procedures for the safe operation or the shut-down of the storage facility or parts thereof in the event of a failure or other emergency, and safety procedures for personnel at emergency site;

— documented emergency procedures to deal with fluid releases including mitigation of the release, notification and protection of operating personnel, documentation for notification and protection of the public in accordance with national regulation and communications with community and regulatory bodies;

— audit and test procedures for operating personnel at frequencies determined by factors such as condition of the system and/or population density;

— a documentation system for audit and test results and recommendations.

9 Abandonment

9.1 General

The definitive closure and abandonment including restoration of the surface area of a storage facility shall be considered for each location, with special attention paid to long-term integrity and gas containment. In the case of the abandonment of one or few wells during operation similar procedures for plugging and abandoning of wells as described in 9.3 shall be applied.

In individual cases, part of the infrastructure may be reused for another purpose but in this European Standard only definitive abandonment will be considered.

The studies and measurements shall prove the safety of the condition left after abandonment. A specific abandonment plan shall be prepared.

Plugging of wells is done to durably ensure the conservation of tightness between the storage reservoir and the major aquifers from bottom to surface.

The abandonment of a storage facility comprises:

- withdrawal of recoverable gas from the storage;
- plugging and abandonment of wells;
- dismantling surface facilities;
- monitoring.

The total abandonment program has to be confirmed by relevant authorities.

All operations comprised in the abandonment process shall be properly documented.

9.2 Withdrawal of the gas

Simulation shall be carried out to assess the recoverable gas and to analyse long-term impact on the integrity of the reservoir. The withdrawal of gas is as well subject to the technical and economic criteria of oil and gas production.

The scenario shall take the water production into account.

A long-term impact assessment of the remaining gas shall be conducted to determine the acceptable amount of gas which can be left in place, including status of the reservoir after blow down and pressure recovery.

9.3 Plugging and abandonment of wells

For the abandonment of wells usually the completion and finally the wellhead is removed.

Integrity of casing and tightness against relevant formation are investigated and repaired if needed to protect relevant horizons.

Plugging the well above the storage reservoir, and if applicable below, can be done by packers, cement jobs or other plugging materials, equipment and procedures, which can demonstrate their long-term tightness.

Plugs shall be designed and positioned properly at specific intervals to seal off formations to be protected. Special attention is to be paid on the plug in contact with the gas, taking in account in particular the final situation after build-up of the reservoir pressure.

The abandonment of the well is concluded by cutting remaining casings below the surface. Subsequently, the casings are sealed by a solid patch welded on their top. The reference of the well is branded on the patch mentioning well name and date. If necessary, soil remediation is carried out, and the platform area may be restored.

9.4 Surface facilities

The abandonment of the surface facilities shall comply with EN 1918-5.

9.5 Monitoring

Monitoring and testing necessary for a safe abandonment should be put in place.

Annex A
(informative)

Non-exhaustive list of relevant standards

Reference	ICS	Title
EN 1127-1	13.230	*Explosive atmospheres — Explosion prevention and protection —Part 1: Basic concepts and methodology*
EN 12954	77.060	*Cathodic protection of buried or immersed metallic structures — General principles and application for pipelines*
EN 13509	77.060	*Cathodic protection measurement techniques*
EN 14505	77.060	*Cathodic protection of complex structures*
EN 15112	77.060 23.040.99	*External cathodic protection of well casings*
CEN/TR 13737-1	91.140.40	*Gas infrastructure — Implementation Guide for Functional Standards prepared by CEN/TC 234 — Part 1: General*
CEN/TR 13737-2	91.140.40	*Gas infrastructure — Implementation Guide for Functional Standards prepared by CEN/TC 234 — Part 2: National Pages related to CEN/TC 234 standards*
EN ISO 10405	23.040.01 75.180.10	*Petroleum and natural gas industries — Care and use of casing and tubing*
EN ISO 10417	75.180.10	*Petroleum and natural gas industries — Subsurface safety valve systems —Design, installation, operation and redress*
EN ISO 10423	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment —Wellhead and Christmas tree equipment*
EN ISO 10424-1	75.180.10	*Petroleum and natural gas industries — Rotary drilling equipment — Part 1: Rotary drill stem elements*
EN ISO 10424-2	75.180.10	*Petroleum and natural gas industries — Rotary drilling equipment — Part 2: Threading and gauging of rotary shouldered thread connections*
EN ISO 10427-1	75.180.10	*Petroleum and natural gas industries — Equipment for well cementing — Part 1: Casing bow-spring centralizers*
EN ISO 10427-2	75.180.10	*Petroleum and natural gas industries — Equipment for well cementing — Part 2: Centralizer placement and stop-collar testing*
EN ISO 10427-3	75.180.10	*Petroleum and natural gas industries — Equipment for well cementing — Part 3: Performance testing of cementing float equipment*
EN ISO 10432	75.180.10	*Petroleum and natural gas industries — Downhole equipment — Subsurface safety valve equipment*

Reference	ICS	Title
EN ISO 10870	13.060.70	*Water quality — Guidelines for the selection of sampling methods and devices for benthic macroinvertebrates in fresh waters (*ISO 10870*)*
EN ISO 11960	77.140.75 75.180.10	*Petroleum and natural gas industries — Steel pipes for use as casing or tubing for wells*
EN ISO 11961	77.140.75 75.180.10	*Petroleum and natural gas industries — Steel drill pipe*
EN ISO 13500	75.180.10	*Petroleum and natural gas industries — Drilling fluid materials — Specifications and tests*
EN ISO 13533	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment — Drill-through equipment*
EN ISO 13534	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment — Inspection, maintenance, repair and remanufacture of hoisting equipment*
EN ISO 14310	75.180.10	*Petroleum and natural gas industries — Downhole equipment — Packers and bridge plugs*
EN ISO 15463	75.180.10	*Petroleum and natural gas industries — Field inspection of new casing, tubing and plain-end drill pipe*
EN ISO 16070	75.180.10	*Petroleum and natural gas industries — Downhole equipment — Lock mandrels and landing nipples*
EN ISO 17078	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment*
ISO 5596	23.100.99	*Hydraulic fluid power — Gas-loaded accumulators with separator — Ranges of pressures and volumes and characteristic quantities*
ISO 10414-1	75.180.10	*Petroleum and natural gas industries — Field testing of drilling fluids — Part 1: Water-based fluids*
ISO 10416	75.100 75.180.10	*Petroleum and natural gas industries — Drilling fluids Laboratory testing*
ISO 10945	23.100.99	*Hydraulic fluid power — Gas-loaded accumulators — Dimensions of gas ports*
ISO 10946	23.100.99	*Hydraulic fluid power — Gas-loaded accumulators with separator — Selection of preferred hydraulic ports*
ISO 13501	75.180.10	*Petroleum and natural gas industries — Drilling fluids — Processing equipment evaluation*
ISO 13535	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment — Hoisting equipment*
ISO 17824	75.180.10	*Petroleum and natural gas industries — Downhole equipment — Sand screens*
ISO 28781	75.180.10	*Petroleum and natural gas industries — Drilling and production equipment — Subsurface barrier valves and related equipment*
ISO/TR 10400	75.180.10	*Petroleum and natural gas industries — Equations and calculations for the properties of casing, tubing, drill pipe and line pipe used as casing or tubing*

Annex B
(informative)

Significant technical changes between this European Standard and the previous version EN 1918-1:1998

Clause	Title/Paragraph/Table/Figure	Change
	Introduction	More details on function and technology of underground storage, including figures
2	Normative references	Addition of this section
3	Terms and definitions	Addition of definitions
5.1	Design principles	Addition of activities and reviews related to safety
5.3.1	General	More details on maximum operating pressure determination
5.4.1	General	Additional elements to take into account in well design
8.8	HSE	Addition of this new chapter
9	Abandonment	Addition of this new chapter
NOTE 1 The technical changes referred to include the significant changes from the European Standard revised but it is not an exhaustive list of all modifications from the previous version. NOTE 2 The previous standard was reviewed concerning environmental compatibility.		

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