BS EN 1918-3:2016

BSI Standards Publication

Gas infrastructure — Underground gas storage

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

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National foreword

This British Standard is the UK implementation of EN 1918-3:2016. It supersedes BS EN 1918-3:1998 which is withdrawn.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.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

ISBN 978 0 580 86101 7

ICS 75.200

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 March 2016.

Amendments issued since publication

Date	Text affected

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1918-3

March 2016

ICS 75.200

Supersedes EN 1918-3:1998

English Version

Gas infrastructure - Underground gas storage - Part 3: Functional recommendations for storage in solution-mined salt caverns

Infrastructures gazières - Stockage souterrain de gaz - Partie 3: Recommandations fonctionnelles pour le stockage en cavités salines creusées par dissolution

Gasinfrastruktur - Untertagespeicherung von Gas - Teil 3: Funktionale Empfehlungen für die Speicherung in gesolten Salzkavernen

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

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COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 1918-3:2016 E

Contents

Page

European foreword

This document (EN 1918-3:2016) 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of an identical text or by endorsement, at the latest by September 2016 and conflicting national standards shall be withdrawn at the latest by September 2016.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 1918-3:1998.

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 1918-3:1998, see Annex B.

This document is Part 3 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 solution-mined salt caverns 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 insitu 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, flowrates, 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 3 of EN 1918 only.

3.2.1
blanket
liquid or gaseous medium in the annulus between the last cemented casing string and the outer leaching string used during the whole leaching period in order to ensure that the planned cavern shape and the protection of cavern roof and casing shoe is achieved

3.2.2
cavern
developed volume in a salt formation by drilling and leaching, including the cavern sump

3.2.3
convergence
reduction in the cavern volume by salt creeping

3.2.4
cavern free volume
volume of the cavern that is available for the storage of gas

3.2.5
cavern height
distance between the bottom of the neck and the lowest point of the cavern, including the cavern sump

3.2.6
pillar
salt body surrounding the cavern required for stability reason and gas tightness

3.2.7
cavern roof
upper part of the cavern located between the bottom of the neck and the vertical wall of the cavern

3.2.8
cavern neck
well segment below the shoe of the last cemented casing string and above the cavern roof

3.2.9
cavern sump
bottom part of the cavern filled with sedimented, mostly insoluble materials and residual brine

3.2.10
hanger
device for supporting the weight of pipes and to assure the pressure tightness of the annulus

3.2.11
leaching step
period between two rearrangements of the leaching completion

3.2.12
solution mining
controlled leaching of the cavern to its desired shape and size

3.2.13
sonar survey
logging method to determine shape and volume of a cavern

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 solution-mined salt caverns 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 the storage of 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.

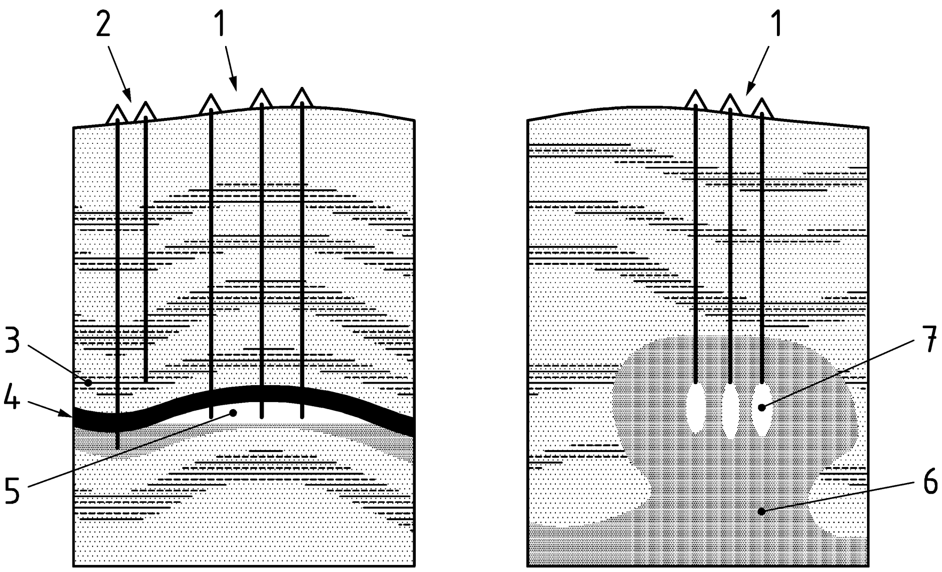
Thus in summary underground gas storage facilities can be used for:

- 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 shall 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 wellhead. 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, 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, 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 salt caverns

Underground storage of compressed natural gas (CNG) and liquified petroleum gas (LPG) in solution-mined salt caverns is a proven technology for providing storage capacities on a short-term and seasonal basis.

Storages of CNG in salt caverns are artificially developed containments in salt rock usually to provide high withdrawal capacities but may as well be used for the storage of large gas volumes in case numerous caverns are tied into one storage facility.

Salt caverns (see Figure 2) are constructed in suitable salt layers or salt domes by drilling a well into a salt deposit with adequate protection for the underlaying, overlaying and lateral surrounding strata, i.e. mainly by thickness of the salt and completion of the well.

NOTE Some salt caverns may have more than one well, so in this standard the term "well" can also mean "wells".

It is known that suitable salt layers and salt domes are impermeable to gas up to certain pressures. In addition, cracks and faults in the salt are healed by the viscoplastic behaviour of the salt under the geostatic pressure.

After drilling, salt caverns are leached by the controlled circulation of water or not saturated brine down the wellbore into the salt zone and back as brine to the surface (see Figure 5). Once the geometrical design volume is reached, the brine is displaced from the cavern by the controlled injection of CNG or LPG.

The pressure in a cavern can be cycled between the minimum and the maximum operating pressure of the cavern while considering approved pressure change rates.

Concerning caverns for liquid petroleum gas (LPG), the displaced brine is normally collected in a pond, which has the geometrical volume of the cavern as minimum volume. When it is necessary to withdraw the LPG from the cavern, the brine stored in the pond will be injected into the cavern. An LPG cavern, in this case, does not require any downhole pumping equipment.

This is the most common method for constructing and operating an LPG cavern in salt. With shallow salt caverns, however, the operation may be similar to the operation of a rock cavern for LPG (see EN 1918-4).

There are more than 40 years of experience of storage of CNG and LPG in solution-mined salt caverns in Europe and the technique is well known and highly developed.

To guarantee a high level of safety, sophisticated techniques are available for:

— the evaluation of the suitability of the geological salt formation for storage;

— the testing and simulation of the salt behaviour under in situ stress conditions;

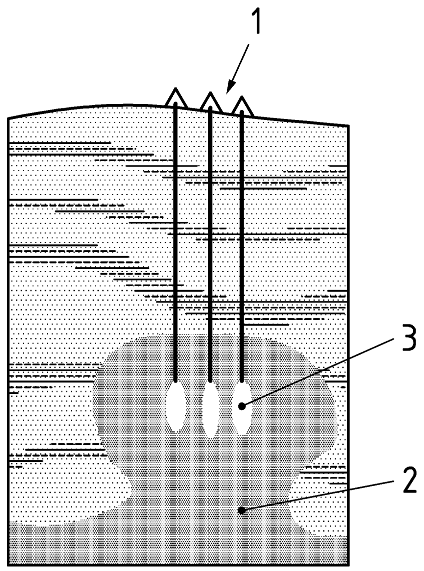
— the simulation of the local stresses around the salt caverns and the demonstration of its mechanical stability;

— drilling, cementing and completion of wells to prevent external gas migration from the cavern towards the surface or upper geological formations;

— controlled leaching of the cavern to its designed shape and size;

— first gas filling under controlled conditions;

— monitoring relevant parameters of the caverns in the operation phase.



Key

1 operating wells

2 salt dome

3 cavern

Figure 2 — Cavern storage

4.3 Long-term containment of stored fluids

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

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.

The facility shall be constructed and operated so as to maintain the integrity of the containment.

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 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.

Preference should be given to technology proven in the oil and gas industry.

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

Emergency procedures should be developed.

All relevant data concerning the design (especially cavern layout, well and wellhead equipment, surveys, operating procedures, material and test documentation) shall be documented and made available to the owner and the operator of the storage facility.

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 exploration

A geological exploration shall be undertaken to obtain sufficient knowledge about the geological site and determine the geological feasibility of the underground storage project by means of geological and geophysical surveys and drilling operations. Water supply and brine discharge options for the solution mining of the caverns should be investigated.

The available geological and geophysical data should be gathered in a pre-feasibility study before deciding on the exploration of a salt formation. The study should include information of a general nature as given by gravimetric or magnetic maps (especially in largely unexplored zones) and regional geological elements, existing seismic profiles and/or data from previous drilling wells.

Additional geological or geophysical surveys may have to be carried out if the existing data are not sufficient. The geometry of the salt mass should be investigated by seismic survey, if seismic data are not available.

In case of insufficient data drilling of an exploration well may be required to determine the quality of the salt and the distribution of the impurities.

A sufficient part of the salt formation shall be cored to provide knowledge of the salt structure and its detailed composition and to enable laboratory tests to be carried out to determine salt composition, mechanical strength and its solution characteristics.

Well logging shall be carried out to determine the salt composition of uncored parts of the relevant salt formation and to evaluate the quality and density of the overlying rocks. The data may also serve for future well-to-well correlations.

The exploration data should be sufficient to decide about the technical feasibility of the site for the construction of salt caverns. A summary of the data should be included in a feasibility report about the exploration.

This summary should also be used to define the most favourable zones for locating caverns, taking into account the depth and thickness and lateral extent of the salt layer, the distribution of insolubles and the proximity of possible tectonic zones.

5.3 Caverns

Caverns (see Figure 3) shall be designed for long-term stability under the permitted operating conditions.

The mechanical properties of the salt and the rock surrounding the cavern, which may be subjected to high levels of stress and strain, shall be evaluated on the basis of laboratory tests on borehole samples and/or in situ tests in the well.

The tests shall also be used as a basis for selecting the rheological model and supplying values for the model parameters that show the rheology of the salt being studied. The model used should take into account appropriate behavioural laws for both analytical studies and a more accurate representation of reality based on modelling e.g. finite elements models.

The main mechanical disturbances that need to be represented or quantified are:

— the change in volume loss by creep in the salt formation (convergence);

— the change of cavern shape ;

— the distribution of stress induced by the cavern in the surrounding rock.

The principal stability parameters that need to be defined within the cavern design are:

— the cavern geometry (shape, height, diameter, roof guard);

— the positioning (e.g. well pattern, depths, pillars, distances to overburden, bed rock);

— the distance to subsurface neighbouring activities;

— the maximum operating pressure, which shall always be less than the overburden pressure;

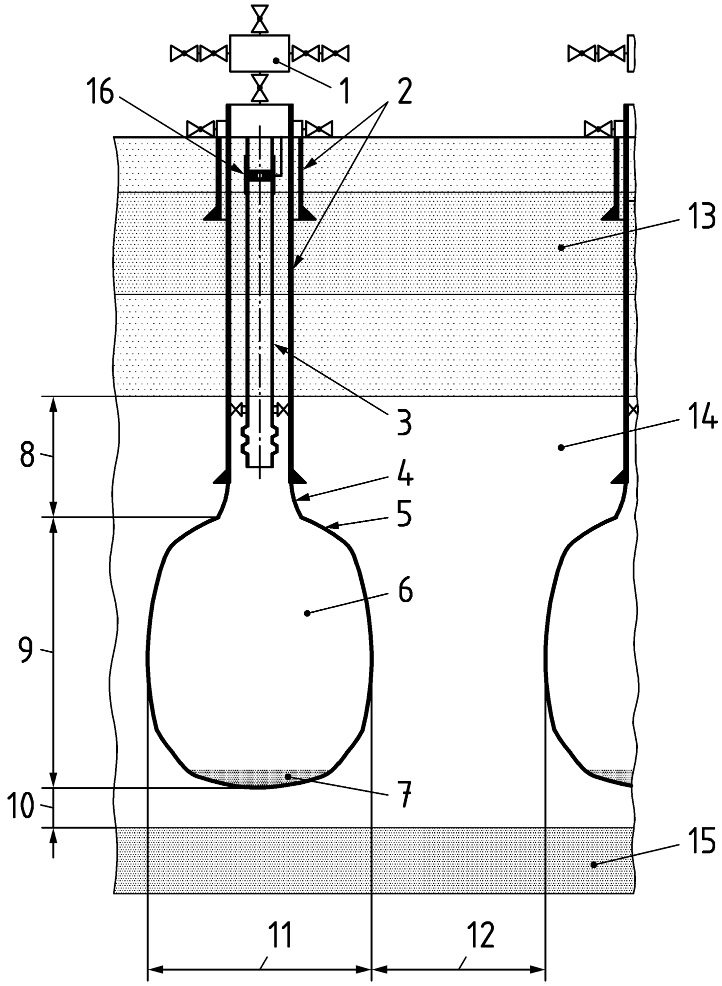
— the minimum operating pressure;

— the maximum pressure change rate.

It shall be demonstrated, that the cavern is mechanically stable under the permitted operating conditions. The cavern behaviour under emergency situations shall be considered. The impact of construction and operation of the UGS with respect to neighbouring sites and environment, in particular subsidence of the surface, shall be considered.

The general rules used as a basis for dimensioning should also take into account the knowledge acquired through prior activities.

The designer shall demonstrate that the cavern is capable of containing gas at the design conditions, using acknowledged geological methods and databases.



Key

1	wellhead	9	cavern height
2	cemented casing	10	distance to underlying strata
3	tubing	11	cavern diameter
4	cavern neck	12	pillar
5	cavern roof	13	overburden
6	cavern	14	salt dome or salt strata
7	sump/remaining brine	15	underlying strata
8	distance to overburden	16	subsurface safety valve

Figure 3 — Cavern layout

5.4 Wells

5.4.1 General

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 4);

and this design shall take into account:

- the integrity of the cavern;
- 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 is necessary to evaluate the wellhead, casing, cement and the completion scheme for all operating conditions.

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

If the status of a well may jeopardize storage containment, remedial action shall be taken.

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

5.4.2 Location

The well site shall allow for the installation and operation of the drilling rig and all necessary equipment for the drilling operation. After drilling and well completion the site will be used for the leaching operation. After the re-completion of the cavern for gas storage the well site is used for the operation of the cavern.

The well site 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.

Safety distances to housing 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 well site shall be designed to avoid any flow of contaminating fluids to the environment during the drilling and leaching process and during 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 Casings

A well (see Figure 4) 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 salt. A sufficient number of casing strings shall be set to avoid uncontrolled fluid movements into the well during the drilling operation (see Figure 4).

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

The grades of the casings shall be selected to ensure that well 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 strings and the strata should be investigated.

The bottom part of the last cemented casing string including the casing shoe should be pressure tested after installation in accordance with Clause 7.

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

5.4.4 Completions

5.4.4.1 Leaching completion

The leaching completion shall enable the cavern to be leached in a controlled manner. It usually consists of two concentric strings within the last cemented casing. The inner string and the middle annulus are used to conduct water and brine to and from the cavern. The leaching strings are supported by hangers within the leaching wellhead.

The outer annulus shall allow a blanket fluid to be injected into the cavern neck and the upper part of the cavern to permit shape control of the cavern (see Figure 5) and prevent any leaching around the cemented casing shoe.

Leaching strings should be fabricated, inspected and tested in accordance with the standards and recommendations in force. Their grades and strengths should be selected for at least the estimated duration of the leaching period.

The couplings should be capable of maintaining tightness to all applied fluids during the leaching periods even with several times of pipe make-up.

5.4.4.2 Storage completion

5.4.4.2.1 General

Well completion for gas storage operation consists of installations for safe operating or inspection purposes inside the last cemented casing and shall enable the installation of the debrining equipment.

Completions shall be designed to withstand the forces from variations in gas pressure and temperature in the range of the permitted operating conditions of the cavern.

Completion should be fabricated, inspected and tested in accordance with the standards and recommendations in force.

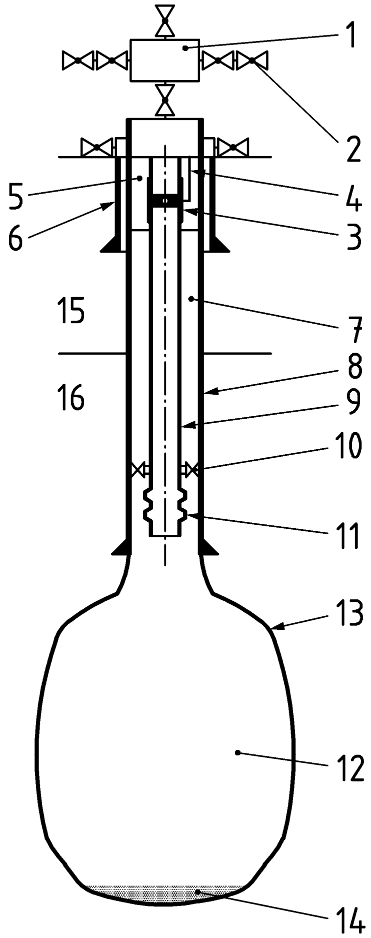
The completion should be selected to last for the designed operational life of the storage under the permitted operating conditions.

5.4.4.2.2 Completions for CNG caverns

Completions for CNG caverns usually consist of:

- a tubing with premium threaded couplings or welded to provide gastight connections;
- landing nipples at strategic positions in 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 stress caused by temperature and pressure fluctuations. If a packer/tubing anchor seal assembly is used the tubing shall be pre-stressed to face the effect of elongation or shrinkage due to storage operation;
- a subsurface safety valve located in the tubing string of operating wells, which may if applicable be surface-controlled and/or can be activated by the subsurface pressure and/or flow rate conditions. The subsurface safety valve normally is set into the upper part of the production tubing several meters below the surface. The subsurface safety valve, controlled by a local wellhead panel and/or by remote operation from a central control room, shall shut down automatically in the event of unallowable operating conditions or emergency. Subsurface velocity safety valves operated without control lines, e.g. "storm chokes", can be installed as well in certain cases. 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;
- a completion fluid for the annulus between the tubing and the casing;
- an injection system for hydrate inhibitor, normally at the wellhead and/or possibly downhole;
- if no retrievable temporary debrining string is used, a permanent debrining (eductor) string, and usually landing nipples are installed to be able to isolate the string from the cavern gas pressure, if necessary.

All equipment and connections shall be gastight.



Key

1	wellhead	9	tubing
2	wing valve	10	permanent packer
3	subsurface safety valve	11	landing nipple
4	control line for subsurface safety valve	12	stored gas
5	casing pressure monitoring gas (Nitrogen)	13	cavern
6	casing	14	remaining brine
7	casing protection fluid	15	overburden
8	last cemented casing	16	salt

Figure 4 — Example of a cavern well completion

5.4.4.2.3 Completions for LPG caverns

Various types of completions for LPG are in use. The most typical completion consists of a single tubing suspended in the wellhead. The lower end of the completion is located just above the bottom part of the cavern.

A double containment system shall be considered.

The production string shall be hydraulically leak tight.

5.4.4.3 Leaching wellheads

The leaching wellhead shall be designed to allow leaching water and brine to pass into and out of the cavern via the inner string and inner annulus. Blanket passes down the outer annulus between the last cemented casing and the outer leaching string.

The leaching wellhead shall be designed to allow a workover/drilling rig to be assembled over it and still allow access for dismantling and rebuilding.

Manual valves on the leaching wellhead may be provided to isolate all inlets and outlets.

Brine or blanket spillages at the leaching wellhead caused by leaks should be prevented by appropriate measures.

Leaching wellheads should be designed to the maximum pressure of the solution mining operation in accordance with standards and recommendations in force.

It shall be demonstrated that the design pressure rating for the leaching wellhead and connected systems cannot be exceeded.

5.4.4.4 Storage wellhead

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

The storage 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.

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

Salt caverns shall have at least one master valve. This valve shall isolate the cavern for operational reasons and in case of emergency or maintenance.

On the major intakes and offtakes the storage 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.

Storage 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 storage 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 pressure;

— failure of power supply;

— 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 storage wellhead to inhibit and control hydrate formation.

5.5 Monitoring systems

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 cavern pressures and annuli pressures, injected and produced gas volumes and qualities and, if applicable, logging results.

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

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.

5.7 Solution mining

5.7.1 General

Solution mining is the controlled leaching of the cavern to its desired shape and size. Solution mining of the cavern is usually achieved by controlled circulation of water or not saturated brine through two concentric leaching strings down the wellbore and up again to the surface. Depending on the flow direction it is defined as either direct or reverse leaching.

The shape development of the cavern is mainly influenced by the solution characteristics of the salt, the amount of impurities in the salt, the circulation method (direct or reverse), the different setting depths of the leaching strings, the blanket level, the water flow rate and the duration of leaching steps. It shall be ensured that the maximum diameter and final shape of the cavern comply with the parameters derived from the rock mechanical design under consideration of the range of the permitted operating conditions of the cavern.

Before starting the construction work a solution mining design shall be prepared. The design shall provide a plan for the total number of leaching steps.

The design shall consider the impact of water offtake and brine disposal on local resources.

The solution mining design should consider:

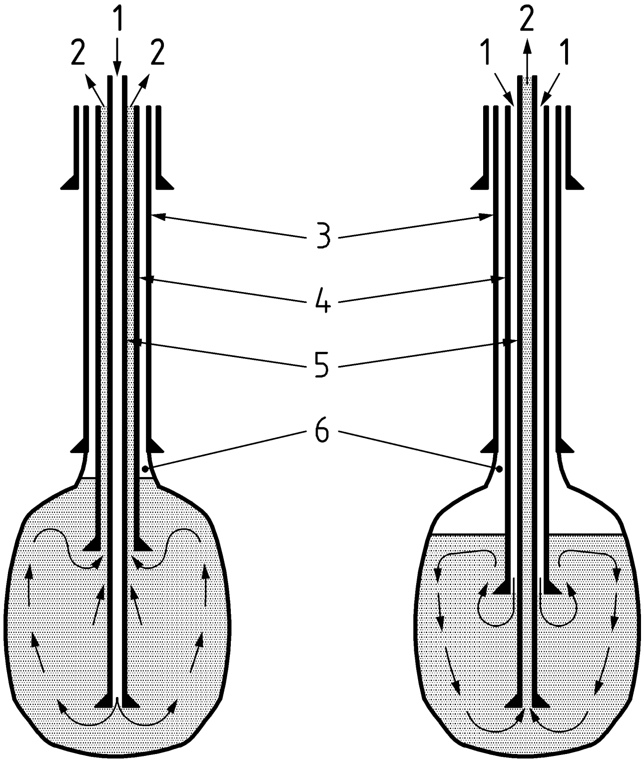
— the different solution parameters (direct, reverse, setting depths of the leaching strings, injection rates, temperatures, amount of NaCl or other components in the brine);

— a design for the roof protection by blanket injection;

— a surveillance method to control the blanket level, the composition of the brine and the shape development through periodic surveys;

— a programme for process control by measurement of the leaching parameters (pressures, rate, brine density at the wellhead);

— safety devices for process control.



Key

1 water

2 brine

3 last cemented casing

4 outer leaching string

5 inner leaching string

6 blanket

Figure 5 — Solution mining

The design shall outline the predicted shape at each phase of the solution mining and provide a total mass balance using the predetermined flow pattern for the cavern.

The design should be based on a leaching simulation or shape analysis that shows the expected cavern shape development. The shape analysis should include as far as possible the influence of impurities in the salt formation.

The calculated shape development shall be consistent with the approved rock mechanical dimensions of the cavern.

The cavern roof shall be protected by a blanket that does not affect the salt, is not water-soluble, is less dense than water and does not affect the future storage medium in an unacceptable manner. The blanket level shall be controlled continuously or on a highly periodic basis.

The leaching equipment shall be designed for the permitted operating pressures and rates.

Safety installations and control devices shall be installed to prevent the equipment from being damaged and brine or blanket from being spilled on the surroundings.

5.7.2 Brine discharge

The brine discharged from the cavern shall fulfil local applicable limits with respect to the content of blanket.

If necessary, a surface treatment plant may be installed to condition the brine before it is discharged from the site.

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 as well as the solution mining.

Drilling, cementing and completion, as well as inspection and testing of all subsurface equipment and the wellhead, shall comply with relevant standards and recommendations.

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 casing shoe shall be monitored. The last cemented casing shall be constructed so 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.

For welded casings pipe materials, which are weldable under site conditions, shall be used. Welding tests on material samples may be necessary prior to the operation.

Suitable welding methods and fillers shall be used.

Non-destructive tests shall be performed to verify and ensure the quality of the welds.

The welding work shall only be carried out by qualified welders.

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 cavern.

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

For welded tubings, pipe materials which are weldable under site conditions shall be used. Welding tests on material samples may be necessary prior to the operation.

Suitable welding methods and fillers shall be used.

Non-destructive tests shall be performed to verify and ensure the quality of the welds.

The welding work shall only be carried out by qualified welders.

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 Solution mining

6.4.1 General

Construction of a cavern by leaching is a continuous water injection process. The leaching process (see Figure 6) shall be monitored and the cavern shape development shall be controlled.

The impact of water offtake and brine disposal on local resources shall be monitored.

During the cavern development, the pressure, temperature and flow rate of the water, brine and blanket to and from the cavern shall be measured continuously.

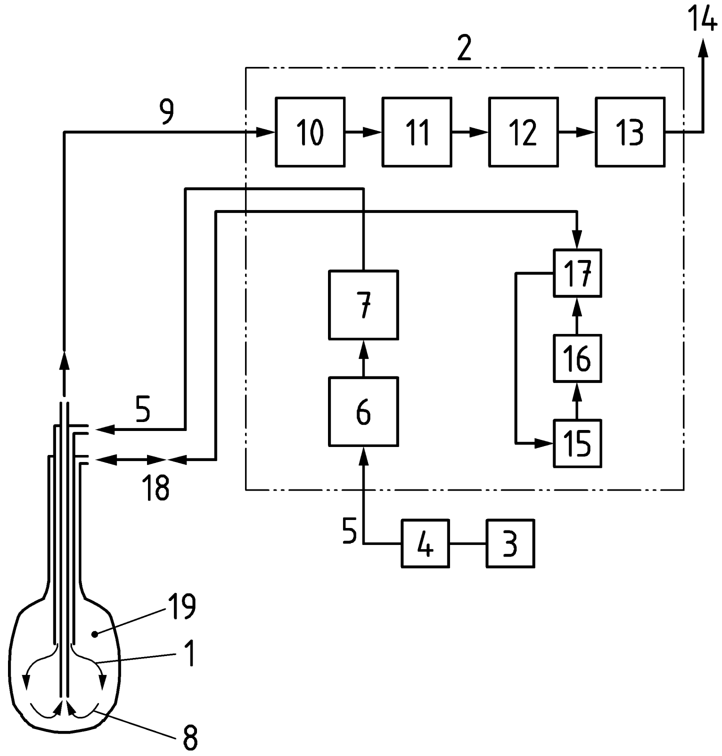
The cavern shape development shall be checked against the cavern design criteria by periodic surveys during the leaching period.

The balance of volumes and masses on the basis of the injected and withdrawn fluids (water and brine, and blanket, if applicable) shall correspond to the anticipated cavern design.

If the shape of the cavern develops in an unexpected way, the cavern design procedure described in 5.3 shall be re-examined to adjust the design parameters of the cavern to the new conditions.

The leaching process shall not be resumed unless the cavern stability under the new conditions is still acceptable.

Once the designed cavern dimensions are reached, the leaching process is finished. The actual cavern shape shall be confirmed and documented by a final survey, e.g. sonar survey.



Key

1	cavern	11	filter
2	leaching facility	12	brine metering
3	freshwater supply	13	transport pumps
4	freshwater intake pump	14	brine discharge
5	freshwater pipeline	15	blanket tank
6	leaching pumps	16	blanket pump
7	freshwater metering	17	blanket metering
8	brine	18	blanket field piping
9	brine field piping	19	blanket
10	brine tank		

Figure 6 — Leaching facility

In some cases it could be of interest to start filling the cavern in the upper part of a salt cavern with CNG while leaching a larger cavern. This process is named Solution Mining Under Gas (SMUG).

SMUG is not described in this standard because that process is particular and is not the usual way of developing salt caverns. However, standard requirements apply to that solution.

6.4.2 Leaching wellheads

Pipework connections to and from the leaching wellhead shall allow easy dismantling and re-connection at workovers.

All flanged joints should be pressure tested.

6.4.3 Cavern volume calculation

The cavern free volume is usually calculated on the basis of the last survey (e.g. sonar survey) after leaching under brine or after the first gas fill under gas.

The cavern free volume available for gas may also be calculated on the basis of the measurement of the extracted brine volume at the first gas fill. Water injected into the brine flow to avoid salt crystallization should be taken into account.

For CNG, the cavern free volume available for gas may also be calculated on the basis of the injected and withdrawn gas volume during first gas fill or in operation using the measured cavern pressure and temperature.

It is advisable to use more than one method and crosscheck the cavern volume calculations.

6.5 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.

6.6 First gas fill (CNG)

6.6.1 General

The initial injection of CNG shall displace the brine out of the cavern.

Safety installations for the first gas fill depend on the system used to remove the brine. The two systems commonly used are:

— a permanent debrining string (brine eductor);

— a temporary debrining string, which is removed once the cavern is full of gas.

In case of a temporary debrining string, the master valve may be non-operational during the brine removal operation and should be locked open to prevent closure on to the debrining string. A manual or actuated valve to shut off the debrining string should be installed at the wellhead.

Pressures should be monitored in the brine outlet, and the brine outlet valve at the wellhead should close, if a predetermined pressure level is reached.

The maximum operating pressure of the cavern shall not be exceeded during the first gas fill.

All actuated wellhead valves should close (apart from the master valve for temporary debrining strings), if an emergency is suspected or if the allowable operation pressure of the cavern is exceeded.

The gas content in the discharged brine may be monitored and the brine outlet valve should close if a predetermined level is reached.

The rate of brine removal may be reduced as the brine/gas interface nears the shoe of the debrining string.

It may be necessary to introduce a two-phase brine and gas separator to ensure that no gas passes into the brine disposal system.

The brine displacement and the wellhead flowing pressure shall be continuously monitored to ensure that salt does not block the debrining string. Brine removal should be stopped and water reinjected, if a minimum brine rate or wellhead flowing pressure is reached due to salt crystallization on the debrining string walls.

Water should be injected in the surface brine pipework to avoid salt crystallization.

In the event of a long-term shutdown of the first gas fill, the debrining string may be refilled with water as well before restarting gas filling to avoid salt crystallization.

Provision shall be made to avoid gas breakthrough into the brine disposal pipeline.

6.6.2 Monitoring the first gas fill

All gas injected into the cavern should be monitored and recorded.

All brine displaced from the cavern should be monitored and recorded.

Daily volume balances should be carried out on both gas and brine to estimate the interface level in the cavern.

If metering errors are suspected or large differences occur between injected gas volumes and brine volumes, a density interface log should be carried out.

6.7 Recompletion after the first gas fill

Once the brine has been removed and the cavern contains gas, it is made ready for operation.

For a permanent debrining string, a subsurface safety valve shall be installed in the tubing string.

Temporarily debrining string shall be removed under gas pressure, the master valve shall be activated and the subsurface safety valve shall be installed and activated.

6.8 First gas filling (LPG)

The whole monitoring system and the safety devices for the cavern operation shall be installed, adjusted and checked before starting the first LPG filling of the cavern.

At the beginning of the first gas filling, overpressure shall be avoided at the shoe of the last cemented casing.

Pressures at the LPG input and brine output shall be continuously monitored and recorded.

The volume of LPG injected shall be measured and related to the volume curve obtained from the survey.

The LPG-brine interface level shall be estimated from the differential pressure at the wellhead. It shall be cross-checked against periodic interface logs.

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.

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 and/or after solution mining, the last cemented casing, including the casing shoe, may be pressure tested.

After the gas storage completion has been set, the mechanical integrity of the completion system, including the casing shoe of the last cemented casing, has to be demonstrated by appropriate testing.

All parts of the wellhead shall be pressure tested before the cavern 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 and the cavern.

Safety devices shall be functionally tested prior to operation.

8 Operation, monitoring and maintenance

8.1 Operating principles

The operation of any cavern gas storage facility consists of many activities. The main part is the control of the injection and the withdrawal of gas. 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, shutdown 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.

If there is evidence that operation of a well is no longer safe or that the well integrity is jeopardized all investigations shall be performed and adapted remediation measures and suitable measures, shall be carried out as soon as possible.

8.2 Cavern monitoring and maintenance

For the monitoring of all wells, an integrated analysis is required.

The operating pressure of each cavern shall be measured continuously at the wellhead or downhole. For pressure measurement at the wellhead, the pressure difference between the wellhead pressure and the pressure in the cavern shall be calculated.

The maximum flow rate of a cavern should be limited. The value should take into account the flow velocity in the surface and subsurface installations considering the rock mechanical and thermodynamic limitations. Wellhead pressures, temperatures, inventory and operating status of each cavern shall be monitored. The inventory of a cavern may be calculated from flow rate measurement and volume balance or from the cavern pressure, volume and temperature.

For monitoring the completion integrity, the annuli pressures shall be 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.

Each cavern location should be periodically surveyed.

The cavern shape shall be monitored periodically by sonar or other acceptable techniques.

A routine inspection and maintenance schedule for surface and subsurface safety equipment shall be prepared and followed up.

8.3 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.

8.4 Maintenance of wells

It is recommended to develop a preventive well integrity plan. 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 wellhead, 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.

8.5 HSE

8.5.1 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 system, HSE management in business and hazards and effects management tools and techniques.

8.5.2 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 and cavern, with special attention paid to long term integrity. In the case of the abandonment of one or more caverns during ongoing operation of the storage 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, based on the assessment of well and cavern.

Plugging of wells is done to durably ensure the mechanical stability of salt formation and the conservation of tightness between the cavern and the surface.

A long time simulation of salt creep and the resulting pressures at casing shoe shall be conducted to assess and prove the structural stability of the cavern to be abandoned.

The abandonment of a cavern comprises:

— withdrawal of recoverable gas from the cavern;

— flooding the salt cavern;

— cavern monitoring;

— 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

Brine or water is injected into the cavern and the storage gas is withdrawn. The cavern is flooded and remains filled with brine.

Near static temperature equilibrium shall be reached before plugging the well, in particular to avoid induced fracturing. This phase may require several years.

9.3 Plugging and abandonment of wells

For the abandonment of a cavern the completion and finally the wellhead is removed.

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

If long time stability is confirmed, plugging the well is done by packer and/or cement jobs or any material, which can demonstrate its long-term tightness.

Plugs shall be positioned properly to overcome any failure of long term casing integrity in ensuring tightness to / and between aquifers

Special attention is to be paid on the plug in contact with the brine, taking into account the final pressure build up in the cavern.

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*
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*

Reference	ICS	Title
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 1918-3:2008

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
5.4.1	General	Additional elements to take into account in well design
8.5	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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