

# **REVIEW AND HARMONIZATION OF NORMATIVE DOCUMENTS GOVERNING CONSTRUCTION AND OPERATION OF UNDERGROUND STORAGE FACILITIES FOR GASES AND LIQUIDS IN ROCK SALT**

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This paper is the result of the analysis and harmonization of standards governing design, construction and operation of underground storage facilities for gases and liquids in Rock salt.

## **1. Introduction**

The growth steady trend of solution mined salt cavern for use in hydrocarbon reserves production requires the improvement of regulation on design, construction and operation of underground storage facilities.

At present construction and operation of underground storage facilities in different countries is governed by national standards which differ in both form and content. The European Standards are in use in Central and Western Europe, while other

standards have been developed in Russia, USA and Canada.

Improvement of scientific and technological cooperation, implementation of joint international projects actualizes the task of harmonization of regulatory and procedural documents existing in different countries which govern underground storage of gases and liquids.

JSC Gazprom developed the standard "Caverns in impermeable and stable rock for gas, petroleum and derivatives storage" which was initiated in 2008 and comprises of salt cavern regulations for design, construction and

operation of underground storage facilities in rock salt and mined caverns based on current world experience. Application of the Gazprom's Regulations permits minimization of risk at new salt cavern project construction.

## **2. Analysis of Russian and Foreign Standards on Underground Storage of Gases and Liquids in Impermeable Rocks**

### **2.1. Russian Standards**

Basic standards pursuant to which the underground storage objects are designed and constructed at the present time in Russia are [1] and [2].

Normative documents [1, 2] have been developed in accordance with the system of normative documents in construction adopted in Russia.

The application area of the analyzed standards is limited by the design and construction of solution mined salt caverns and mined caverns in other impermeable rocks.

The document [1] consists of 10 sections and basically contains regulatory requirements stated in the most general form.

The requirements to power supply reliability, tables with standardized distances under the terms of fire and explosion safety from buildings and constructions of the above-ground complex to the objects whether being the part of the storage facility or not, storage facilities classification according to

designation and requirements to geotechnical and groundwater conditions at the construction sites, types of load and load combinations affecting to structures of the underground complex are given. Operational requirements govern reliability and operation safety of storage facilities, periods of allowable storage of end products, systems of control over conditions of constructions and storage technological processes, reservoir activity factors and reservoir operation peculiarities of different types.

Separate section contains fundamental design norms reflecting general and specific features of the underground complex of storage facilities and of the manufacturing processes of building work depending on the structure of storage facilities of different types.

Separate short section standardizes quality control over construction and commissioning of underground storage facilities.

Section Natural Environment Protection defines general requirements to environment protection, basic and current monitoring of surface, underground water and surface deformation.

The rules [2] are the appendix to [1] and support generalized requirements stated in it and as a rule are permissive. The main volume of this document (about 40%) in terms of rules amount (15) is occupied by the design section. More than a half of rules (7) relates to design of underground storage facilities in rock salt. The rules contain methods of calculation and acceptability appraisal of

rocks for creation of storage facilities and disposal of construction brine into bowels of the earth, technological and constructional requirements.

Section Work Rules (7 rules) reflects specific features of construction processes of different types of reservoir or its structural components.

The rules on leakage test of underground storage reservoir are separated into one section since these tests carried out under special project and performed during the concluding construction stage determine operational suitability of storage reservoir constructed. The summary section Work Acceptance Rules includes the list of as-built documentation necessary for commissioning of the objects.

The rules [3] have the glossary and relate only to the area of underground storage.

Documents [1, 2] in unnecessarily details govern design and construction processes of underground gas storage in rock salt which doesn't meet one of the international standardization principle where it is recommended to be limited in standards only to essential requirements; these documents can be used as a basis for development of harmonized standard in the part of design and construction of all types of underground storage facilities in resistant and impermeable rocks for liquid and gaseous hydrocarbon taking into account revision of accumulated worldwide experience.

## 2.2. European Union Standard

The standard Gas Supply Systems – Underground Gas Storage exists in three official versions (English, French, German) and in force in all EU countries as well as in Norway, Switzerland and Iceland.

This standard consists of independent parts, the first four of which are devoted to separate types of storage facilities, and the latter part which is common. The standard structure – functional recommendations for underground storage:

part1 — in aquifers;

part2 — in oil and gas fields;

part3 — in solution mined salt cavities[4];

part4 — in rock caverns [5];

part5 — as stated above, relates to all parts and contains functional recommendations for surface facilities.

The very name of the standard's parts underlines its permissive nature.

It is stated in Recommendations that the standard supports EU Directives (without specific indication). This standard reflects basic principles for gas supply systems, thereat it is specified that the more detailed national standards and practical codes shall be in EU countries with which this standard cooperates but not substitutes.

When it comes to structure, standards [4] and [5] are the same; therefore there are textual matches in separate sections of general nature relating to storage in rock salt and mined caverns.

Analysis of [4] and [5] shows that:

– documents are developed logically and clearly; their structure reflects sequence of



stages for creation of storage facility from geological exploration to object operation;

– the standard's requirements have general nature and contain no specific recommendations for its implementation since it is assumed that standards and codes of different countries contain specific recommendations. Shall we compare standards with Russian normative documents, the closest in terms of designation and content is [1];

– officially, standard applies to storage of compressed and liquefied gas: oil and petroleum derivatives are mentioned only in one paragraph of recommendations for mine storages; apparently the document applies to these products "by default";

– evidently, the main purpose of this standard is orientation of its requirements to safety of the object and equipment for personnel and population as well as environment protection; it is no mere chance that the word "safety" is the most frequently used word; elements of furniture, equipment and technology processes and requirements to control over them during all stages of storage facility creation are separated in terms of safety, overwhelmingly important significance is attached to observance of the project, documentation of actions, qualification and training of personnel.

### 2.3. US Standard

In US there are two standards: first – for design (includes performance of works [6]), second — for operation [7].

The study of [6] and [7] showed:

– application of [6] is limited to design and construction of underground reservoirs in rock salt for liquid hydrocarbons (though the text does not show this clearly); probably, for UGS (Underground Gas Storage) in salts, the document is used by default, because UGS special standard was not found, and technology of reservoir construction for all hydrocarbons is the same;

– according to the name and foundation of the development (knowledge and practical experience of geoscientists, engineers and other personnel of oil industry), [6] has practical orientation at engineering solutions of designing an technological design issues, tests and removal of underground storage and its elements;

– largest part of [6] has descriptive nature without must imperatives, all specific recommendations on values reflected in the document are given in our description;

– detailing of some issues in [6], related to technical characteristics of pipe equipment, cements and drilling materials is made by referencing to API regulations;

– though [6] is directed to develop reliable and stable underground storage, safety issues are not separated in special division and are not emphasized in the text;

– in [7], largest part of recommendations on operational equipment and tightness tests briefly repeats recommendations of prior standard.

### 2.4. Canada National Standard

Canada national standard CAN/CSA Z341 Series-06 Storage of Hydrocarbon in Underground Formations consists of two standards.

Z341.1 Reservoir storage (meaning porous structures, which are not considered here);

Z341.2 Salt cavern storage [8].

Study [8] showed:

- the standard has wider application area than European and American standards because it regulates storage of compressed and natural gas, liquid hydrocarbon, oil and oil products, as Russian standards;

- document structure is complicated and difficult to understand due to large number of subheadings, which contain one or two provisions, there is frequent repeat of the same requirements in different sections;

- along with poor given requirements related to specifics of construction of underground reservoirs, the standard contains large number of provisions (for instance, in the area of material selection, drilling and well cementing), well known in oil and gas branch industry and in Russian standardization system regulated by proper documents in drilling area.

### **3. Harmonization of JSC Gazprom's Standard with Foreign Standards**

In general, the study showed that industrial countries with developed technologies of underground storage use

norms having international standard status (for EU countries) or national standards (for US and Canada). Russian regulations issued prior acceptance of the Technical Regulation Law, at present time are considered as standards for following organizations: [1], [2] — Russian Gosstroy, [3] — JSC Gazprom.

Application area of considered documents is valid for:

- Russian standards [1,2] for design and construction of natural gas, oil and oil products underground storages in rock salt and mined caverns for the same products except natural gas;

- EU standards [4, 5] — for design, construction and operation of storages in rock salt for natural gas and liquid hydrocarbons and mined caverns for liquid hydrocarbons (according to some items, norms are valid "by default" also for storage of both types for oil and oil products);

- US standards [6, 7] — separate norms: one is for design and construction, other for operation of underground storage in rock salt for liquid hydrocarbons;

- Canada standard [8] — for design, construction and operation of storages in rock salt for the same stored products as Russian standards [1] and [2].

In listed Russian standards (except [3]) only construction of underground parts of storage is regulated, including mouth equipment of operational wells and shafts. [3] contains subsection on design with listed buildings and structures of ground complex.

In EU all type of storage equipment including equipment for porous structures is separated into special standard.

Considering interest and scope of present day cooperation of JSC Gazprom in Europe, the main object of new standard harmonization were EU standards and principles of technical harmonization established by Resolution of Europe Council on New approach.

Considering the fact that JSC Gazprom developed organizational standard but not national standard, the following additional principle was suggested:

- harmonized standard includes specific requirements, which were tested and used in Russia, US and Canada, accounted to be important to support significant requirements of general nature.

As basic regulations for development of new JSC Gazprom standard are taken [1] and [2].

As example of comparative study that was put as a base for harmonization, it is brought comparative table of Russian and foreign standards main provisions in the area of design and construction of underground reservoir in rock salt with recommendations on use of separate provisions (table 1).

In recent decades mined caverns with positive temperature in Russia have not been built. Due too specific Russian weather conditions, where more then 30% of the territory consist of permafrost, mainly mined caverns were developed – specific type of underground structures, which does not have analogues in the world. Therefore, at harmonization of requirements of design and construction of mined caverns in rocks with positive temperature, preference was given to formulation of requirements similar to EU and Canada standards.

As to storage operation, EU standard is limited with very scarce “operation concept”. Most extended material relating to this issue contains in US standard [7], but it works only for solution – mined caverns for liquid hydrocarbons. Safety issues during technological work at the storage, as well as tightness test, maintenance work and tests are described here in general form. Actually, concisely, they repeat recommendations [6] on design. List of harmonized requirements of JSC Gazprom standard relating to operation issues conforms to this standard attracting some provisions of Canada standard.



Sections	EU standard	USA standard	Canada standard	Russian standards [1] and [2]	Recommendations on JSC Gazprom harmonization
1	2	3	4	5	6
<b>Introduction. General provisions</b>					
- Illustrations	There are provided schematic general drawings of underground reservoirs	There are provided schematic general drawings of underground reservoirs	There are provided schematic general drawings of underground reservoirs	Not available	Add
- Long term product storage	General requirement to design quality	Description of construction and operation of underground storages	Not available	Implicitly in different sections [1]	To unite separate provisions and approximate them in view of EU standard interpretation
- Environmental protection	General requirement to environment protection	In form of general requirement is not available	In form of general requirement is not available	Section is available in [1]	Add
- Safety	General requirement to exclude risk for people	Not available	Not available	Is not expressed in general form	Add
- Monitoring	General indication for monitoring necessity	Not available	Not available	In general form is not available	Add
<b>Design</b>					
- Project conception	General requirement to design process that repeat prior one	Not expressed explicitly	Not expressed explicitly	By content corresponds to section [1] "Operation requirements"	Editing is needed
- Exploration works	Expanded description of exploration process	Independent section "Required knowledge of salt geology and structure"	Expanded description of exploration requirements	There are provided requirements to rocks and parts of construction	Expand in the part of requirements to exploration works
- Working - Storage	Expanded requirement to calculation of stableness and surface subsidence consideration	Independent section "Criteria used in Workings Storage design"	Short requirements to form configuration, surface subsiding and prevention of workings breakoff by the way of hydraulic fracturing, appendix provides instruction on ultimate pressure definition in workings	In [1] in the form of section "Loads and exposure", calculation requirements for stableness and in [2] in the form of method of stableness calculation	Editing

Continuation, table 1

1	2	3	4	5	6
- Well: location	Expanded requirements to operation well platform during construction and operation stage	One short general item.	Several requirements in different sections	Section [1] "Master plan" including tables of fire-prevention distance	Editing
- Casing	Expressed in general form the requirement on principles of selection of casing column and casings location; there are indicated general requirements to pipe quality control necessity, column cementing and tightness test.	References to proper standards	Trivial requirements to boring casing and drilling, with frequent references to proper regulations		Editing
- Operation equipment	Formulated general requirements to operation well arming and separately, specific for compressed gas and liquid hydrocarbons (number of suspended column, well equipment)	In such expression special section is not available, separate requirements are available in [7]	The same as in US standard	The same in [2]	Edit with shortening of requirements to well equipment as they are almost not used in Russian practice
- Wellhead equipment for salt dissolution	Contain detailed requirements (7 in total) to wellhead equipment during working construction and 13 requirements to operation equipment. General requirements to design of operation wells is not available	There is available special section, which requires solution of strength at given pressure and materials, it contains expanded requirements to selection and control of materials for drilling works by reference to the proper regulations and practical recommendations on column installation	Requirements are expressed in the form of references to proper regulations. Significant part of document requirements is devoted to material selection for all construction elements, calculation of casing, well cementing, which have crossing requirements to design and construction	[2] contains 6 requirements to wellhead equipment, generally, to functional purpose well and emergency valves. Requirements to boring casing are expressed in the form of reference to the proper regulations generally accepted in branches. It is formulated only few specific requirements related to location of casing in salt rock	Add special requirements directed to safe operation of wellhead equipment conforms requirements of all foreign regulations



Continuation, table 1

1	2	3	4	5	6
- Underground equipment for salt dissolving	It is expressed in general form requirement to well equipment with suspended tubing, their control and possibility of multiple re-connection	There are two short items about purpose of suspended tubing	Has 1 item on tubing about filing of annular space of outer suspended and casing with corrosion inhibitor and requirements to tapped connections	[2] formulates general requirements to design of operation wells for construction period and operation reservoirs	Conforms with requirements of foreign regulations
- Monitoring systems	Shortly expressed general requirements to necessity of control systems of product amount and reservoir tightness	Such separate general requirement is not available, requirement to control are contained in different sections of the document	Independent section "Monitoring and measurements", separate requirements in sections 9, 10	Specific control requirements are contained in section 6 and 9	Unite requirement on control in to separate section that supports general formulation in EU regulation
- Underground works at nearest space	Requirement for construction and operation compatibility of underground storage facilities with underground workings of neighbored territory	Short requirement	Short requirement	Requirement in [1]	Editing
- Construction technology	General requirements to content of construction project (controlled salt dissolution)	Separate section of requirement on injection and brine removal, not solvent, controlled factors, dissolution methods (direct flow, counter flow, etc with illustrations), movement speed in pipes, calculation of workings grow	Construction process actually is not standardized	[1] contains general requirements virtually, similar to requirements standardized in EU standard; [2] regulates technology in details as technology in US standard	Not available
- Brine removal	Contains requirement related to preparation of salt utilization	Not available	Not available	[1] contains requirements to environment protection on brine injection into subsoil, separate section in [2]	Editing in the area of reduction

Continuation, table 1

1	2	3	4	5	6
- Operation technology	In design chapter is not available	Chapter Hydraulics of Workings Storage provides pressure in reservoir	Chapter 7 "Technical Design Criteria" provides standard of operation pressure and injection speed	In section [1] "Operation requirements"	Not available
<b>Construction</b>					
- Wells	Listed contractors' responsibilities on drilling works	There are provided trivial requirements to the process of well drilling, mostly related to design, requirements to geophysical exploration	Construction sections contains only requirements to industrial process control	[1] contains one requirement on specifics of rock salt drilling. [2] contains separate section regulating industrial techniques for driving and bracing of the well in salt, geophysical exploration, descent of suspended columns and tightness test	Not available
- Equipment	Contains requirements to processing of pipe connections and welding of columns	No special requirements	No special requirements	No special requirements	Consider possibility of adding of general item
- Salt solution	Contains requirements on workings volume and shape control, influence of water intake and brine removal upon local resources, review of procedure in case of deviation of workings shape from design	No special requirements	No special requirements	Large section in [2] contains requirements on shape configuration control and size of workings, usage of geophysical methods to control of substances interface, elimination failure techniques during dissolution process, requirements to precision of measurement, dissolution parameters, list of documents on construction control. Appendix contains documentation forms	Not available

Continuation, table 1

1	2	3	4	5	6
<b>Tightness test</b>					
	Vary vague requirement of general type related to pressurizing of operation well and upper part of reservoir without specific indications	Detailed section on tightness test of operation well, upper part of reservoir and suspended column with salt solution and nitrogen with possibility of observation of separation surface. It is also recommended pressurizing with a liquid. Results are interpreted mainly in quality sense. In case of problems, it is recommended assessment made by an expert	In extremely reduced form repeats US standard requirements	[1] contains short requirement for tightness test that exceeds in 1.05 times maximum operation pressure. [2] contains large section with specific recommendations for the test that needs revision of its large. Test ideology is the same as recommendations of US standard	Partial revision of present materials is needed and editing of the section
<b>Commisioning</b>					
- First gas injection	Developed fairly detailed recommendations on first gas injection: fluid movement speed, monitoring of the process	Not available	Not available	Not available	Develop
- First LPG injection	Recommendations refer to re-equipment and installation of liquid hydrocarbons control system and more frequent measurements of parameters in injection process	Recommendations refer to change of construction equipment of a well with operation equipment	Not available	Not available	Develop

\* Figures in brackets contain numbers of chapters, sections, subsections and items of corresponding standards, ref. Appendixes.



## CONCLUSION

Based on development of main harmonization principles and comparative review of application field, structure and content of regulatory documents of different countries, it has been developed harmonized JSC Gazprom's standard "Cavern in impermeable and stable rocks for gas, petroleum and derivatives storage", that is used in present time in new Russian projects of underground storages.

Following development of normative-methodic basis underground storage in rock salt relates to gaseous helium storage (at high helium gas field development in Eastern Siberia), liquefied gas storage in mined cavern, burial and other wastes deposits.

## LITERATURE

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4. The European Standard EN 1918-3:1998. Gas supply systems – Underground gas storage Part 3: Functional recommendations for storage in solution – mined salt cavities.

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7. API 1115, 1994. Operation of Solution – Mined Underground storage Facilities.

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