

Storage of hydrocarbons in underground formations



Legal Notice for Standards

Canadian Standards Association (operating as “CSA Group”) develops standards through a consensus standards development process approved by the Standards Council of Canada. This process brings together volunteers representing varied viewpoints and interests to achieve consensus and develop a standard. Although CSA Group administers the process and establishes rules to promote fairness in achieving consensus, it does not independently test, evaluate, or verify the content of standards.

Disclaimer and exclusion of liability

This document is provided without any representations, warranties, or conditions of any kind, express or implied, including, without limitation, implied warranties or conditions concerning this document’s fitness for a particular purpose or use, its merchantability, or its non-infringement of any third party’s intellectual property rights. CSA Group does not warrant the accuracy, completeness, or currency of any of the information published in this document. CSA Group makes no representations or warranties regarding this document’s compliance with any applicable statute, rule, or regulation.

IN NO EVENT SHALL CSA GROUP, ITS VOLUNTEERS, MEMBERS, SUBSIDIARIES, OR AFFILIATED COMPANIES, OR THEIR EMPLOYEES, DIRECTORS, OR OFFICERS, BE LIABLE FOR ANY DIRECT, INDIRECT, OR INCIDENTAL DAMAGES, INJURY, LOSS, COSTS, OR EXPENSES, HOWSOEVER CAUSED, INCLUDING BUT NOT LIMITED TO SPECIAL OR CONSEQUENTIAL DAMAGES, LOST REVENUE, BUSINESS INTERRUPTION, LOST OR DAMAGED DATA, OR ANY OTHER COMMERCIAL OR ECONOMIC LOSS, WHETHER BASED IN CONTRACT, TORT (INCLUDING NEGLIGENCE), OR ANY OTHER THEORY OF LIABILITY, ARISING OUT OF OR RESULTING FROM ACCESS TO OR POSSESSION OR USE OF THIS DOCUMENT, EVEN IF CSA GROUP HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, INJURY, LOSS, COSTS, OR EXPENSES.

In publishing and making this document available, CSA Group is not undertaking to render professional or other services for or on behalf of any person or entity or to perform any duty owed by any person or entity to another person or entity. The information in this document is directed to those who have the appropriate degree of experience to use and apply its contents, and CSA Group accepts no responsibility whatsoever arising in any way from any and all use of or reliance on the information contained in this document.

CSA Group is a private not-for-profit company that publishes voluntary standards and related documents. CSA Group has no power, nor does it undertake, to enforce compliance with the contents of the standards or other documents it publishes.

Intellectual property rights and ownership

As between CSA Group and the users of this document (whether it be in printed or electronic form), CSA Group is the owner, or the authorized licensee, of all works contained herein that are protected by copyright, all trade-marks (except as otherwise noted to the contrary), and all inventions and trade secrets that may be contained in this document, whether or not such inventions and trade secrets are protected by patents and applications for patents. Without limitation, the unauthorized use, modification, copying, or disclosure of this document may violate laws that protect CSA Group’s and/or others’ intellectual property and may give rise to a right in CSA Group and/or others to seek legal redress for such use, modification, copying, or disclosure. To the extent permitted by treaty or by law, CSA Group reserves all intellectual property rights in this document.

Patent rights

Attention is drawn to the possibility that some of the elements of this standard may be the subject of patent rights. CSA Group shall not be held responsible for identifying any or all such patent rights. Users of this standard are expressly advised that determination of the validity of any such patent rights is entirely their own responsibility.

Authorized use of this document

This document is being provided by CSA Group for informational and non-commercial use only. The user of this document is authorized to do only the following:

If this document is in electronic form:

- load this document onto a computer for the sole purpose of reviewing it;
- search and browse this document; and
- print this document if it is in PDF format.

Limited copies of this document in print or paper form may be distributed only to persons who are authorized by CSA Group to have such copies, and only if this Legal Notice appears on each such copy.

In addition, users may not and may not permit others to

- alter this document in any way, or remove this Legal Notice from the attached standard;
- sell this document without authorization from CSA Group; or
- make an electronic copy of this document.

If you do not agree with any of the terms and conditions contained in this Legal Notice, you may not load or use this document or make any copies of the contents hereof, and if you do make such copies, you are required to destroy them immediately. Use of this document constitutes your acceptance of the terms and conditions of this Legal Notice.



Standards Update Service

CSA Z341 Series:22
March 2022

Title: *Storage of hydrocarbons in underground formations*

To register for e-mail notification about any updates to this publication

- go to www.csagroup.org/store/
- click on **Product Updates**

The **List ID** that you will need to register for updates to this publication is **24296.1**

If you require assistance, please e-mail techsupport@csagroup.org or call 416-747-2233.

Visit CSA Group's policy on privacy at www.csagroup.org/legal to find out how we protect your personal information.

CSA Z341 Series:22
***Storage of hydrocarbons in
underground formations***



®A trademark of the Canadian Standards Association, operating as "CSA Group"

*Published in March 2022 by CSA Group
A not-for-profit private sector organization
178 Rexdale Boulevard, Toronto, Ontario, Canada M9W 1R3*

*To purchase standards and related publications, visit our Online Store at www.csagroup.org/store/
or call toll-free 1-800-463-6727 or 416-747-4044.*

*ICS 23.020
ISBN 978-1-4883-3945-5*

*© 2022 Canadian Standards Association
All rights reserved. No part of this publication may be reproduced in any form whatsoever
without the prior permission of the publisher.*

Contents

Technical Committee on Storage in Underground Formations 14

Preface 17

CSA Z341.1:22, Reservoir storage

1 Scope 20

2 Reference publications 21

3 Definitions 22

4 Location of underground storage facilities 27

4.1 General 27

4.2 Site selection 27

4.3 Proximity to rights-of-way 27

4.4 Well spacing 27

5 Design and development 27

5.1 Risk assessment 27

5.2 Assessment of neighbouring activities 28

5.3 Geological studies 28

5.3.1 General 28

5.3.2 Maps 28

5.4 Fluid compatibility 29

5.5 Observation wells 29

5.6 Operation limits 29

5.6.1 General 29

5.6.2 Maximum operating pressure 29

5.6.3 Delta pressure 29

5.6.4 Reservoir capacity 29

6 Materials 30

6.1 Design conditions 30

6.1.1 General 30

6.1.2 Electrical classification 30

6.2 Qualification of materials 30

6.2.1 General 30

6.2.2 Material qualification categories 30

6.2.3 Use of materials 30

6.2.4 Non-complying materials 31

6.3 Material requirements and specifications 31

6.3.1 Wellhead and Christmas tree assembly 31

6.3.2 Casing 31

6.3.3 Piping 31

6.4 Subsurface pumps 31

7	Well completion and conversion	31
7.1	Open-hole well logging	31
7.2	Core acquisition	32
7.2.1	General	32
7.2.2	Core handling	32
7.2.3	Core analysis	32
7.3	Casing	32
7.3.1	Design	32
7.3.2	Yield strength design	33
7.3.3	Collapse design	33
7.3.4	Tensile design	33
7.3.5	Service conditions	33
7.3.6	Casing setting depths	33
7.3.7	Number of casings	34
7.3.8	Liners	34
7.3.9	Inspection and handling	34
7.3.10	Threads	34
7.3.11	Production casing	34
7.3.12	Casing shoe	34
7.3.13	Casing torque	34
7.3.14	Premium connections makeup	34
7.3.15	Threaded joints	35
7.3.16	Pressure testing — Mill	35
7.3.17	Pressure testing — Field	35
7.3.18	Pressure test records	35
7.3.19	Casing records	35
7.4	Cementing	35
7.4.1	General	35
7.4.2	Design considerations	35
7.4.3	Compressive strengths	36
7.4.4	Cement tops	36
7.4.5	Cement placement	36
7.4.6	Preflushes	36
7.4.7	Casing cementing accessories	36
7.4.8	Pipe movement	36
7.4.9	Cement wiper screens	37
7.4.10	Testing and evaluation	37
7.4.11	Cement integrity evaluation	37
7.4.12	Special cementing considerations	37
7.4.13	Remedial cementing	37
7.4.14	Cementing records	37
7.5	Cased hole integrity inspection	38
7.6	Tubing string completions	38
7.7	Well stimulation	38
7.7.1	General	38
7.7.2	Post-fracture treatment	38
7.7.3	Matrix stimulation design	38
7.8	Well conversions	38
7.8.1	General	38

7.8.2	Inspection and testing	38
7.8.3	Recompletions	39
7.8.4	Casing replacement	39
7.8.5	Relining of casing	39
7.8.6	Internal casing patches	39
7.8.7	Abandonment	39
7.8.8	Conversion records	39
8	Surface facilities	40
8.1	Piping	40
8.2	Wellhead and Christmas tree assembly pressure rating	40
8.2.1	General	40
8.2.2	Wellhead size	40
8.2.3	Wellhead connections	40
8.2.4	Wellhead ports	40
8.3	Emergency shutdown systems	40
8.3.1	General	40
8.3.2	Emergency shutdown valves (ESVs)	40
8.3.3	ESV requirements	41
9	Development and construction	41
9.1	Pre-commissioning pressure test	41
9.1.1	Initial casing test	41
9.1.2	Packer isolation pressure test	41
9.2	Pre-commissioning integrity inspection	41
9.3	Wellbore integrity	41
9.4	Well stimulation	42
9.5	Corrosion control	42
9.5.1	General	42
9.5.2	Cathodic protection systems	42
10	Operations and maintenance	42
10.1	Procedures	42
10.1.1	General	42
10.1.2	Emergency response plan	43
10.1.3	Workover procedures	43
10.1.4	Wireline and logging procedures	43
10.1.5	Isolation and depressurization	43
10.1.6	Records	43
10.1.7	Changes	44
10.1.8	Operating and maintenance procedure audits	44
10.2	Inspections and testing	44
10.2.1	Instrumentation, valving, and emergency equipment	44
10.2.2	Control system testing	45
10.2.3	Wellhead and casing vents	45
10.2.4	Casing inspection	45
10.3	Corrosion control	47
10.3.1	Cathodic protection	47
10.3.2	Interference	47

10.3.3	Monitoring	47
10.3.4	Records	47
10.4	Erosion control	47
10.4.1	General	47
10.4.2	Inspection and monitoring	47
11	Monitoring and measurement — Inventory verification	48
12	Safety	48
12.1	Fire prevention and control	48
12.1.1	Permanent equipment spacing	48
12.1.2	Combustible material control	48
12.1.3	Wellhead enclosures	48
12.1.4	Flaring	48
12.2	Staff training and certification	49
12.2.1	Operating personnel	49
12.2.2	Supervisory personnel	49
12.2.3	Well drilling	49
12.3	Emergency planning	50
12.4	Security	50
12.4.1	General	50
12.4.2	Egress	50
12.4.3	Identification signs	50
12.4.4	Warning signs	50
12.5	Voice communications	50
13	Well abandonment	50
13.1	Design	50
13.2	Downhole equipment removal	51
13.3	Cement quality	51
13.4	Cement volumes	51
13.5	Cement placement	51
13.6	Plug testing	51
13.6.1	General	51
13.6.2	Test failure	51
13.7	Plug intervals	51
13.8	Casing removal from the hole	52
13.9	Uncemented annular space	52
13.10	Perforated casing	52
13.11	Storage zone	52
13.12	Zones containing liquid or gas	52
13.13	Surface casing shoe	52
13.14	Surface plug	52
13.15	Surface cap	52
Annexes		
Annex A (informative) — Commentary on certain clauses in CSA Z341.1		57
Annex B (informative) — Guidelines for risk assessment of underground storage		67

CSA Z341.2:22, Salt cavern storage

- 1 Scope** 74
- 2 Reference publications** 75
- 3 Definitions** 77
- 4 Location of underground storage facilities** 82
 - 4.1 General 82
 - 4.2 Site selection 82
 - 4.3 Proximity to rights-of-way 82
 - 4.4 Spacing requirements 82
 - 4.4.1 Well spacing 82
 - 4.4.2 Cavern spacing 82
- 5 Design and development** 83
 - 5.1 Risk assessment 83
 - 5.2 Assessment of neighbouring activities 83
 - 5.3 Geological studies 83
 - 5.3.1 General 83
 - 5.3.2 Maps 84
 - 5.4 Fluid compatibility 84
 - 5.5 Subsidence 84
 - 5.6 Operation limits 84
 - 5.6.1 General 84
 - 5.6.2 Casing seat maximum operating pressure 84
 - 5.6.3 Wellhead maximum operating pressure 84
 - 5.6.4 Wellhead maximum test pressure 84
 - 5.6.5 Minimum operating pressure 85
 - 5.6.6 Maximum injection and withdrawal rates 85
- 6 Materials** 85
 - 6.1 Design conditions 85
 - 6.1.1 General 85
 - 6.1.2 Electrical classification 85
 - 6.2 Qualification materials 86
 - 6.2.1 General 86
 - 6.2.2 Material qualification categories 86
 - 6.2.3 Use of materials 86
 - 6.2.4 Non-complying materials 86
 - 6.3 Material requirements and specifications 86
 - 6.3.1 Wellhead and Christmas tree assembly 86
 - 6.3.2 Casing 87
 - 6.3.3 Piping 87
 - 6.3.4 Subsurface pumps 87
- 7 Well completion and conversion** 87
 - 7.1 Open-hole well logging 87
 - 7.2 Core acquisition 87

7.2.1	General	87
7.2.2	Core handling	87
7.2.3	Core analysis	88
7.3	Casing	88
7.3.1	Design	88
7.3.2	Yield strength design	88
7.3.3	Collapse design	89
7.3.4	Tensile design	89
7.3.5	Service conditions	89
7.3.6	Casing setting depths	89
7.3.7	Number of casings	89
7.3.8	Liners	90
7.3.9	Inspection and handling	90
7.3.10	Threads	90
7.3.11	Production casing	90
7.3.12	Casing shoe	90
7.3.13	Casing torque	90
7.3.14	Premium connections makeup	90
7.3.15	Threaded joints	90
7.3.16	Pressure testing — Mill	90
7.3.17	Pressure testing — Field	91
7.3.18	Pressure test records	91
7.3.19	Casing records	91
7.4	Cementing	91
7.4.1	General	91
7.4.2	Design considerations	91
7.4.3	Compressive strengths	92
7.4.4	Cement tops	92
7.4.5	Cement placement	92
7.4.6	Preflushes	92
7.4.7	Casing cementing accessories	92
7.4.8	Pipe movement	92
7.4.9	Cement wiper plugs	92
7.4.10	Testing and evaluation	92
7.4.11	Cement integrity evaluation	93
7.4.12	Specialty cementing considerations	93
7.4.13	Remedial cementing	93
7.4.14	Cementing records	93
7.5	Cased hole integrity inspection	93
7.6	Tubing string completions	94
7.7	Well conversions	94
7.7.1	General	94
7.7.2	Inspection and testing	94
7.7.3	Recompletions	94
7.7.4	Casing replacement	94
7.7.5	Relining of casing	94
7.7.6	Internal casing patches	94
7.7.7	Abandonment	95
7.7.8	Conversion records	95

8	Surface facilities	95
8.1	Piping	95
8.2	Wellhead and Christmas tree assembly pressure rating	95
8.2.1	General	95
8.2.2	Wellhead size	95
8.2.3	Wellhead connections	95
8.2.4	Wellhead ports	95
8.3	Emergency shutdown valves (ESVs)	96
8.4	Tubing and casing control	96
8.4.1	Monitoring and venting	96
8.4.2	Chokes	96
8.5	Instrumentation	96
9	Development and construction	97
9.1	Monitoring during development	97
9.2	Intercavern communication	97
9.3	Cavern commissioning	97
9.3.1	Pre-commissioning logging	97
9.3.2	Pre-commissioning mechanical integrity test (MIT)	97
9.3.3	Pre-commissioning MIT results	97
9.3.4	Stored fluid as roof control	98
9.4	Corrosion control	98
9.4.1	General	98
9.4.2	Cathodic protection systems	98
10	Operations and maintenance	99
10.1	Procedures	99
10.1.1	General	99
10.1.2	Naturally occurring radioactive materials (NORMs)	99
10.1.3	Emergency response plan	99
10.1.4	Workover procedures	99
10.1.5	Wireline and logging procedures	100
10.1.6	Isolation and depressurization	100
10.1.7	Records	100
10.1.8	Changes	101
10.1.9	Operating and maintenance procedure audits	101
10.2	Inspections and testing	101
10.2.1	Instrumentation, valving, and emergency equipment	101
10.2.2	Control system testing	101
10.2.3	Wellhead and casing vents	102
10.2.4	Tubing-packer completions	102
10.2.5	MIT requirements and scheduling	102
10.2.6	Periodic MIT results	103
10.2.7	Cavern workovers	104
10.3	Corrosion control	104
10.3.1	Cathodic protection	104
10.3.2	Interference	105
10.3.3	Monitoring	105
10.3.4	Records	105

- 10.4 Erosion control 105
- 10.4.1 General 105
- 10.4.2 Inspection and monitoring 105

11 Monitoring and measurement 105

- 11.1 Inventory verification 105
- 11.2 Cavern dimension monitoring 106
- 11.3 Subsidence monitoring 106

12 Safety 106

- 12.1 Fire prevention and control 106
 - 12.1.1 Permanent equipment spacing 106
 - 12.1.2 Combustible material control 106
 - 12.1.3 Wellhead enclosures 106
 - 12.1.4 Flaring 107
- 12.2 Staff training and certification 107
 - 12.2.1 Operating personnel 107
 - 12.2.2 Supervisory personnel 107
 - 12.2.3 Well drilling 108
- 12.3 Emergency planning 108
- 12.4 Security 108
 - 12.4.1 General 108
 - 12.4.2 Egress 108
 - 12.4.3 Identification signs 108
 - 12.4.4 Warning signs 108
- 12.5 Voice communications 108

13 Pre-abandonment monitoring, plugging and abandonment, and post-abandonment monitoring 108

- 13.1 General 108
- 13.2 Pre-abandonment activities 109
 - 13.2.1 Preparation for stabilization period 109
 - 13.2.2 Stabilization and monitoring activities 109
- 13.3 Requirements for cavern abandonment 110
- 13.4 Wellbore abandonment 110
 - 13.4.1 Abandonment design criteria 110
 - 13.4.2 Wellbore abandonment requirements 110
 - 13.4.3 Wellbore abandonment 111
 - 13.4.4 Cement placement 111
 - 13.4.5 Cement quality 111
 - 13.4.6 Surface abandonment 111
- 13.5 Post-abandonment monitoring 111

Annexes

- Annex A (informative) — Commentary on certain clauses in CSA Z341.2 118
- Annex B (informative) — Calculation of liquid hydrocarbon storage cavern pressure 132
- Annex C (informative) — Guidelines for mechanical integrity testing and inventory verification of storage caverns 135
- Annex D (informative) — Guidelines for risk assessment of underground storage 146

CSA Z341.4:22, Salt cavern waste disposal

- 1 Scope** 153
- 2 Reference publications** 154
- 3 Definitions** 156
- 4 Location of underground disposal facilities** 160
 - 4.1 General 160
 - 4.2 Site selection 160
 - 4.3 Proximity to rights-of-way 161
 - 4.4 Spacing requirements 161
 - 4.4.1 Well spacing 161
 - 4.4.2 Cavern spacing 161
- 5 Design and development** 161
 - 5.1 Risk assessment 161
 - 5.2 Assessment of neighbouring activities 162
 - 5.3 Geological studies 162
 - 5.3.1 General 162
 - 5.3.2 Maps 162
 - 5.4 Waste and fluid compatibility 163
 - 5.5 Subsidence 163
 - 5.6 Operation limits 163
 - 5.6.1 General 163
 - 5.6.2 Casing seat maximum operating pressure 163
 - 5.6.3 Wellhead maximum operating pressure 163
 - 5.6.4 Wellhead maximum test pressure 163
 - 5.6.5 Minimum operating pressure 163
 - 5.6.6 Maximum injection and withdrawal rates 164
- 6 Materials** 164
 - 6.1 Design conditions 164
 - 6.1.1 General 164
 - 6.1.2 Electrical classification 164
 - 6.2 Qualification of materials 164
 - 6.2.1 General 164
 - 6.2.2 Material qualification categories 164
 - 6.2.3 Use of materials 165
 - 6.2.4 Non-complying materials 165
 - 6.3 Material requirements and specifications 165
 - 6.3.1 Wellhead and Christmas tree assembly 165
 - 6.3.2 Casing 165
 - 6.3.3 Piping 165
 - 6.4 Subsurface pumps 165
- 7 Well completion and conversion** 166

7.1	Open-hole well logging	166
7.2	Core acquisition	166
7.2.1	General	166
7.2.2	Core handling	166
7.2.3	Core analysis	166
7.3	Casing	167
7.3.1	Design	167
7.3.2	Yield strength design	167
7.3.3	Collapse design	167
7.3.4	Tensile design	167
7.3.5	Service conditions	168
7.3.6	Casing setting depths	168
7.3.7	Number of casings	168
7.3.8	Liners	168
7.3.9	Inspection and handling	168
7.3.10	Threads	168
7.3.11	Production casing	169
7.3.12	Casing shoe	169
7.3.13	Casing torque	169
7.3.14	Premium connections makeup	169
7.3.15	Threaded joints	169
7.3.16	Pressure testing — Mill	169
7.3.17	Pressure testing — Field	169
7.3.18	Pressure test records	169
7.3.19	Casing records	170
7.4	Cementing	170
7.4.1	General	170
7.4.2	Design considerations	170
7.4.3	Compressive strengths	170
7.4.4	Cement tops	170
7.4.5	Cement placement	170
7.4.6	Preflushes	170
7.4.7	Casing cementing accessories	170
7.4.8	Pipe movement	171
7.4.9	Cement wiper plugs	171
7.4.10	Testing and evaluation	171
7.4.11	Cement integrity evaluation	171
7.4.12	Specialty cementing considerations	171
7.4.13	Remedial cementing	171
7.4.14	Cementing records	172
7.5	Cased hole integrity inspection	172
7.6	Tubing string completions	172
7.7	Well conversions	172
7.7.1	General	172
7.7.2	Inspection and testing	172
7.7.3	Recompletions	172
7.7.4	Casing replacement	173
7.7.5	Relining of casing	173
7.7.6	Internal casing patches	173

7.7.7	Abandonment	173
7.7.8	Conversion records	173
8	Surface facilities	173
8.1	Piping	173
8.2	Wellhead and Christmas tree assembly pressure rating	174
8.2.1	General	174
8.2.2	Wellhead size	174
8.2.3	Wellhead connections	174
8.2.4	Wellhead ports	174
8.3	Emergency shutdown valves (ESVs)	174
8.4	Tubing and casing control	175
8.4.1	Monitoring and venting	175
8.4.2	Chokes	175
8.5	Instrumentation	175
9	Development and construction	175
9.1	Monitoring during development	175
9.2	Intercavern communication	175
9.3	Cavern commissioning	175
9.3.1	Pre-commissioning logging	175
9.3.2	Pre-commissioning mechanical integrity test (MIT)	175
9.3.3	Pre-commissioning MIT results	176
9.4	Corrosion control	176
9.4.1	General	176
9.4.2	Cathodic protection systems	177
10	Operations and maintenance	177
10.1	Procedures	177
10.1.1	General	177
10.1.2	Naturally occurring radioactive materials (NORMs)	177
10.1.3	Emergency response plan	177
10.1.4	Workover procedures	178
10.1.5	Wireline and logging procedures	178
10.1.6	Isolation and depressurization	178
10.1.7	Records	178
10.1.8	Changes	179
10.1.9	Operating and maintenance procedure audits	179
10.2	Inspections and testing	179
10.2.1	Instrumentation, valving, and emergency equipment	179
10.2.2	Control system testing	180
10.2.3	Wellhead and casing vents	180
10.2.4	Tubing-packer completions	180
10.2.5	MIT requirements and scheduling	180
10.2.6	MIT results	181
10.2.7	Cavern workovers	181
10.3	Corrosion control	181
10.3.1	Cathodic protection	181
10.3.2	Interference	182

- 10.3.3 Monitoring 182
- 10.3.4 Records 182
- 10.4 Erosion control 182
- 10.4.1 General 182
- 10.4.2 Inspection and monitoring 182

11 Monitoring and measurement 182

- 11.1 Inventory verification 182
- 11.2 Cavern dimension monitoring 183
- 11.2.1 General 183
- 11.2.2 Roof control fluid monitoring 183
- 11.3 Subsidence monitoring 183

12 Safety 183

- 12.1 Fire prevention and control 183
- 12.1.1 Permanent equipment spacing 183
- 12.1.2 Combustible material control 183
- 12.1.3 Wellhead enclosures 183
- 12.1.4 Flaring 183
- 12.2 Staff training and certification 184
- 12.2.1 Operating personnel 184
- 12.2.2 Supervisory personnel 184
- 12.2.3 Well drilling 185
- 12.3 Emergency planning 185
- 12.4 Security 185
- 12.4.1 General 185
- 12.4.2 Egress 185
- 12.4.3 Identification signs 185
- 12.4.4 Warning signs 185
- 12.5 Voice communications 185

13 Pre-abandonment monitoring, plugging and abandonment, and post-abandonment monitoring 185

- 13.1 General 185
- 13.2 Pre-abandonment activities 186
- 13.2.1 Preparation for stabilization period 186
- 13.2.2 Stabilization and monitoring activities 186
- 13.3 Requirements for cavern abandonment 187
- 13.4 Wellbore abandonment 187
- 13.4.1 Abandonment design criteria 187
- 13.4.2 Wellbore abandonment requirements 187
- 13.4.3 Wellbore abandonment 188
- 13.4.4 Cement placement 188
- 13.4.5 Cement quality 188
- 13.4.6 Surface abandonment 188
- 13.5 Post-abandonment monitoring 188

Annexes

- Annex A (informative) — Commentary on certain clauses in CSA Z341.4 194

Annex B (informative) — Calculation of waste disposal cavern pressure 206
Annex C (informative) — Guidelines for mechanical integrity testing of waste disposal caverns 210
Annex D (informative) — Guidelines for risk assessment of underground disposal 215

Technical Committee on Storage in Underground Formations

M. L. Learn	Enbridge Gas Inc., Chatham, Ontario, Canada <i>Category: Reservoir Storage Operators</i>	<i>Chair</i>
E. McLaren	Pembina Pipeline Corporation, Redwater, Alberta, Canada <i>Category: Cavern Storage Operator</i>	<i>Vice-Chair</i>
D. Longshore	Cavern Logix Inc., Calgary, Alberta, Canada <i>Category: Cavern Disposal Operations</i>	<i>Vice-Chair</i>
J. W. Wickens	Tiberius Energy LLC, Austin, Texas, USA <i>Category: General Interest</i>	<i>Vice-Chair</i>
D. Allibone	Canadian Natural Resources Limited, Calgary, Alberta, Canada <i>Category: Cavern Disposal Operations</i>	
O. Cicchini	Cicchini Projects Ltd., Sherwood Park, Alberta, Canada <i>Category: General Interest</i>	
D. Erickson	Plains Midstream Canada ULC, Calgary, Alberta, Canada	<i>Non-voting</i>
T. Godsoe	Ministry of Labour, Training and Skills Development (Ontario), Canada <i>Category: Government and/or Regulatory Authority</i>	
R. C. Hale	Lonquist & Co. (Canada), ULC, Calgary, Alberta, Canada	<i>Non-voting</i>
F. Khan	Alberta Energy Regulator (AER), Calgary, Alberta, Canada <i>Category: Government and/or Regulatory Authority</i>	

M. Kim	ATCO, Calgary, Alberta, Canada <i>Category: Reservoir Storage Operators</i>	
D. Kinch	SubTerra Engineering, Calgary, Alberta, Canada	<i>Non-voting</i>
D. Lee	Big Guns Energy Services Inc., Calgary, Alberta, Canada <i>Category: General Interest</i>	
D. Legge	Pembina NGL Corp., Redwater, Alberta, Canada	<i>Non-voting</i>
J. S. Manocha	Ameta Projects Inc., London, Ontario, Canada <i>Category: General Interest</i>	
L. Massé	Intragaz Inc., Trois-Rivières, Québec, Canada <i>Category: Reservoir Storage Operators</i>	
K. McConnell	Enbridge Gas Inc., Mooretown, Ontario, Canada	<i>Non-voting</i>
S. Morris	Pembina Projects, Sherwood Park, Alberta, Canada	<i>Non-voting</i>
M. Olesko	Plains Midstream Canada ULC, Calgary, Alberta, Canada <i>Category: Cavern Storage Operator</i>	
A. Ramirez	TC Energy, Calgary, Alberta, Canada <i>Category: Reservoir Storage Operators</i>	
A. C. Reed	Keyera Corporation, Calgary, Alberta, Canada <i>Category: Cavern Storage Operator</i>	
R. Stefik	BC Oil & Gas Commission, Victoria, British Columbia, Canada <i>Category: Government and/or Regulatory Authority</i>	
G. Stroh	Consultant, Regina, Saskatchewan, Canada	<i>Non-voting</i>

L. Swanson	Petronim Projects, Calgary, Alberta, Canada	<i>Non-voting</i>
L. A. Trombley	Dow Chemical Canada ULC, Fort Saskatchewan, Alberta, Canada <i>Category: Cavern Storage Operator</i>	
W. Xu	SaskEnergy Inc., Regina, Saskatchewan, Canada	<i>Non-voting</i>
J. Zhou	Saskatchewan Ministry of Energy and Resources, Regina, Saskatchewan, Canada <i>Category: Government and/or Regulatory Authority</i>	
J. S. Zitterer	Arbalest Projects Inc., Calgary, Alberta, Canada <i>Category: General Interest</i>	
P. Fernandez Marchi	CSA Group, Toronto, Ontario, Canada	<i>Project Manager</i>

Preface

This is the sixth edition of CSA Z341 Series, *Storage of hydrocarbons in underground formations*, which consists of CSA Z341.1, *Reservoir storage*, CSA Z341.2, *Salt cavern storage*, and CSA Z341.4, *Salt cavern waste disposal*. It supersedes the previous editions published in 2018, 2014, 2010, 2006, and 2002. It also replaces CSA Z341, published as a single Standard in 1998 and 1993.

This Series of Standards covers the storage of hydrocarbons and wastes from hydrocarbon production in naturally formed geological reservoirs and solution-mined salt caverns. This Series is intended to establish essential requirements and minimum standards for the design, construction, operation, maintenance, abandonment, and safety of underground storage systems. Users are reminded that this Series is not a design handbook; it is necessary to exercise competent engineering judgment in conjunction with its use.

Major revisions to this edition are found as follows:

- a) CSA Z341.1:
 - i) Clause [7.5](#) (cased hole integrity inspection);
 - ii) Clause [8.2.2](#) (wellhead size);
 - iii) Clause [8.3.3](#) (ESV requirements);
 - iv) Clause [9.1](#) (pre-commissioning pressure test);
 - v) Clause [9.2](#) (pre-commissioning integrity inspection);
 - vi) Clause [9.5](#) (corrosion control);
 - vii) Clause [10.1.2](#) (emergency response plan);
 - viii) Clause [10.2](#) (inspections and testing);
 - ix) Clause [12.3](#) (emergency planning); and
 - x) Annex [A](#) (updates reflecting changes to the clauses above).
- b) CSA Z341.2:
 - i) Clause [1.1](#) (scope);
 - ii) Clause [5.1](#) (risk assessment);
 - iii) Clause [5.6](#) (operation limits);
 - iv) Clause [7.2](#) (core acquisition);
 - v) Clause [7.5](#) (cased hole integrity inspection);
 - vi) Clause [8.2](#) (wellhead and Christmas tree assembly pressure rating);
 - vii) Clause [8.3](#) (emergency shutdown valves);
 - viii) Clause [9.3](#) (cavern commissioning);
 - ix) Clause [9.4](#) (corrosion control);
 - x) Clause [10.1](#) (procedures);
 - xi) Clause [10.2](#) (inspections and testing);
 - xii) Clause [11.1](#) (inventory verification);
 - xiii) Clause [12.3](#) (emergency planning);
 - xiv) Clause [13.2.1](#) (preparation for stabilization period);
 - xv) Annex [A](#) (updates reflecting changes to the clauses above); and
 - xvi) Annex [C](#) (guidelines for mechanical integrity testing of storage caverns).
- c) CSA Z341.4:
 - i) Clause [1.1](#) (scope);
 - ii) Clause [5.1](#) (risk assessment);
 - iii) Clause [5.6](#) (operation limits);
 - iv) Clause [7.3.17](#) [(casing) pressure testing — field];
 - v) Clause [7.5](#) (cased hole integrity inspection);

- vi) Clause [8.2](#) (wellhead and Christmas tree assembly pressure rating);
- vii) Clause [8.3](#) (emergency shutdown valves);
- viii) Clause [9.3](#) (cavern commissioning);
- ix) Clause [9.4](#) (corrosion control);
- x) Clause [10.1](#) (procedures);
- xi) Clause [10.2](#) (inspections and testing);
- xii) Clause [12.3](#) (emergency planning);
- xiii) Clause [13.2.1](#) (preparation for stabilization period);
- xiv) Annex [A](#) (updates reflecting changes to the clauses above); and
- xv) Annex [C](#) (guidelines for mechanical integrity testing of waste disposal caverns).

Annex A in each Standard provides commentary that complements and clarifies the clauses of CSA Z341.1, CSA Z341.2, and CSA Z341.4.

The requirements of this Series are adequate under conditions normally encountered in the storage industry. Requirements for abnormal or unusual conditions are not specifically addressed, and complete details of engineering and construction are not provided. It is intended that all work performed within the scope of this Series will meet or exceed the safety standards expressed or implied in the Series. It is possible that changes will have to be made based on new experience or technology, or both. When necessary, amendments will be issued by CSA.

This Series of Standards was prepared by the Technical Committee on Storage in Underground Formations, under the jurisdiction of the Strategic Steering Committee on Petroleum and Natural Gas Industry Systems, and has been formally approved by the Technical Committee.

Notes:

- 1) *Use of the singular does not exclude the plural (and vice versa) when the sense allows.*
- 2) *Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.*
- 3) *This Standard was developed by consensus, which is defined by CSA Policy governing standardization — Code of good practice for standardization as “substantial agreement. Consensus implies much more than a simple majority, but not necessarily unanimity”. It is consistent with this definition that a member may be included in the Technical Committee list and yet not be in full agreement with all clauses of this Standard.*
- 4) *To submit a request for interpretation of this Standard, please send the following information to inquiries@csagroup.org and include “Request for interpretation” in the subject line:*
 - a) *define the problem, making reference to the specific clause, and, where appropriate, include an illustrative sketch;*
 - b) *provide an explanation of circumstances surrounding the actual field condition; and*
 - c) *where possible, phrase the request in such a way that a specific “yes” or “no” answer will address the issue.*

Committee interpretations are processed in accordance with the CSA Directives and guidelines governing standardization and are available on the Current Standards Activities page at standardsactivities.csa.ca.
- 5) *This Standard is subject to review within five years from the date of publication. Suggestions for its improvement will be referred to the appropriate committee. To submit a proposal for change, please send the following information to inquiries@csagroup.org and include “Proposal for change” in the subject line:*
 - a) *Standard designation (number);*
 - b) *relevant clause, table, and/or figure number;*
 - c) *wording of the proposed change; and*
 - d) *rationale for the change.*

CSA Z341.1:22

Reservoir storage



®A trademark of the Canadian Standards Association, operating as “CSA Group”

*Published in March 2022 by CSA Group
A not-for-profit private sector organization
178 Rexdale Boulevard, Toronto, Ontario, Canada M9W 1R3*

*To purchase standards and related publications, visit our Online Store at www.csagroup.org/store/
or call toll-free 1-800-463-6727 or 416-747-4044.*

*ICS 23.020
ISBN 978-1-4883-3945-5*

*© 2022 Canadian Standards Association
All rights reserved. No part of this publication may be reproduced in any form whatsoever
without the prior permission of the publisher.*

CSA Z341.1:22

Reservoir storage

1 Scope

1.1

This Standard sets out minimum requirements for the design, construction, operation, maintenance, abandonment, and safety of hydrocarbon storage in underground reservoir formations and associated equipment. The equipment considered includes

- a) storage wellhead and Christmas tree assemblies;
- b) wells and subsurface equipment; and
- c) safety equipment, including monitoring, control, and emergency shutdown systems.

Note: *Hydrocarbons covered by this Standard are restricted to natural gas.*

1.2

The scope of this Standard is shown in Figure [1](#).

1.3

This Standard does not apply to

- a) underground storage facilities for gases or fluids other than hydrocarbons, such as storage facilities used for air storage, unless these fluids are used specifically for the displacement of stored hydrocarbons;
- b) underground storage facilities used for storing substances other than hydrocarbons, such as reaction chambers and waste disposal facilities;
- c) underground storage in overburden materials involving the use of tanks, such as gasoline tanks;
- d) design and fabrication of pressure vessels that are covered by pressure vessel codes;
- e) heat exchangers, pumps, compressors, and piping in processing plant facilities, manufacturing plants, or industrial plants that are covered by appropriate codes;
- f) gathering lines, flow lines, metering, compressors, and associated surface equipment beyond the first emergency shutdown valve (ESV) or block valve; and
- g) storage of hydrocarbons containing hydrogen sulphide in concentrations greater than 10 mol/kmol.

1.4

It is not the intent of this Standard to prevent the development of new equipment or practices, nor to prescribe how such innovations should be handled.

1.5

Where the requirements of this Standard differ from the requirements of other standards or codes referenced herein, the requirements of this Standard take precedence.

1.6

The requirements of this Standard do not apply retroactively to existing installations and installations under construction at the time of publication, but they do apply to the extension, replacement, maintenance, and upgrading of such installations.