

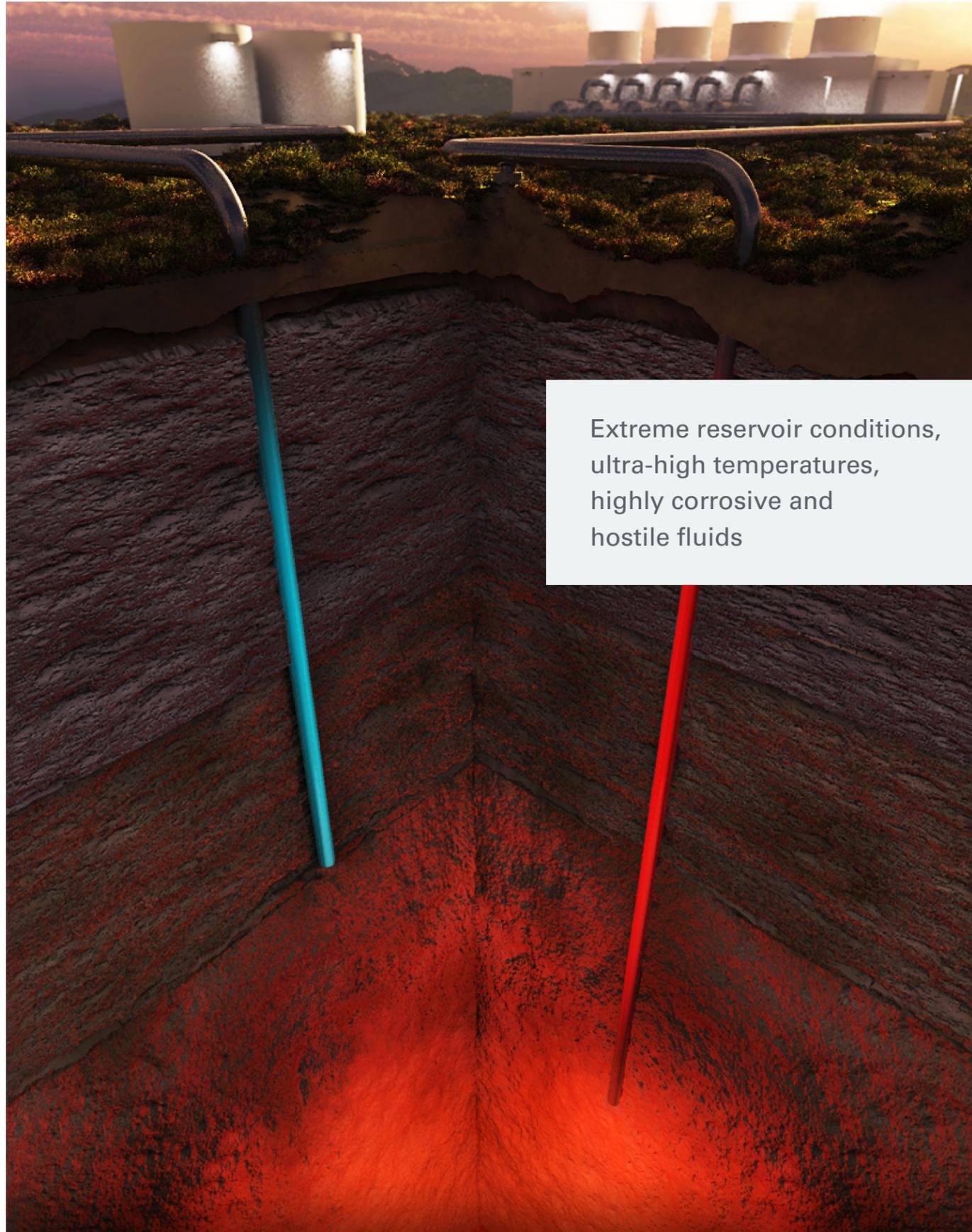


Geothermal energy liner hanger solutions

Meeting the challenges of complex geothermal wells

Many challenges in geothermal development can be addressed with services and technologies used in the oil and gas industry. Halliburton Completion Tools is a leading provider of liner hanger systems with more than 20 years of experience providing engineered liner solutions globally. Our comprehensive portfolio of liner hanger equipment and cementing services is designed to operate at ultra-high temperatures of up to 650°F (343°C), helping you efficiently develop resources and achieve the lowest cost per megawatt in geothermal well construction.





Extreme reservoir conditions, ultra-high temperatures, highly corrosive and hostile fluids

Casing and liner hanger installation challenges



Geothermal formations can be highly fractured, with the chance of excessive fluid loss during drilling and cementing operations. Lost circulation can result in lower rates of penetration, stuck pipe, loss of zonal isolation and wellbore instability.

Downhole conditions in geothermal wells can stress a well's cement sheath and annular seal. The risks of compromised cement include metal fatigue, casing failure, gas migration and loss of zonal isolation. These conditions necessitate correct cement programs that help ensure the cement sheath has a long life, bond and effective placement, as well as liner-top sealing integrity.

Geothermal wells produce high-temperature water, steam and gases that typically consist of carbon dioxide (CO₂), hydrogen sulfide (H₂S), dissolved minerals and other naturally occurring compounds.

Over time, these properties can damage the cement, the casing and downhole drilling tubulars, thus impairing well integrity and requiring remedial workover services or even well abandonment.

The bottomhole drilling circulating temperature can be in excess of 482°F (250°C), and production temperatures can reach 650°F (343°C). Ultra-high temperatures and thermal expansion can harm drilling equipment, accelerate cement fatigue and result in casing collapse.

Comprehensive liner hanger portfolio

Tiered solutions for geothermal well construction

Halliburton Completion Tools offers tiered solutions based on your specific well construction requirements. Whether designing a liner job requiring a liner-top seal, hanging a liner off-bottom or placing a liner on bottom, Halliburton can assist you every step of the way.

TIER LEVEL 1 **Geothermal expandable liner hanger with tieback capability**
 Designing a liner installation that requires a liner-top seal (well barrier) is a very complex operation. The Geothermal Expandable Liner Hanger provides a 360° metal-to-metal seal and high-load bi-directional anchoring capabilities, without requiring cement on top of the liner. The latest innovations in liner hanger technology are built into the system, enhancing the overall operation. Additional tieback capabilities in latched and unlatched (cemented or non-cemented) designs are available.

TIER LEVEL 2 **MatchSet® mechanical liner hanger with tieback capability**
 Designing a liner installation that requires liner support once set and cementing a liner on depth is a challenging application. The MatchSet® Mechanical Liner Hanger provides a superior load-bearing liner anchor mated with a robust tool system to allow for cementing operations. Additional tieback capability in an unlatched (cemented or non-cemented) design is available.

TIER LEVEL 3 **MatchSet Drop-Off system**
 Designing a liner installation that requires liner drop-off and cementing liner on bottom is a straightforward procedure. The MatchSet Drop-Off System provides a latching profile mated with a mechanical-release tool system to allow for cementing operations. Additional tieback capability in an unlatched (cemented or non-cemented) design is available.

From pre-job planning to best-in-class execution, Halliburton offers liner hanger and cementing solutions to meet all of your geothermal operational needs and challenges.

Tier Level 1: Why choose an expandable liner hanger solution?

The Geothermal Expandable Liner Hanger and Packer System is designed with metal-to-metal seals that can handle temperature ranges up to 650°F (343°C) without sacrificing sealing or anchoring capabilities. Its clean-form design offers a smooth radial flow path allowing for an unrestricted bypass area, reducing equivalent circulating densities (ECDs) and potential fluid losses during all phases of the geothermal operation.

Simplicity. Expandable liner hanger systems use no external moving parts (slips, sleeves, etc.) to suspend the liner in the parent casing, helping eliminate risks during deployment. Stress distribution into the parent casing remains uniform, minimizing casing damage and removing the potential for corrosion. These systems have the ability to wash and ream¹ to depth and to rotate and/or reciprocate during deployment and cementing operations.

Reliability. One full set of metal-to-metal sealing elements provides a gas-tight seal (well barrier) to maintain pressure integrity while helping eliminate gas migration at the liner top. By design, the system has redundant metal-to-metal sealing elements to ensure the seal is held through any loading scenarios and temperature cycles during the life of the well.

Integrity. The reduced outer diameter (OD) of the hanger body allows for higher circulation rates, providing a more reliable cement job, mitigating risk of cement packoff, and reducing the potential for well surging while running in hole (RIH). Provision of a latch profile enables pre-tensioning of tieback strings to mitigate compression failures.

Versatility. All common liner and casing configurations for standard and corrosion-resistant services are available.

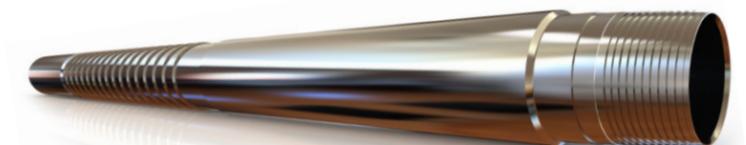
Adaptability. Expandable liner hanger systems can be combined with Halliburton completion products for a superior completion solution tailored to your specific well scenario. A latched or unlatched tieback seal unit can be mated for a tieback to surface system configuration.

LINER SIZE ²	CASING SIZE	CASING WEIGHT
IN. (MM)	IN. (MM)	LB/FT
5 (127.00)	7 (177.80)	23.0 – 32.0
5 ½ (139.70)	7 ¾ (193.68)	29.7 – 33.7
7 (177.80), 7 ¾ (193.68)	9 ¾ (244.48)	40.0, 43.5, 47.0
7 (177.80), 7 ¾ (193.68)	10 ¾ (273.05)	45.5
8 ¾ (219.08)	10 ¾ (273.05)	45.5
9 ¾ (244.48)	11 ¾ (298.45), 11 ¾ (300.96)	65.0, 71.8
11 ¾ (298.45)	13 ¾ (339.73), 13 ¾ (346.08), 14 (355.60)	68.0, 115.53
14 (355.60)	16 (406.40)	84.0, 97.0, 102.9, 103.39, 109.0, 122.5, 127.5, 136.04
14 (355.60)	18 ¾ (473.08)	136.0
16 (406.40)	20 (508.00)	106.5, 133.0

¹ Provided reamer shoe is utilized in place of float shoe.

² Liner size indicated is largest liner that can be deployed below hanger in casing size.

Geothermal Expandable Liner Hangers are available for H₂S/CO₂ service upon request (must be noted at time of order).



Additional sizes available on request

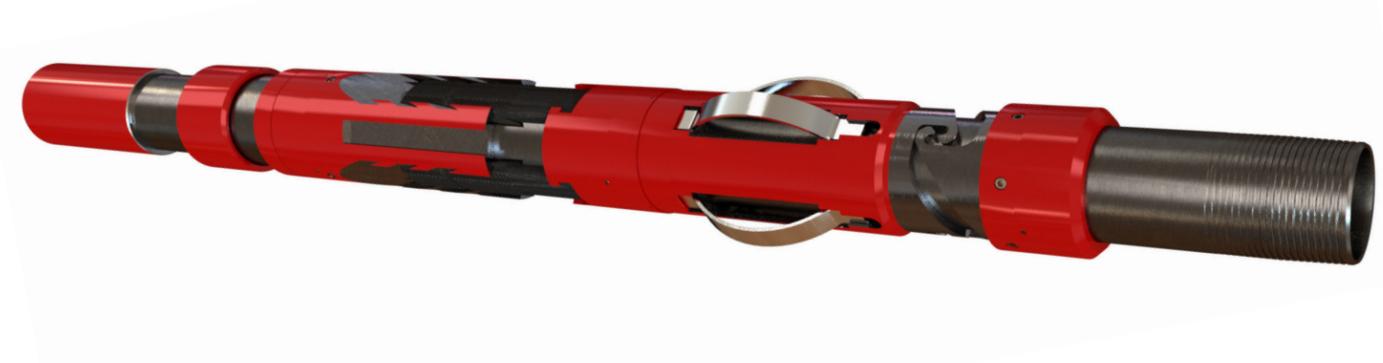
Tier Level 2: Why choose the mechanical liner hanger solution?

When well construction requires hanging the liner off-bottom and securely anchoring it in place, the MatchSet® Mechanical-Set Pocket-Slip Liner Hanger is the hanger of choice. Featuring a unique compact design and large bypass area, the system is suited for drilled geothermal wells in pressure-sensitive formations and allows for reduced equivalent circulating densities (ECDs) when pumping cement.

Reliability. Pocket-slip design provides more casing contact and uniform loading. Its solid-body mandrel has no hydraulic ports, eliminating leak paths.

Versatility. The mechanical-set liner hanger can be set, unset and repositioned to be set again prior to pumping cement. Several common liner/casing configurations for standard and corrosion-resistant services are available.

Adaptability. MatchSet Mechanical-Set Pocket-Slip Liner Hangers can be combined with Halliburton products for a superior completion solution tailored to your specific geothermal application. The system can also be fitted with an upper tieback receptacle to allow for an unlatched tieback to surface configuration.



LINER SIZE	CASING SIZE	CASING WEIGHT
IN. (MM)	IN. (MM)	LB/FT
4 ½ (114.30)	7 (177.80)	23.0 – 38.0
5 (127.00)	7 (177.80)	23.0 – 38.0
5 ½ (139.70)	7 ⅝ (193.68)	29.0 – 45.3
7 (177.80)	9 ⅝ (244.48)	40.0 – 58.4
7 ⅝ (193.68)	9 ⅝ (244.48)	40.0 – 53.5
8 ⅝ (219.08)	10 ¾ (273.05)	32.70 – 55.5
9 ⅝ (244.48)	13 ⅝ (339.73)	54.5 – 72.0
10 ¾ (273.05)	13 ⅝ (339.73)	48.0 – 85.0

Additional sizes available on request

Material available in standard alloys L80, T95, P110, and Q125; exotic alloys 13Cr-80, S13Cr-110, Alloy 825, Alloy 718

Tier Level 3: Why choose the Drop-Off setting sleeve solution?

In some geothermal applications, well construction requirements are not as complex. When a well construction project meets these minimum requirements, the MatchSet® Drop-Off Setting Sleeve might be all that is required to run and cement the liner.

Simplicity. The MatchSet Drop-Off System is designed to deploy and position a liner shoe on bottom. Machined to design tolerances with robust threads, this equipment performs in harsh environments.

Adaptability. The system can be combined with Halliburton completion products to provide a competent solution for geothermal applications. The system can be fitted with a MatchSet Tieback Receptacle to allow for floating tieback to surface configuration.

Versatility. The drop-off setting sleeve includes an external tieback receptacle connection, which allows for installation directly to the setting sleeve if required for a future tieback operation. Several common liner/casing configurations for standard and corrosion-resistant services are available.

MatchSet Drop-Off Setting Sleeve

MatchSet Drop-Off Setting Sleeves provide full functionality for the overall liner assembly, incorporating a latching mechanism for the running tool during deployment and a profile for the retrievable packoff bushing to locate in. Additionally, profiles are provided so that the running tool can torque through the system when rotation of the liner is required.

MatchSet Tieback Receptacle

The MatchSet Tieback Receptacle provides a high-integrity honed sealbore above the drop-off setting sleeve and permits the landing, sealing and extending of the liner uphole or to surface.



LINER SIZE	CASING SIZE
IN. (MM)	IN. (MM)
4 ½ (114.30)	7 (177.80)
5 (127.00)	7 (177.80)
5 ⅝ (139.70)	7 ⅝ (193.68)
7 (177.80)	9 ⅝ (244.48)
7 ⅝ (193.68)	9 ⅝ (244.48)
8 ⅝ (219.08)	10 ¾ (273.05)
9 ⅝ (244.48)	13 ⅝ (339.73)
10 ¾ (273.05)	13 ⅝ (339.73)

Additional sizes available on request

Material available in standard alloys L80, T95, P110, and Q125; exotic alloys 13Cr-80, S13Cr-110, Alloy 825, Alloy 718

Liner hanger accessories, services, and cementing products and services

Depending on the chosen tier level of liner installation needed, Halliburton offers a full range of required accessories and services to provide a superior liner installation. Halliburton can also offer optional products or services that can contribute to a successful operation for geothermal applications.



Accessories

- Tieback seal units (latched or unlatched)
- Auxiliary subsurface equipment
- Liner casing accessories

Services

- Liner hanger tools
- WellPlan® modeling software

Cementing products and services

- ThermaLock™ cement
- iCem® cementing software

Liner hanger accessories

Tieback seal units

Tieback seal units can be utilized in all geothermal tiered applications including drop-off systems, mechanical hanger systems, and expandable geothermal liner hanger systems. During production or remedial operations, the tieback allows for extension of the liner casing string back to the surface. When the tieback seal assembly is landed in the tieback receptacle, a continuous bore diameter to that of the liner is provided. This provides monobore access to the reservoir and may be used temporarily or permanently.

To facilitate both ease of entry and cementing operations, the tieback seal assembly is equipped with a standard mule guide nose. A variety of seal mandrels are designed with an outer diameter that is compatible with liner tieback packers and tieback receptacles in varying lengths. Configured with a box up design, the tieback seal assembly connects directly to the tieback casing string or to other casing accessories for ease of makeup.

Depending on well construction requirements, the tieback seal unit will be either a latched or unlatched-type seal unit.



Latched tieback seal assembly

The latched tieback seal assembly provides a unique capability to anchor by latching into Geothermal Expandable Liner Hanger Systems. The tieback assembly is fully anchored in place and built to withstand high tension or compression loading from the top of the Geothermal Expandable Liner Hanger Systems.

Unlatched tieback seal assembly

Compatible across all tiered systems, unlatched tieback seal assemblies vary in length, inner and outer diameter, (ID and OD) and feature a no-go upset to stop downward travel. Optional elastomeric and non-elastomeric seal packages can be provided depending on a geothermal well's temperature, pressure and environment.

Running tools

The ability to deploy a liner hanger system is dependent on the running tool. Halliburton Completion Tools offers simple and robust running tools for all geothermal tiered applications. Whether deploying a Tier 1, 2 or 3 application, Halliburton engineers can recommend the optimal running tools for your respective scenario.



Top-down squeeze valve

Run in conjunction with the Geothermal Expandable Liner Hanger System, the top-down squeeze valve (TDSV) offers options to better complete a cemented liner hanger operation. The valve is manufactured from high-grade materials and utilizes minimal components, offering a simple solution to complex operations.

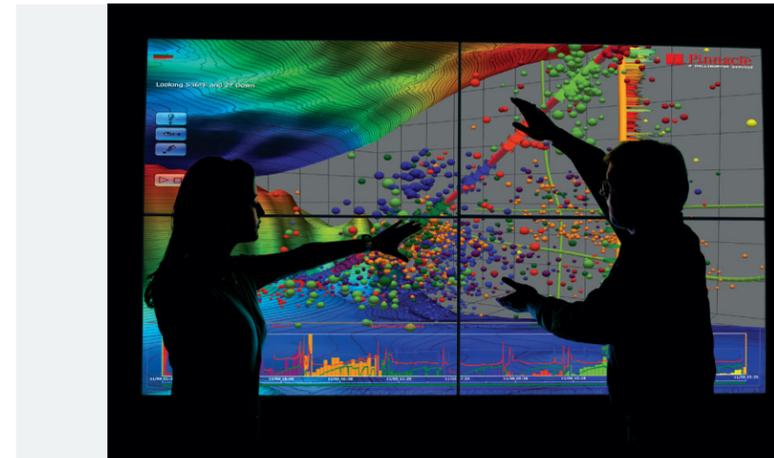
The TDSV provides the option of performing a cement squeeze operation should losses occur during normal cementing operations and the intended top of cement is not achieved. With the TDSV in the workstring above the Geothermal Expandable Liner Hanger System, the valve can be manipulated open with a ball to perform a squeeze job over the top of the liner hanger. Once the job is complete, another ball is dropped to manipulate the TDSV closed, allowing liner hanger setting and running tool retrieval.



Top-down squeeze valve

STANDARD SERVICE TOOL SIZE	IN. (MM)	IN. (MM)
Drillpipe connection type	6 3/4 (168.28) FH	4 1/2 (114.30) NC50
Ball activation size (Open)	2.60 (66.04)	2.25 (57.15)
Ball activation size (Close)	2.75 (69.85)	2.50 (63.50)
Maximum OD	8.50 (215.90)	6.64 (168.66)
Minimum ID	2.56 (65.02)	2.31 (58.67)
Length	31.31 (795.27)	40.44 (1027.18)

Fact-based predictable results during pre-job planning



WELLPLAN® MODELING SOFTWARE

WellPlan® software is utilized in conjunction with liner hanger systems to predict and adequately model liner deployment, torque and drag, hydraulics modeling, and swab and surge analysis during the pre-job planning and operational deployment phases.

Torque and drag analysis

Torque and drag analysis can be used to plan and analyze drilling, casing, and completion running operations, and assess the impact of predicted loads related to torque and drag. The main calculations are tension, torque, side force, fatigue and tri-axial stress. A top-down analysis mode uses surface parameters to accurately understand forces acting along the string to the bottom of the well. It also accounts for the effect of hydraulic parameters, such as fluid properties, flow rates, diverse fluid columns and pressures. Temperature effects on the string are also considered for pipe stretch calculations. Riserless and inner-string configurations are modeled, as well as the effect of standoff devices, such as centralizers and friction reducers.

Hydraulic analysis

Hydraulic analysis models pressure losses across the rig's circulating system and pipe string, estimates equivalent circulating density (ECD) across the annular space, and analyzes formation cuttings transport and its effect on pressure and ECD calculations. Temperature effect is also considered using four different rheological models, fluid compressibility, FANN® viscometer readings at different temperature points, critical fluid velocity, and bit-nozzle size calculations for optimized rate of penetration.

Swab and surge analysis

Swab and surge analysis is performed when drilling wells with narrow mud-weight windows, high pressure, high temperature or low clearance in the annular space. It is critical to control the speed and other movement parameters of the string within the wellbore, thus avoiding induced formation kicks or formation damage caused by excessive swab or surge pressures.

Cementing products and services



PREVENT CORROSION

Geothermal wells produce high-temperature water and steam that typically contains carbon dioxide (CO₂) and other naturally occurring chemicals. Over time, these chemicals can damage the cement, the casing and downhole tubulars, thus impairing well integrity and requiring remedial workover services or even well abandonment.

Halliburton provides geothermal cementing solutions globally. Multiple product offerings that can withstand harsh environments and extreme temperatures can be provided based on your reservoir conditions. A Halliburton engineer can review your downhole conditions and recommend products that will provide the wellbore integrity needed to provide the best zonal isolation. One of these products may be ThermaLock™ Cement.

ThermaLock™ cement

ThermaLock cement helps prevent damage to downhole tubulars resulting from corrosive cement carbonation. An alternative to Portland cement, this specially formulated calcium phosphate cement is resistant to CO₂ and acid and has been proven up to 698°F (370°C) on ultra-high-temperature geothermal wells.

- Minimizes concerns about the long-term effects of CO₂ and acid in wells
- Saves costs in high-remedial, abandonment, re-drilling and recompletion operations
- Easy to deploy without requiring special cementing equipment or techniques
- Tested and proven at low 140°F (60°C) and ultra-high 700°F (371°C) temperatures

iCem® cementing software

iCem® software aids in proper fluid displacement by assessing and monitoring specific variables before, during and after a cement job. Based on computational fluid dynamics and finite element analysis, the 3D simulator models and predicts the risk of cement failure during various stress-induced operations to generate thermal and mechanical properties needed for zonal isolation. This helps operators make better and more informed decisions before cementing operations.

Dynamic temperature modeling allows for a more accurate design of cement slurries by enabling temperature evolution via heat-transfer modeling. Operators can reduce well construction incidents and costs, mitigate health, safety and environmental (HSE) risks caused by poor mud removal, control annular fluid migration, and provide long-term annular-seal reliability throughout the life of the well.

Casing equipment



PROTECT WELL INTEGRITY

Downhole conditions in geothermal wells can stress a well's cement sheath and annular seal. The risks of compromised cement include metal fatigue, gas migration and loss of zonal isolation. These conditions necessitate proper cement selection and placement.

Wellbore integrity through zonal isolation

Guide shoes, float collars, float shoes and other casing equipment help guide the casing to the bottom of the wellbore and hold the cement slurry outside the casing even in the deepest of wells.

Floating equipment provides casing buoyancy and helps prevent cement slurry from re-entering the casing after pumping has stopped. The rounded nose of the guide or float shoe helps the casing enter the wellbore without damaging or sticking the casing. This equipment also provides a landing seat for cementing plugs.

Super Seal II® float collar and float shoe

Super Seal II® high-performance float equipment can be used in wells with temperatures up to 400°F (204°C), high pressure and abrasive flow resistance. Provided in different configurations, landing collars, float shoes and float collars are the three most common tools used in liner applications.



Float Shoe



Float Collar

Cemented tieback accessories

A Halliburton orifice collar is used when a production liner is set and a tieback string is installed from the liner top to the hanger back to the wellhead assembly. For tieback jobs, tieback strings are run with a tieback seal assembly stinger on bottom. The stinger with seals is stabbed into the tieback receptacle to provide a seal where the two casing strings connect. When the stinger and receptacle fit correctly, the tieback string with the tieback seal assembly stinger is pulled several feet from the receptacle so cementing operations can be performed through the stinger and past the seals. When displacement is complete, the tieback stinger is re-inserted into the tieback receptacle slowly so the cement can be metered through the orifice port of the collar, preventing hydraulic lockup.

Casing attachments

Centralizers

Single-body bow spring and solid-body centralizers are available for all downhole applications. Both types can be supplied as slip-on and with set screws in the end rings for attaching to the casing. If the liner is rotated or reciprocated during deployment or the cementing operation, such as with an expandable liner hanger, the centralizer should be allowed to float between the limit clamps or between the limit clamps and casing collars. In such applications, a standard welded bow-spring centralizer should not be recommended or used.



Solid Body



Single-Body Bow Spring

Cement baskets

Halliburton cement baskets are available in metal and canvas. They are run on casing or liners above porous or weak formations that require protection from the hydrostatic pressure generated by the cement column. They can also be used to help support a cement column while the cement sets.

Pulling up the casing on cement baskets can damage the basket and limit use in wells where rotation or reciprocation is necessary. The basket should be installed between limit clamps to allow it to move freely on the casing and compensate for the upward movement of the casing as the slips are pulled.



Cement Basket



Contact a Halliburton representative for your next geothermal project
Visit us at halliburton.com



For more information, contact your local Halliburton representative or visit us on the web at www.halliburton.com

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