Casing-while-drilling successfully applied in Canadian Arctic permafrost environment

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The JV Operator was looking for a combination of technologies to optimize drilling in Canada’s Mackenzie Delta region. The area is characterized by a permafrost section, up to 2,000 ft (609 m) thick, dominated by unconsolidated silt with freshwater ice ranging from 60% volume to pure ice layers. Historically, mechanical heat input has melted the frozen layer, resulting in increased hydrates/shallow gas risks, extreme hole enlargement/cleaning problems, rig support issues, wellbore instability, stuck pipe, hydraulic isolation, and environmental impact issues.

Optimizing drilling operations through the shallow section is critical to maximizing the number of wells that can be drilled with the available rigs in this limited-access area. To move the rig requires approximately 3 ft (1 m) of ice cover, which significantly limits the operating season, increasing the need for rig efficiency and reduction of non-productive time (NPT). The industry has endorsed the importance of mud cooling through the shallow permafrost and the underlying hydrate-bearing formations to avoid borehole instability and to control hydrate dissolution. However, the industry has struggled to maintain sufficiently cold mud at the high pump/power rates required to effectively drill/clean the larger surface holes.

To solve the challenges, the operator used a casing-while-drilling (CwD) and casing bit system with a unique mud-chilling technology and a variety of controlled drilling parameters.

Background

Early drilling campaigns in Arctic regions encountered significant problems drilling through the shallow permafrost sections due to degradation of drilling conditions as a result of permafrost thaw. Experience from earlier operations and experiments conducted by Kutasov et al., 1988, have highlighted the need to maintain chilled drilling mud to minimize permafrost thaw during the well construction process. Production operations in the Canadian Arctic have not yet reached development stage. Industry experience in other Arctic regions as well as Canadian National Energy Board (NEB) regulations dictate a need to protect permafrost substrata through the entire life of the well.

Protecting the permafrost during drilling while using only mud cooling has proven difficult because:

- Drilling the 16-in. (406-mm) or larger surface hole sections typically results in higher pump rates to effectively drill and clean the hole. At the higher flow rates, significant friction loss while pumping down the smaller drill string and BHA bore results in mechanical heat transfer to the drilling fluid, which is difficult to remove downstream of the mud pump.
- The industry has used air/drilling fluid, seawater/drilling fluid, and cooled glycol/drilling fluid heat exchangers in plate and coil configuration to address the mud-cooling challenge. The heat exchangers have been both external to the mud tank system and designed integral to the mud tank. These coolers have been subject to a variety of problems, including frequent packing off, poor heat transfer because of surface filming or freezing, and internal freezing that has resulted in temporary suspension of cooling operations, with the impact of near-immediate borehole degradation and thaw.
- Offset experience has shown there were more problems related to keeping the drilled section in shape from drilling to running and cementing casing than initially drilling the section. This could have been the result of:
  - Shale hydration with water-based mud in the section immediately under the permafrost section, which in the Mackenzie Delta region can be highly unconsolidated as this formation was once within the permafrost section.
  - Thermal convection in a static hole that promotes melting of the permafrost from warmer fluid below the permafrost.

Figure 1: Canada’s Mackenzie Delta onshore region is extremely remote, with unique logistical and operational challenges. The delta region encounters an annual cycle of winter freezing beginning in early October. Winter temperatures, which fall to below -58°F, cause ice growth to about 6.6 ft (2 m) through much of the delta.
The melting effect of the higher-chloride-content mud in contact with the frozen permafrost section during pulling out of the hole with the drill pipe and running the casing.

In response to these problems, the operator for the Mackenzie Delta Joint Venture (MDJV) with two partners pursued the use of new technology. The two key technologies that were implemented in the 2006/2007 winter drilling campaign were:

- The use of CwD with a non-retrievable drill-through PDC casing bit system for the large OD casing strings.
- The use of a high-capacity mud cooling unit comprising an ammonia refrigeration section that cools glycol fluid and an unrestricted spiral heat exchanger to transfer cooling from the glycol to the drilling fluid.

The campaign mandated drilling and testing two wells in a single winter operating season using a single drilling rig.

ENVIRONMENTAL SETTING

Canada’s Mackenzie Delta onshore region is extremely remote with unique logistical and operational challenges. The delta is located in the Canadian north at the terminus of the Mackenzie River as it enters the Beaufort Sea. The delta forms a large low-land system of shallow-water braided channels that separate low-elevation tundra prior to reaching the shallow-water sections of the Beaufort Sea. The delta region encounters an annual cycle of winter freezing beginning in early October (Figure 1). Winter temperatures, which fall to below -58°F (-50 °C), cause ice growth to about 6.6 ft (2 m). The ice thickness continues through the end of March. Land-based operations are generally terminated in the second half of April. By the end of June, high water levels inundate the delta with floodwater.

Land-based operators rely on thick ice to allow transport of heavy equipment over the water channels. To protect the fragile tundra ecosystem, primary access is routed over the water channels using floating ice roads. Where required, overland access requires a minimum of 12 in. (30 cm) of snow and ice cover. The industry standard for ensuring safe load capacity is dictated by a P4 load allowance per Gold’s formulae: $P4 = 4 \times (\text{ice thickness in cm})^2$.

Moving the heavier drilling equipment is largely influenced by the amount of ice build-up. Generally in the delta, conventional drilling rig loads with a gross vehicle weight (GVW) of 55-66 short tons (50,000 to 60,000 kg) cannot move in the southern delta until the end of January. In cases where the equipment is loaded on barges staged near the landfall location, the operation is not dictated by this constraint, and operations can be initiated around mid-December.

This is a factor for follow-up rig moves in the event of a multwell drilling season. For the MDJV program in the winter of 2006-2007, the mobilization schedule was dictated by the ability to move the rig out of the Inuvik area. Operating with smaller mud pumps – which often is the heaviest load on a land-based rig – can be critical to allowing rig mobilization in the early season. For the rig used in this program, the 500-hp mud pumps were relatively small at 40 short tons (36,500 kg).

GEOLOGIC SETTING

The occurrence of relic permafrost is unique to northern Arctic areas, including Canada, Alaska, and Russia. Permafrost is defined by permanent subterranean temperature below the freezing temperature of the formation water, which typically is fresh. It is a relic condition from the latest ice age in the Wisconsin Period. Over geologic time, the base of the permafrost has been slowing. In the Mackenzie Delta region, the base permafrost varies from less than 164 ft (50 m) in the western delta to over 1,969 ft (600 m) in thickness in the eastern delta. Within the Mackenzie Delta permafrost section, unconsolidated fresh water sediments typically are very fine silt and clays, frozen with very high water content.

The very high water content and finer sediments in the delta permafrost contrast with the more consolidated coarser sand and gravel sediment in the Prudhoe Bay area in Alaska, resulting in more instability problems from degradation of permafrost.

Below the base permafrost, stable gas hydrates have been encountered, typically below the deeper-base permafrost sections in the eastern delta and the offshore area where colder temperatures at depth are present. Recent experimental projects in the region are investigating the phase behavior and potential for exploitation of hydrate resources.

Ohara et al, 2000, observed that maintaining effective mud cooling through these hydrate intervals can be critical to retaining safe well control and well stability. Hydrate stability can be managed much more effectively through temperature maintenance than pressure maintenance.

The MDJV drilling operations comprised of five exploration wells on the outer northwest islands of the Mackenzie Delta.

![Diagram of drilling process](Image)

CWD, CASING BIT SYSTEM

Operators exploring in the region are subject to increasing environmental and safety standards. Exploration uncertainty and long lead time to develop infrastructure mandate carefully managed exploration expenditures. The remote location and isolated operations limit the ability to effectively reduce cost by sharing services between operators and operations.

The recent experience of the MDJV concluded the cost to operate a rig for a winter drilling campaign is not highly time dependent as most costs essentially are fixed for the drilling season. Given this situation, maximizing the number of wells that could be drilled with a single drilling rig in an operating season became a primary economic driver to reduce the per-well cost.

A sample of 24 wells drilled in the area from 1969 to 2001 at 4,495 ft (1,370 m) to 14,300 ft (4,360 m) TD was reviewed. The largest common contributors of drilling problems were wellbore instability, wellbore erosion and gas hydrates. The entire sample group of wells used surface casing strings of 13 5/8-in. (339.7 mm) OD or larger, requiring a 17 ½-in. (444.5-mm) hole size or larger for this section of each well. These large wellbore sizes present difficulties with hole cleaning because of the high ROP that are achievable drilling these types of formations. This hole-cleaning problem is the result of inadequate flow rates from smaller, lightweight pumps. Larger pumps will not meet over-water ice road weight restrictions.

Being able to effectively drill through the permafrost section was critical to minimizing NPT and meeting the objective of drilling both wells in a shortened drilling window. Because the rig had to be mobilized from western Canada, the MDJV could not start operations until early February instead of mid-December. Casing-while-drilling and a casing bit system were ideally suited for this application. Being able to effectively drill the larger hole section with reduced pump rates would maintain effective mud cooling. By keeping pump pressure low, the amount of heat energy transferred to the fluid from the mud pump also would be low. By running casing-while-drilling, and not requiring tripping out of the hole with a conventional drilling assembly to run the casing, the time sensitivity concerns around borehole deterioration during trips were minimized. Casing-while-drilling and the casing bit system also effectively allowed smaller rig pumps to be used to drill the larger hole sizes.

WELL DESIGN

The MDJV partnership operated two exploration prospects – Kumak I-25 and Unipkat M-45 – that were to be evaluated in this drilling campaign. Both targeted gas reservoirs in the shallow tertiary formations of the Taglu and Reindeer. Well design for both wells included running tubing and completion with the drilling rig and conducting a rigless test after the rig was demobilized. Both wells were to be designed as exploration wells, but the expectation was that the well design could facilitate their potential future use as development wells.

Retaining a well as a permanent production well would require permafrost protection for the life cycle. To protect the surface pad integrity, insulated and refrigerated conductor pipes would be installed. These have glycol cooling tubes run between a 28-in. (0.7-m) OD outer conductor pipe and a 20-in. (0.5-m) OD inner conductor pipe. Preliminary thermal modeling suggested that with 13 5/8-in. (340-mm) surface casing and 9 5/8-in. (244.5-mm) production casing through the permafrost section, a well producing up 4 ⅜-in. (114.3-mm) tubing could be completed for permafrost protection.

Kumak I-25

This first well followed a standard shallow well design with 13 5/8-in. (340-mm) casing run below the permafrost at 492 ft (150 m) for permafrost protection prior to drilling the deeper sections. A 9 5/8-in. (244.5-mm) intermediate casing string was programmed for 1,804 ft (550 m) MD with TD at 6,562 ft (2,000 m). NEB regulations require that at least 25% of the well be cased following surface casing setting.

Unipkat M-45

This second well was a similar design to the first but shallower. The Unipkat well was planned as a three casing-string design with surface casing drilled to 492 ft (150 m), covering the base permafrost at about 164 ft (50m), much shallower in the western extend of the delta. A 9 5/8-in. (244.5-mm) intermediate casing string was planned to be run at 1,476 ft (450 m).

As a result of the effective mud cooling and casing while drilling on the Kumak well, the Unipkat well plan was changed to eliminate the 9 5/8-in. (244.5-mm) intermediate casing string and extend the setting depth of the 13 5/8-in. (340-mm) surface casing string to 1,148 ft (350 m), allowing drilling to TD of 4,593 ft (1,400 m) as per NEB regulations. The revised well retained the 13 5/8-in. (340-mm) surface casing and incorporated a tapered production casing with 9 5/8-in. (244.5-mm) casing through the surface hole interval and 7-in. (177.8-mm) casing through the section below the surface casing string. This design was adopted over a “slim hole” design because:

- In order to run 4 ⅜-in. (114.3-mm) tubing and retain permafrost protection through the production life of the well, cursory thermal modeling suggested that the larger eas-
ing was required to provide thermal insulation.

- The 9 5/8-in. (244.5-mm) casing was required at the top of the well to allow installation of a subsurface safety valve (SSSV) in the event the well is used as a production well.

- The wellhead and BOP systems that were mobilized for the project were based on setting 13 3/8-in. (340-mm) surface casing.

**MUD COOLING**

Based on previous experience, the mud system selected for both of these wells included a KCl-polymer mud for the surface hole section through the permafrost with 8-10% KCl to provide freeze depression of 23-24.8°F (-5 to -4 °C). This is required because the mud may freeze in the permafrost section of the annulus if there is pump failure.

For the remaining hole sections, an amine-partially hydrolyzed polyacrylamide (PHPA) system was run with 4-5% KCl to provide freeze depression to 27.5-28.4 °F (-2.5 to -2 °C). The KCl amine-PHPA system was selected because this system maintained good borehole quality in two previous wells drilled by the MDJV. The highly hydratable unconsolidated sediment in the Mackenzie Delta has resulted in borehole erosion and poor solids-control capability as the drilled solids are dispersed readily to colloidal size. The amine-PHPA mud was evaluated to be the best water-based mud option to mitigate this problem.

At the start of the MDJV drilling project, an ambient heat exchange system cooled the drilling fluid in the surface wellbore section only. The limitations of this cooling method introduced significant wellbore stability issues.

The well design on the Langley K-30 well required the building of angle at shallow depths to reach the upper-most geologic target. During multiple wiper trips, difficulties were encountered in the original wellbore as a result of the degrading permafrost. On Ellice I-48, the second year of the project, a system using refrigerated ammonia circulated through coils in the mud tanks. The same system was used for the Olivier H-01 well, in which the mud was cooled throughout the entire well. The limitation in the refrigerated ammonia-coil system was the lack of effective heat exchange between the drilling fluid and the system. With this system, achieving sufficient contact with the drilling fluid and the cooling coils was difficult.

A system designed specifically for mud cooling in high-heat applications associated with heavy-oil and steam-assisted gravity drainage (SAGD) projects was used for the Kumak I-25 and Unipkat M-45 wells in 2007. This highly automated system (Figure 2) uses heat transfer from an ammonia refrigeration system to glycol using a plate and frame heat exchanger, then using the cooled glycol to control mud temperature through a spiral heat exchanger. The cooled glycol was also circulated through refrigeration coils installed in the conductor pipe to ensure frozen conditions were maintained around the conductor and retain foundation support for the rig.

This system provided a significantly more reliable mechanism for cooling the drilling fluid. The unit included a larger capacity 220.5-short ton (200-tonne) ammonia refrigeration unit driven by a 250-hp screw compressor that cooled glycol through a plate heat exchanger. The key technology of this equipment was the spiral heat exchanger. By using
a large-aperture spiral exchanger, the primary problem of drilling mud plugging off the heat exchanger was minimized, while retaining maximum contact time and area in the exchanger. The mud cooler was plumbed into the mud tank to circulate and cool the suction pit. The cooler was fitted with an automated setpoint temperature control that would maintain the mud at the desired temperature automatically.

The unit operated very well through both wells and could readily maintain mud temperature in the pump suction of 26.6°F (-3°C) for the surface hole and around 30.2-32°F (-1 to 0°C) in the intermediate and main hole sections. The unit capacity was more than adequate for the demands from this well. Maintaining mud temperature reliably through the surface hole section was instrumental in extending the surface hole TD on the Unipkat well and reducing one casing string.

THE RIG

The 2007 MDJV drilling project focused on drilling two wells approximately 22 miles (35 km) apart on the outer parts of the delta region. The well depths were significantly less than that of the wells that previously used larger Arctic-class land rigs. The well depths and the desire to move the rig during the project from the first location, Kumak I-25, to the second location, Unipkat M-45, required a rig that was designed for shallower depths and more efficient rig-up, rig-down and move.

A conventional western Canada jackknife double rig rated for the well depths of this project and designed for Arctic drilling was chosen as a cost-effective solution. Considerable changes and modification to the rig were required, including the addition of a top drive system, drilling fluids and solids control systems, a mud cooler and a larger BOP stack. The well design and the use of a modern, high-performance, amine-based drilling fluid system also required a larger and more complex mud-pit system, including additional tank volumes, more advanced mixing technologies and more complex solids-control systems.

Typical western Canadian well designs in the 6,562 ft (2000 m) depth range are significantly smaller in diameter. The rig’s mud-pit system was designed for the more conventional mud volumes, so the mud-tank system volume was increased by installing an additional premix system. The KCl amine-PHPA mud-system inhibitors and encapsulators required additional polymer-shearing mechanisms to mix these drilling fluid chemicals effectively. The solids-control system also was upgraded to include multiple-stage centrifuging to reduce low-gravity solids build-up in the mud as a result of drilling the Mackenzie Delta’s young geologic formations. It was also necessary to increase drilling fluid density to extremely high levels, and a bulkbag mixing system was installed.

The rig was equipped previously with a conventional Kelly drilling system. A top drive drilling system was required to perform the CwD operation. Because of the potential for extremely low temperatures, an electrical top-drive system was installed as opposed to a hydraulic portable unit. The rig was fitted with the service company’s casing drive system for the CwD operation. The rig was equipped previously with an 11-in. (279.4-mm), 5,000 psi (34,500 kPa), class-III BOP stack with an adequate accumulator system for this operation. The well design required a change to a 10-1/2-in. (266-mm), 5,000 psi (34,500 kPa) class-IV BOP stack. A larger accumulator system was required to operate the larger BOP and have adequate contingency hydraulic fluid volumes. The stack also was outfitted with a set of blind-shear rams in one of the single-gate ram bodies. An accumulator booster system was installed to effectively shear pipe with these rams.

The rig’s power supply was provided by a twin 575-kW generator system, and two 500-kW generators were installed for the additional power required.

CASING DRILLING

Casing makeup and handling

To allow casing to be used as the drill string, the service company provided a casing drive tool to allow simultaneous rotation, reciprocation and circulation, the foundation of all drilling requirements. The tool maintained thread integrity by keeping all connections to a one-time makeup. In the cold climate of the Arctic, pump downtime and, ultimately, freezing was a continuous concern. The time and safety efficiency of the tool, hydraulic links, and elevators enabled the crews to complete connections with minimum pump downtime and handling of the tubulars. To facilitate the use of the casing drive tool and automated elevators, a hydraulic source was supplied by an independent hydraulic unit. With the environmental sensitivity of the Arctic and the extreme temperatures, the full hydraulic system was equipped with synthetic hydraulic oil to ensure reliable operations.

Torque monitoring

To address torque concerns and minimize the risk of connection fatigue failure, premium high-torque connection was used on the casing string. The initial makeup torque was confirmed using a torque-monitoring device. This data-acquisition system can withstand the Arctic’s harsh environment.

BIT SELECTION

A key goal for the drilling program was to address flat time: reduce the time to TD utilizing CwD with a casing bit system. A well-known concern with non-retrievable CwD systems is that a programmed interval can be drilled in a single bit run (Davis et al, 2006). In a conventional drilling operation, a drill bit is tested to analyze the drilling performance and the bit’s dull condition after the run. In casing and liner drilling with non-retrievable systems, the bit is left downhole, eliminating the opportunity to learn from the bit’s dull condition.

In the absence of dull information, a staged approach often is recommended to minimize this risk. The PDC casing bit system is first tested on a conventional drill string to evaluate rates of penetration and durability; results are compared with offsets drilled with standard bits. The operator decided not to use the staged approach and instead built into the project plan a contingency to drill the wells conventionally in the event CwD with a casing bit system was unsuccessful. This plan carried some risk because financial success was contingent on drilling and testing the two wells within a limited weather window.

Selecting the casing bits for this project required a good understanding of the geological setting and the dull characteristics of the standard bits used in the offset wells. Extensive testing data and case studies of large-bore PDC casing bit systems used around the world was provided. With these resources, a hazards identification and mitigation matrix was developed to assist in bit selection and performance optimization. In this application, bit balling and damage to the PDC cutting structures were identified as major concerns; therefore, hydraulics, bit cleaning and PDC cutter durability were given a high priority in the selection of the casing bit design.
In the 17 ½-in. (444.5-mm) surface sections, the casing bit system was expected to drill the Iperk formation that comprises primarily ice-bonded sand with occasional conglomerate, silt and clay layers with abundant detrital organics often extending down to about 984 ft (300 m) TVD in the delta. Based on offset data, an expected average (including connection time) ROP of 19.4 ft/hr (5.9 m/hr) for the casing bit system was required to achieve the desired time and cost savings.

In the 12 ¼-in. (311.2-mm) intermediate sections, the casing bit was expected to drill the Richards formation, which comprises mainly highly reactive, sticky, gumbo-type shale interbedded with more consolidated sandstones and silt sequences. An expected average ROP of 37.8 ft/hr (11.5 m/hr) was required.

Based on performance case studies from wells drilled with large-bore casing bit systems in Australia, Argentina, Gabon and the Gulf of Mexico, the following were selected: a six-bladed PDC casing bit with 3/8-in. (339.7-mm) casing strings through the permafrost: 1 hr. The 17 ½-in. (444.2-mm) PDC casing bit, (thought to be part of the casing bit system), was found lodged between the cones. The bit was dull graded and tagged ice/cement at 68 ft (20.72 m). The casing bit was drilled out successfully with a tungsten carbide roller cone bit in about 2.5 hr. On evaluation of the dull characteristics of the bit-out, a piece of metal (thought to be part of the casing bit system), was found lodged between the cones. The bit was dull graded I-1-NO-A-E-I-NO-BHA.

Overall, the surface section was drilled from spud to TD in 22.5 hr. On-bottom drilling time accounted for only 14 hr. Unscheduled events recorded while drilling this section include:

- Rotary hose blow down tool failure: 0.25 hr.
- Troubleshoot casing-drive tool: 0.25 hr.
- Circulate to service rig: 0.75 hr.
- Repair frozen top-drive breather valve: 1.25 hr.
- Overload at shale shakers and change screens: 0.75 hr.
- Drill with one pump at 1.4 sq m/min controlled ROP: 0.75.
- Drill reduced flow rate to minimize overflow at shakers: 2.75 hr.
- Circulate gas-cut mud at the base of the permafrost: 1 hr.

**Kumak I-25**

17 ½-in. (444.5-mm) surface section

Drilling objectives included:

- Casing drill 17 ½-in. (444.5-mm) hole to 492 ft (150 mm) base of the permafrost.
- Minimize the amount of hole erosion.
- Cement 13 ¾-in. (339.7-mm) casing full length: maintain cement returns at surface.

**PERFORMANCE SUMMARY**

**Kumak I-25**

17 ½-in. (444.5-mm) surface section

Drilling objectives included:

- Minimize unscheduled event time
- Minimize the volume of drilling fluid discharged to the sump while ensuring all fluids transferred to the sump would meet maximum freeze point depression of 27.5 °F (-2.5 °C) and meet toxicity limitations based on acceptable product concentration.
- Evaluate the technical and economic potential to use casing while drilling with a PDC casing bit system to set casing strings through the permafrost of the Mackenzie Delta region.

The drilling parameters were controlled to minimize cuttings over flow at the shaker and hole packoff with average values ranges for WOB of 0-22.5 klbf (0-10 kdaN), rpm of 50 to 90, and flow rate of 475 gpm to 581 gpm (1,800 lpm to 2,200 lpm). The Kumak I-25 drilling parameters plot is shown in Figure 3.

The rig crew employed drilling practices to account for hydraulic lift – defined as the combination of the upward force caused by fluid flow in the annulus and the lift or end force acting on the casing bit – to minimize delays. Hydraulic lift monitoring is a key indicator of how clean the annulus is (Steepe II et al, 2005). While drilling this section, a hydraulic lift force no greater than 1.0 klbf (0.44 kdaN) was recorded with an average mud weight of 9.35 ppg (1,120 kg/cu m). Deviation surveys taken at surface casing recorded a maximum deviation of 0.25° inclination.

The surface casing was cemented successfully with 191.2 bbls (30.4 cu m) of 8.44 ppg (1012 kg/cu m) cement slurry and 37.7 bbls (6 sq m) returned on surface. Estimated cement required for the interval was 163.5 bbls (26 sq m). The casing bit was drilled out successfully with a tungsten carbide roller cone bit in about 2.5 hr. On evaluation of the dull characteristics of the bit-out, a piece of metal (thought to be part of the casing bit system), was found lodged between the cones. The bit was dull graded I-1-NO-A-E-I-NO-BHA.

Overall, the surface section was drilled from the surface casing point 78 ft (24 m) deeper than prognosed, in 22.5 hr. On-bottom drilling time accounted for only 14 hr. Unscheduled events recorded while drilling this section include:

- Rotary hose blow down tool failure: 0.25 hr.
- Troubleshoot casing-drive tool: 0.25 hr.
- Circulate to service rig: 0.75 hr.
- Repair frozen top-drive breather valve: 1.25 hr.
- Overload at shale shakers and change screens: 0.75 hr.
- Drill with one pump at 1.4 sq m/min controlled ROP: 0.75.
- Drill reduced flow rate to minimize overflow at shakers: 2.75 hr.
- Circulate gas-cut mud at the base of the permafrost: 1 hr.

**Kumak I-25**

12 ¼-in. (311.2-mm) intermediate hole section

The drilling objectives for this section include:

- Rotary hose blow down tool failure: 0.25 hr.
- Troubleshoot casing-drive tool: 0.25 hr.
- Circulate to service rig: 0.75 hr.
- Repair frozen top-drive breather valve: 1.25 hr.
- Overload at shale shakers and change screens: 0.75 hr.
- Drill with one pump at 1.4 sq m/min controlled ROP: 0.75.
- Drill reduced flow rate to minimize overflow at shakers: 2.75 hr.
- Circulate gas-cut mud at the base of the permafrost: 1 hr.

The drilling objectives for this section were similar to the surface section, including:
• Casing drill 12 ¼-in. (311.2-mm) hole to the required depth of 1,804 ft (550 mm).

• Cement the 9 5/8-in. (244.5-mm) casing full length.

• Set the 9 5/8-in. (244.5-mm) casing in the Richards shale; stay above Taglu A sand with sufficient depth to obtain a minimum fracture pressure at the shoe of 12.52 ppg (1500 kg/sq m).

• Minimize unscheduled event time.

• Minimize the volume of drilling fluid discharged to the sump.

• Evaluate potential to use CwD with a PDC casing bit system to set casing strings through the shallow.

The 12 ¼-in. (311.2-mm) PDC casing bit was run on a CwD assembly inside the 13 3/8-in. (339.7-mm) casing to bottom at 636 ft (194 m). The PDC casing bit drilled to 1,847 ft (563 m) intermediate casing point, 42.6 ft (13 m) deeper than predicted, in 35.75 hr with a controlled average ROP of 33.9 ft/hr (10.3 m/hr) compared with 37.8 ft/hr (11.5 m/hr) expected average.

The drilling parameters were controlled to minimize cuttings overflow at the shaker and hole packoff with average values for WOB of 0 to 27 klbf (0 to 12 kdaN), rpm of 60 to 65, and flow rates of 370 gpm to 660 gpm (1,400 lpm to 2,500 lpm). Figure 4 shows the Kumak I-25 intermediate drilling parameters plot.

Connection times varied from 15-30 min because on more than one occasion, the crew needed to work the string at least twice before making the connection. This was necessary to account for hydraulic lift forces while drilling this section. Hydraulic lift forces up to 15.765 klbf (7.0 kdaN) were recorded with an average mud weight of 9.43 ppg (1,130 kg/sq m). There were indications of bit balling and hole packoff, requiring several walnut plug sweeps to clean the bit and BHA. Deviation surveys taken at the intermediate casing shoe recorded a maximum deviation of 0.35° inclination.

The intermediate casing string was cemented successfully with 163.5 bbls (26.3 sq m) of 15.7ppg (1880 kg/sq m) cement slurry. The casing bit was drilled out successfully with a tungsten carbide roller cone bit in 0.75 hr. No significant damage was found on the drill-out bit. The bit was dull graded 1-1-NO-A-E-I-NO-BHA.

Overall, the intermediate section was drilled to casing point 1,847 ft (563 m) in a total time of 35.75 hrs. On-bottom drilling time only accounted for 26.50 hr. Unscheduled events recorded while drilling this section include:

• Change shaker screens: 1.75 hr.
• Repair leak on top drive: 0.25 hr.
• Circulate at reduced flow rate to repair depth encoder: 0.75 hr.
• Circulate walnut weeps to reduce bit balling: 1 hr.

• Drill at a reduced flow rate to minimize overflow at shakers: 1 hr.
• Circulate gas cut mud at the base of the permafrost: 1 hr.

### Unipkat M-45

17 ½-in. (444.5-mm) surface section

The drilling objective for the surface section included:

• Casing drill the 17 ½-in. (444.5-mm) hole to 1,148 ft (350 m) in the Richards formation.
• Minimize the amount of hole erosion.

• Cement 13 3/8-in. (339.7-mm) casing full length: maintain cement returns at surface.

• Minimize unscheduled event time.

• Minimize the volume of drilling fluid discharged to the sump.

• Evaluate the potential to use CwD with a PDC casing bit system to set casing strings.

As noted earlier, this well originally was designed for three casing strings but changed to two strings following successful application of CwD in the Kumak well and dispensation from the NEB not to log the intermediate section. This allowed the operator to set the surface casing deeper. The 17 1/2-in. (444.2-mm) PDC casing bit was run on a CwD assembly inside the 20-in. conductor and tagged ice/cement at 82.6 ft (25.19 m). The PDC casing bit drilled to 1,178 ft (359 m) surface casing point in 43.5 hr with a controlled average rate of penetration of 25.2 ft/hr (7.7 m/hr), exceeding the expected target average ROP of 17.8 ft/hr (5.4 m/hr).

The drilling parameters were controlled to minimize cuttings over flow at the shaker and hole packoff with average values ranges for WOB of 0 to 33.8 kbf (0 to 15 kdaN), rpm of 50 to 75, and flow rate of 515 gpm to 696 gpm (2,000 lpm to 2,700 lpm). The Unipkat M-45 drilling parameters plot is shown in Figure 5.

The rig crew employed drilling practices to account for hydraulic lift forces and recorded up to 11.25 kbf (50 kdaN) with an average mud weight of 9.97 ppg (1195 kg/m³). Mud funnel viscosity rose up to 120 seconds toward the end of the interval due to poor solids control on surface. Walnut sweeps were pumped every 164 ft (50 m) to minimize balling and mud rings. Deviation surveys taken at the surface casing shoe recorded a maximum deviation of 0.32° inclination.

The surface casing cement job did not go as planned, and a top job was required to get to surface. The casing bit was drilled out successfully with a tungsten carbide roller cone bit in about 1.25 hr.

When the bit was pulled, there was no major damage.

Overall the surface hole was drilled to casing point in 43.5 hr. The recorded on-bottom drilling time was 32 hr. Unscheduled events recorded while drilling this section include:

- Circulate gas-cut mud: 0.75 hr.
- Reduce flow rates to keep flow on shakers: 0.50 hr.
- Circulate out mud rings: 1.25 hr.
- Recalibrate torque gauge: 0.25 hr.
- Pumped walnut sweeps every 164 ft (50 m) to reduce bit balling: 1.50 hr.
- Increase in mud funnel viscosity up to 120 see resulted in significantly higher recorded hydraulic lift and therefore connection time: 2.25 hr.

CONCLUSION

Overall, CwD helped with hole cleaning in the surface and intermediate sections and reduced the flat times associated in drilling theses intervals compared with the plan and the offset wells. No significant hole issues encountered in the previous wells occurred while drilling the surface and intermediate sections of the Kumak and Unipkat wells, respectively.

The mud-chilling equipment combined with CwD and the casing bit system were efficient in cooling the mud and preventing degradation of the permafrost layer. As a result of the effective mud cooling, retaining very cold fluid and low pump pressure while casing drilling, some problems were experienced in maintaining an effective seal with the triplex pump heads. This was addressed through the use of colder temperature rated pump elastomers.

By controlling instantaneous ROP below 49 ft/hr (15 m/hr) for the surface section and ROP of 66 ft/hr (20 m/hr) for the intermediate section, the rig crew was able to minimize the effects of hydraulic lift and, therefore, eliminate the need to repeatedly stop drilling and circulate the hole clean. Continuous monitoring for hydraulic lift force by adjusting the applied WOB is critically important when drilling with large OD casing strings and PDC casing bits that require very low WOB. In the case of drilling much of the permafrost, and the shallow section below the permafrost, the hydraulic lift force was comparable to the desired WOB. Using the automatic driller helped to control large variations in WOB and, therefore, minimize the effects of hydraulic lift. Monitoring and measuring hydraulic lift will improve the drilling efficiencies.

Because of bit-balling and mud rings and the limited capacity of the rig pumps, the crew had to circulate walnut sweeps to clean the bit and casing string components. In this case, the use of a six-bladed PDC casing bit system was favored over a coarser four-bladed casing bit system to ensure bit durability, potentially at the expense of bottomhole cleaning.

Although CwD facilitates the ability to get a higher percentage of hydraulic power and pressure drop to the bit (as the internal string pressure is very low), concerns around washing out the bit ports/nozzles with extended circulation and drilling time will limit the ability to increase bit pressure drop and bottomhole hydraulic power. ROP must not exceed the hydraulic capacities of the rig. Sometimes, going slower is better than going faster.
Finally, assembling the CwD string components and the casing bit system prior to the rig site will save handling time on the rig floor.

While this project documented significant time and cost saving, consideration should be given to increasing the number of wells drilled by a single rig using the CwD with the PDC casing bit system during the winter drilling season. Adequate solids-control equipment capacity will help to eliminate the mud problems. The inability to reduce the colloidal fractions may have contributed to the bit balling and mud ring problems. Good control of the mud properties, including selection and sizing of the mud-cleaning equipment, is important for reducing the effect of hydraulic lift. Proper selection of the nozzle configurations to optimize HHP at the bit is key to preventing bit balling. A more erosion-resistant drillable nozzle is being proposed for future applications. A four-bladed casing bit design is being considered that will minimize bit balling while still providing the required bit longevity.

Through the use of high-capacity mud cooling and CWD with a PDC casing bit system, the ability to extend the surface casing setting depth significantly below the base of the permafrost without risk of permafrost thaw has been demonstrated. It is likely that these setting depths could be extended. Given existing mud-cooling capability, mud temperature at the stand pipe can likely be maintained at 23°F (-5°C) or lower. Location-specific application of thermal modeling of circulating mud temperature will be able to support what depth the surface casing can be run to without risking significant permafrost degradation.

The operator intends to evaluate the use of this type of CwD in future Arctic exploration applications, including exploration wells in the Alaska North Slope area. Alaskan Arctic wells only require surface casing for the geologic evaluation of deeper formations.

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