Microdrilling Field Tests at RMOTC in 2004

Objectives

To drill and case a series of four microholes for use as seismic monitoring holes for instrument evaluation and during future CO_2 injection at Rocky Mountain Oilfield Testing Center (RMOTC) north of Casper, WY.

The work is being done in collaboration with Lawrence Berkeley Laboratory (LBL), and under the sponsorship of the Department of Energy National Energy Technology Laboratory. Drilling these wells provides the Los Alamos National Laboratory (LANL) microdrilling team the opportunity to advance the microwell drilling performance and demonstrate new well completion designs at RMOTC.

Planning and Preparations

The original completion plan proposed a single PVC flush joint string to be installed to total depth and the annulus sealed to surface with bentonite grout. The RMOTC staff was concerned with the permanent installation of a PVC casing across the Shannon reservoir, and after discussing the proposed well completion with the Wyoming Oil and Gas Conservation Commission (WOGCC), decided that a steel casing string should be installed and cemented to the surface across the producing Shannon zones. The RMOTC staff also decided that blow-out prevention equipment (BOPE) should be run while drilling below the Shannon to allow the well to be shut in if a productive fracture system was penetrated in the Steel Shale. A revised completion plan called for a 2-3/8-in.-OD 4.7-lb/ft steel flush joint string to be cemented in a 2-5/8-in.-diameter hole drilled below the Shannon sands. After drilling a 1-7/8-in. hole from the bottom of the 2-3/8-in. casing to 800 ft, a 1-1/4-in. schedule 80 PVC flush joint pipe grouted to surface with 20% bentonite grout. Previous experience demonstrated that a 2-5/8-in. hole was the largest practical size that could be drilled with commercially available 1-11/16-in. and 1-3/4-in. mud motors. A proprietary flush joint connection was cut on 2-3/8-in.-OD steel tubing to serve as an intermediate microcasing that provided adequate annular space for cement placement and sufficient internal area for passage of a 1-7/8-in.-OD bit.

The RMOTC staff obtained the required regulatory approvals (including drilling permits from the WOGCC for the holes and a NEPA permit for the surface locations). RMOTC was responsible for construction of the well locations including excavation of reserve pits and shallow cellars needed to make room for BOPE under the LANL coiled tubing unit injector.

Demonstration Hole

A demonstration hole was drilled in June 2004, primarily to verify that the planned microwell-completion design was feasible with the equipment available using the propose procedures. The ability to pump cement and bentonite grout into the tight annular spaces was a major concern. A surplus LANL-owned trailer-mounted mud-mixing system was acquired and modified for use in microhole cementing/grouting. The microhole drilled at RMOTC in 2003, Well 53-4-X-3, was cemented by an oilfield contractor using equipment that was grossly oversized and overpriced for the job. It was hoped the new micro-cementer would provide a more appropriate and affordable alternative to accomplish microhole completions. The pressure limitation was 280 psi while pumping cement or grout with the new unit. and 700 psi during

fresh water displacement. (There was uncertainty that this pressure capability would be adequate to accomplish the required tasks with the limited annular space.) Other changes in the microdrilling system made after drilling Well 53-4-X-3 in '03 were: the addition of a basket strainer on the mud-pump suction, the acquisition of shaker screens with a more robust design, and the acquisition of bits and hole openers to drill the required hole sizes. The June '04 drilling demonstration intended to determine whether the new completion design was viable and whether the new cementing equipment would be adequate. In addition, the demonstration would providing an opportunity to shake down other modifications to the drilling system before deploying to drill the four seismic monitoring holes later in 2004**.**

Note: Following the campaign in June, LANL was "stood down" for an extended period in response to security and safety incidents unrelated to the drilling team, delaying our return to RMOTC until late September. The drilling and completion plans used in the later campaign were modified as a result of lessons learned in June.

The 2004 field operations were also used as a test bed for two emerging technologies from Dennis Oil Tool and Quality Tubing, Inc.. Dennis Oil Tool has developed a concept using two counter-rotating mud motors to minimize torque and increase rate-of-penetration (ROP). An early prototype was run in October, and consisted of a 1-3/4-in.-PDC pilot bit, a LANL-owned, 1-7/16-in. high-speed, 1:2 lobe 3-stage motor, a 2-3/8-in. reamer/stabilizer, and a LANL-owned 1-11/16-in. 5:6-lobe 5-stage motor. A counter-clockwise rotating-motor was not available at the time. The results of this test are summarized in Attachment I. Quality Tubing, Inc. fabricated two strings of 1-in.-OD QT-13-Chromium (13Cr) stainless-steel coiled-tubing on a cost-share basis for demonstration. This new 16Cr product has demonstrated prolonged tubing life and reduced friction loss. Surface pumping pressures were observed to have been reduced 10% to 20% with the new tubing. A third technology, HeviPac Weight Transfer Assembly developed by StrataLoc Technology, was proposed for demonstration, but a micro-prototype was unavailable at the time.

Operations in June

The first hole, designated 64-1-X-3, was drilled on a location just east of Microwell 53-4-X-3, which was completed in September 2003. RMOTC had obtained drilling permits for both holes prior to the 2003 operations. A RMOTC contractor drilled conductor pipes (consisting of two 21-ft joints of 3-in.-nominal ID, schedule 40 line pipe and some short nipples for spacing) to 44 ft in September 2003.

A 3-ft-diameter by 2-ft-long piece of corrugated metal pipe was installed in a 2-ft-deep cellar excavated around the conductor pipe. The cellar provided the space required for tubing rams and a 3-in., full-opening ball valve to serve as blow-out preventors on the wellhead. The fluid end of the high-pressure mud pump was rebuilt, and a 4-in., 325-mesh basket strainer was installed on the mud-pump inlet line in an attempt to prolong the life of the packing and plungers. Numerous difficulties were encountered at start-up, some of which could be attributed to leaving the equipment exposed to the Wyoming winter. These problems included the corroded set screws in the coiled tubing connector, that had to be drilled out, a ruptured hose caused by freezing, and mechanical damage to threaded connections on the bottom hole assembly (BHA).

The first drilling assembly was a 2-5/8-in. PDC drag bit with 25-degree back rake on a 1-11/16-in. 5:6 lobe 5-stage motor with a 2-1/2-in. stabilizer run on top. The penetration rate was a dismal 16 ft/hr and

control of weight-on-bit was poor. The BHA was pulled after drilling to 69 ft and 10 gallons of hydraulic fluid was added to the oil reservoir in an effort to improve oil cooling, enhance hydraulic-system performance, and improve the control of weight-on-bit. While pulling out of the hole, the BHA became stuck when the pieces of the foam pig used to cement the conductor wedged beside the drilling motor in the conductor pipe, and the BHA had to be jacked out of the hole. A summary of each bit run is provided in Attachment II.

The second drilling assembly was a 2-3/8-in. PDC drag bit with 25-degree back rake on a 1-11/16-in. 5:6 lobe 5-stage motor with a 2-1/4-in. stabilizer run on top. This configuration yielded an ROP of only 28 ft/hr so the BHA was pulled and a third drilling assembly that included a 1-11/16-in. 1:2 lobe 3-stage high-speed motor in place of the 5:6 motor, was run. Hydraulic-system performance was still poor due to elevated oil temperature. The 5:6 lobe motor requires considerably more flow than the 1:2 motor, and it was hoped that the reduction in flow would also reduce hydraulic oil temperature. The 325-mesh basket strainer developed a hole and was replaced with a 200-mesh strainer. The pump packing began to leak and was replaced.

The third drilling assembly, a 2-3/8-in. PDC bit with 25-degree back rake on the 1-11/16-in. 1:2 lobe 3-stage motor with 2-1/4-in. stabilizer on top, drilled 125 ft/hr to a depth of 501 ft. Hydraulic oil temperatures were 20-30 degrees cooler than while running the 5:6 lobe motor, and system performance improved as a result. Short pump-packing life continued to be a problem. The combination of the cuttings from the 60-ft bentonite interval above the Shannon formations along with the fine sand of the Shannon formation itself, created major difficulties for the mud-cleaning system. Cleaning the plugged strainer required suspension of drilling, as often at times as every five minutes. The mud pits were dumped and cleaned twice through this interval.

The 2-3/8-in. hole was then opened using a 2-3/8-in. by 2-5/8-in. hole-opener. Stalling and downhole vibration was a problem with the 1:2 lobe motor, so it was replaced with a 5:6 lobe low-speed motor. The ROP with the hole-opener/5:6 lobe motor combination was poor, so the hole-opener was modified by a bit shop in Casper by increasing the back rake angle and moving the cutters slightly outward. The reworked hole opener provided an increased ROP of 15 to 30 ft/hr while reaming to 205 ft. A 1-11/16-in, 1:2 lobe motor was subsequently used to open the hole to 500 ft at penetration rate of approximately 100 ft/hr. The hole-opener modifications reduced the stalling and vibration previously seen while running the 1:2 lobe motor.

The CTU was moved off the hole to make room for a RMOTC pulling unit, which ran 493 ft of 2-3/8-in., 4.7-lb/ft, steel flush-joint tubing in the hole to serve as an intermediate-casing string across the oil-producing Shannon formations. We used the newly acquired LANL micro-cementing system to cement the annular space. Cement slurry consisting of 14 sacks of type 1-2 portland cement with 2% bentonite, 0.5% fluid-loss additive and 1% friction-reducer was pumped down the tubing. A foam pig was installed on top of the cement to serve as a wiper plug, and the cement was displaced down the tubing with 76 gallons of water. The cement mixing, pumping, and displacement were flawless using the Los Alamos micro-cementer.

A pressure test of the CT connector at the surface revealed a leak through the O-ring seals. After cutting off 2 ft of tubing and replacing the O-rings, it became obvious that the outside diameter of the tubing had been reduced as a result of compression in the tubing injector to the point that the CT connector could not

adequately grab or seal on it. A new string of 16Cr stainless-steel tubing, acquired from Quality Tubing, Inc. on a cost-share basis, was installed with the assistance of RMOTC personnel and equipment.

The 1-7/8-in. hole was drilled from below the 2-3/8-in. intermediate-casing to a total depth of 810-ft. In spite of the frequent shut-downs that were required to clean the basket strainer, a penetration rate of approximately 100 ft/hr was achieved using a PDC bit with a 1-11/16-in., 1:2-lobe, 3-stage motor with no stabilizer; 800 ft of 1-1/4-in., schedule 80 flush-joint PVC pipe was run to total depth by hand with the help of RMOTC personnel. RMOTC furnished a small crane and an operator to help pull the PVC string if problems were encountered while grouting the annulus. Five sacks of Black Hills Bentonite BH-20 grout were mixed with 115 gallons of water and 2.5 lbs of soda ash to delay the thickening time. With 80% of the bentonite slurry in the hole, the pumping pressure reached the 280-psi pressure capability of the Moyno grout pump. A foam pig, 10 ft of cement slurry, and a second pig were installed in the top of the PVC string, and were displaced with water using a small, triplex positive displacement pump. The pressure relief valve, which was set at 600 psi, opened almost immediately but the flow of mud up the annulus indicated that the grout was being displaced. Therefore the displacement was continued without an accurate measurement of the displacement volume until pumping pressure decreased and the displacement was terminated and the hole shut-in. A subsequent run with a sinker bar on a slick-line unit indicated that the cement top was at 771 ft—exactly where it should be.

Operations in October:

The objectives of the first campaign had been met at that time, and the microdrilling crew returned to Los Alamos to prepare for the drilling of the four seismic holes. Although the PVC pipe string was successfully installed and sealed, it became obvious during the grouting of the PVC annulus that bentonite grout will not provide sufficient pumping time even with the addition of soda ash. Future completion plans were modified to include the use of cement with dispersant instead of bentonite grout. Based on a nominal setting depth of 400 ft for the steel intermediate casing and an 800-ft depth for the PVC pipe, we ordered 2-3/8-in. steel, 4.7-lb/ft flush-joint steel tubing, and 1-1/4-in. schedule 80 flush-joint PVC pipe to complete the next four wells. Because the basket strainer that was used on the pump suction during the June operations had proven to be moderately successful, a manifold was built to accommodate parallel redundant strainers so that they could be cleaned without shutting down the drilling operation. Pump maintenance had become a major issue during the June campaign, and the pump power end had developed a knock. A new Kerr Model KP-XP3300 triplex with 1-3/4-in. plungers and a maximum operating pressure of 2500 psi was procured, and replaced the Myers-Aplex Model SC-65 triplex plunger pump. Due to the LANL "stand down" and delays in obtaining permits needed to construct the surface well locations, the microdrilling crew was unable to return to RMOTC until late September.

A local geotechnical contractor was commissioned to drill and case four conductor pipe holes. The holes were drilled to using 8-in. hollow-stem augers to 44 ft, and cased with two 21-ft joints of 3-in. nominal ID (3-1/2-in. OD) schedule 40 threaded-and-coupled line pipe with two 12-in.-long nipples, and couplings run on top to provide space below ground level to rig up blow-out preventors below the tubing injector. A foam plug was installed in the bottom of each of the pipe strings and taped in place. The strings were set on bottom, and after the inside of the pipes were filled with water and valves installed on top, the conductor pipe annuli were filled with portland cement slurry with 2% bentonite.

The first hole, Well 67-1-X-34, is located at the southeast end of the line that roughly intersects the four wells. LBL had indicated that this hole was the highest of their priorities. The well location was moved farther to the southeast from the originally planned site at the request of LBL after pre-survey modeling was used to optimize the seismic data acquisition for monitoring the CO2 injection. The move put the site across a fault from the original location where the Shannon formation is considerably deeper. Therefore the 2-5/8-in. hole was drilled to 600 ft before setting the steel intermediate casing, as opposed to the 400 ft originally planned.

A 2-ft deep, 3-ft-wide cellar was excavated and lined with corrugated metal pipe. The top two 12-in.- long nipples were then removed from the top of the conductor pipe. BOPE consisting of a 3-in., full-opening ball valve below a manual 1-in. tubing-rams, with a 3-in. ball valve on the flow line, were installed on top of the conductor pipe. The usual tubing pack-off, a standard polished rod stuffing box, was used on top of the blow-out preventer stack. A reserve pit was dug by a RMOTC backhoe and operator. Figure 1 shows the microdrilling system on location at Well 67-1-X-34.

Figure 1. Microdrilling Site at RMOTC-operated Tea Pot Dome Field.
From left to right: the Los Alamos drilling mud-cleaning system, the Los Alamos coiled tubing drilling rig, and two pickup trucks. In the foreground is the reserve pit and flush-joint tubing that will be run as a production casing for a Shannon oil well.

The effects of rodent infestations delayed the beginning of drilling after it was determined that one of the CTU's data transmission cables had been damaged, and that a nest had been built in one of the hydrocyclones resulting in persistent shaker-screen plugging. The foam plug used to seal the bottom of the conductor pipe wedged itself between the BHA and the conductor pipe while it was being drilled. The first drilling assembly included the previously used Griffith-Vector 1-11/16-in. 1:2 lobe 3-stage and a 2-3/8-in. PDC bit with 25-degree back raked cutters. A 2-1/4-in.-OD stabilizer was run on top of the motor. Previous experience was that drilling 2-3/8-in. hole then opening it to 2-5/8-in. in two runs was more effective than drilling a 2-5/8-in. hole, due to the limited power available from the small drilling motors.

The elastomer in the motor stator came apart after drilling to 105 ft. Arrangements were made to replace the damaged stator, and a purchase order for back-up rental motors was placed. A Black Max 1-3/4-in., 1:2 lobe 3-stage motor was then run, and an average ROP of 52 ft/hr was achieved while drilling from 105 ft to 353 ft. A subsequent check of the bit nozzles revealed that two of the three 5/16-in. jets were plugged with small chunks of rubber from the failed stator. The improvement in bit hydraulics during the following run produced ROP of over 100 ft/hr while drilling to 594 ft. Strainer plugging from the Shannon sand slowed drilling considerably even though the strainer manifold worked as planned and one strainer was cleaned while pumping through the other. Another delay occurred when the packing in the new pump washed out prematurely as a result of abrasive fine solids from the Shannon formation. Backup packing had not arrived and the wrong replacement packing was shipped, further delaying progress.

A newly acquired 2-3/8-in. x 2-5/8-in. hole opener with less aggressive cutter exposure and a tapered profile was run the Black Max 1:2 lobe motor with a 2-1/12-in.-OD stabilizer. The tapered profile more than offset the less aggressive cutters, and frequent stalling of the motor was presumably caused by wedging of the bit in the hole and resulted in a low rate of penetration. The previously used 3-cutter 2-5/8-in. hole opener was redressed and run, producing an ROP of 63 ft/hr while opening the hole to a depth of 272 ft. A packing failure on the new mud pump lead to a cracked plunger. A new set of plungers was shipped with an additional delay of a couple of days. The hole was eventually opened to bottom, and 585 ft of 2-3/8-in. steel flush-joint casing was run and cemented using the LANL micro-cementer. The cement was displaced from inside the tubing with a precisely measured 89.3 gallons of fresh water behind a foam wiper plug to a calculated depth of 565 ft. Clean cement was circulated to surface. The recipe used for this and all cement jobs during this campaign was:

Portland Type I-II cement
Fresh water - 6.5 gallons per sack of cement
Bentonite – 2% of the weight of the cement
Diacel RPM dispersant - 1% of the weight of the cement
Diacel FL fluid loss additive - 0.5% of the weight of the cement

The cement top was tagged at 536 ft, and wiper plug and cement was drilled with a new 1-7/8-in. bit that was built with 25-degree back rake and dampeners to reduce torque. Pieces of the foam wiper pig persistently wedged between the bit and the casing as it was drilled up causing the motor to stall repeatedly. The pressure-relief valve on the mud pump washed out and was replaced. A comparison of the performance of the new 1-7/8-in. bit with the one used in June indicated that 15-degree back rake produced the best performance in the Steel shale. After changing bits, we drilled ahead to 626 ft before a coupling in the motor sheared, probably as a result of the fatigue caused by severe BHA vibrations while drilling out the foam pig. Subsequent examination of the motor revealed that the rotor had multiple stress cracks and the stator was a little ragged; a rebuild was ordered from Black Max. The 1-7/8-in. bit was run on the rebuilt Griffith-Vector 1-11/16-in. 1:2 lobe motor, and drilled from 626 – 808 ft with an average ROP of 91 ft/hr. A chart of drilling data from this section is shown in Figure 2 below.

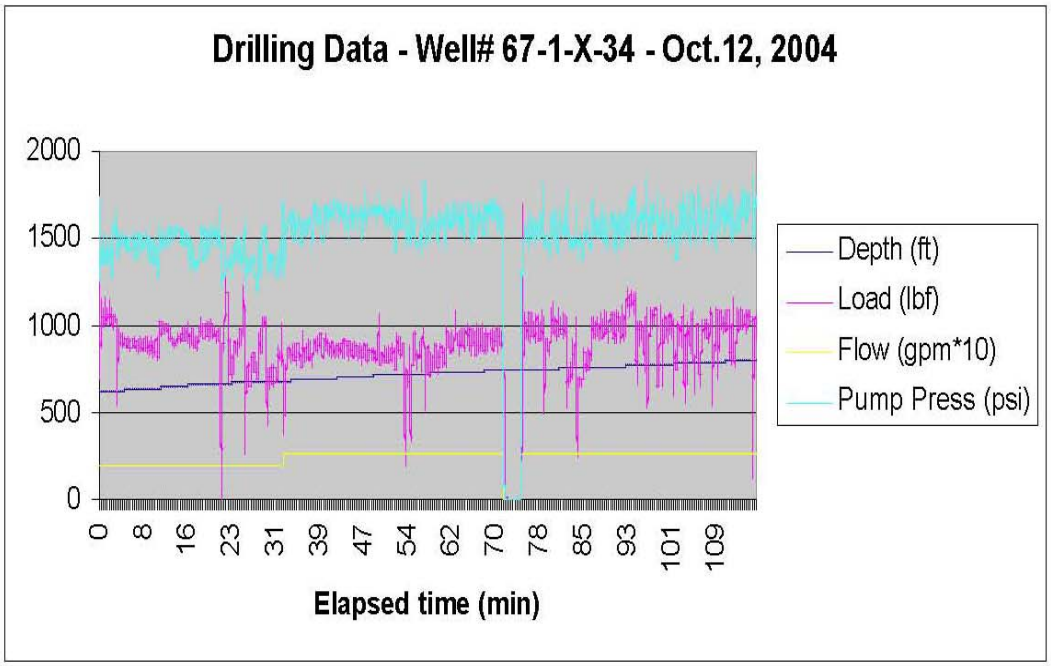

Figure 1. Drilling data from October experiments at Well# 67-1-X-23. at the Mcrodrilling Site at RMOTC-operated Tea Pot Dome Field.

An 800-ft string of PVC flush joint tubing was run in the hole with the help of a RMOTC hydrocrane and operator. Concerns were raised while running the pipe because many of the threaded connections were cut off-center. The thread configuration relies primarily on a shoulder-to-shoulder seal, and the shoulders didn't appear to line up very well. The primary concern was that the connections wouldn't seal, and that we would end up with either cement inside the string or a bad cement job. The pipe vendor and manufacturer were contacted with these concerns. They offered sufficient assurance that the connections would seal to justify cementing the annulus the following day. The cement job went well; there were no indications of a problem at the surface. A RMOTC crew ran a sinker bar to 780 ft six days later verifying that a successful cement job was in place. However, a previous run with a square-bottom sinker indicated that the misaligned internal shoulders create restrictions in the internal diameter. LBL had designed one of the three seismic instrumentation arrays to fit in a 1.25-in.-ID pipe. The inside diameter of the string that was run was more like 1.235-in. LBL's solution was to turn down the outside diameter of their instruments.

The microdrilling system was then moved to the farthest northwest of the four locations to drill Well 12-1-X-34. A RMOTC backhoe and operator moved the corrugated metal pipe from the old location to the new, and dug another 2-ft deep cellar and reserve pit. The BOPE was installed as described for the previous well. After drilling out the foam pig and cement at the bottom of the conductor pipe with an aggressive 3-blade tungsten-carbide bit on a 5:6 lobe motor, the Dennis Oil Tool tandem-motor assembly was run in the hole for field demonstration. (Attachment I gives a summary prepared by the Dennis Tool company's on-site representative of the equipment and operations.) The tandem-motor assembly drilled 2-3/8-in. hole to 129 ft. A 2-3/8-in.-PDC bit on a 1-11/16-in. 1:2 lobe 3-stage motor with a 2-1/4-in. stabilizer on top was used to drill to the intermediate-casing setting depth of 407 ft. The hole was then

opened to 2-5/8-in. with the Short Bit & Tool 3-cutter hole-opener on the same motor with a 2-1/2-in. stabilizer on top. The average ROP for the combined drilling and hole opening exceeded 120 ft/hr. Strainer plugging from the Shannon sand was particularly disruptive while drilling this section. A 394-ft-long string of 2-3/8-in. steel 4.7-lb/ft flush-joint tubing was then run in the hole by a RMOTC pulling unit and crew. The annulus of the intermediate-casing string was successfully cemented using the LANL micro-cementer and the standard cement recipe described above.

The PVC pipe that was procured for the completion of the remaining three wells was returned to the vendor for a credit. Numerous strings of 1-1/4-in. flush-joint PVC pipe have been run during the life of the microdrilling project, and this was the first encounter with quality control problems. Subsequent research determined that the manufacturer that made the pipe used a less stringent set of tolerances for their product than do the other manufacturers. No high-quality PVC pipe needed to complete Well 12-1-X-34 was in stock but was available with a two-week lead-time; operations were suspended due to the onset of winter weather and the long-term forecast precluded a re-start before spring.

Results:

The highlights for the 2004 drilling campaign include:

1. Microdrilling with BOPE was demonstrated for the first time.
2. A microhole with an intermediate-casing string was designed and demonstrated for the first time.
3. A microwell-sized cementer was demonstrated and performed well.
4. A replacement mud pump performed well; maintenance and downtime were reduced; initial start up issues were resolved.
5. Suction strainers were shown to be effective, and a manifold was demonstrated that improved the performance of the strainers.
6. Maximum penetration rates were increased with the optimization of bit design for the Steele Shale and Shannon Sand formations.
7. Quality Tubing's 16Cr stainless-steel coiled tubing was successfully demonstrated in drilling service, and initial performance was very good.

Addition work is needed to improve microdrilling performance, increase completion reliability, and reduce downtime.

1. The drilling-mud cleaning-system performance needs to be improved. This will reduce the mud pump and downhole drilling-motor maintenance repair costs as well as reduce the drilling downtime associated with these activities.
2. The sealing system for PVC pipe needs be modified. We are exceeding the recommended working pressure of the pipe and have far exceeded the recommended pressure for the flush-joint connections. High internal pressures are the result of (1) flow losses due to a rapid increase the viscosity of bentonite grout and (2) the very high hydrostatic pressures that occur when high-density cement is displace with water. A low-density cement or an effective thinner for grout is needed to seal PVC casing to the well bore.

3. The Dennis Tool drilling assemblies will be redesigned to drill a 2-5/8-in. hole and include a left-hand rotating motor on the pilot motor. Los Alamos is investigating the feasibility of increasing the maximum allowable working pressure for the coiled-tubing unit to support drilling fluid circulation pressure up to 5000 psi, so we can provide the flow rates and differential pressure needed to power two drilling motors in tandem through a 1-in. or 3/4-in.-OD coiled-tubing system.

Micro-instrumentation holes could be drilled in about half the time required for the present well design by using 1.660-in.-OD integral-joint steel tubing with 1.880-in.-OD connections cemented from total depth to the surface. The design eliminates the need for a 2-5/8-in. hole and the intermediate string. We proposed to complete one of the four micro-instrumentation holes with this design in spring 2005. This will provide a platform for the comparison of the acoustic performance of PVC-cased and steel-cased micro-instrumentation holes.

Summary:

A total of three holes were drilled at RMOTC in 2004. The first, a prototype seismic-monitoring hole, was successfully drilled in June to demonstrate the feasibility of a completion design with a steel intermediate-casing string and very small annular spaces. The second hole was drilled and completed with 585-ft of 2-3/8-in. steel casing, and cased to total depth with 800 ft of 1-1/4-in.-PVC pipe cemented to surface. The third hole was drilled to 407 ft., and an intermediate-casing string was cemented to 394 ft. A replacement string of PVC pipe was not located to case the lower section of the hole, and drilling operations were suspended for the winter.

Field operations provided the opportunity to demonstrate some new technology consisting of a 16Cr stainless-steel coiled-tubing work string from Quality Tubing, and the tandem-motor drilling concept developed by Dennis Oil Tool. A micro-cementing system was developed and deployed, and demonstrated to be effective in mixing, pumping, and displacing cement and bentonite grout slurry in the batch sizes and low pumping-rates required for completion of microholes. It was shown that cement could be pumped into annular spaces as small as 0.104-in. with the proper use of cement additives. This allowed the use of multiple casing strings in microhole completion to be demonstrated in the Steel Shale and Shannon formations. Problems with drilling motor life once again became evident, illuminating the need to develop more robust high-speed PDMs in the 1-1/2-in., 1-11/16-in., and 1-3/4-in. sizes. The addition of parallel basket strainers in the pump suction proved to be effective in reducing the number and length of drilling interruptions and extending the life of the pump expendables.

Attachment I

DENNIS TOOL COMPANY, CONTRA ROTATING BIT PROJECT,
MICRODRILLING TEST.

Objective:

To carry out a test with tandem PDMs as the first stage in the development of a contra-rotating, zero-reactive torque drive system for coil tubing.

Test information & equipment:

Date: 14 Oct 2004.

Lease: NPR # 3. Field: Teapot Dome. Well #: 12-1-X-34. County: Natrona. State: Wyoming.

Rig: LANL CTU # 1, with 900' of 1″ OD, 0.81″-ID coil tubing. Supervisor: Jim Thomson.

Pump: One Kerr KP3300XPBC triplex pump, with 1.75″ liners rated at 2500 psi, 0.0937 gal./rev.

PDM's: 1-11/16″ Vector 5:6 lobe, 5-stage & 1-7/16″ Vector 1:2 lobe, 3-stage (both LANL owned).

Bit: Dennis Tool Company, 1-3/4″-diameter pilot bit with 2x7/32″ jets.

Hole opener: Dennis Tool Company 2-3/8″-diameter (no jets) with a 1-11/16″ stabilizer.

Previous casing: 3″-ID line pipe run to 44′ below surface with top of line pipe 1-1/2′ above surface.

Drilling fluid: Fresh water, 8.3 lb/gal.

Formation: Shale, expected ROP approx 100′/hr.

BHA:

CTU conn, xo, 2-1/4″ stab, xo, 1-11/16″PDM, 2-3/8″ HO/1-11/16″ stab, 1-7/16″ PDM, 1-3/4″ pilot bit. (bha length 20.87').

Summary:

Prior to running the tandem PDMs, a 5:6 lobe, 5-stage PDM was used to drill out the foam plug in the 3″-ID linepipe conductor plus 3′ of new hole to 47′.

The tandem motor assembly was picked up and RIH at 11:30 AM. The assembly drilled from 47′ to 55′ with an ROP of about 20′/hr. The 8′ drilled included 7-1/2′ of pilot hole (pump 340 strokes per minute [spm], flow 32 gpm, pressure 1700-2200 psi). The ROP in the pilot hole was much lower than expected. At 55′ there was a 200-psi drop in pressure and a complete loss of progress so the string was pulled. The upper PDM had a larger than normal thrust bearing measurement and the tool was changed out. The rest of the BHA looked ok.

The tools were run back in the hole and drilling recommenced at 1:00 PM. A further 74′ was drilled in 2 hr. 25 min at an average ROP of 30.6′/hr. The ROP fluctuated between 20 and 50′/hr during the run and at the end dropped to 12′/hr. At this stage it was impractical to continue with the low ROP and the run was terminated at a depth of 129′ (pump 320 spm, flow 30 gpm, pressure 1800-2100 psi).

Very frequent stalling was a problem throughout with the tandem motors. The weight on bit ranged from 400 to 700 lb.

The next run was with a 1-3/4″ Black Max 1:2 lobe, 3-stage PDM with a Bill Short 2-3/8″ bit. The 7-1/2′ of 1-3/4″ pilot hole was opened to 2-3/8″ and 56′ of new hole drilled at an average ROP of 124′/hr (pump 232 spm, flow 21 gpm, pressure 1400 psi with no load to 1800 psi.). Drilling was terminated for the day at a depth of 185′. There was very little PDM stalling on this run.

Remarks:

- The Dennis Tool Co bit and hole opener were run and pulled in good condition with no plugging or damage.
- The pump strokes were counted by hand. With the pump running at 230 to 320 st/min an accurate stroke count is very difficult, so the above flow rates are only approximate figures.
- The recorded flow and pressures with the tandem Vector motors was 30 gpm and 1800 to 2100 psi versus 21 gpm and 1400 to 1800 psi, with the Black Max motor on the following run. A significantly higher pressure should have been seen on the tandem motor run with a 43% higher flow rate.
- The low ROP in the pilot hole suggests that it was the 1-7/16″ PDM that was stalling and most likely dictating the ROP throughout the run. Comparisons made last year also showed that the 5:6 lobe, 5-stage Vector motors were drilling significantly slower than the 1:2 lobe, 3-stage Black Max PDM. (We were made aware of this in January).
- The observations on pressure and ROP suggest that the Black Max motor has a much higher efficiency than the Vector PDMs.
- At the moment we have too many variables to draw firm conclusions from this first test, the tandem motor arrangement worked but in this case the ROP was unsatisfactory. Jim Thomson′s suggestion of running the bit and hole opener on the Black Max PDM on the next well will give us a comparison of bit performance on the same motor. Afterwards, further tests should be made with tandem motors.

Roy Powell.

Attachment II – Summary of bits and hole openers run in 2004

Bit Run No.& date	Bit S/N	Bit Description	Motor Description	Interval Drilled (ft)	Feet drilled* (cumulative)	ROP (feet/hr)	Flow rate (gpm)/Bit rpm	WOB (lbf)	Pressure (psi)	Comments
1 6/4/04	V093	2-5/8" PDC 25° backrake	1-11/16" 5:6 5-stage	44-69	25 (25)	16	35 / 550	1000-1600	1200-1600	Start Well# 64-1-X-3 2-1/2" stabilizer run
2 6/5/04	V093	2-3/8"PDC 25° backrake	1-11/16" 5:6 5-stage	69-180	111 (196)	28	36 / 600	1200-1600	1200-1600	2-1/4" stabilizer run with all 2-3/8" bits
3 6/6/04	V093	2-3/8"PDC 25° backrake	1-11/16" 1:2 3-stage	180-501	312 (508)	125	23 / 1100	800-1400	1200-1900	
4 6/7/04	N/A	2-3/8x2-5/8" hole opener	1-11/16" 1:2 3-stage	69-114	45 (45)	41	23 / 1100	500-1000	1100-1500	New hole opener design didn't work
5 6/7/04	V119	2-3/8x2-5/8" hole opener	1-11/16" 5:6 5-stage	114-118	4 (13)	-	35 / 550	800-1400	1200-1900	Ran damaged hole opener
6 6/8/04	V119	2-3/8x2-5/8" hole opener	1-11/16" 5:6 5-stage	118-205	87 (100)	25	34 / 500	100-500	1200-1700	Ran repaired hole opener
7 6/9/04	V119	2-3/8x2-5/8" hole opener	1-11/16" 1:2 3-stage	205-499	294 (394)	125	25 / 1200	100-500	1100-1900	
8 6/12/04	W096	1-7/8" PDC 15° backrake	1-11/16" 1:2 3-stage	456-552	96 (96)	110	25 / 1200	500-1200	1100-1900	Stabilizer was not run with 1-7/8" bits
9 6/14/04	W096	1-7/8" PDC 15° backrake	1-11/16" 1:2 3-stage	552-752	200 (296)	67	25 / 1200	500-1200	1100-1900	
10 6/15/04	W096	1-7/8" PDC 15° backrake	1-11/16" 1:2 3-stage	752-810	58 (354)	64	25 / 1200	500-1200	1100-1900	Finish well# 64-1-X-3
11 10/3/04	V093	2-3/8"PDC 25° backrake	1-11/16" 1:2 3-stage	44-105	61 (569)	50	17 / 850	500-800	1200-2100	Griffith vector motor rotor came apart
12 10/3/04	V093	2-3/8"PDC 25° backrake	1-3/4" 1:2 3-stage	105-353	248 (817)	52	17 / 850	500-800	1200-1900	Start well# 67-1-X-34
13 10/3/04	V093	2-3/8"PDC 25° backrake	1-3/4" 1:2 3-stage	353-594	241 (1058)	96	17 / 850	500-800	1600-2000	
14 10/4/04	V119	2-3/8x2-5/8" hole opener	1-3/4" 1:2 3-stage	45-82	37 (431)	100	17 / 850	400-800	1600-1900	2-1/2" stabilizer was run with hole openers
15 10/5/04	V119	2-3/8x2-5/8" hole opener	1-3/4" 1:2 3-stage	82-136	54 (485)	54	17 / 850	500-800	1500-2100	

- None of the bits or hole openers showed any significant wear.

Attachment II continued….

Attachment II – Summary of bits and hole openers run in 2004 (cont'd)

Bit Run No.& date	Bit S/N	Bit Description	Motor Description	Interval Drilled (ft)	Feet drilled* (cumulative)	ROP (feet/hr)	Flow rate (gpm)/Bit rpm	WOB (lbf)	Pressure (psi)	Comments
16 10/6/04	V119	2-3/8x2-5/8" hole opener	1-3/4" 1:2 3-stage	136-272	136 (621)	70	17 / 850	400-600	1600-2100	Hole opener V119 was redressed
17 10/8/04	V119	2-3/8x2-5/8" hole opener	1-3/4" 1:2 3-stage	272-593	321 (942)	64	25 / 1200	300-500	1700-2100	
18 10/10/04	W161	1-7/8" PDC 25° backrake	1-3/4" 1:2 3-stage	546-619	73 (73)	37	22 / 1000	700-1200	1600-2000	New bit design w/ dampeners not effective
19 10/10/04	W096	1-7/8" PDC 15° backrake	1-3/4" 1:2 3-stage	619-626	7 (361)	-	22 / 1000	700-1200	1600-2000	Black Max motor came apart
20 10/12/04	W096	1-7/8" PDC 15° backrake	1-11/16" 3-stage	626-808	182 (543)	91	19 / 900	400-700	1400-1800	Finish Well# 67-1-X-34
21 10/14/04	N/A	2-3/8"3-blade TC chevron	1-11/16" 5:6 5-stage	44-47	3 (3)	-	28 / 480	400-1000	1600-2000	Attempt to drill-out foam pig w/blade bit
22 10/14/04	N/A	Dennis Oil Tl Tandem assy	See Attach-ment I	47-129	82 (82)	31	30	400-700	1700-2200	Drilling Well# 12-1-X-34
23 10/14/04	V093	2-3/8"PDC 25° backrake	1-11/16" 1:2 3-stage	129-185	56 (1114)	124	21 / 1000	400-700	1600-2200	
24 10/15/04	V093	2-3/8"PDC 25° backrake	1-11/16" 1:2 3-stage	185-407	222 (1336)	49	25 / 1200	300-700	1600-2000	Drill to casing setting depth Strainer plugging slowed avg. ROP