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# Particle drilling alters standard rock-cutting approach

## Millions of impacts per minute break rock faster than standard bits for high ROP, while field testing improves particle injection.

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One of the largest plums that bit and service companies have wanted to pick for the last 30 years is the ability to drill hard rock much faster than normal rates. Many developments have been made in roller cone bits, polycrystalline diamond compact bits, and impregnated diamond bits with continual progress. Primarily through innovations in material science and engineering design, the technology stream has chipped away at improvements in the speed at which hard rock is drilled. Even with very significant improvement, these bit types still rely on high applied weight, torque and/or rotational speed to marginally increase penetration rates. Both high applied weight and high rotational speed contribute to shorter bit life, requiring more trips to change out worn bits or creating deviation problems in the wellbore that cost significant time and money to remediate.

In spite of constant progress, operators today are still often faced with the "80-20 rule." Difficult intervals represent roughly 20% of the total footage drilled, but can often account for as much as 80% of the intangible drilling costs to reach total depth. This disproportional cost is often due to very slow drilling rates in the deeper hard rock intervals, where typical ROP is in the 1–15 ft/h (24–360 ft/d) range.

Hydraulic horsepower is very important in conventional drilling, since it helps bits perform at optimal levels. It is common to see hydraulic horsepower approaching 2,000 on rigs today. The application of that horsepower is not fully leveraged when it is only used to remove cuttings and clean the bit. The hydraulic energy can be put to more efficient use by accelerating high density particles through the drill bit's nozzles, thereby using the particles as the primary cutting mechanism. This emerging technology is known as Particle Impact Drilling (PID).

### PARTICLE DRILLING

Very hard and dense spheres, sized to pass through the internal diameter of conventional drill bit nozzles are accelerated to high velocities. The particle mass and velocities are high enough that, when particles impact the rock surface, they fracture and eject a small rock volume. It does not seem apparent that significant ROP improvement can be made by removing such small rock volumes. If, however, the impact number is very large, then the multiplication of individual small volumes can result in an impressive total volume removed. In fact, the PID system is designed to deliver over four million impacts per minute.

Excavation rates from four million small volumes of rock removed every minute result in unprecedented performance. In terms of days to drill a well, PID rates can be ⅓ to ⅕ the time to drill the interval that represents 80% of the drilling time and expense. The value of drastically reducing the number of days to drill a well and thereby reducing much of costs associated in drilling those wells is huge.

PID works because of the very high stresses applied to the rock at the moment of particle impact. The applied stress is a function of three things:

1. Applied energy
2. Contact area
3. Collision time.

The applied energy is the particle mass multiplied by its velocity squared. For a given applied energy, the force imparted is inversely related to the time of collision. Since the particle collision occurs over a very small time period, the force generated is much larger. This combination of applied force, during a very short period of time and over a tiny contact area results in huge contact stresses. These stresses can be orders of magnitude greater than the contact stresses applied by cutting structures on conventional bits. Conventional bits with nine contact points at 0.110 in.$^2$ each yield contract stress of 61,000 psi, which at 60 rpm equals 540 impacts per minute. With PID, a single-point contact yields a calculated 830,000 psi of contact stress, producing high excavation rates at 4 million impacts per minute.

When compared to conventional roller cone bits, the impact force of particle drilling can be likened to that of applying force with an ice pick versus applying force with a hammer, Fig. 1. With the ice pick, the same amount of force is applied to a much smaller area resulting in much higher contact stress. In this analogy, the ice pick strikes its target over 4 million times per minute and the hammer strikes 540 times per minute.

Because the contact stress imparted is much greater than the strength of hard and ultra-hard rock, these hard-to-drill rocks are easily excavated by the particle barrage striking, stress fracturing and separating small rock volumes on each impact.

It should be noted that rocks having lower failure stresses are also easily drilled by PID. The system will cut any

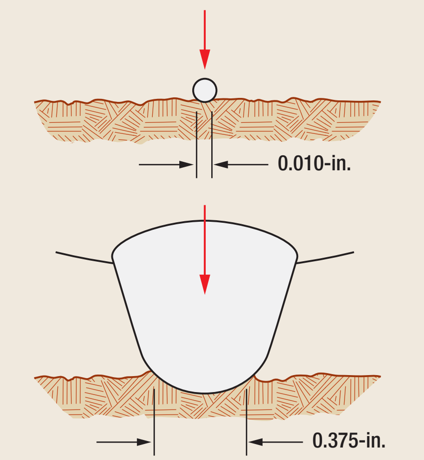

**Fig. 1.** Conventional bits (bottom) yield 61,000 psi of contract stress, while a particle contact (top) yields a calculated 830,000 psi of contact stress, producing high excavation rates.

rock formation at rates higher than conventional drilling. This allows hard and soft lenticular formations or soft plastic formations sandwiched between hard strata to be drilled at high rates without a bit change.

## COMPONENTS AND RIG INTEGRATION

The system consists of three primary components: the PID bit, the Particle Process System (PPS) and the Particle Injection System (PIS).

**PID bit.** The bit does its work downhole by delivering spherical particles at the velocities necessary to fail and excavate the rock formations being drilled. The nozzles and bit geometry are designed to create a specific cutting pattern, Fig. 2. This optimizes rock removal and directs rebounding particles away from the bit's surface.

Tough areas removed by particle impacts include the gauge corner of the bottomhole profile, the center and the nose/flank. The remaining area forming a rock ring is relieved from depth stresses and is easily removed when pressed by an angled surface on the bit body using only 5,000 to 15,000 pounds of applied weight.

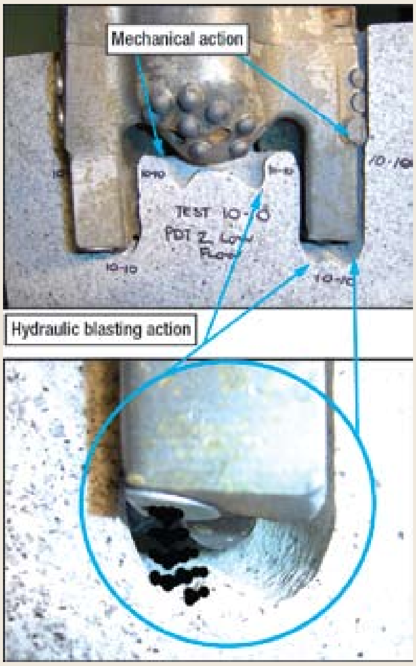

**Fig. 2.** Testing in Sierra White Granite increased penetration rates from 20 ft/h to almost 70 ft/h at a simulated 5,000 ft wellbore depth.

The angled surface and relatively light weight on bit induces tensile stresses to the weak rock ring, continuously breaking it into marble sized pieces. The pieces along with the particles and other cuttings are directed through the bit's very large junk slots into the annulus, where they are pumped out of the hole with the circulating mud.

**PIS.** This surface equipment entrains the particles into the pressured mud flow, sending the mud/shot slurry down the drill pipe to the bit.

The PIS equipment consists of a tower and frame 11.5-ft wide × 8.5-in. deep × 53-ft tall with a duplicate injector set for complete system backup. Vertical conduit with a chain/disk system serves as an elevator for moving the particles to a hopper at the tower's top. Gravity feeds the necessary particle volumes into two "in-line" pressure chambers (upper and lower), and through a laterally-oriented barrel and screw chamber (extruder) located at the base of the injector tower.

Initially, both in-line chambers and the extruder are filled with particles. The chambers are closed and pressurized, based on hydraulic requirements of the well being drilled, typically at an operating pressure of 2,500 psi up to 4,500 psi.

The injection process begins and the "shot pack" is mechanically conveyed at about 15 gpm through the extruder and is entrained into a flow of about 450 gpm drilling fluid, which then carries the particle-laden mud into the standpipe and delivers it downhole to the bit. The entire flow consists of about 3% particles and 97% drilling fluid.

When the particle level falls below the upper chamber, a valve is actuated to isolate the lower chamber from the upper chamber. Pressure is then bled from the upper chamber, so it can be opened and re-filled. After it is re-filled, it is re-pressurized and opened to the lower chamber. This cycle is continuously repeated, allowing the system to maintain constant particle flow at 15 gpm.

**PPS.** This component includes a rotating drum, circular separators and magnet separators. Once the particles return to the surface, they are captured at the shale shakers along with the cuttings and drilled solids. From that point, they are conveyed back to the PPS through the circular separators and magnetic separators.

The separators and magnets remove cuttings and drilled solids from the steel particles. The cleaned particles are returned to the rotating drum, and cuttings are transported to the reserve pit.

The drum stores particles and keeps them agitated to prevent the particles from adhering to one another and clumping. From the drum, particle volumes are metered into the PIS.

The entire system (both PPS and PIS) is powered by 375 kW generator and all surface com-

**Fig. 3.** Initial field tests of the PID system were done at the Gas Technology Institute drilling facility in Catoosa, Oklahoma during July 2005.

ponents are automated and operated by PLC control. The system's footprint occupies a 42-ft × 42-ft area. It can be set up on location without interfering with the drilling operation in progress. The only point of connection to the drilling rig is the installation of a "T" in the standpipe and a hopper placed downstream of the rig's shale shaker. The "T" can be installed during a normally scheduled bit run, just prior to tripping the PID bit downhole.

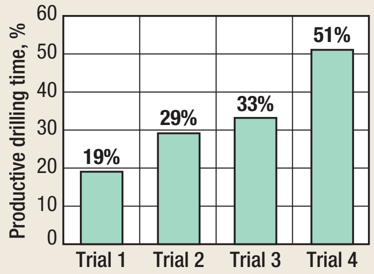

**Fig. 4.** The first three trials drilled the Mesaverde interval (Utah) with increasing productive drilling time (percentage of total time the PID bit is drilling).

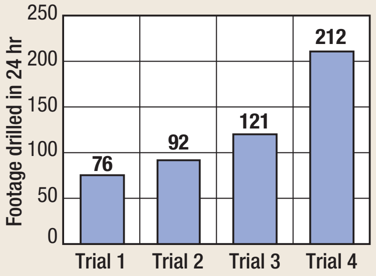

**Fig. 5.** Using prototype equipment, ROP ranged from 150% to 350% faster than conventional drilling in the same interval, compared to offset wells.

## FULL-SCALE TESTING

Twelve separate series of tests for developing the PID bit and operational parameters were performed at the TerraTek Drilling and Completions Laboratory in Salt Lake City, Utah. Most of the testing was performed in Sierra White Granite, which has a Unconfined Compressive Strength (UCS) of 28,000 psi to 32,000 psi. Sierra White Granite is generally used in for this testing because it closely simulates very hard rock found at depth in drilling deep boreholes.

Through iterations of bit design and based on various WOB, rpm and flow rates, penetration rates were observed from 20 ft/h to almost 70 ft/h while the rock target was under simulated stresses found at 5,000 ft wellbore depth. Atmospheric tests with 8½-in. bits in the same granite registered ROP up to 100 ft/h. These tests were key to verifying that the PID concept can excavate hard rock at relatively very high rates and what parameters are necessary to achieve those rates.

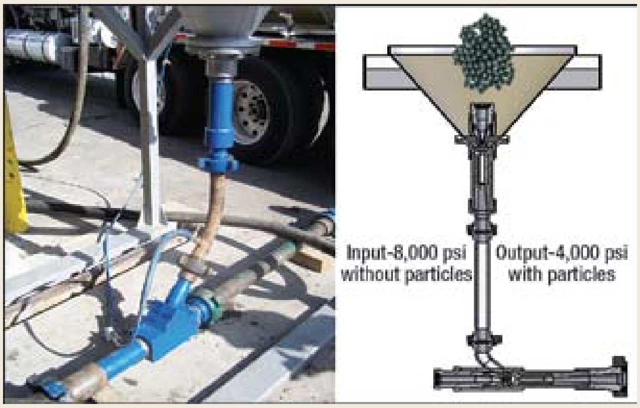

**Fig. 6.** In March 2007, the upper limits of the frac-pump or "hydraulic-based" injection system were tested and could not deliver a consistent particle flow at the necessary volumes.

Following bit testing, initial field tests were scheduled at the Gas Technology Institute drilling facility in Catoosa, Oklahoma, Fig. 3. These were done to confirm that the system could be applied under field-drilling conditions. Hard and difficult formations, which are typically encountered much deeper, occur at depths above 3,000 ft at Catoosa. These include the Mississippi Limestone (40,000 psi UCS), the Arbuckle Dolomite (25,000 to 40,000 psi UCS) and a variety of other hard and soft strata, ranging from relatively soft shales and sandstones to very hard sandstones and limestones up to 60,000 psi UCS.

During the first 10 hr of drilling through most formation types, the system averaged 113 ft/h, drilling some extremely hard formations ranging from 20,000 to 60,000 psi UCS without noticeable drilling breaks. Drilling in the long sections of the Mississippi Limestone and the Arbuckle Dolomite yielded an average ROP of 30 ft/h, which was the targeted rate for the initial drilling sites for the system. After verifying target rates and further demonstrating the system's viability, commercial trial applications were identified and scheduled.

## FIELD TRIALS

Following laboratory and Catoosa testing, the system was used at four separate commercial trials; the first three drilling the Mesaverde interval in the Uintah Basin of eastern Utah at depths between 10,000 ft and 11,500 ft. The fourth trial drilled a portion of the Travis Peak formation in the deep Bossier trend of East Texas at depths below 12,000 ft.

With each trial, PID demonstrated step-change drilling rates. Each trial resulted in system performance improvements measured by productive drilling time and footage drilled, Figs. 3 and 4. Productive drilling time is the percentage of total time that the PID bit is engaged and drilling. Footage drilled is the total footage penetrated during a 24-hr period. In each case, using prototype equipment and tools still being developed, the ROP observed ranged from 150% to 350% faster than conventional drilling in the same interval, as compared with the nearest three, recently-drilled, offset wells.

During the first three trials, most of the learning and system developments involved the PPS. During the early trials there was also learning associated with rig integration due to the frac pump used at that time.

During the fourth field trial in March 2007, the PPS system was reliable and robust. However, at that time the upper limits of the frac-pump or "hydraulic-based" PIS, Fig. 6, was tested and could not deliver a consistent particle flow at the necessary volumes. Performance degraded with increased pressure requirements and depth, and with sudden variations in operating pressure that occur in the field.

Thus, in April 2007 a program was begun to design and build an entirely new injection method, relying on mechanical means to move particles into the standpipe. Several approaches were evaluated and prototype testing was performed. As a result, a new PIS was developed, Fig. 7.

## CONCLUSIONS

Based on the test data and field trial work to date, PID technology has demonstrated considerable potential for delivering step-change drilling rates in hard and abrasive rock formations. Because of the technology's enabling nature, it promises to open drilling plays that are presently uneconomic. Many of the primary challenges have been overcome in bit design, particle recovery and particle processing/

**Fig. 7.** The new injection method moves particles into the standpipe mechanically with a extruder-screw system.

cleaning. Conquering what has proved to be the single largest obstacle, continuous particle injection into high-volume, high-pressure drilling fluid, appears to be within reach. Design efficiencies and an optimization program will develop rapidly as the technique gains industry experience and increases the sample size of drilling opportunities.

As of early May 2008, a test program continues to more fully evaluate the system and to make adjustments to components and design elements for field use. Once it is established that the new PIS is capable of continuous and reliable operation, the system will return to the field for a fifth trial, again drilling the Travis Peak in East Texas. **WO**

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## THE AUTHORS

**Gordon Tibbitts** earned a BS in mechanical engineering from the University of Utah. He has over 30 years of direct experience in the oilfield tools industry, including 17 years in management of engineering, research and development. He is formerly the director of Research and Development at Hughes Christensen and holds over 70 patents for drilling, coring and diamond cutting tools. Tibbitts is the Vice President, Technology for Particle Drilling Technologies Inc. since June 2003.

**Greg Galloway** has 30 years of oilfield experience in drilling and enhancing drilling performance. Prior to joining Particle Drilling Technologies, Mr. Galloway was Product Line Manager for Weatherford's Drilling with Casing and Solid Expandable Tubulars product lines. He is the Vice President of Engineering and Operations for Particle Drilling Technologies Inc. where he is responsible for development and implementation of the PID system. Galloway earned an Associates degree in petroleum technology from Tyler Jr. College.