HYDRODYNAMIC CAVITATION TOOL

"KROT-CT"

TECHNICAL INFORMATION

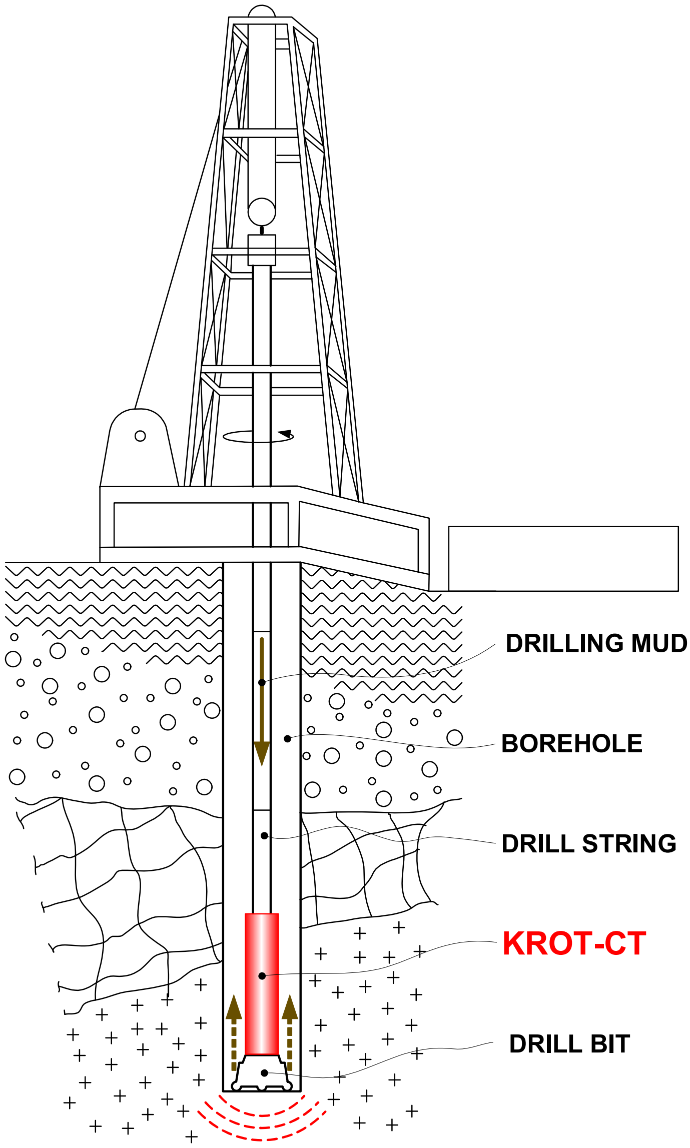

Fig.1 Drilling Rig

The KROT-CT is a downhole, liquid driven cavitation tool for drilling boreholes in earth formation. It overcomes all of the limitations of piston driven mud powered percussion tools known hitherto while at the same time improving performance, flexibility and reliability. It is powered by pressurized wellbore fluids supplied through the hollow rotating or non-rotating drill string in combination with a generic pumping system. The KROT-CT design has taken an entirely different approach to generate strong vertical impact on the drill bit without the need for complicated and failure prone mechanics.

The strong pulses are generated hydro-dynamically by means of resonance waves that can be tuned for optimum performance in varying drilling conditions. The KROT-CT cavitation tool will help improve overall rigperformance and return on investment while at the same time reducing cost & risk involved. This is achieved in many ways such as the impressive improvement of ROP in difficult and varying drilling conditions, the improved borehole quality and well performance through permeability induction, the increased footage between bit trips, the reduced vibrational stress on drill-bit, drill-pipes and collars thus reducing material replacement & repair, and ultimately maximizing overall productive-time and rigefficiency.

It is suitable for both rotating and non-rotating drill strings and can be applied onshore and offshore. Due to the unique possibility to modulate and remote control the impulse pattern on-line the KROT-CT is an ideal backbone of a new generation of smart drilling systems able to sense conditions at and ahead of the drill bit and to adapt to these varying conditions while drilling.

BACKGROUND

Drilling is required for exploration and exploitation of oil, gas, geothermal energy and other resources. Drilling costs are a critical factor in determining the financial returns from an oil, gas or geothermal investment. This is particularly true when operating costs are becoming higher due to the depletion of shallow resources, as deeper and harder rock formations are penetrated and drilling problems are more likely to occur. Such regions include for example the Rockies, Tuscaloosa trend, Anadarko basin, Cretaceous limestone, and several areas in Texas as well as deep Gulf of Mexico formations, Bolivia, Colombia, Egypt, Argentina, Kazakhstan, South East Asia, and Oman. Under these conditions, the problems such as drill string failure, wellbores out of gauge, stuck pipe and fluid losses due to fractures produce significant material damage, and even the loss of wells. The associated Non-Productive-Time (NPT) may be as high as 50 % of all rig time. In terms of money the average NPT presently is about $1.5 million per well. *(1,5)* The number of rotary rigs running worldwide remains on a high monthly average of 2,500, the number of wells exceeding 80.000 per year. *(16)* In terms of annual footage this is about 200 million feet in the US alone. Thus, any increase in the rate of penetration (ROP) and reduction of NPT will result in major cost savings. The estimated yearly cost to drill hard rock in the United States is USD 1,2 billion (2002) with potential savings of USD 200 - 600 million if the penetration rate in hard rock is doubled. *(2)* Whereas saving a day or two drilling onshore or nearshore is desirable, it has never before been possible to realize the kind of substantial financial benefits derived from shortening time for drillship or deepwater semisubmersible, that may include a USD 250,000 dayrate.

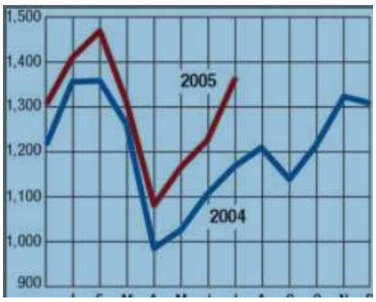

Fig. 2 Rotary Drilling Rigs Int.l Count

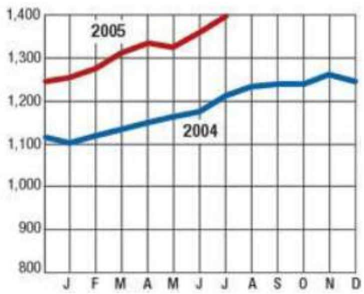

Fig. 3 Rotary Drilling Rigs U.S. Count (16))

STATE OF THE ART

Rig performance has considerably increased over the last decades. If average drill days between spud date and rig release are taken as a measure of changes in efficiency the improvement is impressive. Drill time has come down from 90 -120 days to only 20 -25 days. The advances may be grouped as follows: ***Improved Lithological Information*** Today's exploration geologists and geophysicists have a large array of computer assisted electronic tools available like 3D seismic that didn't exist previously. Thus the risk of drilling dry holes has come down to a much lower level compared to the old times when the experts had to rely on old single-fold data and subsurface mapping by the geologists.

New Generation of Rigs Recently introduced all electric, self-contained, self-erecting onshore and offshore rigs provides greater capacity for making holes faster and permit finer control of the drilling process. Where subtleties in the process were masked by drilling rig coarseness in the past, the higher sensitivity of monitoring devices and control systems now allows drilling optimization to a high level. Rig crew safety has increased, too. Better well control equipment, alarm systems and monitoring have reduced the incident of blowouts and the number and severity of kicks has dropped significantly. ***Improved Drilling Tools*** Modern drill bits like polycrystalline diamond cutters (PDC) and tricone bits used in combination with new high-performance downhole drilling motors have both contributed to the high ROP achieved today. For hard and abrasive drilling conditions in deep wells drilled with mud, tricone bits have the highest ROP, but their susceptibility to wear and bearing failure limits their drilling time. In deeper hole sections, where tripping times are longer, thermally stable polycrystalline or natural diamond bits are major competitors of the tricone bit, especially in smaller hole sizes. Thermally stable polycrystalline and natural diamond bits have a much longer bit life to offset their lower ROP and reduce overall cost per foot compared with tricone bits. Wells that would previously require up to 50 drill bits now require just 1 or 2.
Downhole motors are drilling at considerably higher speed with less cutter wear. Oversized mud-pumps now provide greater motive power for new PDC bit designs and flush larger volumes of debris out of the wellbore during the drilling process. HHP increased more than 200% over the last four years in the company's East Texas drill fleet, reducing drilling days up to 45%. *(15)* Typical hydraulic pressures went up from 1,800 to 2,000 psi in 2001, to 2,500 to 3,200 psi in 2004. New mud systems, fluid separation systems, mud cleaners and countless chemical additives are available. In addition to these hardware improvements the use of smart drilling tools has made a significant impact on overall drilling efficiency. Advanced PVT systems and alarms provide a high standard of safety and precision in downhole monitoring ultimately resulting in fewer trips to replace MWD/LWD/PWD tool strings and worn bits.

CAVITATION DRILLING TOOLS The KROT-CT is a completely new type of drilling tool which will help the contractors to push the limits of performance further. Some decades ago it has been found that repetitive impact pulses on a roller drill-bit increase the penetration rate of the drill-bit and that, because of the short duration of each impact blow, the deviation of the borehole is significantly reduced. Impact pulses, therefore, are being used ever since as a substitute for part of the weight on the drill bit. *(i.e. Maurer, W.C., 1980; Rao, U.M., 1980, and Mishra, B, 1998).*
One of the first technologies developed for this purpose many years ago was the pneumatic downhole percussion drill using a gas to reciprocate a hammer piston exerting repetitive impact forces to the roller drill bit. Air hammer drilling is now widely used in the mining industry, where extensive research has been done about this technology. Anyhow, in deep oil and gas wells, high borehole mud pressure creates a different and less well explored environment. As demonstrated in extensive laboratory studies *(TeraTek)* under high borehole pressures the rock strengthens and behaves in an apparent ductile manner *(i.e. Robinson, L.H., 1958, Green, S.J., et. al. 1972, and Maurer, W.C., 1980).* High strain rates, too are a major concern as rocks tend to behave differently under such conditions. Studies are complicated by pore fluid effects *(Green, S.J. et. al. 1968, 1974, 1982).* Also cuttings removal becomes more difficult *(Van Lingen, 1962). (3)*
Percussion tools are typically applied in rock formations. Hammer drilling with percussion bits in clear water is a relatively new alternative that is being applied with encouraging results but is limited to relatively shallow holes i.e., less than 3,000 ft. Deep boreholes in rock formations are mostly mud-flushed to improve drilling and flush-out drilling debris generated in the borehole during the drilling operation. In order to overcome the depth limitations of hammer drilling performance in clear-water applications, new hydraulic hammer systems have been developed using weighted mud for both impact generation and debris flushing. These systems have been studied over the last years by a consortium of Dept. of Energy (DOE), operator, and industry participants. An executive summary details the results of full-scale testing of two 7 3/4-in.-diameter mud hammers with 8 1/2-in. hammer bits and compares their performance with a conventional tricone bit.

The following was concluded: * The new generation mud hammers have the ability to operate in 10- to 15-lbm/gal WBM. * There is no advantage in using mud hammers with conventional IADC 537 tricone bits. * Drill bits designed to exploit both rotary and impact-applied loads provide better performance used with mud hammers. * Current mud hammer designs have a limitation of about 3,000 psi wellbore pressure i.e. approximately 6,000 feet at 10 ppg *(3, 17)*
Most of the systems developed to date imply a direct mud drive approach, i.e. the drilling mud is directed first to a piston chamber containing the back end of a piston to drive the piston downwardly to strike the drill bit, and then the drilling mud is selectively directed to an other piston chamber containing the front end of the piston to drive the piston back to the top of its stroke. Drilling-mud exhausted from the piston chambers through nozzles provided on the drill bit can flush debris from the cutting face of the drill bit and up the borehole. *(10)*

Probably the most important disadvantage of any such system is the conceptual limitation of all piston driven mud powered percussion tools, namely:
1. The drilling mud generally contains abrasive material such as sand, which cannot be completely eliminated by a filtering system due to the required flow-rate of the system. This causes erosion at the exposed edges, in the clearance spaces of the piston and the valves of the impact drill, resulting in a short operating life and high replacement costs.
2. The impact between the piston and the drill bit takes place in a mud bath altering the impact force by squeezing mud out from between the drill bit and the anvil prior to and at the moment of impact. This effect is complicated further by a number of variables which are beyond the control of the operator including: the viscosity and weight of the drilling fluid, the drill bit face, the porosity of the formation, and the borehole pressure.
3. The borehole back pressure against which the drilling mud must be exhausted at the end of each piston stroke, increases with the depth of the borehole. This reduces the pressure gradient across the piston, which in turn reduces the impact force exerted on the drill bit, ultimately reducing the ROP.
4. As the pressure and flow rate of the drilling mud are largely adjusted on the requirements of the borehole flushing, the pressure and flow rate to drive the piston will mostly be suboptimal. Such a system cannot provide the possibility to vary the force or frequency of the impact pulses and adopt the tool to variations in the rock formations encountered in the borehole. Consequently there is no possibility for feed-back steering control based on the extensive litho logical real-time information generated by the extensive sensory system offered for this kind of percussion drill tools.

A number of R&D projects for new drilling technologies are presently supported by the US Department of Energy (DOE), Federal Energy Technology Centre, including a smart steerable, down-hole mud actuated hammer is being researched in collaboration with Novatek and, more recently the development of high-speed rotary steerable systems for microhole drilling i.e. coiled tubing drilling (CTD) in collaboration with Sperry/Halliburton et al. *(11)* Such systems shall suit particular requirements such as the growing re-entry drilling market in mature fields in addition to the ongoing quest to further improve ROP and productivity/BBL. They are optimized to sidetrack horizontally from an existing horizontal motherbore. Some designs attempt to integrate a mud-actuated hammer in a rotary steerable drilling system generating a pulsing fluid flow from the nozzles thus increasing the drilling rate *(6)* and/or acting as an at-bit-steering *(8,9).*

THE KROT-CT

The KROT-CT is a downhole, liquid driven, fluid operated cavitation tool for drilling boreholes in earth formation. It overcomes all of the above said limitations of piston driven mud powered percussion tools while at the same time improving performance, flexibility and reliability. It is powered by pressurized wellbore fluids supplied through the hollow rotating or non-rotating drill string in combination with a generic pumping system. The system involves the generation of special downhole adjustable patterns of acoustic pulses in the drilling fluid exerting a strong vertical impact on the drill bit. The high pressure amplitude pulses are generated hydro-dynamically with a very favourable coefficient of performance (COP). The unique design is based upon many years of research and development in the field of nonlinear acoustics. Mechanical energy is amplified by means of acoustic resonance. The highly efficient exploitation of acoustic energy for the generation of mechanical work is a breakthrough technology comparable to the development of the optical LASER, with potential application in many fields of engineering.

.KROT-CT Features and Advantages

1. A truly unique KROT-CT feature is the possibility to create a distinguished acoustic wave field based upon the combination of 3 different pulse patterns which can be applied simultaneously and tuned within a range of 500 - 15,000 Hz.
2. The very significant improvement of ROP observed in various formations including hard-rock results from a synergy of effects including improved crack propagation, reduced cutting resistance, improved cutting face lifetime, and diminished vibration of drill-string. In terms of benefits this means: higher impact, more available torque from any used drive, improved footage, reduced wear & tear, less downtime, better directional control and well trajectory, higher reach of the well, higher rate of production, lower cost, lower risk and ultimately higher ROI.
3. The possibility to remote-control and adapt the generated pulse pattern on-line to optimize the drilling operation according to varying conditions makes the KROT-CT a very adequate backbone of a new generation of MWD-guided drilling systems able to sense conditions at and ahead of the drill bit and highly capable to adapt to these varying conditions while drilling. Consequently this will be one of the most suitable systems with greatly improved overall performance and cost/benefit ratios in deep-hole and directional drilling.
4. The possibility to generate special wave fields to remove scale and other dispersible or soluble material from formations, perforations and casing without fracturing reservoir rock. This may help to mitigate near-wellbore formation damage by bypassing drilling mud, completion fluid or other restrictions like perforation plugging from mineral scales (CaCO4) or precipitated clay, fines, zone compaction or gun junk, thus restoring and/or considerably improving well performance while reducing the use of aggressive acids.
5. The significant reduction of lateral and torsional stress as well as axial compression - due to the phonon nature of the propagated waves - with many benefits such as: lowering the drop-out rate of drilling equipment, reducing adverse effects on wellbore casing, cement and formation matrix and consequently improving overall productive rig time and performance.
6. Due to the elimination of failure-prone mechanisms like pistons and valves the KROT-CT system can tolerate a large range of drilling-mud profiles including those with high solids content without increase of wear & tear and associated system failure. Its unique design has a low sensitivity to elevated borehole pressures and temperatures and requires little maintenance and repair. Consequently operational reliability, productive time and overall rig performance are improved.

7. The broad range of usable drilling fluids, including oil or water-based drilling mud, brine, water, and emulsions is a considerable advantage, too. By using water-based drilling fluids, environmental exposure is reduced and cost savings are provided, both on the drilling fluid itself and on the cost and operational risk of skip-and-ship cuttings disposal.
8. The KROT-CT operator has a large flexibility to choose from a spectrum of available drill-bit types. By selection of the most suitable drill bit he is able to support the advantages of the KROT-CT for any given application.
9. The KROT-CT is available in many different sizes starting with a diameter as slim as 2 3/4" and in any bigger size used in the drilling industry. It may be particularly suited for re-entry drilling in mature fields, extending horizontal production sections and enabling small targets to be reached and drained more efficiently.
10. The applicability of the KROT-CT is as broad as one would possibly imagine:
* onshore and offshore drilling * rotating and non-rotating drill strings * downhole and top-drives

OUTLOOK

Using casing essentially as drill pipe, with BHA retrieval on wireline internally through the casing, is an overdue idea. Casing running and cementing downtime has been a flat spot on the drilling curve hitherto. With casing drilling however, since the casing is already in place, tripping, conditioning and running casing time are obviously eliminated. The advantages are evident particularly when done without sacrificing ROP as possible with the KROT-CT.

Another exciting perspective is the implementation of the KROT-CT in the emerging field of "natural resonance drilling" i.e. the attempt to produce a resonance field between the percussion tool and the formation ahead of the drill bit. This has been speculated to produce a tremendous amplification of the generated impact forces by the factor of 10 to 100. Laboratory studies have shown that improvements in drilling speed can be achieved by an appropriate coupling of the generated wave field to the 'natural frequency' of the local crack propagation in the drilling zone. When tested in the laboratory on glass and alumina the new approach provided a cutting speed ten times that of conventional drilling. *(12, 13, 14)* Anyhow, this giant leap in performance has not been field applied to date due to the lack of adequate percussion tools. With KROT-CT the exciting possibility may become real.

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Fig. 3 KROT-CT Wave Pattern

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