UNDERBALANCED HORIZONTAL DRILLING • THE ULTIMATE COMPLETION TECHNIQUE

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INTRODUCTION

The combination of **u**nder**b**alanced drilling and **h**orizontal **d**rilling (UBHD®) has created the ultimate completion technology to maximize productivity of oil and gas from many reservoirs. Horizontal drilling is now an accepted drilling method that has numerous benefits for the recovery of hydrocarbons. The challenge has been how to drill laterally without damaging a reservoir's primary or secondary permeability. The technique that drills a well with downhole pressures that are less than that of the formation is widely known as "underbalanced drilling". Underbalanced drilling permits a well to be drilled while producing naturally. Many industry experts believe that UBHD will become the completion technology of choice when the cost becomes equal to the cost of conventional completion techniques such as hydraulic fracturing. The quickest path to cost equality will require the integration of all UBHD equipment with a top drive drilling rig, cross training of personnel and implementation of new technology.

WHY DRILL HORIZONTALLY

Horizontal drilling technology has come a long a way in the past 20 years. It can be utilized both as an exploration tool and as a completion technique. The benefits of horizontal drilling when used as part of a completion method include increased drainage area, connecting fracture permeability to the wellbore and reducing drawdown pressures. There is a strong desire in the industry to reduce the surface foot print caused by drilling activities. The use of horizontal wells has proven to be an effective application of this drilling technology to reduce the number of wells required to develop a field.

The application of horizontal drilling is important in the exploitation of reservoirs that have little to no primary permeability. To achieve maximum productivity a horizontal well can be oriented in a particular direction to intersect the greatest number of fractures. As a result of being able to connect fractures to a wellbore, horizontal drilling technology has turned non-economic reservoirs into economic successes. Vertical wells have a much lower probability of intersecting fractures on repetitive basis than horizontal wells because nearly all fractures are oriented vertically. Horizontal drilling has also been applied in water drive reservoirs to eliminate coning because a properly placed lateral has been shown to dramatically lower the drawdown pressure across the face of the wellbore.

WHAT IS UNDERBALANCED DRILLING

Underbalanced conditions exist in a wellbore when the hydrostatic pressure exerted by a column of fluid is less than the reservoir pressure. The underbalanced condition is usually achieved by the injection of a gas into the drilling fluid to lower its density. The process typically requires compression and wellhead control equipment This intentional and controlled method to create light weight fluids using a gas and compression equipment to lower hydrostatic pressure is what differentiates underbalanced drilling from a technique known as "flow drilling". Flow drilling is not true underbalanced drilling because flow drilling relies on the reservoir and not on equipment to create the underbalanced condition. Flow drilling is a technique that was utilized in the Austin Chalk because it is a reservoir that is in part characterized by lost circulation. Loosing circulation to lower the hydrostatic pressure in a well is usually unintentional and uncontrolled. Controlling a series of kicks while drilling is what defines flow drilling.

WHY DRILL UNDERBALANCED

Underbalanced drilling techniques and equipment are the primary aspects of drilling a reservoir without causing any damage to its permeability. The attempt to quantify the degree of damage to the near wellbore area is known as "Skin Damage". In the past with high volume wells, eliminating skin damage in a reservoir with high permeability has not been a priority with many engineers. After all, if a reservoir with 600 md of permeability and has 50% of its pore throat system plugged with fines from overbalanced drilling there is still 300 md of permeability left. This is probably the reason for the old saying "You can't hurt a good reservoir." Unfortunately the same amount of damage applied to a reservoir with only 300 md could reduce the permeability to zero. Low permeability reservoirs are extremely susceptible to damage because they are drilled the same way high permeability reservoirs are drilled. In other words, they are drilled without regard for the damage being done to the reservoir. These tight reservoirs will realize the greatest benefit from underbalanced drilling because until recently they have been ignored.

Many exploration and exploitation energy companies are beginning to target unconventional reservoirs. Generally, these reservoirs are characterized by low permeability and porosity. A characteristic of tight rock is that it tends to be more brittle and thus more intensely fractured. Fractures can have a significant impact on productivity if they are connected to the wellbore and not plugged with drilling fines. Fractures are usually described by their aperture as being macro or micro. It is generally understood that macro fractures are ones that can be detected with the naked eye (> 35µ) and fractures that are undetectable by a person with good vision (< 35µ) are described as micro fractures. It is important to remember that a fracture with an aperture of 25µ has 54 darcies of permeability. The short length of a micro fracture is the characteristic that reduces its effective permeability. Fortunately micro fracturing density can be very high and thus the distance from fracture to fracture is very short. Studies have shown that on an average there are as many as 80 micro fractures per one inch of rock. The other problem with micro fractures is that they are easily plugged with fines when drilled overbalanced.

DESIGNING A UBHD WELL

There are several design options for operators to consider when planning a UBHD well. The most common technique is to inject a gas such as air or nitrogen into the stand pipe to reduce the density of the liquid phase that was selected as the drilling medium. The biggest operational problem with this technique is that it is nearly impossible to stay underbalanced 100% of the time while drilling the horizontal leg of the well. STAYING UNDERBALANCED 100% OF THE TIME IS CRITICAL TO THE SUCCESS OF A WELL WHERE UBHD IS CHOSEN AS THE COMPLETION TECHNIQUE.

The likelihood of going overbalanced when drilling an underbalanced well occurs after a connection is made and circulation is being reestablished. During the connection two events can occur to increase the bottomhole pressure when the pumps and compressors are turned back on. An influx of reservoir fluid just prior to and during the time it takes to make the connection and the separation of the injected gas from the liquid phase creating a slug of fluid at the bottom of the hole. The pressure required to get this fluid moving uphole again can cause the well to go briefly go overbalanced.

The best well design to employ that will not allow the underbalanced condition to be jeopardized while drilling is the "concentric casing technique". This technique requires a work string of casing to be hung in the production casing to create a second annulus. This construction allows the density altering gas to be injected in the annulus between the work/concentric string of casing and the production string at some pre selected point downhole where the compressed gas is allowed to enter the return annulus. The return annulus is the space between the drill pipe and the concentric string. This design allows circulation of the vertical hole to be maintained even during connection. This method is so simple to use that the floor hands do not need to change any of their drill pipe connection procedures because circulation of the vertical well does not involve the drill pipe. There are numerous other advantages to the concentric such as MWD telemetry can be used because 100% liquid is pumped down the drill pipe.

INTEGRATION OF UBHD EQUIPMENT AND CROSS TRAINING

In order for UBHD to achieve cost equality with conventional completion methods the UBHD equipment and services, including a top drive drilling rig, should be owned and managed by a single company. Currently, there can be as many as eight different companies requiring up to 30 people to perform the UBHD completion process. The list of services and equipment needed for the operation include (i) a top drive drilling rig, (ii) a rotating pressure control head, (iii) the BOP stack, (iv) a four phase separator, (v) data acquisition service, (vi) compression equipment, (vii) nitrogen membrane units, (viii) directional drilling services and equipment, (ix) multi-lateral junction tools, (x) solids control equipment, (xi) gyro orientation service, (xii) wireline unit and (xiii) tool rentals including onsite housing.

For the operator the situation of coordinating this many service providers can turn into a costly logistic nightmare when trying to get every company to show up on location at the time they are needed. Having multiple companies can cause very high cost overruns when a piece of equipment owned by one company is in need of repair and has the operation shut down. Other service companies will continue to charge their normal day rate because the problem is not with their equipment. Having one company responsible for the entire operation can eliminate much of the "finger pointing" that takes place during a job when there is a problem, especially a downhole problem. Unfortunately at this time there is no incentive for a service company to become integrated. In fact the opposite is true because a more efficient operation would reduce the number of days on location and the service companies would make less money. Service companies who provide much of the expensive UBD equipment may often smile when they show up on location and see a 50 year old rig over the well.

All service companies provide trained personnel to run their equipment, many of whom are capable of handling more responsibility. In order for service technicians to be able to manage more than one process or piece of equipment a central command and control center is essential. The obvious place to centralize everything is with the driller. This is because the drilling rig is the most important piece of equipment on location in a UBHD operation. Efficiency and reduction of personnel begins with the rig through automation of rig floor activities such as pipe handling. For example, directional drillers always locate their steering tool equipment near the driller so they can communicate. It also makes it easy for the directional hands to train the driller to make tool face corrections. This small example of cross training can be expanded to allow technicians the opportunity to handle more responsibility but only if the controls for the equipment are centralized and managed by one company.

NEW UBHD TECHNOLOGY

New UBHD technology is also needed to achieve cost equality. Underbalanced drilling has evolved from conventional air drilling, which has a 50 year history. The primary difference between historical air drilling and underbalanced drilling today is that air drilling is typically used to improve drilling performance, such as faster penetration rates and reducing lost circulation problems in non-reservoir rock. Underbalanced drilling is primarily used to improve productivity in reservoir rocks. If properly applied, a two to three fold increase in the recovery factor can be realized. Air drilling technology is in many situations unable to meet the challenge of staying underbalanced while a reservoir is producing significant quantities of oil and gas. The way to reduce costs is to simplify many of the procedures involved in underbalanced drilling. Currently there is a need to simplify the orientation process for bottomhole assemblies, improve BHA build rate accuracy while shortening the drilling footage to get to horizontal, eliminate snubbing and eliminate the need for compression equipment.

SEMI-SMART DRILL PIPE

To simplify the process of orienting bottomhole assemblies a new self aligning tool joint for drill pipe has been developed. This connection is a three piece tool joint that uses a set of differential threads on the box end where a removable coupling is installed. The coupling has two sets of threads. The upper set is the same as any normal drill pipe thread that screws onto the pin end. The lower set of threads is a non-interfering fine thread that secures the coupling to the drill pipe. The pin end is internally notched to stab into the box end that is externally splined. After stabbing, the collar is rotated to make up the connection. The spline inside the box is machined with two splines that are of different widths for the purpose of joining each end in only one orientation.

During the manufacturing process the larger spline on the box end and the receiving larger notch on the pin end are aligned with each other before the welding process is complete thereby creating an imaginary line that runs the length of each joint of pipe. The imaginary line will run parallel to the drill pipe from surface to TD because every joint of drill pipe, tubing or casing are made the same way where the tool joints can only be assembled in one orientation. Except for a small gap between the collar and the upset on the box end the assembled tool joint will look very similar to other conventional upset tool joints.

A few of the potential benefits and applications are: (i) the creation of an imaginary straight line created by the aligned tool joint allows for the mechanical orientation of downhole tools such whipstocks, tubing conveyed perforating guns and directional drilling tools; (ii) the installation of one or more electrical conductors is now possible because the tool joints “plug together” and do not screw together; (iii) use of production tubing made with this tool joint can allow for the imbedding of multiple internal wires to provide power to run down hole electrical motors and other equipment; (iv) drill pipe that can be rotated to the left without unscrewing; (v) the coupling can also serve as a centralizer that can be replaced when it wears out; and (vi) higher torque ratings are possible because torque is transmitted through the splines and not the threads.

ROTARY STEERABLE DRILLING TOOL

A Rotary Steerable Drilling Tool is being developed employs a different technique to drill a curve than conventional steerable motor assemblies currently being used by most directional service companies. Typical motor driven BHA’s utilize a bent housing to tilt the axis of the drill bit in order to drill a curved borehole. The orientation of the obtuse angle created by the fixed bend is known as tool face. This rigid dogleg in the drill string points the face of the bit in a direction that is tangential to the longitudinal axis of the drill string. Such a steerable assembly can only drill a curved wellbore when the drill string is not rotating, since the bent housing is a fixed part of the drill string. This curve drilling procedure is commonly referred to as “slide drilling”. Should the drill string be rotated it will drill a relatively straight hole because the bent housing angle is cancelled out by the constantly changing direction in which it is pointed.

The RSDT has four primary components. They include a hydraulically activated pad that is mounted within a non-rotating external sleeve, an internal re-alignment device, a flexible universal joint to replace the fixed bent housing and a drill bit. The

RSDT is able to steer the bit by using the hydraulically activated pad to force the drill pipe to the low side of the hole, thereby causing the axis of the bit to be tilted from the wellbore centerline. The amount of tilt is enhanced when a flexible, fluid conducting, universal joint is placed between the non-rotating sleeve/pad assembly and the drill bit. This allows the bit and bit sub to be tilted to a predetermined angle of up to 15º. When circulation begins the pad is activated by pump pressure and will push the drill pipe to the low side of the hole, thereby creating the obtuse angle and tool face orientation. This bit tilt action will cause a planar curve to be drilled in the direction that the pad is pointing.

The hydraulically activated pad housing and non-rotating sleeve will use special bearings and seals to minimize the friction forces between the sleeve/pad assembly and the inner rotating drive mandrel. This allows the drill pipe and bit to rotate freely independent from the sleeve/pad assembly. The sleeve/pad assembly orientation is held in place by the pad, which has been shaped to engage the high side of the wellbore and track the inside of the curve as drilling proceeds ahead. The RSDT also incorporates a unique orientation method that employs a simple internal mule shoe alignment lug and profile configuration. This allows the orientation profile and lug, which have been oriented with a gyro to automatically re-align the pad with the alignment lug by engaging the slot of the orientation profile that is attached internally to the sleeve body. The re-alignment process takes place when the mud pumps are turned off and the pressure inside and outside the drill pipe is allowed to equalize. The sleeve is then shifted to the original orientation by an internal coiled spring.

The RSDT has seven major advantages over conventional steerable motor assemblies. (i) reactive torque no longer affects tool face orientation because the tool face (pad) operates independently from the drill string. This means smoother, more accurate curves will be drilled from vertical to horizontal because there will be no tool face corrections made during the drilling process. After the assembly has been oriented and drilling begins, the extended pad will simply track high side and cause a planar curve to be drilled. (ii) the drill string is rotated while building angle, hence the name "rotary steerable". This will allow significantly faster penetration rates because of better hole cleaning. Slide drilling will no longer be required to drill a curve. Rotating the drill string also reduces friction, which makes it easier to accurately transfer weight to the bit. (iii) since the bit rotation is provided by the drill string, downhole motors are eliminated, thereby greatly reducing the operating cost while drilling the curve section of the well. (iv) the steering device can easily be adapted to use with an air hammer instead of a conventional bit assembly because the hammer can be rotated without affecting tool face orientation. Rotation of an air hammer by the drill string is essential to its operation because the buttons on the bottom of the hammer bit need to be repositioned after each cycle of the hammer for percussion drilling to be effective. (v) inclination measurements are made only 6-7 feet behind the bit. (vi) in slim-hole situations, the assembly can be run inside small diameter casing without dragging against the casing ID because the pad is not extended and the fluid conducting universal joint allows the assembly to be suspended in a straight position when tripping. The assembly bends to the predetermined angle only when weight is applied to the bit at the bottom of the wellbore. In other words the OD of the assembly over its entire length is smaller than the effective OD of a conventional BHA with a bent housing. (vii) the RSDT will be able to drill short radius curves of ≈ 50 feet and accurately target zones only 2 feet thick.

DOWNHOLE SHUT-OFF VALVE

Early in the history of underbalanced drilling a surface rotating pressure control device was developed to allow a well to be drilled safely while producing. Just as important to controlling pressures on the rig floor while drilling is the need to control pressures downhole while tripping. Tripping pipe while a well is flowing can be dangerous and expensive, especially if snubbing equipment is required. A downhole shut-off valve and surface activation system is currently being developed that will simplify this process over the currently available method. The system being developed is designed to take advantage of the concentric string of casing that is often run in a well for the purpose of providing a separate annulus to inject compressed gas during the underbalanced drilling process.

Another benefit of the concentric string is to use it as a mechanical arm. This retrievable string of casing is normally hung from a wellhead that is located below the BOP stack. Alternatively, this inner string of casing can also be supported by a "casing jack" that will be able to raise and lower the casing to actuate certain downhole tools. The casing jack's operation will be similar to that of modified hydraulic cylinder that is able to move up and down with three feet of axial travel. The casing is raised by hydraulic pressure to the chamber below the piston and is lower by bleeding the pressurized fluid back to a reservoir tank.

One of the tools that the casing jack can actuate is a modified subsurface (flapper style) safety valve. This is a normally closed flapper valve that is opened by a tube that moves down to open the flapper when hydraulic pressure is supplied. Instead of using hydraulic pressure to open and close the value, the tube can be attached to the end of the concentric string. A packer can then be used to anchor the flapper valve housing to the production casing. The flapper is driven open when the casing string is lowered. This valve and actuation method using a casing jack should provide a significant advantage over other methods employed to open flapper valves because the weight of the casing can be used to overcome high differential pressures across the flapper. The casing jack and concentric string of casing can also be used to open and close ported subs. Probably the single most important feature of this system is its simple design that allows a downhole flapper valve to be controlled by a switch making the process of controlling a live well "worm proof".

ARTIFICIAL LIFT WHILE DRILLING

Another technology that is currently under developed is a technique to use artificial lift technology to lower the hydrostatic column in a well while drilling. This alternative method would dramatically reduce the cost to induce under balanced conditions. The conventional method currently used in the industry utilizes compression equipment to inject gas into the drilling or return fluid contained in a wellbore. The objective of this method is to lower the density of the fluid and thereby reduce the hydrostatic pressure at the bottom of the hole to a level that is lower than the pressure contained within the formation being drilled.

A new technique using downhole jet pumps while drilling is being designed to lower the fluid level in order to reduce bottomhole pressure. The challenge with this new technique is to use artificial lift equipment that will not interfere with the drilling process. The problem can be able to be solved by installing multiple jet pumps on a concentric string of casing near the bottom of the well. Jet pumps designed for this purpose are currently being developed.

Jet pumping technology has been used as a means of artificial lift for more than 30 years. The jet pump is simple in design because it has no moving parts. It does require a power fluid (instead of compressed gas), which is pumped down the outer annulus between the concentric string and the production casing. It then travels through a nozzle, throat and diffuser to entrain drilling and produced fluids and lift them to the surface. Jet pumps are known for their ability to pump large volumes of fluid. Jet pumps can also handle gas and abrasive material such as cuttings that are generated from the drilling process. The most significant advantage of the concentric jet pump is the reduction in cost to induce under balanced conditions. This method will eliminate the need for compressors, boosters and nitrogen membrane units. All that is required is a second tri-plex pump at the surface to pump clean power fluid to the jet pump.

GENERATION OF PURE N_2 ONSITE

A new method to generate pure N_2 is also being developed to lower the cost of providing an inert gas onsite for underbalanced drilling or field repressurization. The process combines air and hydrogen that are compressed into a catalytic converter where the hydrogen combines with the oxygen to produce water leaving pure N_2 and minor (< .99%) associated gases. The process is simple and unique because of how the components are plumbed together. It uses readily available equipment such as an electrolyzer to generate the hydrogen. The by product of the electrolysis process is industrial grade oxygen that can be captured and sold. Depending on transportation costs, sales of oxygen are capable of paying for all equipment and future operating costs. This method for generating N_2 may not be suited for all UBHD projects except for those projects where there are a large number of wells are to be drilled. It also can to be used for in secondary recovery projects to maintain reservoir pressure.

CONCLUSION

Domestic energy companies who plan to use UBHD technology can capitalize on an opportunity that has never before existed in the oil and gas industry. The opportunity exits because of how drilling techniques evolved from the early 1900's. Looking back on the history of drilling technology we should first say thanks to Howard Hughes for inventing the tri-cone drill bit because its use brought an end to the original underbalanced drilling technique known as cable tool drilling. The tri-cone drill bit unknowingly gave birth to overbalanced drilling and formation damage that have significantly inhibited hydrocarbon recovery. We should also thank the many exploration companies from the past 100 years that have spent millions of dollars to locate billions of barrels of oil and trillions of cubic feet of gas but were unable to recover the large majority of those reserves because the completion technology available to the industry during that time was not effective in the recovery of hydrocarbons from low quality reservoirs thereby leaving those reserves for the "next generation" of producers to recover with advanced technology such as under balanced horizontal drilling "UBHD".

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