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Izlaganje na znanstvenom skupu *

DRILL BITS FOR HORIZONTAL WELLS

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Key-Words: Horizontal well, Drainhole, Drill bit

This paper underlines the importance of the correct drill bit application in horizontal wells. After the analysis of the peculiarities of horizontal wells and drainholes drilling techniques, advantages and disadvantages of the application of both roller cone and fixed cutters drill bits have been discussed. Also, a review of the potential specific features useful for a correct drill bit selection in horizontal small diameter holes has been highlighted. Drill bits for these special applications, whose importance is quickly increasing nowadays, should be characterised by a design capable to deliver a good penetration rate low WOB, and, at the same time, be able to withstand high RPM without premature cutting structure failure and undergauge. Formation properties will also determine the cutting structure type and the eventual specific features for additional gauge and shoulder protection.

Ključne riječi: Vodoravna bušotina, Bočna drenažna bušotina, Bušaće dlijeto

Rad naglašava značenje uporabe odgovarajućih dlijeta u vodoravnim bušotinama. Nakon analize osobitosti tehnologije izrade vodoravnih i bočnih drenažnih bušotina, razmotrene su pogodnosti i nepogodnosti uporabe bilo žrvanjskih dlijeta, bilo tzv. kompaktnih, tj. dlijeta s nepokrenim sjekačima. Također, naglašeno su prikazani potencijali osobitih oblika pogodnih pri odabiru dlijeta za izradu vodoravnih bušotina malog promjera. Dlijeta za ove posebne namjene, čije se značenje u suvremenim uvjetima brzo povećava, karakterizirana su konstrukcijama koje omogućavaju velike napretke bušenja uz mala opterećenja dlijeta, a istovremeno izdrže i velike brzine okretanja bez brzog habanja radnih površina i bokova. Osobitosti bušenih stijena također određuju odabir strukture radnih površina i možebitne posebne oblike zaštite bokova dlijeta.

Introduction

Hydrocarbon production from horizontal holes is a well known concept since a long time. Several wells were drilled some 60 years ago in the former Soviet Union, but problems related to directional control and the absence of an adequate drilling technology, together with economic reasons, caused a drop of interest in this subject. At the end of the seventies,under the push of high oil prices, the industry started to re-examine the economical aspects of horizontal well projects, stimulating and financing the research. Today, the situation has changed, and drilling technologies have evolved rapidly, causing a dramatic upsurge in horizontal drilling activity; in the last few years, thousands of horizontal wells have been economically drilled around the world.

Basically, horizontal wells are drilled to enhance reservoir contact, in order to increase well productivity, especially when reservoir bedding planes are vertical. The main difference between horizontal and vertical wells is that the productivity of horizontal wells depends upon the well length, and well length is related to the drilling technique used to drill the well. It is important to recall the differences between the two terms "horizontal well" and "drainhole": the first one indicates a new well drilled from the surface, whose path is turned into horizontal; drainholes (or "laterals") are horizontal sections normally drilled from an exisitng well. Horizontal wells can be classified into four categories, dependently on the drilling technique adopted, which determines the turning radius, i.e., the radius required to turn wellpath from vertical to horizontal. The four categories are the following (Fig. 1):

1. **Ultrashort radius**: turning radius is below 1 m; build up ratio is 40 ° to 60 °/0.30 m.
2. **Short radius**: turning radius is 6 to 12 m; build angle is 2 ° to 5 °/0.30 m.
3. **Medium radius**: turning radius is 100 to 250 m; build angle is 6 ° to 20 o/30 m.
4. **Long radius**: turning radius is 300 to 900 m; build angle is 2 ° to 6 °/30 m.

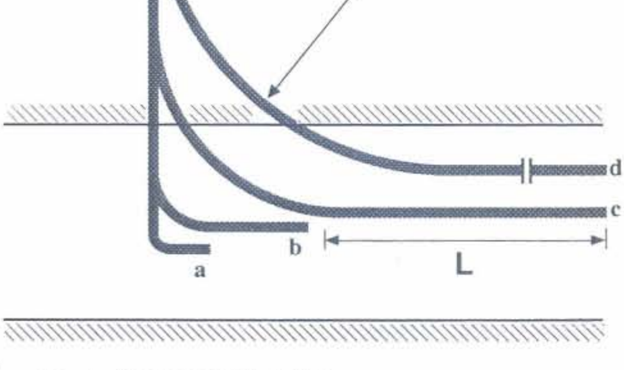

Fig. 1. Horizontal well profiles:
a) Ultrashort Radius, R=0.3 - 1.0 m, L=30 - 60 m
b) Short Radius, R=6 - 12 m, L=30 - 300 m
c) Medium Radius, R=100 - 250 m, L=300 - 1500 m
d) Long Radius, R=300 - 900 m, L>1500 m

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Driling Conditions and Bit Requirements

Apart from the formation type, the proper drill bit application in horizontal wells (or drainholes) depends mainly upon type of drilling technique; on the other hand, the required wellpath (depending mainly on reservoir geology and geometry) determines the drilling technique, which in turn will affect drill bit applications.

Common to all horizontal wells is the borehole diameter of the non-vertical section, which is generally a small diameter hole. Most common hole size ranges from 3-3/4" to 6-1/4" (to a maximum of 12-1/4" for long radius wells); to a certain extent, this will be one of the problem of drill bit application. Small diameter bits are the most critical as far as life on bottom and performances are concerned.

Another aspect of horizontal wells is represented by drilling parameters, which are strictly dependent upon the horizontal drilling method; low Weight On Bit (WOB) and high Revolution Per Minute (RPM) are typical of most of the techniques. The directional section of the hole causes the drillstring to contact the borehole wall in many points, increasing torque, drag and reducing drastically the weight available on bit. High RPM are due to the use of downhole motors (generally, Positive Displacement Motors, PDM); RPM can range from 100÷150 (rotary table and/or slow speed motors) to 500 and more (turbines). In case of abrasive formations or formations characterised by low drillability, high RPM, together with unusual load geometry, can cause severe wear on bits.

A fundamental drilling requirement in all horizontal wells is represented by the absolute necessity of not leaving any type of junk in the hole, since the standard fishing and milling operations are not possible in the horizontal section. A junk in the hole before the well target means, most of the times, the forced abandonment of the already drilled horizontal section.

As a result of extensive differences in drillability of formations encountered, a large variety of bit types is required. Because the drillability of each formation requests a bit type which combines various factors of design, each type must be designed for a specific purpose. In the light of the above, in order to optimise overall drilling performances of the horizontal section, the most appropriate drill bit should be characterised by a design capable to deliver a good penetration rate under low WOB, and, at the same time, be able to withstand high RPM without premature cutters and/or bit structure failure. A special attention is needed to design features that can help to maintain cutters effective also in high RPM applications, which induce, most of the times, accelarated wear. Formation properties will then determine the cutting structure type and the eventual specific features for additional gauge and shoulder protection, to ensure an adequate bit life on bottom.

Roller Cone Bits

Roller cne bits, also known as rock-bits, are characterised by the cutting structure located onto three cones, free to rotate independently one from each other: cone rotation is dictated bu cutters indentation on bottomhole pattern. WOB and RPM are supported by three bearings, usually sealed friction (or roller) with greasy lubrication, onto which the cones are assembled. Typical cutting structures of rock-bits are the "milled tooth bits" (steel tooth cutters hardfaced with special tungsten carbide compouns) and the "insert bits" (tungsten carbide cutters pressed outside the cones). Chipping and crushing are the primary bit action on bottom, gouging and scraping being only a secondary issue.

Rock-bits are characterised by a high number of mechanical elements (cutters, cones, bearing, seals, lubrication system, etc.). Inasmuch as every element of the bit must be confined within circle representative of the hole diameter, the size of each is necessarily restricted. This might be detrimental to overall mechanical properties of the bit itself. Applications in horizontal holes must take in account the possible problems of a premature bit failure, with the eventual loss of some part of the bit downhole. The situation is critical in horizontal holes, where slim bits (<6-1/4") are required: the small diameter decreases the reliability of bearing parts, especially when high RPM are expected (Fig. 2). Despite of this limitation, commercially available sizes start from 3-1/2" (two-cones bit) to 3-7/8" and 4-3/4" (Fig. 3).

Some very good rock-bit applications have been recorded in 6-1/8" size, for the horizontal drilling of very hard and abrasive foramtions; for this purpose, the bits were re-designed with a very robust cutting structure, characterised by tungsten carbide inserts cladded with polycrystalline diamond, to enhance wear resistance. In this case, penetration rate and gauge wear was competitive with performances

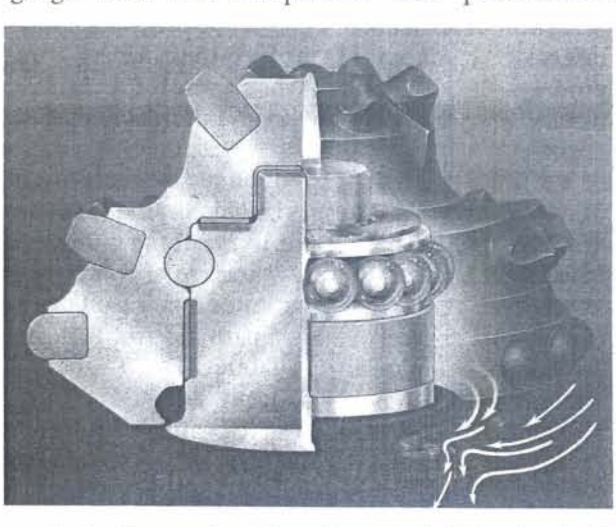

Fig. 2. Cross section of precision turned friction bearing for slim hole rock-bits. (Source: Smith International)

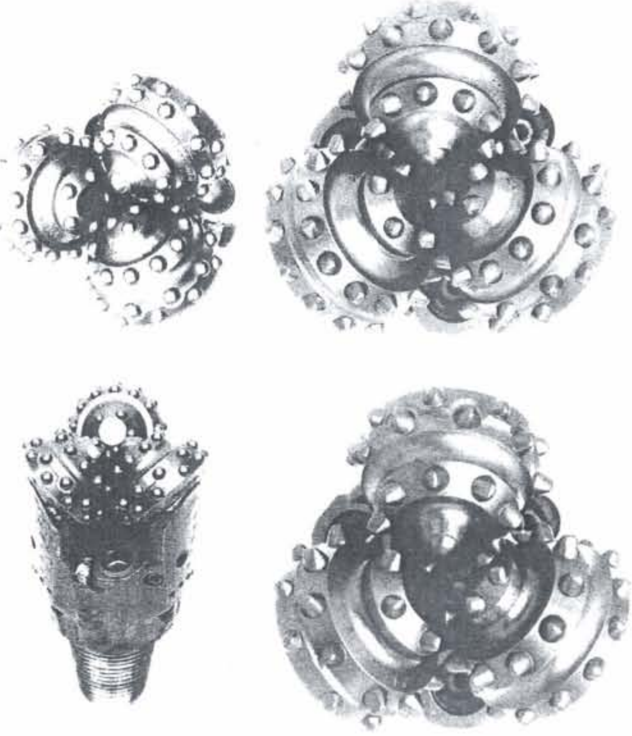

Fig. 3. Slim hole roller cone bit with diamond reinforced gage cutting structure. (Source: Smith International)

shown by fixed cutters bits (in fact, hard abrasive formations require more crushing than scraping). Other fair applications have been shown in brecciated and fractured formations, since rock-bit rolling action helps to get past fractures without increasing abnormally the torque or even stalling the bit.

Anyhow, the best rock-bit applications can be seen mainly in cement milling jobs and/or build-up section drilling, especially if hole diameter is not less than 5-7/8". They are not recommended for heavy drilling operations, where high speed PDM are required. The optimum RPM range for roller cone bits must not exceed rotary table RPM. A good point for rock-bits, if properly used, might be the price, which can be up to 10 times cheaper than the one of the equivalent fixed cutters bits.

Fixed Cutters Bits

The basic concept of fixed cutters bits is to design a single-piece drilling head onto which cutters can be placed, accordingly to particular layouts derived from theories, validated by rock failure models, and to formations behaviour with respect to drilling action. No moving parts are present on such bits. Gouging and scraping are the only actions on bottom: in fact, crushing is the most undesirable event, leading to premature cutters failure, and it is prevented by an appropriate bit design. Since the only cutting action is then referred to formation breakage by shear, these drill bits are also known as **shear bits**: they can be classified into the four following categories, referred to the type of cutters adopted, all based on natural or synthetic diamond technologies:

1. Natural diamond bits.
2. Polycrystalline Diamond Compact (PDC) bits.
3. Thermally Stable Polycrystalline (TSP) diamond bits.
4. Impregnated diamond bits.

The basic features that make these types of bits extremely suitable for most of horizontal drilling applications are: a) the peculiarity of not loosing junks in the hole; b) the higher durability on bottom; c) the superior resistance to wear, due to diamond-based ultra-hard cutters. The following are the main advantages and disadvantages of the above four categories in horizontal drilling applications.

1. Natural diamond bits, the first fixed cutters bit introduced in the drilling industry, are constituted by a shaped tungsten carbide matrix body on which natural diamonds are set (2 to 15 stone per carat size). A central fluid port and waterways are established by design, and it is not possible to change the Total Flow Area (TFA) of the bit; this could be a limitation in some PDM application. Basically, these bits are designed for hard rock drilling, where other tools suffer from very early cutter wear; the scarce cutter exposure do not allow to get particularly high penetration rates. Recent technological advances in other types of diamond tools are causing the obsolescence of these bits, which can find anyhow some application in horizontal drilling as well.

2. PDC bits are the most widely known fixed cutters bits. PDC was introduced in 1973, and drill bits with PDC cutters became commercially available in 1974. PDC cutter embodies a layer of "sintered" diamond powder (polycrystalline diamond) for wear resistance, backed up by tungsten carbide (compact) for mechanical resistance. The cutter can be shaped in such a way to resist to high exposure, allowing to get penetration rates comparable or higher than the ones of roller bits, if the formation is appropriate. Moreover, PDC cutters life far exceed the one of other hard materials (e.g. diamond is 10 times harder than steel and twice as hard as tungsten carbide), ensuring a longer bit life on bottom. PDC bits usually have good applications when long times on bottom are required, or when high RPM drilling (turbine or PDM) is expected. They are most effective in unconsolidated or poorly consolidated sediments (sands and silts), but can be used also in moderately strong formations (silty clays, soft shales, porous carbonates and evaporites). PDC are less effective in hard and cemented formations (abrasive sandstones, chert, dolomite).

Fixed cutters, interchangeable nozzles, long lasting cutters, high penetration rates and wide availability of bits design make PDC bits the best tools for applications in horizontal drilling. Moreover,

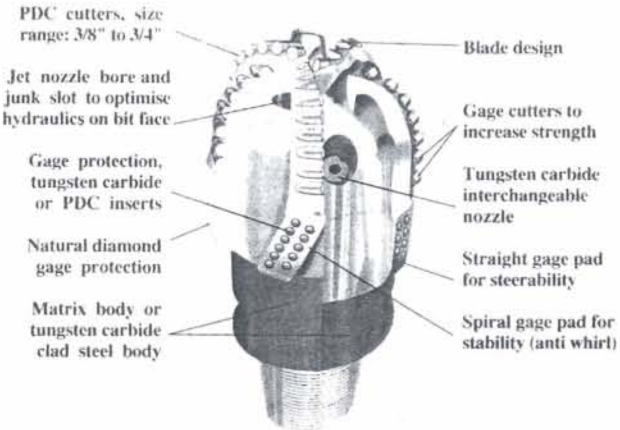

Fig.4. Main features of PDC bits.

numerous features are easily available to make the bit suitable even for the worst drilling conditions. They can be designed with a crown profile and a gauge length appropriate for the necessity of directional control (i.e., bits more sensitive to steering, or able to hold the wellpath straight also under high RPM), can be manufactured with a matrix body to improve wear resistance, can be fitted with a variety of additional gauge protection (carbide inserts, PDC studs, natural diamonds) and can be designed with blades to improve penetration (Fig. 4). PDC are also ideal for heavy applications, from low speed/high torque motors even to turbines. The only problems, common to both vertical and horizontal drilling, are related to the correct bit selection for given formation and to bit whirl, both increasing the probability of early cutter breakage. At present, even though PDC manufacturers offer several bits with "*anti-whirl*" feature, no one design seems adequate to prevent whirl in all situations. PDC bits are manufactured in all sizes, from 3-1/8" to 17-1/2". The smallest commercial PDC cutter is 3/8" diameter, which makes the cutter-to-bit diameter ratio quite

Fig. 5. Typical small diameter PDC bits, blade design, flat profile. (Source: Hughes Christensen)

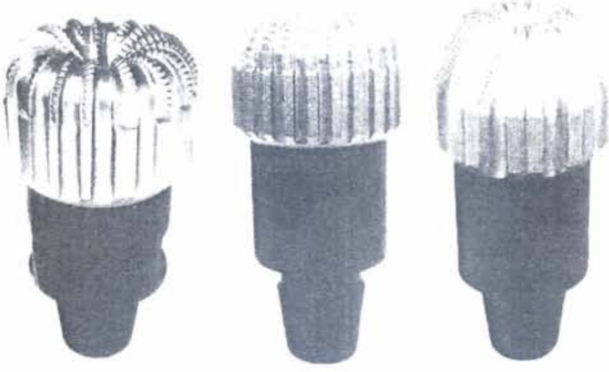

Fig. 6. Typical TSP bit, radial flow fluid courses (double cone and short parabolic profile). (Source: Hughes Christensen)

high, allowing to place only few cutters on slim hole bits (Fig. 5).

3. TSP bits (Fig. 6) consist of a shaped matrix body on which thermally stable diamonds are arranged. Thermally stable polycrystalline diamond is an artificial material produced by diamond grits, and possesses a higher resistance to thermal degradation than natural diamond. Moreover, it can be appropriately shaped (most of the times, in a self-sharpening mode), and cutters can tolerate a higher exposure on the bit face than the natural diamonds. TSP cutters are baked into the matrix, enabling them to effectively shear also hard rock formations while withstanding the high temperature developed by friciton while drilling (diamond cutting edge stability up to 1200°C). TSP offers the same advantages of PDC, but extends the field of application also in moderately abrasive formations with high compressive strength: these formations are not PDC drillable because of the increased fricitonal heat that exceeds PDC thermal stability. Likewise to natural diamond bits, also TSP central fluid port and waterways are established by design, and it is not possible to change the bit TFA. Obviously, it is possible to design the bit with all features for additional gauge protection and stability/steerability options.

TSP bits present the same very good applications of PDC bits in horizontal wells, especially in the drilling of abrasive section. The possibility of loosing junks in the hole (i.e., cutters) is virtually eliminated. They are available in all sizes, up to 17- 1/2", with a preference towards slim hole bits. Their cost is slightly higher than the one of PDC bits.

4. Impregnated bits (Fig. 7) are speciality tools who find application in drilling of ultraabrasive formations, where standard bits cannot drill. The bit is constituted by a rounded crown profile drilling head, manufactured with sharp, grit-size diamonds sintered directly into the bit matrix in a high temperature-high pressure process. The cutting structure is thus made of a very hard "abrasive" matrix characterised by thousands of cutters with no macroscopic exposure; formation is drilled with a mechanism more similar to abrasion than pure shear. Impregnated bits can find some applications in the horizontal drilling of very hard formations, and have no particular drawbacks, apart from low penetration rate. Hydraulic is permanent, usually with radial flow fluid courses.

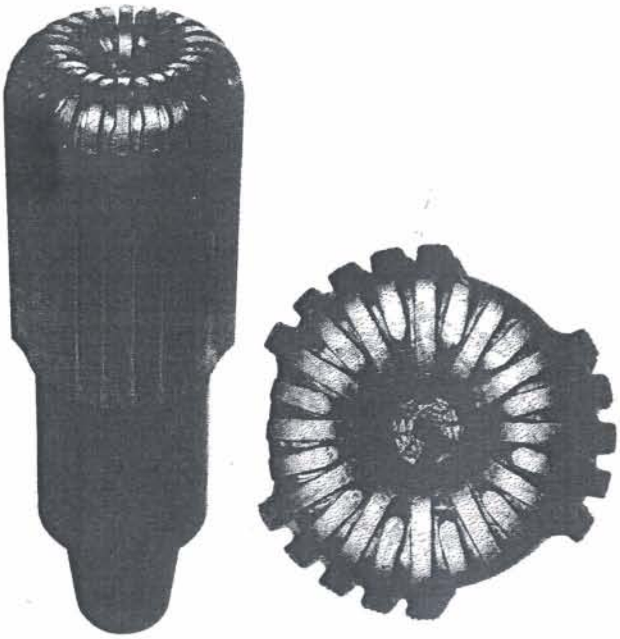

Fig. 7. Impregnated bit, rounded crown profile, radial fluid flow courses. (Source: Hughes Christensen)

Conclusions

Horizontal drilling is today a widespread, reliable and proven tecnology which can help to improve project economics by reducing the number of wells required to drain the reservoirs. Advances in horizontal drilling have also cut the costs, enlarging applications also to marginal fields. The correct drill bit application is thus of paramount importance to optimise overall drilling performances and to increase the efficiency of the planned drilling operations.

Horizontal sections are characterised by small diameter holes (usually <6-1/4"), while drilling parameters very often show low WOB and high RPM. A fundamental requisite of horizontal wells is represented by the categorical necessity of not leaving any type of junk in the hole, since fishing and milling operations are not possible in the horizontal section. A junk in the hole before the well target means the forced abandonment of the already drilled horizontal section.

The ideal features of a drill bit for horizontal application would be a cutting structure capable to deliver high penetration rates under low WOB, and, at the same time, a design able to withstand the extreme wear condition imposed by high RPM. A good directional control might be required to the bit as well, together with the ability to stay in gauge for the entire run. Finally, long life on bottom is essential, to improve performances and to reduce difficult trips. All the above features are today fairly available on most of the commercial drill bits, both roller cones and fixed cutters. For a given horizontal drilling project, involving a particular drilling technique, characterised by formation type and well planning, it is possible to find the most appropriate bit for a specific application. Recent advances in hard materials, hydraulics and cutter geometry, if have not reduced the still high prices of some special tools, have allowed to drill longer and more effectively in a greater number of formations.

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