EXTENDED-REACH DRILLING: EXPLORATION STRATEGY FOR THE YURHAR GAS FIELD BENEATH THE TAZOVSKAYA AND OBSKAYA BAYS

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Russia
Expected gas resources of the hydrocarbon fields beneath the Obskaya and Tazovskaya Bays are estimated over 3 trillion cubic meters. In this respect, the unique experience of the “NOVATEC” Joint Stock Company in the commercial development of the difficult-of-access reservoirs of the multi-pay Yurhar oil and gas-condensate field is very valuable. The innovative technical and technological solutions adopted at the I.M.Gubkin Russian State University of Oil and Gas provided for successful construction and putting into operation of the first line of horizontal extended-reach wells beneath the Tazovskaya Bay.
# TABLE OF CONTENT

Abstract

1. Introduction

2. Novel drilling methods

3. Application of the proposed methods to production

4. New solutions for the arctic shelf field development

5. List of tables

6. List of figures
1. INTRODUCTION

The world experience in extended-reach well (ERW) construction in England, Argentina, China, Norway, Denmark and other countries has confirmed their ecological and economic efficiency. At the Wytch Farm oil field (England), British Petroleum and Schlumberger have drilled a well of 10658 m measured depth (MD) with 10114 m departure from vertical. Hundreds of wells have been constructed with departure from vertical in excess of 5000 m. Works are carried out concerned with feasibility study of construction of wells with departure from vertical up to 20000 m.

The term ERW suggests the well with the departure / true vertical depth (TVD) ratio $\geq 1$. It is difficult or almost impossible to apply conventional techniques to complete ERW in reservoirs composed of incompetent and loose sands occurring directly beneath loose rocks prone to borehole collapse and key-seating. To stabilize the borehole walls, it is necessary to use expensive drilling muds, run more casing strings or to give up the idea of tapping the reservoir at the location which is considered optimal from the point of view of the field development or exploration.

2. NOVEL DRILLING METHODS

To increase the reliability of ERW construction and to reduce the labor input and material expenses, the novel drilling method has been introduced (Fig. 1). The vertical section 1 is drilled within the interval $I$ of incompetent rocks prone to key-seating and borehole collapse. The inclination angle is built which should not exceed the critical value for the given geological conditions that otherwise might lead to infringement of the borehole stability. When drilling the section 3, the inclination angle is maintained constant up to the interval $III$ of competent rocks which lie beneath the bottom of the producing formation $II$. Then, the inclination angle is built to 90° and the horizontal section 4 is drilled for the distance required to tap the producing formation at the planned point 6, after the inclination angle is built updip in excess of 900. Fig. 1 shows the aqueous part 8 of the Tazovskaya Bay 25 m in width which overlies the gas reservoir 9. The major natural gas reserves are accumulated in the Cenomanian deposits at the depth of 1200 m. The geologic profile up to the top of the producing formation is represented by permafrost clays, sands, opoka-type and marine clays. The producing formation is composed of incompetent sands prone to washout and collapse, the underlying horizon – of more stable calcareous silt sandstones. To tap the Cenomanian deposits, e.g. those of the Yurhar field, the departure from the border of the water-protection zone should be in the order of 1.5 – 5 km. Three drilling options are possible.

Fig. 1. ERW vertical profile

1. The inclination angle built to 82-89° and maintained in plastic and prone to balling marine clays of the Kuznetsovskaya sedimentary suite and near-roof rocks with possible susceptibility to key-seatimg, collapse and shows of gas.

2. Drilling of a horizontal borehole in incompetent productive sandstone prone to shows of gas and other complications.
3. Drilling of a long horizontal borehole in competent calcareous silt sandstones 20-40 m beneath the bottom of the producing formation and tapping the producing formation updip at the planned point.

The third option permits to increase the reliability of ERW drilling by reducing the slant hole length within the incompetent rock interval.

As concerns the absence of competent rock intervals beneath the bottom of the producing formation, the novel approach has been proposed to provide reliable ERW drilling to tap the producing formation located beyond the bounds of the drilling rig, in the section of unconsolidated beds prone to borehole collapse and key-seatng, by optimization of the borehole length to the point of tapping the producing formation and prevention of uncovering the water-bearing zone of the reservoir, optimization of the well trajectory to the planned point of tapping in the given corridor, taking into account the dip angle.

Distinct features of ERW:
- commensurability of the subhorizontal borehole with the field dimensions;
- location of the drilling rig beyond the field confines;
- considerable dependence of accuracy of the borehole trajectory upon the reservoir geometry: its thickness, dip and updip angles.

The proposed ERW drilling technique is applied in the following way. In incompetent rocks prone to key-seating and borehole collapse, the vertical section is drilled from the rig A, B or C. When drilling the initial deviation section 1-2, the inclination angle is built to the extent not exceeding the critical value for the given geologic conditions that might infringe the borehole stability. The inclination angle is then stabilized along the trajectory corresponding to the minimal possible borehole length within the section 2-3 thus providing the least borehole length in loose rocks at the expense of tapping the producing formation at the point 3 of the anticline which is the nearest to the wellhead 0 of the well (Fig. 2a). The inclination angle in the section 3-4 is built to 90° while in the section 4-5 it is kept > 90°. The subhorizontal section 5-6 is drilled for the length which, after correction of the section 6-8 trajectory, provides exit to the specified corridor \( h_{min} \) of the producing formation \( H \) at the planned point 8.

To prevent exposing the water-bearing part of the formation \( III \), the minimal acceptable vertical distance \( h_{min} \) from the point 3 of tapping the formation top to gas-water contact (GWC) in a gas reservoir or to water-oil contact (WOC) in an oil reservoir is (see Fig. 3a):

\[
h_{min} \geq R(1 - \sin \alpha) + h + h_w,
\]

where \( R \) - the specified inclination radius in the section 3-4 when building the inclination angle up to 90°;
\( \alpha_c \) - the inclination angle at the point 3 of tapping the formation II top;

\( h_j \) - maximum possible error of vertical position of the point 3 of tapping the formation top;

\( h_w \) - maximum possible error of the vertical location of GWC or WOC.

\[ \text{Fig. 3. The borehole trajectory that prevents uncovering the water-bearing part of the reservoir} \]

Drilling the production section 8-9 of the formation II located in the descending part of the anticline opposite to the drilling rig is preceded by drilling the horizontal or subhorizontal section 4-6 directed to the point 6 located from the starting point 8 of the production section 8-9 at the distance \( A_H \) which is determined by the formula (see Fig. 3b):

\[ A_H = R (\cos \alpha + \sin \theta) \]

where \( R \) - the specified inclination radius in the section 6-8;

\( \alpha \) - the inclination angle at the point 6;

\( \theta \) - the formation dip angle.

3. APPLICATION OF THE PROPOSED METHODS TO PRODUCTION

Reviewed below is the example of executing the proposed method of drilling to tap the Cenomanian gas reservoir PK1.2 with the GWC depth at 1200 m (\( H_{GWC} = 1200 \text{ m} \)). The updip and dip angle of the top of the producing formation \( \theta = 5^0 \). The distance from vertical, through the wellhead, to the point of the intersection of the producing formation and GWC \( A = 1000 \text{ m} \) (point D in Fig. 2c); the distance to the starting point of the producing section – 2050 m; the distance to the end of the producing section – 2550 m. The length of the vertical section – 270 m, the inclination radius of the initial deviation section 1-2 \( R_1 = 382 \text{ m} \); the radius of the inclination angle build to 90\(^0\) section 3-4 \( R_2 = 286.5 \text{ m} \). The maximum possible error of tapping the top of the formation \( h_j = 2 \text{ m} \) and of location of GWC \( h_w = 2 \text{ m} \). The critical deviation angle exceeding which can result in loss of the borehole stability beyond the reservoir zone, \( \alpha_c = 65^0 \).
Let us determine the designed bottom hole deviation \( A_{\text{des}} \) from vertical at \( \alpha_{cr} = 65^0 \) (table 1).

Table 1. Calculations for the designed bottom hole deviation \( A_{\text{des}} \) at \( \alpha_{cr} = 65^0 \)

<table>
<thead>
<tr>
<th>Section profile, m</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>( a_{v,1} = 0 )</td>
<td>( h_{v,1} = 270.0 )</td>
</tr>
<tr>
<td>Build of inclination angle</td>
<td>( a_{v,2} = R_{1} (1 - \cos \alpha_{cr}) = 382 \times (1 - \cos 65^0) = 220.6 )</td>
<td>( h_{v,2} = R_{1} \sin \alpha_{cr} = 382 \times \sin 65^0 = 346.2 )</td>
</tr>
<tr>
<td>Rectilinear</td>
<td>( a_{v,3} = h_{v,3} \tan \alpha_{cr} = 552.8 \times \tan 65^0 = 1185.5 )</td>
<td>( h_{v,3} = h_{v,2} - h_{v,1} = 1169 - 270 - 346.2 = 552.8 )</td>
</tr>
<tr>
<td>Total:</td>
<td>( A_{\text{des}} = a_{v} + a_{v1} = a_{v2} = 0 + 220.6 + 1185.5 = 1406.1 )</td>
<td>( h_{\text{top}} = 270.0 + 346.2 + 552.8 = 1169 )</td>
</tr>
</tbody>
</table>

At \( A_{\text{des}} = 1406.1 \) m the thickness of the producing formation PK1-2 (the distance between the formation top and GWC) is \( h_{f} = (A_{\text{des}} - A) \tan \alpha_{cr} = (1406.1 - 1000) \tan 50^0 = 35.5 \) m and the borehole trajectory finds room in the formation PK1-2 without uncovering GWC, thus the required condition is met:

\[
\frac{h_{f}}{h_{\text{min}}} > 286.5 (1 - \sin 65^0) + 2 + 2 = 27 + 4 = 31 \text{ m}.
\]

The proposed method of ERW construction which takes into account the rock instability of the Berezovskaya and Kuznetsovskaya suites has been first applied at the horizontal gas well No 106 of the Yurhar oil and gas-condensate field beneath the water area of the Tazovskaya Bay. The top of the producing formation was tapped at the depth 1228 m at the inclination angle 66°.

The maximum inclination angle 95° was built at the depth 1520 m. 727 m of hole were drilled in the producing formation composed of more competent rocks as compared to the overlaying rocks, comprising 37% of the overall well length. The record horizontal borehole length in a gas well drilled to the Cenomanian deposits has been achieved. The producing section was drilled within the specified corridor of the reservoir, the production string perforated in 1792-1955 m interval, near the top of the producing formation.

The comparison of the overall drilling speed as determined by the inclination angle at the top of the Kuznetskaya suite comprising 4 horizontal wells drilled in equal geologic and technical-technological conditions showed indisputable advantages of the introduced ERW construction method.

Owing to such ERW drilling method, the risks of complications and accidents, construction steel intensity and casing string consumption are reduced. Besides, the updip subhorizontal borehole in the producing formation enhances the effect of the well self-cleaning from the mechanical debris and water brought from the borehole environment by the gas stream.

Basing upon the gained experience, further projects have been initiated to drill the second line of ERW at the Yurhar field beneath the water area of the Tazovskaya Bay with the view of reaching the annual gas production rate of 30 billion m³.

4. NEW SOLUTIONS FOR THE ARCTIC SHELF FIELD DEVELOPMENT

At the same time, the significant remoteness of the fields from the water-protection zone on land, in aqueous environment of rivers and on the shelf, especially in the arctic sea conditions, necessitates to apply ecologically unsafe means, e.g. the formation of the ice-resistant complex that comprises well drilling during the ice-free period from a self-elevating floating offshore unit, withdrawal of the unit from the site, construction of the ice-resistant foundation and subsequent field development. The disadvantage lies in the necessity of constructing and long-term exploitation of the expensive ice-resistant foundation in ecologically sensitive offshore environment and the seasonal mode of well drilling from the self-elevating floating unit. The ice-resistant complex designed for oil and gas field development on the arctic shelf must envisage an ice-resistant foundation rigged with operational and power equipment, as well as fit with the accommodation block-module. On the arctic shelf and in shallow water conditions the given method is quite expensive and unrealizable because of vulnerability of
the ecosystem. Problematic is feasibility of using the subsea technologies of hydrocarbon field development in shallow water conditions which require designing special technical means for well drilling and application of protective structures to safeguard underwater production facilities from hummocked ice, fishing boats, cargo vessels and transport ships.

Radical technical solutions have been found, alternative to all other previously known technologies of hydrocarbon field development in conditions of extensive water-protection zones, shallow rivers, bays and the arctic sea shelf. The horizontally directed well (HDW) design opens principally new possibilities of construction and production of wells by combining the functions of well drilling, workover, stimulation and hydrocarbon transportation.

The field development using HDW is implemented as follows. The field is located beneath the water-protection zone or the arctic shelf water body where it is impossible to install the drilling or production equipment (Fig. 4). The drilling rig and the cellar pit are installed on the border of the water-protection zone. The horizontal conductor borehole is drilled applying the trenchless method or a trench is routed prompt to the ground surface and (or) the water body floor at a distance providing protection of the well from hummocked ice, fishing boats, cargo vessels and transport ships. Simultaneously, laying and (or) pulling of the welded pipe stalk for the horizontal conductor is performed. The end of the stalk is bent downward at the specified inclination angle at the section where the conductor, pipes of smaller sizes are preliminarily installed as part of the surface and (or) intermediate casing strings with protectors which provide considerable friction reduction and centering. Also installed are systems of telemetry and technological control of the tubing-casing annular space.

The horizontal conductor borehole is drilled or built according to the project azimuth at the distance that provides for drilling the directional borehole from the bent downward and turned to the specified inclination angle section 7 and tapping the producing formation at the planned point. Drilling from the bent downward and turned to the specified inclination angle section 7 is executed using the bottomhole assembly with the bit and reamer run through the surface and intermediate casing strings which have been preliminarily installed in the horizontal conductor hole. Drilling the directional borehole is accomplished simultaneously with the surface reaming, driving the surface casing string by adding its length to the target depth, and cementing operations. The intermediate casing is run to the surface casing shoe to provide for the drilled cuttings transport to the surface. The borehole is then drilled and reamed, with stepwise running and cementing the intermediate casing. From under the shoe of the intermediate casing string, the directional or horizontal borehole is drilled for running the production string or liner. After installation of the downhole equipment for hydrocarbon production and perforating the section of the production string, the well is tested and production of hydrocarbons from the reservoir is commenced. To provide for trouble-free drilling and (or) laying the horizontal conductor borehole by trenching during the period of maximum freezing of the water body, the water body floor ground is refrigerated to the depth within the project azimuth.
To produce a part or the whole of the hydrocarbon reservoir from a single wellhead, the horizontal conductor is made of a large diameter pipe that permits to install several surface strings with preliminarily outfit lateral and central exits from the horizontal conductor to drill boreholes with reaming to required alignment tolerance for mounting conductors.

Owing to such application of the hydrocarbon production method using the horizontal conductor, development of fields previously inaccessible for installation of drilling and production facilities, distant at tens of kilometers inward the nature protection zones and areas (on the shelf of arctic seas with complicated ice conditions, the Obskaya and Tazovskaya Bays etc.) is now possible; the number of cluster well foundations, offshore field drilling and production platforms is reduced; horizontal conductors can be used for commingled production of hydrocarbons from wells drilled from a floating rig during the interglacial period or from ice.

As compared to the stationary platforms, subsea well completion systems and the floating technical means, the proposed method has the following advantages:

- utilization of the horizontal conductor as a structure for well drilling, workover and hydrocarbon transportation;
- independence of hydrometeorologic, ice and geological conditions of the continental shelf;
- accelerated bringing of the field to the planned production capacity on the account of using the horizontal conductors preinstalled during the winter period;
- the year-round construction of horizontal conductors in conjunction with drilling-in the production end of wells from the floating rig;
- high flexibility of the horizontal conductor technology owing to the possible quick replacement of the technological equipment (e.g., when switching from flowing to gas-lift well operation);
- exclusion of expenses to replace one technological platform by another during long-term field development;
- possibility of all-seasonal development of fields located in regions with unfavourable hydrometeorologic conditions (e.g., in arctic seas involving ice fields, hummocks, icebergs) etc.

Thus, the subsea and surface well completion are not the only methods of the Arctic shelf field development.
5. LIST OF TABLES

Table 1. Calculations for the designed bottom hole deviation \( A_{\text{des}} \) at \( \alpha_{cr} = 65^0 \)

6. LIST OF FIGURES

Fig. 1. ERW vertical profile

Fig. 2. Vertical and horizontal profiles of the anticlinal structure

Fig. 3. The borehole trajectory that prevents uncovering the water-bearing part of the reservoir

Fig. 4. Design of the well with the horizontal conductor