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Technological solutions for drilling a trap intrusion section on the Srednebotuobinskoe oil gas condensate field, East Siberia

Yevgeniy V. Tuzov[a], Tatiana Yu. Kutuzova[b],
[a,b]LLC Taas-Yuryakh Neftegazodobycha, Irkutsk, Russia
Corresponding author: Yevgeniy V. Tuzov, TuzovEV2@tyngd.rosneft.ru

Abstract. One of the largest trap intrusion provinces, Siberian traps, is located in the East-Siberian Platform in Russia. A trap intrusion zone usually has abnormally low reservoir pressures and natural fractures. Consequently, trap drilling is associated with fluid losses that can be catastrophic. The section of trap intrusion is a part of a Ø 174 mm production casing section of the Srednebotuobinskoe field. The basic well design of this section also includes the Osinsky horizon, which features an abnormally high reservoir pressure zone. The latter creates incompatible with drilling conditions environment due to the presence of catastrophic loss zones in traps. Time spent on drilling a trap intrusion zone accounts for up to 30 % of the total well drilling time. The abovementioned geological issues in directional wells become the key topic in solving it. The method to resolve this issue is an integrated approach employing all the technologies and technical facilities aimed at finding a technological solution. First of all, in order to optimize the well construction cycles and reduce the complications, all the wells were classified in three categories as per the type of behavior in trap intrusion. This allowed to work out multi-level activities, that depended on severity of losses and non-operational time spent on drilling through this section. An alternative well design was developed and trialed on several wells, which showed positive results on decreasing non-productive timing. The main concept of this design was significantly different from the basic well design that was used in the past on the Srednebotuobinskoe field. The main difference was isolation of traps from the high pressure Osinsky horizon lower section with a Ø 245 mm casing string, which allowed safe splitting of two incompatible drilling zones. The economic effect of this solution allowed saving of up to 10.4 days or 15 % of the construction time in the wells of first category. These results were reviewed at the Technical Committee of the Company and agreed to implement the alternative well design on first category wells on the Srednebotuobinskoe field. In addition, for the rest of well categories the Drilling Team has produced and successfully implemented the preventative measures that allowed drilling through traps with lost circulation material. It is worth to mention that this method assumed a by-passing mud-cleaning system on the rig to allow building up a solid phase thus stemming the losses while drilling. For all the categories of the wells the Drilling team has selected and trialed different types and designs of drilling bits that would allow drilling hard rock such as dolerite section in traps with minimal number of runs. For the last five years the Drilling team together with the bit producing companies have designed a new type of PDC cutters that would allow to enhance durability as well as improve drilling speed both in dolerite formations and in overlying formations in the Production casing section. The Drilling team has also managed to reduce the number of trips associated with early bit wear decreasing them from five to two runs and create an experimental basis for drilling the entire section of the production casing in one run. From 2019 team continue looking for further solutions that would allow to improve bottomhole assembly elements balancing between durability and drilling rate in different types of formations above and below traps. A range of proposed technological solutions significantly reduced the impact on the well construction performance by preventing and reducing the downhole losses events in the section of trap intrusion on the Srednebotuobinskoe field.

Keywords: well design, lost circulation material pill, cementing, trap intrusion, dolerite, drilling, drilling bit

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РАЗВЕДКА И РАЗРАБОТКА МЕСТОРОЖДЕНИЙ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

Научная статья
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Технологические решения в бурении трапповой интрузии на Среднеботуобинском нефтегазоконденсатном месторождении (Восточная Сибирь)

Евгений Виссарионович Тузов[a], Татьяна Юрьевна Кутузова[b]
[a,b]ООО «Таас-Юрях Нефтегазодобыча», г. Иркутск, Россия
Автор, ответственный за переписку: Тузов Евгений Виссарионович, TuzovEV2@tyngd.rosneft.ru

Резюме. Одна из самых крупных трапповых провинций Сибирские траппы расположена на Восточно-Сибирской платформе. Зона распространения трапповых интрузий, как правило, имеет аномально низкие пластовые давления и естественную трещиноватость, вследствие чего проходка интрузивов сопровождается поглощениями промывочной жидкости вплоть до катастрофических. Участок трапповой интрузии на скважинах Среднеботуобинского месторождения находится в секции эксплуатационной обсадной колонны Ø 174 мм. Базовая конструкция скважин данной секции также включает в себя осинский горизонт, в котором присутствует зона с аномально высоким пластовым давлением, создающая условия, не совместимые с бурением из-за присутствия зон катастрофических поглощений в участке трапповой интрузии. Временные затраты по проходке зон интрузии составляют до 30 % от общего баланса циклов строительства скважин. Вышеизложенная проблематика геологических осложнений в наклонно-направленных скважинах является приоритетной задачей, и методика борьбы с ними представляет собой комплексный подход всех технологий и технических средств, которые обращены к одной цели. Так, для оптимизации циклов строительства скважин и снижения количества осложнений была проведена классификация трапповой интрузии по трем категориям, которая позволила разработать многоуровневый ряд мероприятий по проведению работ в трапповых интрузиях в зависимости от характера поглощений и аварийного времени, потраченного на прохождение данного участка. Была разработана альтернативная конструкция скважин, а также проведены опытно-промышленные испытания по ее применению, которые показали положительный результат по снижению аварийного времени. Основная концепция данной конструкции значительно отличается от принятой базовой конструкции скважин на Среднеботуобинском месторождении. Одной из отличительных особенностей явилось то, что участок трапповой интрузии разделялся от нижнего участка аномально высокого пластового давления осинского горизонта обсадной колонной Ø 245 мм, что позволило разобщить несовместимые зоны бурения. Экономический эффект от применения данной конструкции на скважинах первой категории составил до 10,4 суток или 15 % от всего цикла строительства скважины. На научно-техническом совещании был рассмотрен и оценен эффект от применения альтернативной конструкции на некоторых из кустовых площадок, а также принято решение о тиражировании ее на Среднеботуобинском месторождении. Для остальных категорий скважин был разработан и успешно внедрен комплекс мероприятий по превентивной кольматации поглощающих интервалов в зоне интервала прохождения трапповых интрузий. Следует заметить, что в данный комплекс вошла методика с бурением с наработкой твердой фазы из-за циркуляции в обход системы очистки бурового раствора, что позволило более эффективно проводить кольматацию участка катастрофических поглощений. Для всех категорий скважин были апробированы различные дизайны долот, которые позволили бы проходить участок твердых долеритов трапповой интрузии с минимальным количеством спусков. За последние пять лет бурения технологической командой совместно с производителями долот был подобран и разработан новый тип резцов долот PDC, благодаря чему не только улучшилась износостойкость, но и значительно повысилась скорость бурения как в долеритах трапповой интрузии, так и в вышележащих пластах в секции под эксплуатационную обсадную колонну. Удалось снизить количество спуско-подъемных операций, связанных с ранним износом долота, с пяти до двух и создать экспериментальную основу для поиска возможности бурения всей секции эксплуатационной обсадной колонны в один спуск. С 2019 года ведется подбор элементов рабочей компоновки, который позволил бы сбалансировать и сочетать в себе элементы износостойкости и скорости проходки при бурении различных горных пород, присутствующих в данной секции. В результате введения данного комплекса мероприятий удалось минимизировать возникновение поглощений при прохождении трапповой интрузии на всех кустовых площадках и существенно сократить сроки строительства скважин на Среднеботуобинском месторождении.

Ключевые слова: конструкция скважин, кольматационная пачка, цементирование, трапповая интрузия, долериты, бурение, породоразрушающий инструмент

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Introduction

Trap magmatism is a distinct type of continental magmatism, which is characterized by huge volumes of basalt eruption during a geologically short period (first few million years) over large territories [1]. Several studies are devoted to the geological structure of trap intrusions of the Siberian Platform by M. M. Odintsov, I. I. Krasnova, V. S. Obruchev, V. S. Masaitis, et al. These studies offer several hypotheses regarding trap intrusion characteristics, such as:

– Eruption of traps potentially occurring in uplift conditions with predominantly a central eruption type;

– Ingress of dolerite sills through the monoclinal dip from Kansk-Taseevo depression, which is a localized trap magmatism zone;

– Crystalline basement fault zone;

– Deep magma-conductive faults, which define maximum trap thickness zones, yet do not delineate separate magmatic bodies or elements of their morphology [2].

In East Siberia, within the boundaries of the Srednebotuobinskoe Oil Gas Condensate Field, traps are represented as intrusions in sedimentary deposits. The field is located along the edge of a trap body and has mostly evenly distributed interval thickness yet differing interval depths (Fig. 1). In the Srednebotuobinskoe Oil Gas Condensate Field, trap intrusion thickness varies significantly from one well pad to another ranging between 140 and 450 m along the borehole [3, 4].

Trap intrusion intervals are composed of hard rock, dolerite, which is found in various rock formations. Given the physical-mechanical strength of a trap intrusion: ρ = 2930 kg/m^3, hardness category 100–150, 600–700, abrasiveness category 1–3, medium-to-hard, drilling in the interval has some complicating factors [5, 6]:

– Total losses (Fig. 2);

– A reduced rate of penetration to 0 m/h;

– Critical wear of drilling bits;

– Extra trip to replace polycrystalline diamond compact (PDC) bits with tri-cone bits;

– More extended well construction period as trap intrusions are drilled by tri-cone bits;

– Destroyed and left in hole bit's parts.

A combination of the above factors resulted in significant time lost in drilling such intervals [7, 8]. To optimize drilling in trap intrusion intervals, three categories of traps behavior were identified:

– Wells where losses occurred immediately after penetrating the top of traps, were referred to as Category 1 of trap behavior (10–20 % of the well stock)[1];

– Wells drilled with lost circulation material pill (LCM) without any losses were referred to as Category 2 of trap behavior. Once the hole was cleaned of LCM, however, losses occurred again (70–80 % of well stock);

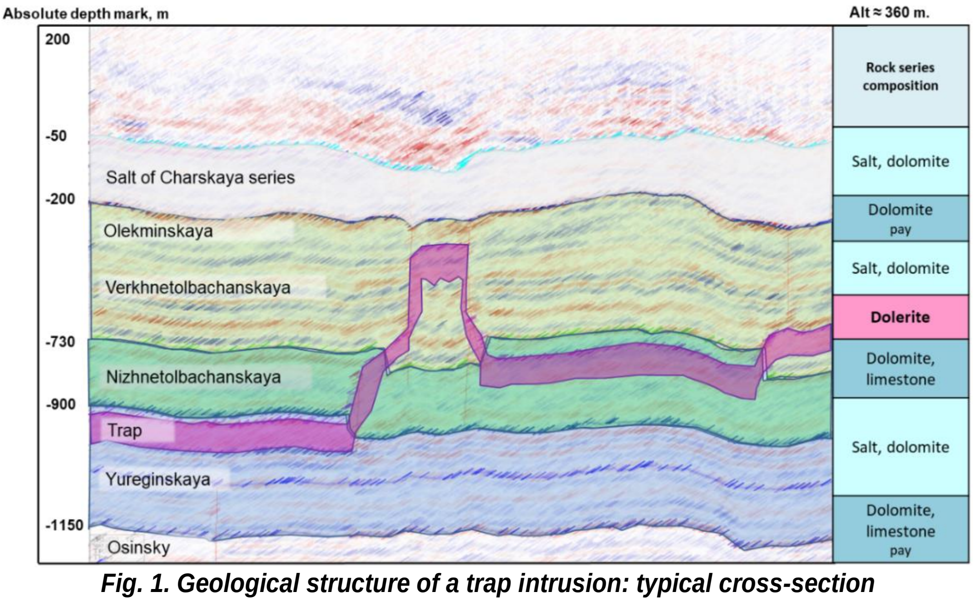

Fig. 1. Geological structure of a trap intrusion: typical cross-section
Рис. 1. Усредненный разрез геологического строения трапповой интрузии

[1] Басарыгин Ю. М., Булатов А. И., Проселков Ю. М. Осложнения и аварии при бурении нефтяных и газовых скважин: учеб. для студентов вузов. М.: Недра, 2000. 678 с.

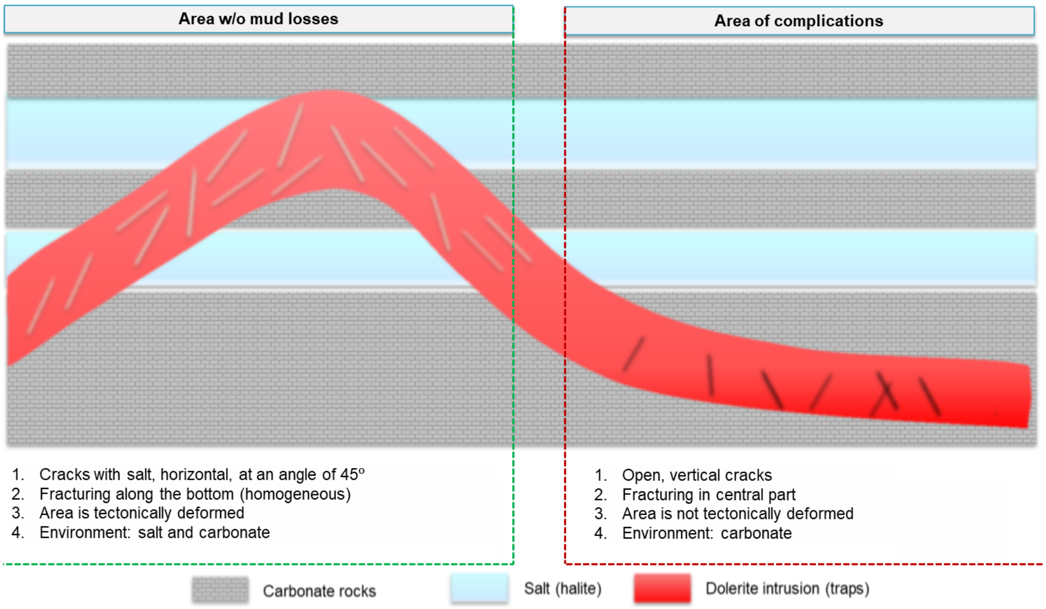

Figure 2. Losses in trap intrusion: a geological concept
Рис. 2. Геологическая концепция поглощения в трапповой интрузии

– Wells drilled without any problems were referred to as Category 3 of trap behavior (10–20 % of the well stock).

The above-described geological challenges constitute a priority issue to be addressed, and the methodology for resolving the problem requires an integrated approach with a range of technologies and operational ways to achieve a single goal. This goal, is to optimize the well construction cycle and to reduce the number of complications, in order to achieve this, a multi-tier action plan was developed to improve drilling operations in trap intrusions.

Materials and methods of research

Alternative Well Design. The underlying objective for improving drilling technologies is to reduce the well economics and cost per meter drilled in certain intervals while maintaining the overall quality of the drilling operations. The current well design was optimized by adjusting the 245 mm casing shoe depth to provide additional isolation mechanical for the trap interval [9, 10].

Alternative well design, therefore, entails significant potential for resolving geological issues that are not technology-induced. The critical areas for further studies include:

– Selection of an optimal cementing solution for an extended 245 mm casing, without using a stage cementing collar and applying light cement slurry and LCM [11];

– Selection of 293/219 mm bit design allowing drilling with higher Rate of penetration (ROP) in the surface casing and production casing intervals, as well as the selection of bottomhole assembly (BHA) components with an alternative logging while drilling signal channel that will allow pumping viscous LCM pills.

Based on the situation in 2020, a decision was made to conduct a set of pilot tests: drill five wells according to the alternative 3-casing design [12, 13]. Figure 3 shows a comparison of the two well techniques. The alternative design isolates two of three incompatible drilling zones (both traps and Olekminsky formation) from the Osinsky Horizon [14].

The Osinsky Horizon contains hydrocarbons and requires a blowout preventer as an additional barrier before penetrating it. To ensure the reliability of cementing 245 mm casing, two-stage cementing is planned using a stage cementing collar[2]. The main advantages of this solution include:

– Separation of two incompatible drilling intervals: trap intrusions and Osinsky [15, 16];

– Reduction of the non-productive time due to losses in trap intrusion interval (up to seven days on specific well pads);

[2] Семенов Н. Я. Разработка методов выбора и управления технологическим процессом изоляции поглощающих пластов: дисс. … канд. техн. наук: 05.15.10. М., 1984. 290 с.

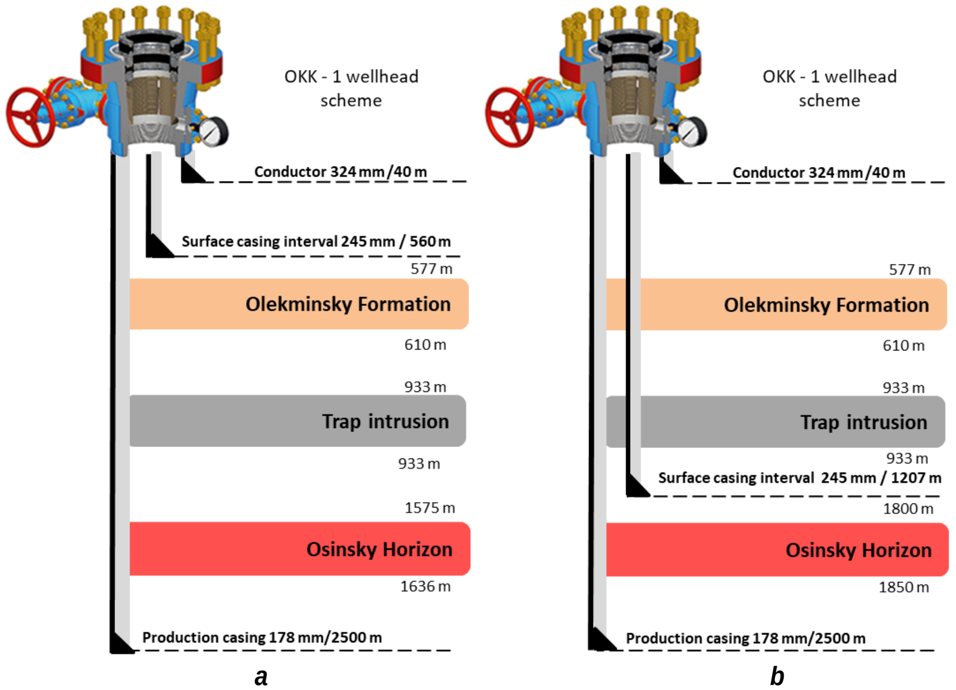

Fig. 3. Comparison of two well designs:
a – current three-string design; b – alternative three-string design
Рис. 3. Сравнение двух конструкций скважин:
а – текущая трехколонная конструкция; b – альтернативная трехколонная конструкция

– Reduction of well costs through lower consumption of cement and drilling mud;

– Reduced cementing length of 178 mm casing and avoidance of inter-casing pressures [17].

Key disadvantage: increased cost due to a longer 245 mm casing and use of a stage cementing collar.

Based on the results of drilling two alternative design wells on a pilot well pad in 2021, in comparison with three wells drilled in 2020, the following dynamics (Fig. 4) can be observed:

– Surface casing interval drilling time reduced by eight days;

– Production casing interval drilling time was reduced by 2.6 days, while the depth of the production casing interval increased by 230 m.

A comparison of the drilling results of five wells with the current design and alternative design indicates a reduction in drilling time by 8.6 days per well; due to a reduced time spent on loss elimination in trap intrusion intervals.

Development of Losses Fighting Concept. Losses encountered while drilling in trap intrusion intervals are often catastrophic (Fig. 5), i. e. a total loss of mud circulation is observed. Given the physical-mechanical strength of trap intrusions (circa 52,000 psi), the interval is drilled at a low penetration rate (0.3 to 3 m/h).

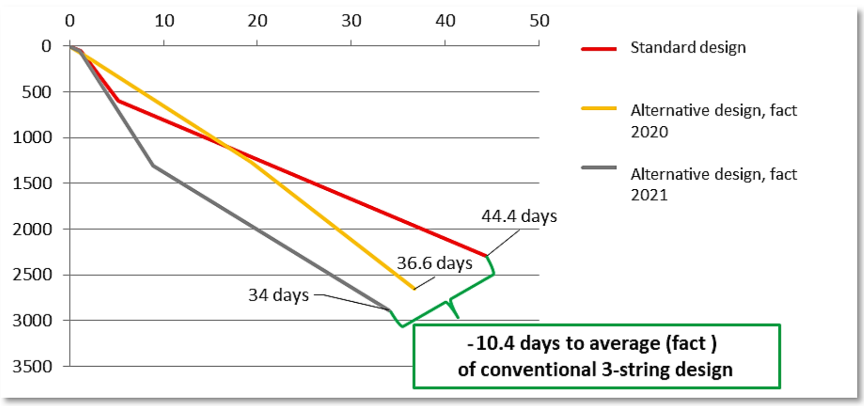

Fig. 4. Reduction dynamics of well construction time at a pilot multi-well pad
Рис. 4. Динамика снижения сроков строительства скважин на экспериментальной кустовой площадке

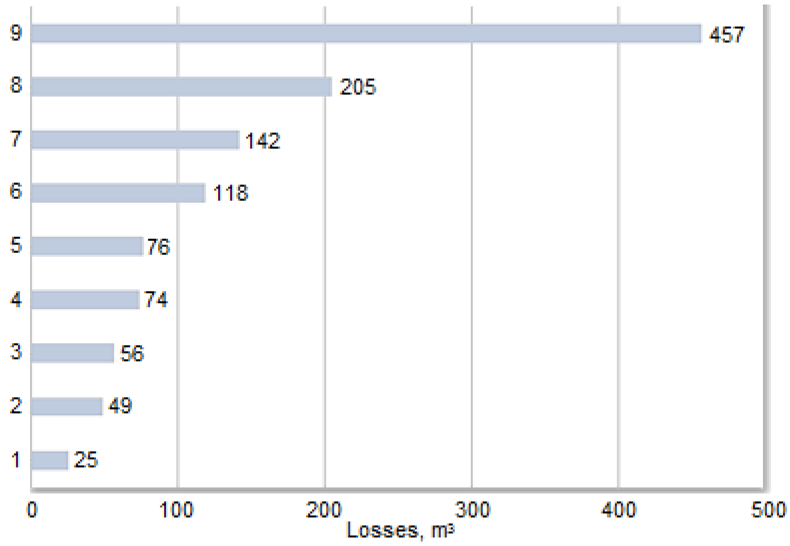

Fig. 5. Average mud loss per well on drilling pads in 2021 (6 months), m^3
Рис. 5. Средний объем поглощения, приходящийся на одну скважину по кустовым площадкам в 2021 г. (6 месяцев), м^3

A review of current drilling data revealed a connection between loss occurrence and the position of traps within the cross-section. Deeper trap intervals result in higher losses. Losses are also pad-specific and depend on pad location within the field. The probability of intensive losses is high on well pads located in the North of the Srednebotuobinskoe Field. Attempts at analyzing and determining loss dependence on azimuth or deviation did not yield any results. High deviation angle in drilling resulted in a longer trap interval in the well, which created a more significant complication with more losses and more cement plugs installed. It should be noted that cement quite frequently provided only temporary isolation, and losses recurred later. This can be explained by the fact that subsequent drilling under the trap interval exposed cement to significant vibration resulting from the rotating drill string, which consequently caused the glue to fall off from cracks [18].

The first step was developing preventive Measures for Drilling Trap Intrusions. To develop a concept for fighting losses in trap intrusion intervals, a complex strategy was developed and tested: preventive LCM for mitigation of risks of mud losses [19]. The strategy includes preliminary treatment of drilling mud 50 m before penetrating into trap intrusion top and in the process of drilling in the trap intrusion in line with the following scheme:

– Remove screens from shale shaker and treat active mud system with BAROFIBRE COARSE: 8 kg/m^3, CF-1: 20 kg/m^3, BARACARB 150: 50 kg/m^3, BARACARB 600: 50 kg/m^3;

– Prepare LCM pill (10 m^3) as follows: BAROFIBRE COARSE: 20 kg/m^3, CF-1: 30 kg/m^3, NUT SHELL MEDIUM; 50 kg/m^3, STOPPIT: 15 kg/m^3;

– Ensure rheological parameters of mud, which prevent LCM particles from dropping out and forming seal plugs;

– For the period of drilling with LCM-containing mud, avoid using screens ≤ 5 mm in the circulation system of the BHA.

– Once the bottom of trap intrusion is reached, install shale shakers screens to take LCM out and clean drilling mud for further drilling.

The preventive LCM strategy showed a positive result in category three wells with trap intrusions. When attempting to drill trap sections, which refer to category 2, using preventive activities, there was no success as mud losses occurred straight after washing out LCM.

The second step was developing preventative Measures in case of total losses in Trap Intrusion Intervals. In the event of a complete loss of circulation, it is required to stop circulation and align the circulation system to the mud pit (to drill with a “floating water column”) for utilizing the liquid phase. “Floating water column” principle envisages drilling with technical water taken from the mud pit simultaneously adding brine (CL-180000 mg/l) into the annulus from the fill-up tank at a rate of 1 m^3 every 30 minutes.

If the circulation is partially restored, circulate the well via the deep clean circulation system tank and add the remaining brine into circulation to maintain its concentration at CL-180000 mg/l.

If the tripping is required, the well should be filled up with salt-saturated mud (double the well volume).

These measures yield a positive effect in saving in water consumption (given the unavailability of technical water), in chemical consumption, and in time required for mud conditioning.

The third step was conducting the Pilot Tests with Litefill and with two-phase solutions. During pilot tests, various litefill and two-phase solution (HALKER) were trialed. Based on the results of the tests, we noted that the effect of decreasing the number of cement plugs per well, but due to the time required for mixing and the risk of premature setting in a drill string, a decision was made not to use these chemicals. Attempts to select the isolating material guarantee 100 % isolation did not bring any sound results.

Development of Drilling Bits approaches to drill in Trap Intrusions. Starting from commercial production drilling in the Srednebotuobinskoe Oil Gas Condensate Field, drilling in trap intrusions was performed according to the following approach: drilling above the trap intrusion, drilling in the trap intrusion, and drilling below the trap intrusion.

Trap bodies were drilled with tri-cone bits as PDS bits with classic cylinder bit inserts but did not allow us to achieve desired ROP results, and there was also fatal fatigue after drilling 10–15 meters into the trap body [20]. The drilling technology is based on the following: once a trap intrusion interval was penetrated, the BHA was pulled out to change bit type from PDC to tri-cone. Tri-cone bits (code LADS 637) were used to drill through the trap intrusions. Due to high trap body strength, the ROP was in the range of 0.7–3.2 m/h. On average, drilling in a trap body (thickness: 150–200 m) was taking from 3 to 12 days.

As a result of the continuous use of tri-cone bits, problems with bit parts breaking off and falling to the bottomhole occurred quite often. The problem was significant when additional time was required to retrieve lost details from the well (1.5 to 3 days on average). To solve the problem and to optimize the drilling process in trap intrusions, a range of suitable PDC bits were developed (series FT716 and SKH1616D-A1D) and (MDS1616 and MDS1617).

As a result of the adaptation of new bit designs, improvements were made in the efficiency of drilling intervals before traps and in traps using PDC bits. Were achieved the following indicators: an average gap of trap intrusion drilled by PDC bits is from 30 to 70 m, ROP is from 3 to 4 m/h.

In addition, new bit designs were developed with the following results: Tektonic 219.1mm series: in trap intrusions with a thickness of up to 140 m, ROP was 4 m/h; StingBlade series: in trap intrusions with a thickness of up to 130m, ROP was 4.5 m/h, and in 152 m thickness, ROP was 4.5 m/h. Due to high-quality drilling performance, the bits were used for drilling in trap intrusions. A chart was developed with a complete description of the required parameters for more effective drilling.

Thanks to the high resistance of Stinger inserts to mechanic impact and wear, StingBlade bits ensure 100 % trap intrusion drilling in one trip. New records were set in drilling trap intrusion thickness of up to 400 m in one trip:

– Average ROP in the interval before the trap intrusion is 16.4 m/h;

– Average ROP in the trap intrusion interval is 5.08 m/h;

– Average ROP in the interval before trap intrusion and trap intrusion is 9.52 m/h.

A specific feature of the bits is cone-shaped diamond inserts (Stinger), an innovative, upgraded solution for blades that is significantly more effective than any other PDC bit. The insert, located in the center, ensures even load on a bit and more effective rock destruction, which increases bit life and penetration rates. Bits of this series have demonstrated that they can drill the trap intrusion intervals in a single trip (Fig. 6).

Research results and discussion

Implementation of the above measures allowed us to minimize mud losses when drilling in trap intrusions on all well pads and to reduce well construction period and costs.

1. The “alternative design” application on five pilot wells indicated that the average time required for well construction is 8.6 days less than

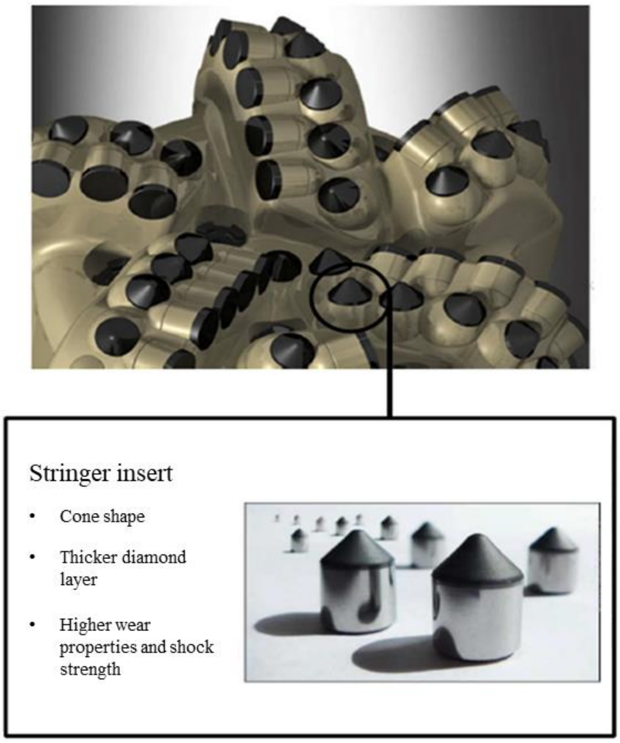

Fig. 6. Design of a StingBlade series bit
Рис. 6. Дизайн долота серии StingBlade

the time needed for the construction of conventional design wells on the same well pad. The design yields a positive effect only for Category 1 wells (10–20 % of the stock).

2. Time spent drilling above and in traps is 108.8 hrs (4.5 days), allowing to drill them in a single stage rather than two in the past.

3. The application of StingBlade bits reduced drilling time to 64.6 hrs (2.7 days). Non-productive time (NPT): -1.8 days and saving time for tripping to replace the bit.

4. The application of LCM pills shows a positive economic effect in Category 2 and Category 3 wells (in time reduction by up to 2 days and in the cost of drilling mud chemicals).

5. The search for reliable mud motor systems which allow the usage of high concentration LCM and drill solids would allow to drill all three sections of Production casing interval in a single stage and achieve further improvement in drilling time and economics.

Summary

The pursuit of technological solutions to the current problem in trap intrusion allowed Drilling Engineering Team to look at the problem from different prospective. Namely, alternative casing design implementation revealed several weak points in the old casing design and their potential to lead to issues like Well Control, etc. The trial of Alternative casing design allowed to expand of this solution to other neighbor fields once economic upside was weighed against the cost of the casing design. The introduction and implementation of preventative measures like drilling with LCM solids allowed us also revisit traditional drilling in fractured formations.

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Information about the authors / Информация об авторах

Yevgeniy V. Tuzov,
Head of Drilling Technology and Engineering Department,
LLC Taas-Yuryakh Neftegazodobycha,
Irkutsk, Russia,
TuzovEV2@tyngd.rosneft.ru,
https://orcid.org/0000-0003-4149-8522.
Тузов Евгений Виссарионович,
начальник Управления технологий и инжиниринга бурения,
ООО «Таас-Юрях Нефтегазодобыча»,
г. Иркутск, Россия,
TuzovEV2@tyngd.rosneft.ru,
https://orcid.org/0000-0003-4149-8522.

Tatiana Yu. Kutuzova,
Lead Specialist of the Drilling Technology Department,
LLC Taas-Yuryakh Neftegazodobycha,
Irkutsk, Russia,
TY_Kutuzova@tyngd.rosneft.ru,
https://orcid.org/0000-0002-3800-0618.
Кутузова Татьяна Юрьевна,
ведущий специалист отдела инжиниринга бурения,
ООО «Таас-Юрях Нефтегазодобыча»,
г. Иркутск, Россия,
TY_Kutuzova@tyngd.rosneft.ru,
https://orcid.org/0000-0002-3800-0618.

Contribution of the authors / Вклад авторов

The authors contributed equally to this article.
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