Abstract. The drilling of the production section in the development wells in South Iraq could face numerous problems related to the partial or total losses, flow of sulphurous water, significant change in pore pressure along the wellbore, tight hole and caving among others. One of the main issues observed in several fields across South Iraq during well construction is the stability of in the production section of wellbore (especially in the shale formations). The instability of the open hole led to time consuming incidents related to an inability to run open hole logs to the wells total depth. Additional time has also been spent on wiper trips, reaming and backreaming, and on incidents related to hole pack off and stuck pipe.

To solve the problem several steps were taken starting with the creation of a mechanical earth model which identified the main problematic formations presented by shale and the possible root causes of instability. This involved core characterization analysis including X-ray diffraction, cation exchange capacity and thin section analysis were performed to identify the structure of the shale. In addition the fracture development tests
were performed on the samples of core and from this the main root causes of instability were identified.

Based on the theoretical research and the laboratory tests new drilling fluid formulation together with best drilling practices were proposed that would allow the elimination of the problem due to the stability of the wellbore in the shale formations.

**Annotation.** Burzenie skvazhin na mestorождениях Южного Ирака сопряжено с решением различных проблем связанных с потерей циркуляции, водо и газопроявлениями, значительными изменениями пластового давления, посадками и затяжками при спуско-подъемных операциях и обрушением ствола скважины. Одной из главных проблем наблюдаемых на нескольких месторождениях является стабильность ствола скважины при бурении под эксплуатационную колонну. Нестабильность стенок скважины приводит к значительному непродуктивному времени связанному с проработками и обратными проработками, недохождением приборов каротажа до проектного забоя, дополнительным шаблонировкам ствола скважины и прихватам колонны бурильных и обсадных труб. В некоторых случаях секция скважины была пробурена за 4.5 дня и дополнительные девять дней требовались для устранения проблем связанных с потерей стабильности стволом скважины и получения необходимых каротажных данных.

Дополнительные шаблонировки ствола скважины не всегда решали проблему и требовали значительных временных затрат. Из нескольких скважин шаблонировки помогли записать требуемые каротажи в открытом стволе только на одной. Полученные данные показали значительное кавернообразование в отложениях сланцев.
Для решения этой проблемы было предпринято несколько шагов начиная с создания геомеханической модели, которая определила основные проблемные отложения представленные сланцами. Помимо создания модели так же были выполнены лабораторные исследования отобранных образцов керна такие как: рентгеноструктурный анализ, определение катионообменной способности (КОС) минералов слагающих сланцевые отложения и шлиховой анализ керна. Так же был выполнен тест на образование трещин. Всё это позволило установить основные причины нестабильности сланцевых отложений.

Основываясь на теоретических изысканиях и лабораторных исследованиях была разработана новая система бурового раствора и предложены параметрами бурения, что позволило полностью устранить проблемы связанные с нестабильностью ствола при бурении вертикальных скважин.

Key words: shale, stability, washout, wellbore, core test, microfracture, drilling fluid, graphite.

Ключевые слова: сланцевые породы, стабильность, кавернообразование, скважина, керн, микротрещина, раствор, графит.

Introduction

During drilling of the production section through the shaley formations huge amounts of cavings were observed on the shale shakers which required additional circulation time, reaming and backreaming while tripping, extra wiper trips and in some cases even lead stuck pipe incidents. This instability of the open hole causing such events when section has been drilled within four and half days and then an extra nine days were required
to remedy these problems and provide the required logging data. The tight hole and wellbore instability prevented the logging tools to pass to the bottom and resulted in the failure to deliver the first objective of the well - to obtain open hole wireline logs, pressure data and sidewall coring for reservoir and non-reservoir formations. This resulted in the inability of the field operator to characterize the formation and thus affect the field development plan.

Additional wiper trips did not always solve the problem and were very time consuming. Out of several wells it helped to acquire required logging data only on one well after four wiper trips that involved reaming and backreaming.

The logs that were obtained showed significant washouts in the shale formations which was assumed to be where the cavings were coming from.

The wellbore instability of wellbore also caused of several incidents requiring reaming the casing to reach bottom. In some cases the casing got packed off and could not be cemented conventionally.

**Geology of the region**

The production section typically starts in the Sadi and finishes in the Zubair formation which is the main pay zone (Figure 1). The Zubair formation is divided into five members on the basis of the sand to shale ratio and these have been named from top to bottom: Upper shale member, AB sand, K Shale, Lower sandstone member (main pay) and Lower shale member. The main pay is comprised of three dominated sandstone units, separated by two shale units. The shale units act as good barriers impeding vertical migration of the reservoir fluids except in certain areas where they disappear.
The upper formations above the Zubair are composed mainly of limestone. The Sadi formation is predominantly limestone (chalky), shale and porous limestone. The Tanuma formation contains grey shale interbedded with porous limestone. The Khasib formation contains limestone (chalky and argillaceous) with thin beds of shale. The Mishrif formation is separated from the overlaying Khasib formation by a regional unconformity distinguished by limonitic limestone and glauconitic limestone; which is mainly porous and vuggy. The Rumaila formation contains limestone (chalky and argillaceous) and shale. It is conformable with the Ahmadi formation lying below and marked at the top by black shale. The Ahmadi contains shale and argillaceous limestone which becomes porous in some fields. The Mauddud formation is separated from the overlaying Ahmadi formation by an unconformity and contains a porous limestone at the top containing orbitolina with argillaceous limestone at the bottom. The Nahr Umr formation contains shale, sandstone interbedded with limestone, and sandstone interbedded with shale. The Shuaiba contains both chalky and dolomitic limestone.
Table 1. General lithology of the production section of South Iraq fields

<table>
<thead>
<tr>
<th>DEPTH</th>
<th>Formation</th>
<th>Lith</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>Sadi</td>
<td>LITH</td>
<td>Limestone and shale</td>
</tr>
<tr>
<td>2088</td>
<td>Tanuma</td>
<td>LITH</td>
<td>Shale with porous limestone</td>
</tr>
<tr>
<td>2120</td>
<td>Khasib</td>
<td>LITH</td>
<td>Limestone grey shaly</td>
</tr>
<tr>
<td>2170</td>
<td>Mishrif</td>
<td>LITH</td>
<td>Limestone and shale</td>
</tr>
<tr>
<td>2297</td>
<td>Rumaila</td>
<td>LITH</td>
<td>Limestone</td>
</tr>
<tr>
<td>2402</td>
<td>Ahmadi</td>
<td>LITH</td>
<td>Shale and limestone</td>
</tr>
<tr>
<td>2534</td>
<td>Maudud</td>
<td>LITH</td>
<td>Limestone</td>
</tr>
<tr>
<td>2660</td>
<td>Nahr umr</td>
<td>LITH</td>
<td>Shale, sandstone interbedded with limestone</td>
</tr>
<tr>
<td>2945</td>
<td>Shuaiba</td>
<td>LITH</td>
<td>Limestone and dolomite</td>
</tr>
<tr>
<td>3042</td>
<td>Zubair</td>
<td>LITH</td>
<td>Shale and sandstone</td>
</tr>
</tbody>
</table>

Figure 1. General lithology of the production section of South Iraq fields

Wellbore instability

The shale containing formations of Tanuma, Ahmadi, Nahr Umr and Zubair were the main contributors to the wellbore instability. The amount of cuttings overloaded the shale shakers while drilling through these formations. The size varied but could easily reach 2-3 inches and in some cases exceeded 5 inches. On the occasion the sonic logging tool could not be operated due to cavings stuck the pads of the tool (Figure 2).
Figure 2. Cavings

The obtained 8.5 in hole caliper logs showed very stable or under-gauge hole in non-shale formations and significant washouts across shale intervals with a diameter of more than 16 inches (Figure 3).

Figure 3. Caliper log in sand and shale intervals

Prior to performing the in-depth study, several things were attempted in order to eliminate the instability:
• The section was drilled in some wells with a mud weight as low as 1.18 SG, and in other wells the mud weight was as high as 1.31 SG. No difference in well bore stability was observed.

• The shale formations were drilled with high rate of penetration (ROP) to reduce the expose time and with low ROP to decrease the impact on formation

• Different types of BHA including Rotary and Motor BHAs and different types of the bit
  • The section was drilled with wiper trips and without wiper trips
  • The concentration of KCL was increased up to 8%
  • The salt saturated drilling fluid was used with 26% of NaCL
  • The Yield Point (YP) of the drilling fluid changed from 19 to 32 lb/100ft²

None of these actions taken individually did not yield any significant results because the failure mechanism was not properly understood.

**The study**

To understand the root cause leading to the instability of the open hole section the comprehensive analysis of the offset wells was performed. It covered all aspects of the operation including the position of the wells in the fields, the configuration of the BHAs, mudlogging reports, formulation of the drilling fluid, configuration of the logging tools, the drilling strategy, hydraulics, reaming and backreaming data and wiper trips.

Following this it was concluded that the wellbore instability experienced in the drilled wells was not related to tectonic stresses, BHA design or logging tool string configuration.
Simultaneously a geomechanical study was performed to identify wellbore stability associated with the geology and well design, which lead to the construction of a Mechanical Earth Model (MEM). The result of the study yielded the following:

- Time-dependent wellbore instability was observed while drilling Tanuma, Ahmadi, Nahr Umr and Zubair formations with the possibility that some pressure shale cavings could be due to drilling fluid pressure penetration. Drilling fluid optimization would therefore be highly beneficial to mitigate the drilling problems due to time-dependent wellbore instability in these formations.

- Flaky shale cavings could indicate failure along existing micro-fractures and/or bedding planes. The recommendation is to use micro-fracture blocking additives in the drilling fluid to mitigate this type of failure.

The geomechanical study also identified a few gaps in the available data for wellbore stability analysis and it was recommended to perform some laboratory tests on core samples.

The core samples were taken and sent to the research and engineering laboratory for analysis and evaluation with fluids (Figure 4). The X-ray diffraction (XRD), Cation Exchange Capacity (CEC) (Table 1) and thin section analysis were conducted to characterize the rock material. The thin section analysis showed that the shale had a fractured structure with fractures prorogating along the bedding planes. In addition it could be seen that there were fractures perpendicular to bedding plane covering significant area of the sample. With perpendicular fractures in these formations some of them will cross the wellbore and will provide a channel for drilling fluid penetration. Therefore the pressure front will move inside
the formation, swelling will occur with increased capillary pressure which could lead to the wellbore instability (Figure 5, 6).

Table 1. XRD/CEC mineralogical data from cutting and shale samples

<table>
<thead>
<tr>
<th>Mineralogical data</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smectite *</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Illite</td>
<td>16%</td>
<td>11%</td>
<td>14%</td>
</tr>
<tr>
<td>Calcite</td>
<td>6%</td>
<td>13%</td>
<td>8%</td>
</tr>
<tr>
<td>Quartz</td>
<td>44%</td>
<td>42%</td>
<td>46%</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>22%</td>
<td>19%</td>
<td>18%</td>
</tr>
<tr>
<td>Pirity</td>
<td>2%</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>CEC, meq/100 gr</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5. Thin section. Scale 500 micron.
The blue lines represent the fractures across the rock.

Figure 6. Thin section. Scale 200 micron.
The blue line represents the fracture across the rock.
The fracture development test was used to evaluate the stability of the formation in the presence of the drilling fluids. Core fragments were exposed to the fluids for six days (Figure 7, 8, 9, 10). The results of the tests also confirmed the presence of fractures which extend along the bedding plane. Some fractures also extend in diagonal and perpendicular fractures to the bedding plane. The existing fractures from the Nahr-Umr formation have a tendency to enlarge with time. The enlargement rate depends on the fluid (Figure 11).

Figure 7. Core sample exposed to fresh water for 6 days. Significant enlargement of some pre-existing fractures observed
Figure 8. Core sample exposed to 20% NaCl for 6 days
Enlargement of some pre-existing fractures observed
Figure 9. Core sample exposed to 7% wt KCl for 6 days
Enlargement of some pre-existing fractures observed
Figure 10. Core sample exposed to 7% KCl with 3% v/v KLA-STOP for 6 days. Slight development of small fractures along the bedding plane.
Figure 11. Microscopic view of a thin layer of a sample showing a micro-fracture crossing the bedding plane. A few fractures are present and are mostly 5-30 µ in width. The maximum fracture width is 70 µ

The studies [1,2] related to the stability of Nahr Umr shales identified potential root causes which can be summarized as:

- shales present bedding planes with smaller weak planes/natural fractures which weakens the shale;
- cores recovered from Nahr Umr were easily broken along the bedding planes;
- small piece of sample immersed in fresh water and low salinity brine (5% KCl), were easily penetrated by the fluid through the bedding planes. The sample was separated along the bedding planes;
- low content of reactive Smectite and mixed layered Illite / Smectite which represent moderate reactivity.
As a result of the studies a mechanism was determined as to the cause of the wellbore instability problems related to the shale formations and this lead to two different approaches being required for drilling these formations [4]:

- Tanuma requires higher drilling fluid weight to maintain wellbore stability;
- Ahmadi, Nahr Umr and shales in Zubair require lower drilling fluid weight due to stability of wellbore mainly related to the fluid invasion.

Tarsuhiko et al [3] described the mechanism of the shale instability problem in the Nahr Umr formation in an offshore field in the UAE, which is also one of the problematic shales on the fields in South Iraq. It has been concluded that the rest of the problematic shaly sections also follow the same mechanism. Their paper stated that the stability problems were due to the drilling fluid penetration into the laminations/fractures causing the mechanical failure and thus the loading of the well with cavings. In other words, the fluid invasion clearly weakens the shale making the shale stability very sensitive to the drilling fluid design. If the drilling fluid weight is too low, the risk of wellbore collapse increases. If drilling fluid weight is too high, drilling fluid invasion into these fractures and subsequent shale weakening makes the wellbore prone to instability. In addition, the above studies indicated that the following components are essential to control the shale stability [4]:

- a shale Inhibitor; in the form of a liquid additive. It functions as a clay hydration suppressant by inhibiting the water migration into, and uptake by, the clay mineral that would cause the swelling;
- an encapsulator; in the form of a mildly cationic co-polymer
capable of encapsulating and stabilizing shales and shale cuttings;

- an enhanced sealant; to seal the permeability and microfractures present in shales thus limiting pressure transmission into the shale bodies.

**Drilling fluid**

During project execution the drilling fluid was changed several times. Initially, drilling of the production section was started with a KCL polymer system. The section drilling fluid weight was 1.28 to 1.30 SG while drilling, and the drilling fluid was treated by asphalt which supposedly helps to reduce the amount of cavings. Initially significant problems with the stability of the wellbore while using this system led to the suspicion that (due to salinity difference between the drilled formation and the drilling fluid) an osmotic effect was causing the instability. Therefore, the drilling fluid system was changed to the PHPA/NaCl polymer. This change did not provide any positive results in a drilling fluid weight range of 1.20 to 1.24 SG over the section huge amounts of cavings were observed.

As part of the geomechanical study and core characterization analysis a PHPA/KCL/lubricant polymer drilling fluid system was proposed. This system is classified as a non-dispersed, inhibited system and specifically designed to minimize problems associated with swelling and highly dispersive and micro fractured shales.

No chemical thinners or dispersants were used. Instead, a polymeric encapsulator was used to prevent clay from dispersing in the system. This prevents the breaking up of drill solids into smaller particles and improves the efficiency by which the solids control equipment (SCE) can remove them. The system provides a thin, slick filter cake to reduce friction
between the drill string and the wellbore. The low plastic viscosity (PV) / low solids content reduce the risk of differential sticking specially while drilling through the high permeable formations. This drilling fluids inherent slick, thin, tough filter cake would also reduce the risks of differential sticking. The filter cake can further be enhanced with addition of both sized CaCO$_3$ and graphite and help to plug the induced micro fractures in the wellbore shale to prevent it from hydrating and dispersing into the drilling fluid.

Graphite assists with mechanical protection of the wellbore. It has a particle size range that will act as a plugging agent to help bridge/seal permeable formations as well as reduce the risk of differential sticking. Graphite also has good lubrication properties.

In the implementation of the above drilling fluid system, the following best practices were identified:

- Maintaining pH in a range 8.0 to 9.5 allowing the polymers in drilling fluid react better
- Usage of HPHT test instead of API fluid loss test to be able simulates wellbore temperature and pressure.
- Reduction of spurt loss to minimize the expose of fractures in the formation to drilling fluid. This way those fluid paths are sealed before enough drilling fluid passes through to destabilize the shale and cause wellbore instability.
- Improving the drilling fluids rheology: the changes in the rheology were achieved by keeping the low shear rate viscosity (LSRV) in high range – 3 rotation per minute (RPM) reading = 7-8; 6 RPM reading = 11-12. This LSRV would ensure a laminar flow at the wellbore wall which would minimize the wall erosion. This resulted in YP value in the high
range which helped to improve the carrying capacity of the system.

- Drilling fluid weight while the drilling production section should be kept in the lowest range 1.18-1.20 SG.

**Drilling strategy**

A change of the drilling fluid system alone would not solve the problem. Another vital aspect with respect to dealing with hole stability problems is the application of the right drilling practices, and so steps were taken to address this. First of all the bit design was changed to drill the 8.5” production section with a more aggressive bit which allowed to increase the rate of penetration (ROP) and limit the exposure of the wellbore to the drilling fluid. Changes to the bottom hole assembly (BHA) design were implemented. In the vertical wells, a semi-packed BHA was used to reduce the torque and drag, and to minimize the need for reaming/backreaming. The new BHA design also allowed maintaining the verticality of wells. In deviated wells a rotary steerable system was run to increase the ROP, decrease the risk of differential sticking, minimize tortuosity, eliminate steering problem improve hole cleaning and reduce reaming/ backreaming.

In addition, the flow rate while drilling was adjusted to avoid erosion of the formation. Procedure was put in place to minimize shocking of the wellbore when starting or stopping the mud pumps. The survey planning was optimized to eliminate circulations against shale formations. The wiper trip practice was reviewed and optimized; all non-necessary wiper trips were eliminated. Hole cleaning practices while drilling were also reviewed and some points were removed such as pumping of weighted sweeps to avoid wellbore disturbance due to sudden change in wellbore pressure and some points were added such as pumping bridging sweeps.
Finally the effect of equivalent circulating density (ECD) was taken into account and hi-vis pills were potted prior to pulling out of hole.

**Conclusion**

The stability of shale formations is a costly problem while drilling the production section of wells in South Iraq. The studies performed to solve the problem identified the invasion of drilling fluids into the shale micro fractures as the most common mechanism. Inhibitors, encapsulators and sealant components are therefore required to prevent this invasion. Also, the drilling strategy especially across the shale formations needs to be adjusted to eliminate the exposure of formation to excessive ECD and to the negative impact of reaming/backreaming, circulation.

The implementation of the study recommendations totally eliminated the non-productive time due to the wellbore instability. Note that this represent 90 to 200 hrs per well on the first five wells drilled. The recommendations were further implemented on several oilfields in South Iraq and more that seventy wells were drilled without any indication of wellbore instability.

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References


Список используемых источников


2. Мехтар М. Обеспечение стабильности сланцевых отложений на оффшорных месторождениях Абу-Даби путём применения высококачественного раствора на водяной основе. // Журнал общества инженеров-нефтяников. Ноябрь 2010. №138564.12 с.
3. Тарсухико В. Устранение дополнительных расходов при бурении связанных с нестабильностью ствола скважины в отложениях трещиноватых сланцев формации Нар Умр // Журнал общества инженеров-нефтяников. Ноябрь 2006. № 101383. 6 с.

4. Мухамед Я. Устранение проблем связанных со стабильностью ствола скважины при бурении скважин в сланцевых отложениях. Конференция Шлюмберже. 7-9 августа 2011. № 5727978. 27 с.

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