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Application of risk analysis in drilling well problems and operations- field case study

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Abstract. The objective of this paper is to present specific drilling problems and their solutions, and then apply risk analysis for them. Drilling data for actual drilled wells and performing the risk analysis resulted in medium risk for the most operations done before starting the drilling process. Drilling well operations showed a various risky levels for operations. Formation problems that resulted from a constantly formation /fracture pressures curves may sometimes lead to not being able to select the casing setting depth CSD, and use high rate of penetration ROP without logging may provide a good results. The application of this method resulted in a proper selection of CSD for two drilling wells (I) and (II). In addition, the treatment of a large layer of shale formation X2 for well (I) was done by using common methods to prevent shale problems but these methods will add another 5-6 days to the number of drilling days. However, the proposed high ROP method, without logging, and with quick cementing and casing operations is almost perfect and leads in reducing the drilling hole days by 5-6 days for well (I), and that’s why the final drilling hole days will be 59 days instead of 65 days. Another real drilling well case which is suffering from a lot of well problems was controlled using suitable methods and the required mud additives to all geological sections safely drilled.

Keywords: drilling, risk analysis, wells, ROP, CSD.

1. Introduction

Drilling is the second step after the exploration process and main job in the procedure of finding and reaching the hydrocarbon, in preparation of getting it out of its location underground. Well planning is the key to being able to safely and economically drill a usable hole for oil and gas production. Planning for drilling an oil/gas well requires many detailed studies evaluating every aspect that directly or indirectly influences the successful economic outcome of the project. These studies

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were presented by Adams (1985), and Azar (2007). In addition to perform an excellent well planning, offset data are obviously needed. If offset wells exist, their drilling reports and logs may prove extremely useful for evaluating the conditions under which the newly well is going to be drilled, and also in its economic estimations. If no attempt is done to obtain these data, this will lead to an extremely worst problem as actual case study appeared that presented by Adams (1985). These offset wells data help in implement drilling program or prognosis. A drilling program or prognosis as it is usually called is composed of a number sub-programs and sections. These include mud program, casing program, cementing program, bit program, drill string program, hydraulic program, directional program, data from offset wells and geological work.

However, the operation of drilling is a complicated process which involves many complex calculations. The main difficulty in drilling is the great uncertainty present about the nature of the formations to be encountered making it tough to estimate the possible hazards and risks. Also drilling a well should be carefully studied economically as well as environmentally to avoid any unaccepted damage to the environment.

During drilling operations, some type of a drilling problem will almost certainly occur, even in very carefully planned wells. The reason is that geological conditions for two wells that are near each other may differ (nonhomogeneous formation); therefore, different problems can be encountered. The key to success in achieving well objectives is to design drilling programs based on anticipation of potential hole problems, rather than on containment and caution. Drilling problems, when encountered, can be very costly, presented by Robert (2011), Rabia (2002), Darley (1988) and Azar (2007) are:

- Pipe sticking
- Lost circulation
- Hole deviation
- Pipe failures
- Borehole instability
- Mud contamination
- Formation damage
- Hole cleaning
- Hydrogen sulfide–bearing formations and shallow gas
- Equipment- and personnel-related problems

An understanding of these problems, their causes, their anticipation and planning for solutions is essential to estimate the possible hazards and risks, to control overall well cost control and succeed in reaching the intended target zone. This paper addresses some of these problems, their effects on well design, possible solutions, and when applicable, preventive measures. Risk assessment analysis for these problems is also required for better selection of a predictive method to solve the problem. Drilling well operations are highly affected by formations problems so risk matrix will also be performed.

Can you face the drilling well problems?

Our target here, firstly, is to ask yourself " Can you face the drilling well problems?" in order to fully evaluate all faced problems with a scientific methods and in effective, economically, and safely manner. Therefore, let`s start with two of the most common problems.

1. Non-Uniformed Formation/fracture pressures curves

One of the most common problems today during drilling is a constantly formation/ fracture pressures curve. This curve shows no changes in formation pressure and fracture pressure with depth as appeared in the two actual wells figure (2) and figure (3). This problem leads to fails in casing setting depth (CSD) methods. Any attempts to execute methods presented by Adams (1985), Rabia (2002), Bourgoyn (1991), Azar (2007), and Hossain (2015) result in selecting one casing for the drilling well. Therefore, a predictive method should be used in order to accurately select the best CSD for all types of casings. Here, the proposed method is based on geological column, formation layer types, their problems, and some practice experience. We should look for the previous four factors to choose the CSD which guarantee wellbore stability and integrity. In field cases section, this method resulted in a good selection in case of no or little changes in formation/fracture pressures.

2. A large section of shale formations

It is known that shale formations have a serious problems which may lead to loss the hole or well stability. Also, this problem was studied by a lot of authors and most of them suggested more effective solutions in order to fully overcome shale swelling and sloughing. However, here, a large section of shale formation will studied from two sides: time and previous proposed solution. Some of actual drilling wells which have a large section of shale will be studied. Shales are major obstacles to maintain hole integrity, although other rock types (e.g., loose gravels or conglomerates) can cause problems as well. Shale Problems (Chemical-Physical) can be recognized by the certain indicators such as sloughing shale, hole enlargement, bridges and fill on trips, stuck pipe and fishing difficulty, hole-cleaning problems, high fluid-maintenance cost, and solids-control problems. Most of practical methods presented by several author proved their effectivity such as stabilizing shales through chemically and physically inhibition. But, here, the proposed solution is depend on the time factor. This is done through drilling the large shale section with high speed, high rate of penetration (ROP), ordinary water-based mud (the cheapest mud in petroleum industry), no open hole logging, then faster casing and cementing operations for the well. This method needs a high experience driller with high knowledge about the drilled zone.

3.The most common problems presented by Robert (2011), Rabia (2002), Darley (1988) and Azar (2007) were also studied with the application in actual drilling wells. All these problems require operations to stop and when they occur can result in a large nonproductive time (NPT). At the time of writing this paper, the average NPT in the drilling industry is more than 25%.

Defining the type of the hole problems, putting the problem controls, and selecting the required chemicals, additives or predictive methods to solve is the main aim in this section in order to actually answer the question with "yes".

2. Risk assessment

However, the improvement in well integrity is an inevitable continuous process. Anything fulfilling a function by time become worn out. This means the more wastes, the higher unsafety becomes. Follow up of anything sustains integrity, and sustain safety results in profit. Therefore, the risk assessment or risk analysis (RA) is not about creating huge amounts of paperwork, but rather about identifying sensible measures to control the risks in your workplace [5]. Risk Analysis is any method — qualitative and/or quantitative — for assessing the impacts of risk on decision situations. The goal of any of these methods is to help the decision-maker choose a course of action, to enable a better understanding of the possible outcomes that could occur. That`s why, the main goal in this section is to express mathematically, or define total risk (R_{total}) as the sum over individual risks (Ri), which can be computed as the product of potential losses or severity (Si), and their probabilities (P_i)as follows [5]:

$$R_i = S_i \cdot P_i(S_i) \tag{1}$$

$$R_{total} = \sum_i R_i = \sum_i S_i \cdot P_i(S_i) \tag{2}$$

Therefore, the risk matrix for the potential hazards of well process due to formation effect. Also, risk controls should be determined to keep wellbore stability such engineering controls, administrative controls, or others risk controls.

3. Drilling problems risk assessment

Oil and gas companies spend about $20 billion annually on drilling. Unfortunately, not all of that money is well spent. A significant portion, around 15%, is attributed to losses. These include loss of material, such as drilling equipment and fluids, and loss of drilling processes continuity, called non-productive time (NPT). These losses are incurred while searching for and implementing remedies to drilling problems. Avoiding drilling problems cuts finding and development costs and allows billions of dollars now spent on losses to be better spent-building and replacing reserves. No well is drilled without problems. Managing drilling risk means not letting small problems become big ones. Knowing what the risks are and when they are likely to occur keeps surprises to a minimum. Most of the time spent drilling, and most of the cost, is encountered not the reservoir, but in getting to it. Numerous problems taunt the driller, and solutions may be expensive if not impossible in some cases. Drill pipe can become stuck against the borehole wall by differential pressures or lodged in borehole irregularities, requiring skill and force to free it. When this fails, sometimes the only solution is to abandon the stuck portion and drill a sidetrack around it.

4. Field case studies, results and discussion

For drilling well operations, we selected well planning, LWD, MWD tools, mud motors, rotary steerable system, BOP, drilling activities, and drilling operations such as tripping, cementing, casing, and circulating; then we performed the risk evaluation for what happened if it goes wrong and for proposed solutions. Risk matrix for previous operation is shown in table (1) and figure (1) a & b.

Table 1. Risk matrix for drilling well and methods of solution matrix.

Step	Operation Item	What can happen if it goes wrong?	Risk evaluation			Methods of prevention	Residual risk		
			P	S	R.R.		P	S	R.R.
1	Well planning	1. Collision of adjacent wells. 2. Stop of drilling job. 3. Increase in cost due additional repairs and rig cost.	1	3	3	1. Good training of the well planning engineers 2. Good supervision from the senior well planners. 3. Good well planning software updates.	1	2	2
2	LWD and MWD tools	1. Harmful effects to the people subjected to radioactive elements (in the MWD, LWD tools) on the long run. 2. False logging readings leading to false parameters estimations. 3. False inclination angle, toolface, azimuth surveys leading to drilling to a wrong track/path; hence missing target, loosing time and money.	2	4	8	1. Periodic change of the LWD/MWD team to reduce the contact with radioactive. 2. Periodic inspection of LWD/MWD tools before installation. 3. Good equipment maintenance in the yard before sending it to jobs. 4. Pre-job safety meeting 5. Good training of LWD/MWD engineers.	2	2	4
3	Mud motors	1. Wrong build and drop inclination angles. 2. Not reaching required targets. 3. Need for side tracks to correct path. 4. Differential sticking. 5. Mechanical sticking, key setting. 6. Increase of cost.	3	3	9	1. Good training for DD engineers 2. Good well planning to give a smooth path. 3. Use suitable mud weight and mud additives to suit the mud motor. 4. Good Supervision. 5. Pre-job safety meeting. 6. Good equipment maintenance in the yard before sending it to jobs.	3	2	6
4	Rotary steerable system	1. Rotary steerable motor failure. 2. Drill string failure. 3. Surface control equipment	2	4	8	1. Good training for DD engineers. 2. Good well planning to give a smooth	2	2	4

		failure to send commands. 4. Wrong build and drop inclination angles. 5. Not reaching required targets. 6. Need for side tracks to correct path. 7. Increase of cost.				path. 3. Good Supervision. 4. Pre-job safety meeting. 5. Checking and testing pressure valves in surface control equipments. 6. Good equipment maintenance in the yard before sending it to jobs.			
5	BOP	1. Occurrence of kicks. 2. Blow outs of rigs. 3. Loss of equipments 4. Death or injury of people. 5. Waste in time and money.	1	4	4	1. Good testing for the BOP rams before installation. 2. Periodic inspection of the BOP. 3. Good BOP maintenance. 4. Periodic fire and blow out drills. 5. Training of workers on safety actions in case of blow outs.	1	2	2
6	Activities in drilling operation (tripping, circulating, cementing, casing,.etc)	1. Severe Injury of people. 2. Death of people. 3. Loss of equipments 4. Waste of time and costs.	3	4	12	1. Pre job safety meetings. 2. Good training of the people involved in the operations. 3. Good equipment maintenance in the yard before sending it to jobs. 4. Putting safety signs around the rig site.	3	2	6

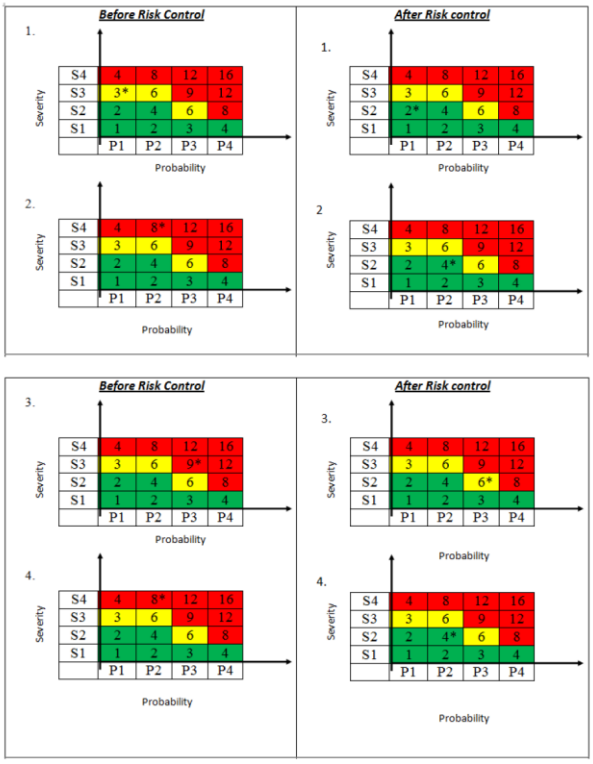

Fig. 1. *a.* Risk matrix for drilling well and methods of solution matrix.

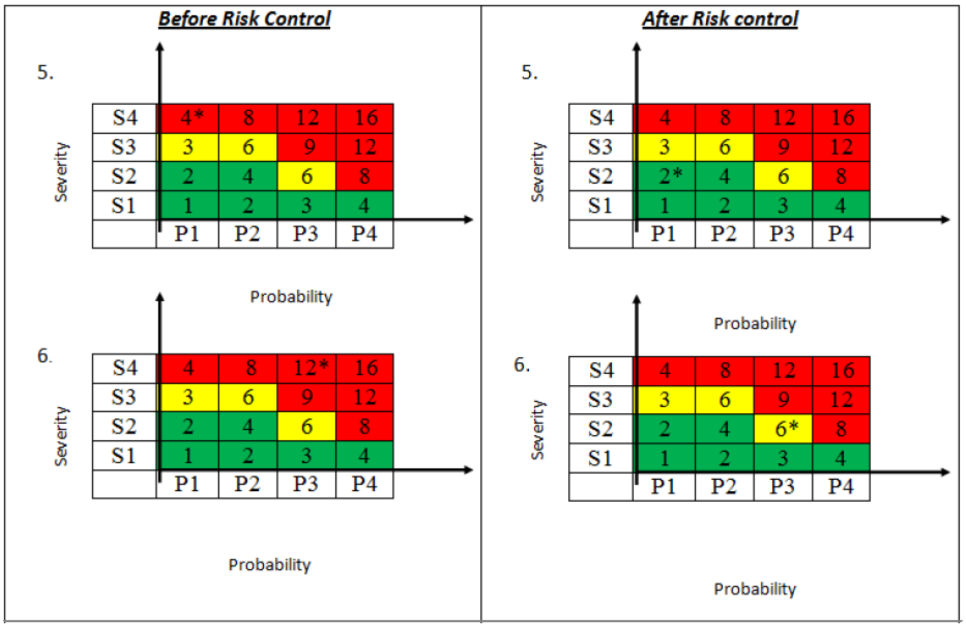

Fig. 1. *b.* Risk matrix for drilling well and methods of solution matrix.

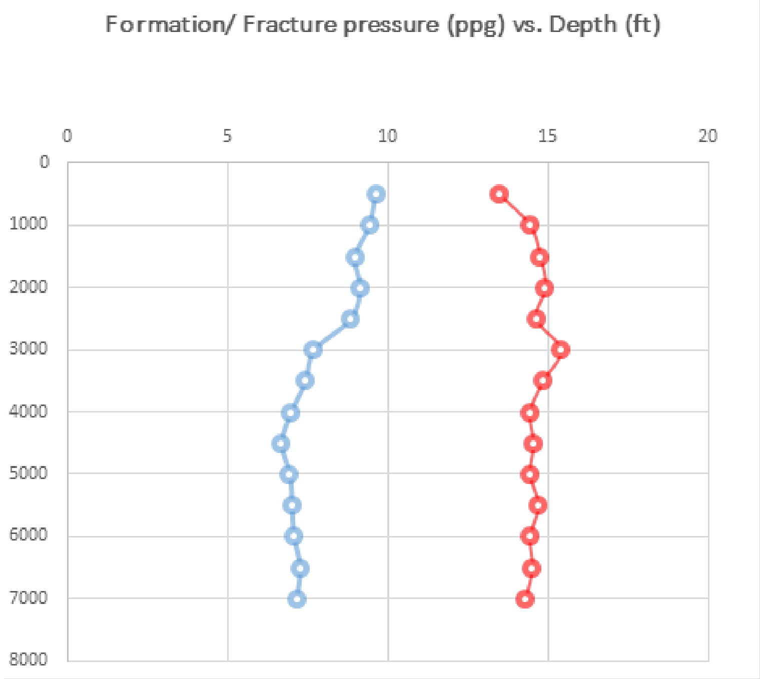

Fig. 2. Actual formation/ fracture pressures curve for well I.

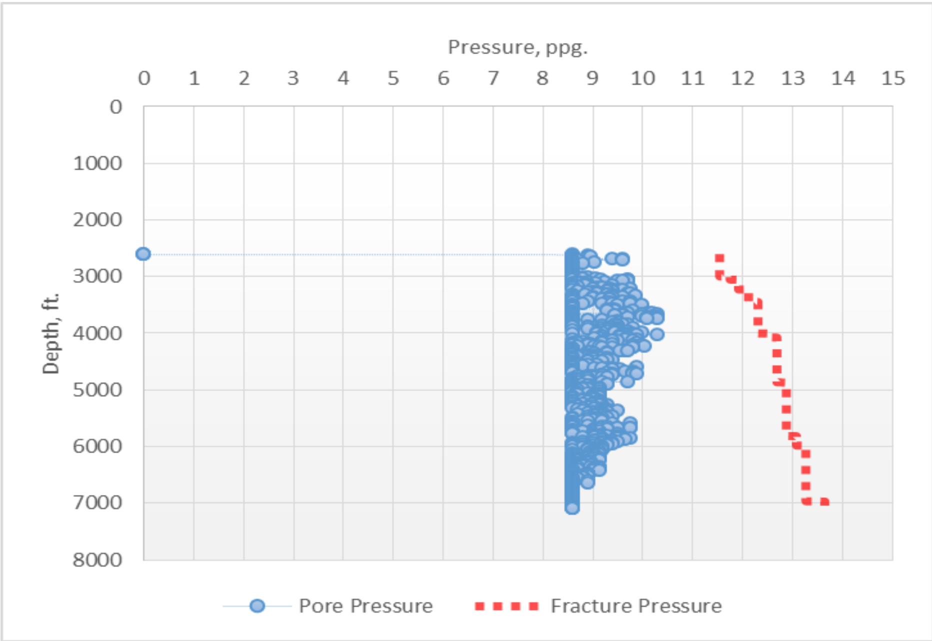

Fig. 3. Actual formation/ fracture pressures curve for well II.

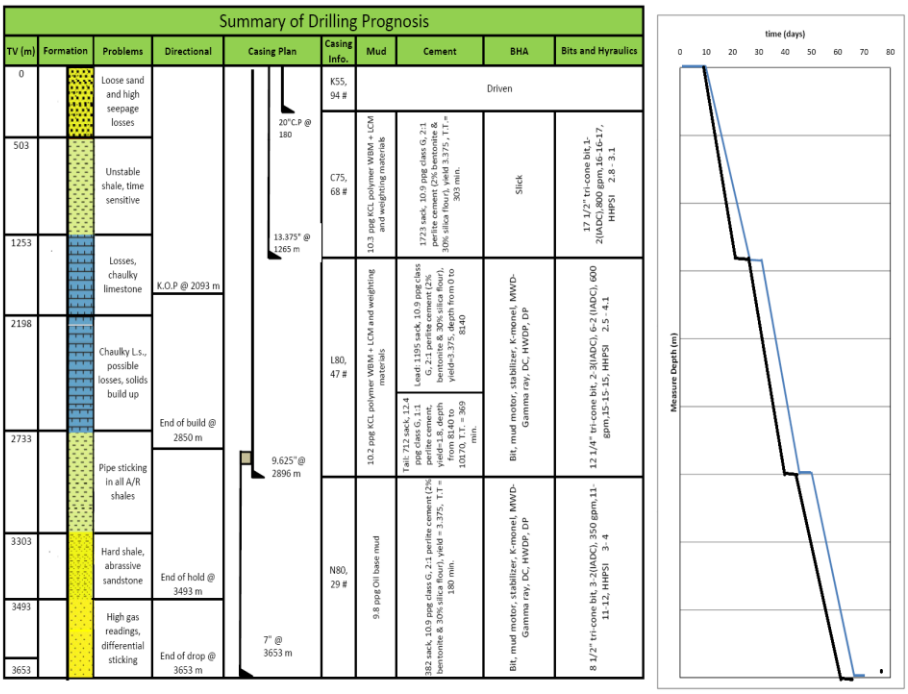

Fig. 4. Summary of drilling well prognosis for well I.

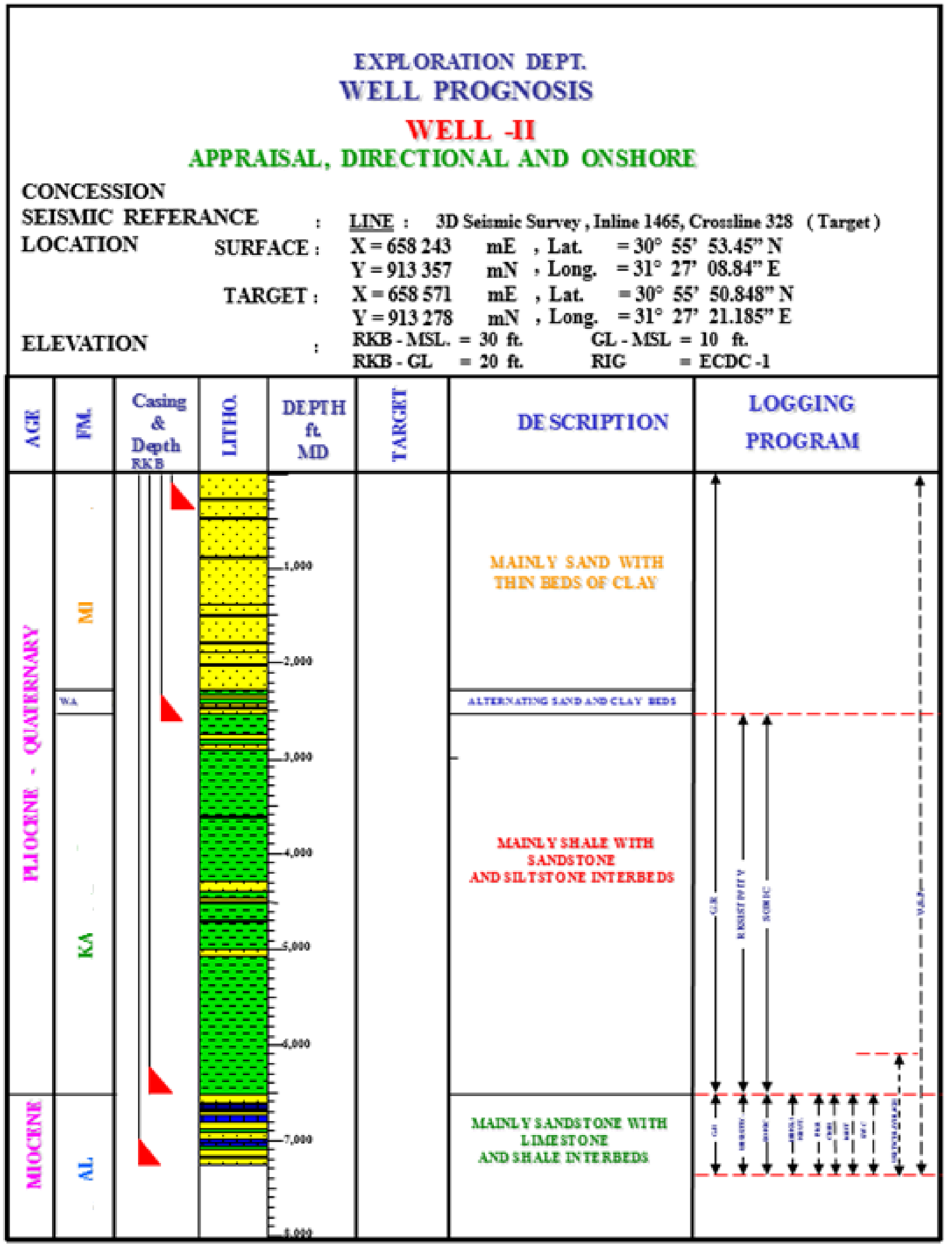

Fig. 5. Selecting casing setting depths based on formation problems well II.

MD, ft	lithology	TYPE	MUD WEIGHT	HOLE PROBLEMS	CONTROL	ADDITIVES
0	A		spud mud wt 9.8	surface	hummerd	
603	B	WBM	8.7 : 9.3	1. Possible losses 2. Shale elsewhere 3. Soft limestone	1. Control filtration losses 2. Increase rate of penetration 3. Reduce mud weight, as possible 5. Reduce weight on bit (WOB) 4. Adequate mud rheology	1. LCM 2. Polymers 3. Caustic soda
1658	C	WBM	9.3 : 10.6	1. Instability hole 2. Shale bed	1. Inhibiting shale 2. Increase mud weight	1. Polymers 2. Barites (KCl) 4. Caustic soda
2518	D	WBM	9.1	1. Complet loss of circulation	1. Control filteration losses 2. Squese cementing 3- dec.gpm 4-	1. Barites
2753	E	WBM	9.0 : 9.4	1. Possible losses when fractred & diff.stick 2. Solids build up 3. Bit and BHA balling tendency 4. Tight hole & stuck pipe	1- Adequate mud rehelogy 2. Good hole cleaning 3. Increase viscosity 4. Assure laminer flow 5. Increase mud weight	1. Polymers (to increase yield point and gel strenght) 2. Caustic soda 3. Barites
3606	F A/R G	WBM	9.1	1. Pipe sticking & ledges,erratic torqe.. It is soft shale& hard L.S A/G :have pressrized shale with mech.stick	1. Inhibting shale	1. Polymers 2. Lubricants (KCl) 4. Caustic soda
5886	H	WBM	9.1 : 9.2	1. Hard shale 2. Abrasive sandstone	1. Reduce ROP 2. Increase WOB	1. Polymers 2. Shale Inhibitor (KCl) 3. Caustic soda 4. Barites
6300						

Fig. 6. Actual well problems and selected solutions.

Formation problems resulted from a constantly formation /fracture pressures curves as appeared in figures (2) for well (I) and figure (3) for well (II) led to unable to select CSD and use the proposed method previously discussed. The application of this method which depends on wellbore problems resulted in selecting casing setting depths as: 180 ft conductor, 1265 ft surface casing, 2896 ft intermediate casing, and 3653 ft for production casing as shown in figure (3) for well (I) and 150 ft conductor, 3000 ft surface casing, 6650 ft intermediate casing, and 7200 ft for production casing as shown in figure (4) for well (II).

A large layer of shale formation X2 appeared in figure (4) for well (I) was treated by the previous proposed solutions. First of all, using KCl/polymer mud to prevent shale problems is practically quite good but it will add another 5-6 days as shown in time-depth drawing in figure (4). However, using high ROP, nu logging, and quick cementing and casing operations is perfectly well and leads to reduce the drilling hole days by 5-6 days as shown in time-depth drawing in figure (4) for well (I) that`s why the final drilling hole days will be 59 days instead of 65 days. This means the authority for expenditures for the drilling well will be reduced. After fast drilling for a large shale section, surface casing will be landed till depth 1285 ft to isolate X2 shaly formation. This will also done for well (II) and intermediate casing will be set at 6500 in order to full prevent 3500 ft KA shaly formation problems as shown in figure (5) for well (II). Finally, figure (6) represents another actual drilling well which is suffering from well problems, and selecting the controlling methods and the required additives to drilled these layers safely such as for shale inhibition of layer C, water based mud with polymer, barite (KCl), or caustic soda (NaCl) will be used.

5. Conclusions and recommendations

Based on the results and analysis, the following conclusions are extracted:

1. Risk analysis for drilling operations is highly successful in order to determine the risk operations and take all needed precautions.
2. Application of risk analysis in drilling operation will reduce the number of accidents and increase drilling well performance.
3. Selection of CSD based on the wellbore problems is perfectly suitable but sometimes it needs to be accompanied with selection of mud weight to reduce the number of casing strings in wells.
4. The proposed method of drilling a large shale section is highly succeed in reducing drilling days and save a lot of money from the total costs of well.
5. This proposed method is highly recommended in development wells and is highly needed a well experience engineer whose safety and risk principles are considered the mainly part in his personality and work procedures.

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