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SYSTEMIC APPROACH TO MINIMIZE STUCK PIPE INCIDENTS IN OIL WELLS

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ABSTRACT

Stuck pipe is one of the major drilling problems in petroleum industry, leading to losses of hundreds of millions of dollars each year. Expensive corrective action may include fishing operations, side track the hole, or plug and abandon the well. Significant production loss and delayed drilling operations may result. Therefore, major efforts have been made worldwide to determine the causes and to minimize the occurrence of stuck pipe.

The severe impact of this drilling problem was one of the prime incentives to prepare this paper. The impact of stuck pipe on both cost and safety can be avoided by better planning, understanding, communication, and perfect execution.

More than 50 stuck pipe incidents are analyzed and investigated in detail including twenty two stuck pipe cases in two Arabian Gulf countries. Thorough investigation, lessons learned and statistical analysis were used during 18-month period to check for improvement in incident rate and corrective action success rate.

The majority of stuck pipe incidents in the Arabian Gulf study area was found to be caused by Differential sticking, then Mechanical Sticking plus Wellbore Geometry, then Hole Pack-off due to formation instability.

Stuck pipe prevention awareness and training is mandatory for the drilling team in order to raise the level of awareness and to improve the competency of all relevant personnel. A poster is also proposed to highlight the risk of stuck pipe and to raise awareness among drilling personnel.

The paper presents the statistics analysis for all the captured cases and concludes the best practices and recommendations to reduce the stuck pipe occurrences.

1. INTRODUCTION

Stuck pipe is one of the old drilling problems and operational challenges in the oil industry and the consequences of this problem is very high in both cost and safety concerns, the estimated costs of stuck pipe may exceed billions of dollars yearly.

Furthermore, significant safety risks occur during pipe freeing operations, including well control and catastrophic pipe or equipment failure during pipe back-off and fishing operations. Consequently, a huge effort has been made worldwide to determine the causes of stuck pipe and to minimize the occurrence of this problem.

Stuck pipe costs are a major drilling trouble cost for the oil industry. Historically BP's stuck pipe costs have exceeded $30 million per year and various estimates indicate industry stuck pipe costs exceed $250 million per year [(4)].

The recent increase in drilling activity and the requirement to drill in depleted and high risk reservoirs have led to increase the risk of stuck pipe which affects badly in the company reputation in terms of Higher NPT “Non productive time”and great cost loss. Consequently the big oil and gas companies have allocated task force team to study the cases and introduce technical solutions to prevent this problem.

Often during drilling operations the drill string becomes stuck and cannot be raised, lowered, or rotated. This conditions can be brought about by a number of causes, such as sloughing of the hole wall, settling of large particles carried by the mud, accumulation of mud filter cake during long stoppage of circulation and, finally, sticking by pressure of the mud column holding the pipe against the filter cake on the hole wall[(3)].

The objective of most stuck pipe task force teams is to collect details of the incidents and then to analyze this data. The results are then used to determine the primary reasons for the stuck pipe and then to prepare solutions and preventive actions in order to minimize stuck pipe events.

Similarly Muhammad A. Muqeem introduced the results of the assigned task force team in Saudi Aramco for 2009 , he stated that 69.5% of the total stuck pipe ,were due to mechanical sticking and 30.5% were attributed to differential sticking .Furthermore, based on the team findings , a customized training plan was formulated to certify key drilling personnel every two years[(5)].

This paper analyzes the stuck pipe problem by focusing on twenty-two actual stuck pipe cases from a major oil company in the Arabian Gulf area during 2012 and the first half of 2013 in an attempt to determine the root causes of the stuck pipe. The study strategy is developed to prevent stuck pipe and to improve the stuck pipe reporting system.

Regarding the best hole cleaning practices for highly deviated wells, Ogunrinde[(6)] discussed the concept of hole cleaning methodology. He showed that optimal hole cleaning is the efficient removal of the drill cuttings during drilling operations and the effect of the average annular fluid velocity is a dominant parameter for cuttings transport, i.e., the higher flow rate, the less cuttings bed development.

The most important considerations for efficient cuttings transportation include:

1. Hole angle
2. Fluid annular velocity
3. Fluid rheological properties and density
4. Cuttings size ,shape, and concentration
5. Cuttings transportation ratio
6. Rate of penetration (ROP)
7. Fluid flow regime (laminar or turbulent)

2. STRATEGY AND OBJECTIVES

The strategy included the capture and complete analysis for all cases in all fields in order to identify the most common root causes. The next stage was to provide the necessary technical solutions and preventive actions to reduce these incidents, and to share this knowledge with all the drilling teams to increase awareness about stuck pipe prevention.

The final stage was to provide updated procedures to the drilling teams to help freeing stuck in a safe and effective manner. One example of a new technology was the introduction of down-hole vibration technology. A fishing agitator tool was found to improve the success rate of fishing operations in challenging wellbore environment where traditional fishing techniques were inadequate.

The main contributor in most stuck pipe events was human error. This in turn was largely due to inadequate procedures, inadequate training and knowledge, inadequate supervision, insufficient planning and ineffective communications. The study found that the correct first action is a primary method to minimize or eliminate stuck pipe occurrences.

3. CASE STUDIES

The paper presents some stuck pipe cases that are related to different stuck pipe mechanisms through detailed nonconformance report.

3.1 .Hole Pack-off due to wrong tripping procedures:

Whilst RIH for conditioning trip prior to running 7" liner, the drill string got stuck at 10,499 ft in the reservoir formation. A set-down weight of 50 k Ib was applied, followed by pick-up to 50 kIb over-pull. The operation was repeated with 50 klb slack-off followed by 50 klbs over-pull before the string was confirmed stuck, cost to resolve the issue was estimated to be $ 400,000 with more than 10 days NPT.

3.1. A. Root causes analysis:

The primary immediate cause of the incident is a failure to react to hole conditions encountered whilst running in hole as shown in fig.1.
Contributing factors include complacency or over-confidence, the time of day that the incident occurred, high-solids content in the mud and the static conditions of the well for 3 days prior to the event.

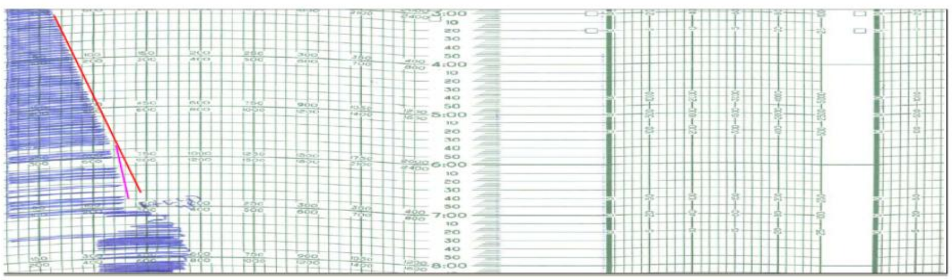

Fig. 1. Geograph chart showing increased drag when RIH

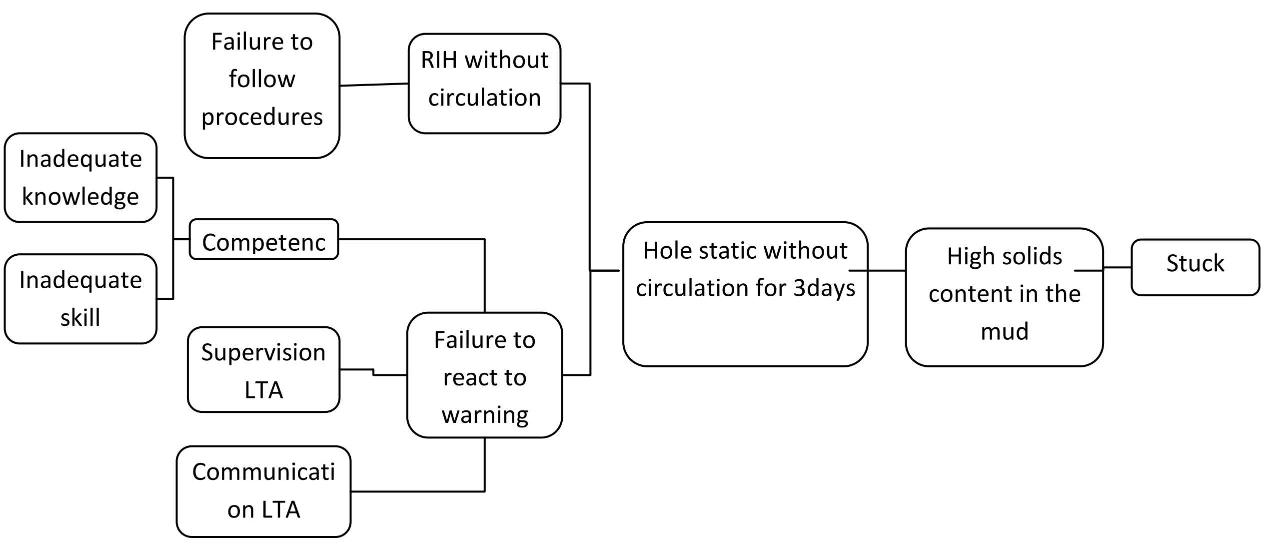

Fig. 2 Fault Tree Analysis Case Study 1

3.1. B. Incident lesson learnt:

Follow up the tripping procedures, while RIH after long static time it is recommended to circulate while RIH to break the gel and to ensure the circulation, Observe any change in drag while RIH as shown in Fig.2.

3.2.Stuck at 6" Horizontal hole due to Hole cleaning:

After drilling 6" horizontal hole to 13751ft, .a wiper trip was started to check the hole conditions before drilling ahead. Fig-3 represent the recovered cuttings after RIH during conditions trip .When POOH the first three joints, tight hole occurred with high drag. Worked out a tight spot with 25 Klb over pull at 13610 ft. Decision was made to pull out to 13520ft. The string was free when going down, but upward movement was not possible. The hole was circulated with 200 bbl's fresh mud at 300 GPM while reciprocating the drill string. It was assumed that the tight hole was caused by carbonate rocks falling into the well, so carried out three acid jobs. The pipe was backed off after applying torque and more than 45 Klbs over pull. The fish was chased to TD and screwed in successfully 50 bbls of 15% HCl were spotted. Acid was got back to surface. The string slipped at 5928ft, replaced the damaged joints, continued fishing operations and managed to screw into the fish and confirm the string integrity. By Continued working pipe with rotation and circulation upwards to the 7" liner shoe with slight and safe over pull. The hole was back reamed using weighted pills, acid and lubricant pills. Conditioning trip was carried out with a roller reamer before resuming drilling. The hole was free. Precautionary washed down to bottom was followed. A huge amount of cuttings was circulated out while washing down to the bottom .The remaining 6" of horizontal hole was drilled to the desired target depth and completed as per plan.

3.2.A. Root cause analysis :

The root causes of these incidents were clearly due to the fact that hole cleaning procedures in highly deviated well were not fully implemented.

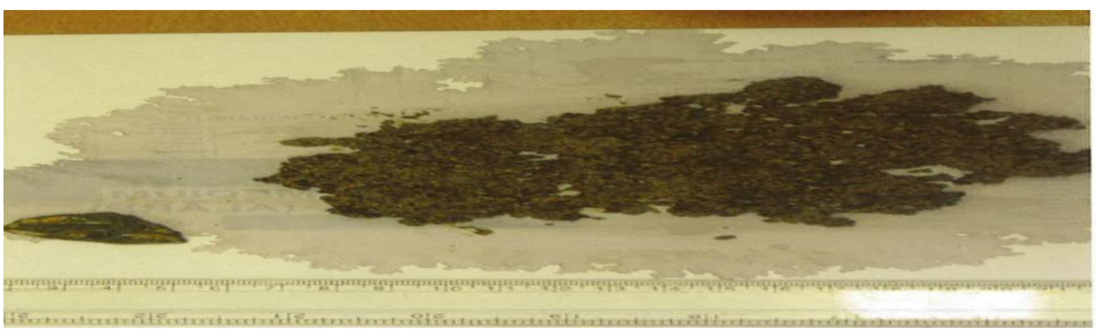

Fig. 3 Recovered cuttings after RIH during conditions trip for hole cleaning.

3. 2. B Incident lesson learnt:

From the root cause analysis and findings, it was clear that hole cleaning practices for highly deviated and horizontal wells were not followed properly. Supervision and practices were less than adequate.

The following recommendations are proposed:

- Enhanced planning, including all operational risks and hazards, to be included in the job orders
- The key to clean the highly deviated section is to rotate the string with Maximum RPM and circulate with maximum circulation, sweep the hole with weighted pills.
- Job orders to be more detailed and more specific, and communicated to all the concerned parties
- Sharing best practices and standard procedures must be improved
- Ensure proper communication between all the drilling team members; drilling engineer, drilling supervisor and mud supervisor.

4. DIFFERENTIAL STUCK PIPE AT 8.1/2" SECTION.

After Drilling 8-1/2" hole to 9780ft with 91pcf (12.1 ppg) mud weight, 40 Klbs overpull was observed after making a connection. Over pull was Cleared by reaming. Drilling was continued to 10,033ft with intermittent sticking tendency in permeable formation Zone X. A short wiper trip was performed to 8950ft (previous trip depth). Drilling ahead was continued with intermittent sticking problems every connection in highly overbalanced permeable Zone X and Dense Zone Y.

By using various practices to avoid stuck pipe, e.g. minimizing surveys and connection time. Landing the build section of the well at 88.5° deviation at 10387ft MD (9590ft TVD) at top of Zone Y. After the final circulation and picked up to 10370 ft and racked back the Kelly (string was rotated while racking back Kelly). POOH was started, but while picking up the string, over pull was observed and the string could not be rotated. Kelly was made up and worked the string. The string was stuck. The drilling jar was also stuck and could not jar down or up. Diesel Pipe-Lax pill was spotted (proprietary pipe freeing lubricant) twice. By circulating two 25 bbl pills, hydrostatic head was reduced and worked the string, but without success.

After many attempts to free the stuck pipe, including 21 acid jobs with 15 - 28% HCl, three separate attempts to free the string with the agitator fishing tool, jar, and intensifier were also failed. Ultimately the string was backed off from 9545ft, leaving 825ft of fish and two radioactive sources left in the hole at 10310ft MD and 9585.9ft TVD.

Five cement plugs were placed from 9542 ft back to 6800 ft. A whip stock was set in the 9-5/8" casing at 6740ft as a mechanical protection for radioactive sources as well as for isolating reactive shale in Zone Z. Cut a window in the 9-5/8" casing from 6728 - 6741 ft and the well was kicked off and side tracked. 8-1/2" hole was sidetracked without radioactive sources using 87 pcf (11.6 ppg) OBM with 5" HWDP (instead of 5-1/2" HWDP) to 10289ft MD (9578ft TVD). 7" liner was run and set without any problems.. This problem caused the company lost ~808 Hr.'s and 2,500,000 $

4.1. A. Finding:

The incident investigation determined the following findings:

- Drilled high angle hole with 1900 psi overbalance in a permeable reservoir formation.
- At TD, the drilling jar was located in the tangent section (82° deviation) in permeable Zone X. When the BHA became stuck, the jar was also in stuck zone and could not be activated.
- The successful sidetrack was drilled with a lower mud density and smaller diameter HWDP to help reduce the differential sticking force.

4.1. B. Root Causes

The root cause of this incident was differential sticking due to high overbalance pressure causing a high differential sticking force in permeable Zone X. The long tangent section of ~300 ft of BHA with 5-1/2" HWDP at 82° hole angle provided a large surface area in contact with the borehole wall.

4.1. C.Incident lesson learnt

The following recommendations were proposed:

- Shut-in the water injector wells within 1 km at least 3 months prior to penetrating the 'high pressure' zone to allow lower mud density and minimize pressure overbalance.
- Revise well design if possible to isolate the high pressure zone, e.g. use heavy casing design and extend 9-5/8" casing to the Dense Zone below Zone Y (the high pressure zone).
- Avoid using 5-1/2" DP in the permeable high overbalance zone. Instead, use 5" DP or 5" HWDP to help reduce borehole wall contact surface area.
- Avoid running radioactive sources if possible in highly overbalance hole sections.
- Usage of well bore strengthen material non-compressible sized marble along with sized resilient sintered graphite was used to replace the traditional $CaCO_3$ bridging agent. This dual combination carbon-based material allows highly packed particles under compression to expand or contract slightly in pores and fractures without collapsing or being dislodged, This material can also help to reduce toque and drag significantly [(2)].

5. CASE STUDY STATISTICS RESULTS & DISCUSSION.

Data was gathered from a total of 29 stuck pipe incidents. Statistical analysis was then performed in order to identify the primary stuck pipe causes. This data was then used to help prepare a stuck pipe preventing plan.

Analysis Results – Year 1

5.1.Stuck pipe mechanisms and NPT

The first year recorded 20 stuck pipe cases and the complete analysis was found to be as follows:-
During the first year it was observed that the majority of stuck pipe mechanisms were: Differential (35%) , Mechanical / Wellbore Geometry (35%) , Hole Pack-off (25%) and Hole Cleaning (5%)

Table 1. First Year Stuck pipe Analysis

Stuck Mechanism	No of wells	Total NPT, Days	Cost ,USD	% of Total
Differential sticking	7	34.25	1,840,000	35
Hole pack-off	5	78.58	4,547,000	25
Mechanical +Wellbore geometry	7	62.85	5,740,000	35
Hole Cleaning	1	16.67	80,000	5
Total	20	192.35	12,927,000	100

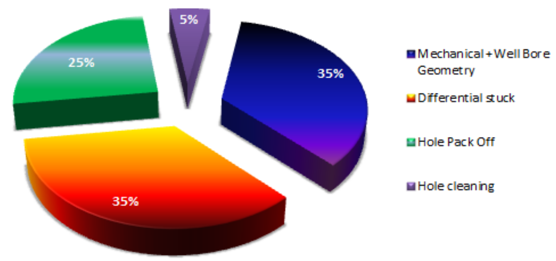

Fig. 4. First Year Stuck pipe mechanisms

NPT related to stuck pipe was almost 24% of total NPT reported for this year (Fig.4). Stuck pipe NPT accounted for 192.35 days out of 800.56 days total NPT (Table.1), the cost attributed to stuck pipe was $13 MM for this year.

5.2. Stuck pipe hole size.

The main hole sizes where stuck pipe occurred were the 8-1/2" section (60%), 12-1/4" (15%), 6" (15%) and 17-1/2" (10%).(Fig. 5)., Consequently a focus on differential sticking, especially in the 8-1/2" section, should be a priority for the task force team to introduce the corrective plan that will reduce the problem and associated cost.

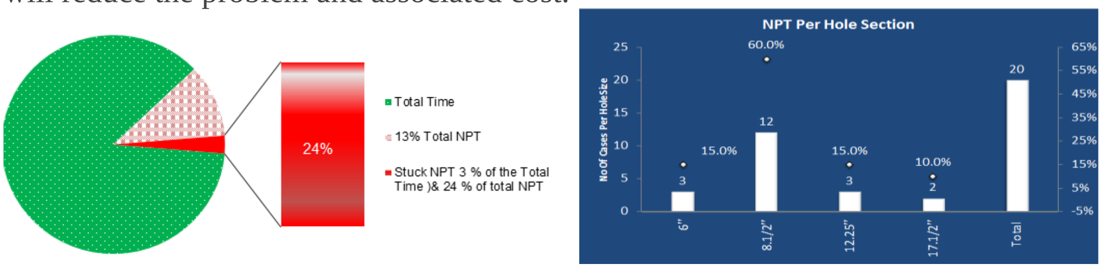

Fig. 5. NPT percentage for year one and per hole Section

5.3 . Stuck pipe root causes.

The majority for the root cause was related to Procedures (48%), personnel (34%) and Equipment (17%), A lack of procedures and poor implementation indicate that human error is the main reason behind the incidents, with almost 83% related to humans (Fig.6)

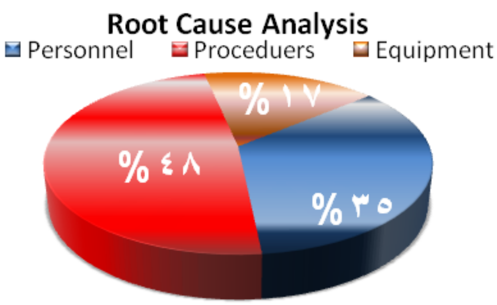

Fig. 6. Root Cause Analysis for year one

6. ANALYSIS RESULTS – FIRST HALF OF YEAR 2

Analysis results continued to the middle of second year and allocate the problems, stuck mechanism and root cause and the following statistics had been recorded:

6.1. Stuck pipe mechanisms and NPT

The middle of the second year recorded 9 stuck pipe cases and the complete analysis found to be as follows:-

During the middle of the first year it was observed that the majority of stuck pipe mechanisms were: Differential (45%), Hole Pack-off (33%), Mechanical / Wellbore Geometry (22%) and Hole Cleaning (0%) (Table.2 and Fig.7)

Table- 2 First year stuckp pipe analysis

Stuck Mechanism	No of wells	Total NPT, Hr's	Cost ,USD	% of Total
Differential sticking	4	120.50	224,000	44%
Hole pack-off	3	321.50	617,000	33%
Mechanical +Wellbore geometry	2	41.50	83,000	22%
Hole Cleaning	0	0	0	0%
Total	9	483.50	924,000	100%

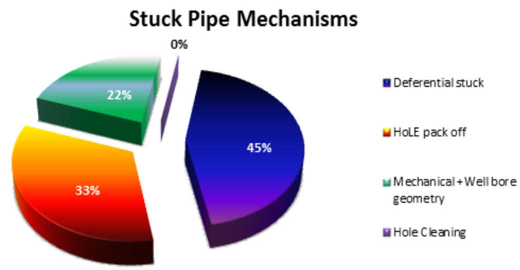

Fig. 7. First Year Stuck pipe mechanisms

It was clear that a reduction in the severity of stuck pipe cases had been achieved relative to the previous year; NPT related to stuck pipe was accounted for 20 days. The cost attributed to stuck pipe was $924 M for this half year.

6.2. Stuck pipe hole size and root causes.

The majority for stuck pipe was found to be in the 8.1/2" section (33%) , 6" section(33%), 12.1/4" section (22%) and at 17.1/2" section (11%) (Fig. 8), the focus should be on differential sticking, especially in the 8-1/2" and 6" sections. The root cause was related to Procedures (50%) and Personnel (50%) (Fig.8).

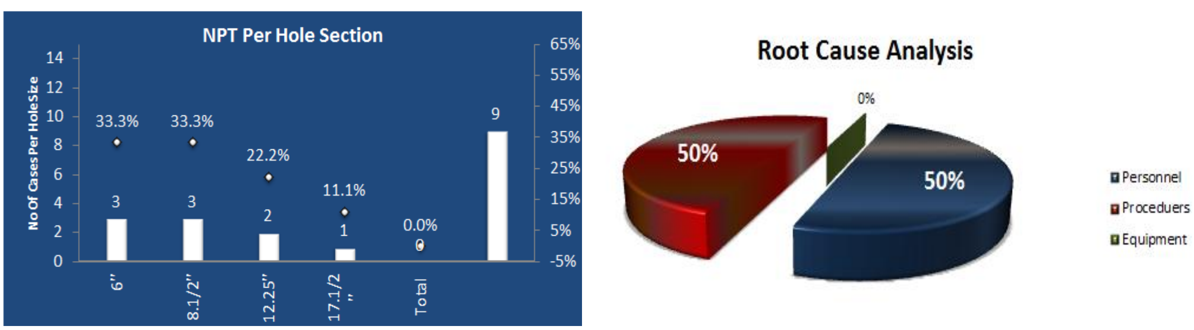

Fig. 8 NPT per hole section and Root Cause Analysis

7. STATISTICS RESULT COMPARISON

A stuck pipe severity comparison was conducted between the first half in both study years results to check for improvement in curing this problem. The comparison was very interesting, with the following conclusions being made.

1. The first half of the second year reported 9 cases compared with 13 cases in the first half of the first year (Fig. 9). The 30% reduction in the number of cases is very significant and confirms the importance of stuck pipe monitoring, root cause analysis and awareness training.

2. Differential and Mechanical sticking cases were reduced by 33%. Hole pack-off had the same number of cases and hole cleaning incidents had been prevented.
3. Although the number of cases was reduced by 30%, the NPT comparison between the first half of both years shows the greatest improvement. NPT was reduced by 83%. A great reduction of approximately 100 days of recordable NPT was saved in the first half of year 2 relative to year 1 (Fig 9).
4. The cost saving due to NPT reduction was significant, with more than $6,400,000 saved. This was 87% reduction in NPT cost in year 2 relative to the same period in year1 (Fig 10).
5. A greater focus on where the majority of stuck pipe cases occurred, i.e. in the 8 1/2" section, showed a 62% reduction in stuck pipe incidents see (Fig.11).
6. Finally, the comparison showed great improvement in procedures follow up and equipment failure avoidance as the maintenance and inspection implemented as per plan.

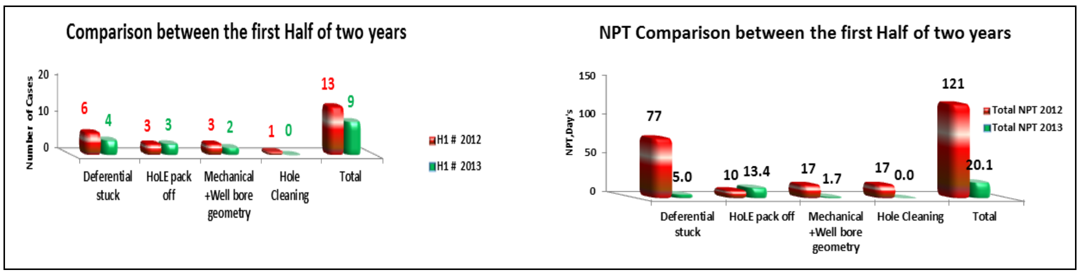

Fig. 9. Number of stuck pipe cases &NPT comparison.

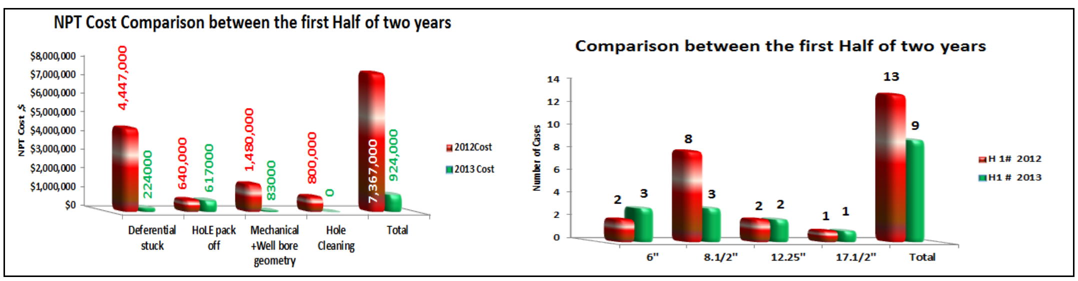

Fig. 10 NPT Cost Comparison & NPT per hole size for the 1st half of year 1 and 2 .

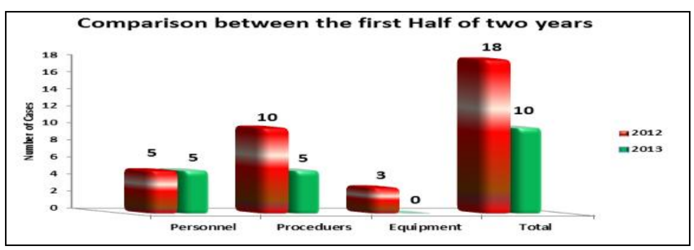

Fig. 11 Root Cause Comparison for first half of year 1 and year 2.

8. CONCLUSIONS AND RECOMMENDATIONS:

Based on the analysis of the used cases which are actual examples, the following conclusions can be cited:

1- The majority of stuck pipe incidents in the Arabian Gulf study area was found to be caused by differential sticking, then Mechanical Sticking plus Wellbore Geometry, then Hole Pack-off due to formation instability.

2- Stuck pipe prevention awareness and training is mandatory for the drilling team in order to raise the level of awareness and to improve the competency of all relevant personnel .A poster is also proposed to highlight the risk of stuck pipe and to raise awareness among drilling personnel.

3- Stuck pipe reporting form was compiled to help track all the information related to the stuck pipe incidents, including the stuck pipe mechanism, root cause, corrective actions, preventive actions, and lessons learnt.
4- Proper planning and risk assessment to ensure that depleted zones are recognized, and the overbalance pressure is thoroughly determined. If the overbalance pressure exceeds 3000 psi, then it is recommended to change the casing design.
5- Consider TLC logs on drill pipe or tubing as an option to mitigate the risk of getting wire line tools stuck, as this allows for mud circulation and for greater over pull, if required.
6- Ensure a smooth directional plan prior to drilling with low dogleg severity. Consider alternatives if high dogleg rate is needed. Avoid significant steering changes in the lateral section.
7- Ream and Back-ream across ledges or significant changes in formation hardness are mandatory. Closely monitoring pick-up weight, slack-off weight, rotating weight, on- bottom torque and off –bottom torque are essential.
8- Optimized mud properties are the best line of defense to prevent stuck pipe incidents related to hole cleaning and annulus pack-off, Mud properties should be within the optimum range as per the Drilling Program. Maintain good hole cleaning rheology. Keep the cuttings concentration < 10% by volume in every section of the well. Control ROP. Ensure low filtrate rate and thin, tough, impermeable filter cake, Maintain shale stability by adequate mud weight and good clay swelling inhibition, Utilize a decanting centrifuge to maintain low gravity solids (LGS) <5% by volume. The mud weight should be recorded every 30 minutes while drilling or circulating.

SUMMARY

Stuck pipe incidents can be avoided if the following controls are implemented.

- Proper planning, design and risk assessment
- Effective communication between the drilling team members
- Enhanced field competency and stuck pipe awareness
- Correct first action
- Compliance with drilling best practices and standard procedures.
- Effective stuck pipe prevention training program
- Also stuck pipe can be virtually eliminated by careful focus and tracking of the problem. A competent investigation team and comprehensive reporting and database system can analyze the problem, identify the root cause, and introduce an effective action plan.

REFERENCES

1. ADCO Drilling Manual. UAE: ADCO, 2009.
2. AL-Muhallan. M.S. Novel Lubricant Bridging agent Combination cures differental sticking problems in high pressure North kuwait . Asia Pacific Drilling Technology conference held in Bankok ,Thiland ,August 2014: 170550-MS (2014).
3. Annis, M. M.. Differential Pressure Sticking-Laboratory Studies of Friction Between Steel and Mud Filter Cake. Journal Journal of Petroleum Technology (1962).
4. Bradley, W. B., & Jarman, D. P.. A Task Force Approach to Reducing Stuck Pipe Costs. SPE/IADC Drilling Conference, 11-14 March 1991, Amsterdam, Netherlands: 21999-MS (1991).
5. Muhammad A. Muqeem, S. Stuck Pipe Best Practices -. SPE Saudi Arabia Section 8-11 April 2012, Al-Khobar, Saudi Arabia,: 160845 (2012).
6. Ogunrinde J.O., S. a.. Hydraulics Optimization for Efficient Hole Cleaning in Deviated and Horizontal Wells. Nigeria Annual International Conference and Exhibition, 6-8 August 2012, Lagos, Nigeria: 162970 (2012).

Apendex.1

Nomenclatures:

AFE	Authorized for Expenditure
Assy.	Assembly
Bbl.	Barrel
BHA	Bottom Hole Assembly
BPH	Barrel per Hour
DE	Drilling Engineer
Deg	Degree
DS	Drilling supervisor
DTL	Drilling team leader
ECD	Equivalent circulating density
ERD	Extended reach drilling
Ft	Feet
GPM	Gallon per Minute
HWDP	Heavy Wall Drill Pipe
Klb	Kilo Pound
LTA	Less Than Adequate
MS	Mud Supervisor
NPT	Nonproductive Time
OBM	Oil Base Mud
OP	Over Pull
PCF	Pound per Cubic Feet
POOH	Pull Out Of Hole
PPG	Pound per Gallon.
PSI	Pound per Square Inch
RIH	Run In Hole
RM	Rig Manger
SOE	Senior Operation Engineer
TD	Total Depth
TLC	Tough Logging Conditions.