EVALUATION OF DRILLING DESIGNS FOR SMART MRC WELLS APPLIED IN SAUDI ARAMCO

BY

Khalifah Mohammed Al-Amri

A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

PETROLEUM ENGINEERING

JANUARY 2011

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN 31261, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

This thesis, written by **KHALIFAH MOHAMMED AL-AMRI** under the direction of his thesis advisor and approval by his thesis committee, has been presented to and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN PETROLEUM ENGINEERING**.

Thesis Committee

a. a. almajed

Dr. Abdulaziz A. Al-Majed (Thesis Advisor)

M. A. Marhoun

Dr. Muhammad A. Al-Marhoun (Member)

Dr. Mahmoud E. Doklah (Member)

a. a. almajed

Dr. Abdulaziz A. Al-Majed
(Department Chairman)

Dr. Salam A. Zummo
(Dean of Graduate Studies)

6/6/11

Date

Acknowledgement

All praise and thanks be to Almighty Allah, the most Gracious, the most Merciful. Peace and mercy be upon His Prophet.

Acknowledgment is due to King Fahd University of Petroleum & Minerals for being the greatest home for me and Saudi Aramco for supporting this research.

I offer my sincerest gratitude to my advisor, Dr. Abdulaziz Al-Majed, who has supported me throughout my thesis with his patience and knowledge whilst allowing me the room to work in my own way. I attribute the level of my Masters degree to his encouragement and effort and without him this thesis, too, would not have been completed or written. One simply could not wish for a better or friendlier thesis advisor. I would also like to thank my thesis committee members: Dr. Mohammed Doklah and Dr. Mohammed Al-Marhoun for their invaluable cooperation, understanding and support.

Acknowledgment also goes to the person that inspires me the most, Mr. Adib Al-Mumen.

Last but not least, I would like to thank my family members for being patient and for their words of encouragement to spur my spirit at moments of depression.

Khalifah Mohammed Al-Amri

DEDICATION

This thesis is dedicated to my older sister, my loving wife and my unborn child.

Table of Contents

Acknowledgment ………………………………………………………............ iii

Dedication …………………………………………………………………… iv

Table of Contents ……………………………………………………………. v

List of Tables ………………………………………………………………… viii

List of Figures ……………………………………………………………….. ix

Thesis Abstract (Arabic) ……………………………………………............... xi

Thesis Abstract (English) ……………………………………………………. xii

CHAPTER 1

Introduction ……………………………………………….………. 1

1.1 Geology and Drilling Environment in the Mother-Field ..…………………. 2

1.2 Actual Mother-Field Casing Design of Single Lateral Wells ……………… 4

1.2.1 26”-24” Conductor Pipe ……………………………………………. 4

1.2.2 18-5/8” Casing Point ……………………………………………….. 4

1.2.3 13-3/8” Casing Point ………………………………………………. 5

1.2.4 9-5/8” Casing Point ………………………………………………… 6

1.2.5 7” Casing Point …………………………………………………….. 7

CHAPTER 2

Background of the Work…………………………………….…. 10

2.1 Evolution of Smart MRC Wells …………………………………………… 10

2.1.1 Review of Technology …………………………………………… 11

2.1.2 Maximum Reservoir Contact Wells ………………………………… 13

2.1.3 Smart MRC Wells ………………………………………………… 15

2.2 Statement of Problem ……………………………………………………….. 16

2.3 Objectives and Approach of the Study ……………………………………… 18

2.3.1 Objective of the Study ……………………………………………… 18

2.3.2 Approach of the Study ……………………………………………… 18

CHAPTER 3

BIG CASED HOLE DESIGN ……………………………………………… 20

3.1 Application to the Mother-Field…………………………………………... 20

3.2 Justification of the Design ………………………………………………… 22

3.3 Technical Problems and Challenges Related to the Design …………………. 23

3.3.1 Casing Design …………………………………………………... 24

3.3.2 Loss of Circulation Challenge ……………………………………….. 25

3.3.3 Liner Cement Job Quality ……………………………………………. 27

CHAPTER 4

SLIM OPEN HOLE DESIGN ……………………………………….…. 30

4.1 Application to the Mother-Field ……..……………………………………… 30

4.2 Justification of the Design ………………………………………………… 30

4.3 Technical Problems and Challenges Related to the Design …………………. 32

4.3.1 Well Control Issues ………………………………………………….. 33

4.3.2 Differential Sticking Concerns ………………………………………. 34

4.3.3 Equipment Miss-Placement ………………………………………….. 36

4.3.4 Steel and Cement Separation ………………………………………… 38

4.3.5 Junctions Integrity and Laterals Accessibility ………………………. 39

4.3.6 Future Workover …………………………………………………….. 40

CHAPTER 5

PROPOSED SLIM CASED HOLE DESIGN ………………….…… 42

5.1 Drive for the Proposed Design ……………………………………………… 42

5.1.1 Cap-rock Built-in Feature …………………………………………… 44

5.1.2 Retaining the Norm in Hole Size Versus Type of Formations ……… 45

5.1.3 Problematic Large-Expensive Open Hole Completions …………….. 45

5.2 Technical Problems and Challenges Related to the Design …………………. 46

5.2.1 Rate of Penetration …………………………………………………… 46

5.2.2 Advanced Geo-steering ………………………………………………. 48

CHAPTER 6

RESULTS AND DISCUSSION ………………………………………… 50

6.1 Big Cased Hole Design Technical Problems and Challenges Mitigation …… 50

6.1.1 Slim Casing Design ……………………………………………….. 50

6.1.2 Avoiding Loss of Circulation ………………………………………… 51

6.1.3 Ultimate Cement Job Quality ………………………………………… 52

6.2 Slim Open Hole Design Technical Problems and Challenges Mitigation…… 54

6.2.1 Safe Drilling Conditions ……………………………………………… 54

6.2.2 Elimination of Differential Sticking Concerns ……………………….. 54

6.2.3 Intact Steel Junction and Smooth Lateral Intervention ……………….. 55

6.2.4 Proper Equipment Placement ………………………………………. 56

6.2.5 Proper Steel and Cement Separation ………………………………….. 56

6.2.6 Possible Future Workovers …………………………………………. 56

6.3 First In-class features …………………………………………………….. 57

6.3.1 Extra Assurance of Eliminating Laterals Communication ……………. 57

6.3.2 Full Equalization of Each Lateral ……………………………………… 58

6.4 Total End of Well Time and Cost ……………………………………………… 61

6.4.1 Target Days Comparison ………………………………………………. 62

6.4.2 Cost Comparison ……………………………………………………… 64

CHAPTER 7

CONCLUSION ……………………………………………………… 66

References …………………………………………………………… 68

Vitae ………………………… …………………………………… 74

List of Tables

Table No.	Table Title	Page No.
Table 3.1	Some of wells that encountered loss of circulation while drilling 8-1/2” hole	26
Table 3.2	Morning report snap shot for cementing 7” casing with losses	29
Table 4.1	Morning report snap shot showing stuck smart completion in open hole	35
Table 5.1	Morning report snap shot showing the ROP across Formation-14 anhydrite	47
Table 6.1	Morning report snap shot shows additional runs before choosing the window depth	53
Table 6.2	Casings lengths required for each design	62
Table 6.3	Time required to drill each section for all designs	63
Table 7.1	General comparison between all designs	67

List of Figures

Figure 1.1	Field-A conventional horizontal single lateral well layout with conductor pipe	8
Figure 1.2	Field-B/Field-C conventional horizontal single lateral well layout	8
Figure 2.1	Smart completion components with sliding sleeve to control each lateral	12
Figure 2.2	Two examples of Field-X MRC wells	14
Figure 2.3	Fish bone MRC smart well design	15
Figure 3.1	Existing Big Cased Hole design layout	23
Figure 3.2	Smart completion string seated within a casing within the reservoir	25
Figure 3.3	Simulation map of fractures across Formation-15 (reservoir)	27
Figure 3.4	Big Cased Hole laterals hosting the 7” casing and smart completion	28
Figure 4.1	Slim Open Hole well design layout	31
Figure 4.2	Slim Open Hole laterals hosting smart completion	32
Figure 4.3	Actual miss-placement of smart completion in Field-X well	37
Figure 4.4	Lateral and fracture communication isolation means in the Slim Open Hole design	38
Figure 5.1	Proposed Slim Cased Hole well design layout	44
Figure 5.2	Periscope log helps to detect Formation-15 Z-1 before penetrating it	49
Figure 6.1	Each lateral represents a unique replacement of single lateral wells	51
Figure 6.2	Smart completion seating section on the two designs	55
Figure 6.3	Deficiency in full equalization at the Big Cased Hole design	59
Figure 6.4	Deficiency in full equalization at the Slim Open Hole design	60

Figure 6.5 Full equalization in the proposed Slim Cased Hole design 60

خلاصة الرسالة

إسم الطالب: **خليفة محمد العمري**

عنوان الرسالة: **تقييم تصاميم حفر الآبارالذكية متعددة الخطوط الفرعية المطبقة في ارامكو السعودية**

التخصص الحقلي: **هندسة البترول**

تاريخ الدرجة: **محرم 1432**

تكنولوجيا الابار الذكية هي واحدة من أهم الاكتشافات في مجال تكنولوجيات الإنتاج خلال السنوات الأخيرة. أرامكو

درجة ماجستير العلوم

جامعة الملك فهد للبترول والمعادن

الظهران – المملكة العربية السعودية

التاريخ: محرم 1432

Thesis Abstract

Student Name: **Khalifah Mohammed Al-Amri**

Title of Study: **Evaluation of Drilling Designs for Smart MRC Wells Applied in Saudi Aramco**

Major Field: **Petroleum Engineering**

Date of Degree: **January 2011**

Smart well technology is one of the most significant breakthroughs in production technologies during recent years. Saudi Aramco has paid a quite large attention to such field development schemes especially in mature and remote fields. Initially the well construction design was effected greatly with the additional requirement of an extra casing string placed within the reservoir in order to act as a safe seat for the smart, expensive and complicated equipment of the smart completion. Further optimization steps introduced a design that was based on the elimination of the installed-for-purpose casing within the reservoir and to complete the well with open hole smart completion equipment. The thesis evaluates thoroughly the two designs by highlighting their pros and cons from the technical and economical side of the designs. Finally it will propose a unique design that bridges the gaps and combines the benefits of the two designs as well as demonstrate its incremental savings.

MASTER OF SCIENCE DEGREE

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

Dhahran – Saudi Arabia

Date: January 2011

CHAPTER 1

INTRODUCTION

Planning any well type is an investment whether it is water, oil or gas well. Achieving the original objectives is the main goal for any project. Constructing wells have been going under tremendous changes since early 1990's. Moving from vertical to slanted wells and reaching to horizontal wells which proved their reliability. Retaining surface footprints to the smallest possible areas resolves many issues such as population growth, facilities and other congested surface locations. Development in drilling Multi-laterals wells that extends to maximum reservoir contract (MRC) resolved the concerns of surface footprints. Well intervention of such complex wells is quite complicated and that was the primary reason for complementing such wells and others with smart completion systems. The continuous growth of the Smart MRC wells proves reliability and increases believe in investing in such wells. Such wells must be planned very well in a watchful scheme to deliver their original targets.

1.1 Geology and Drilling Environment in Ghawar:

The surface section is usually consisted of incompetent sand which has the tendency of collapsing. Fresh water Aquifer-1 and Aquifer-2 are followed by Formation-3 then bottomed by Formation-4 which is a salty water zone. The first occurrence of a chalky white gypsiferous anhydrite is the start of Formation-3 and can be identified by the rate of penetration (ROP). ROP slows down at the top of Formation-3, as the sub-layers of the formation changes. Circulation to surface is mostly lost while drilling Formation-4. Formation-4 is then followed by Formation-5 which is mainly shale. The start of Formation-5 must be picked on drill time chart. It is generally characterized by a gradual decrease in drill time and may be determined by comparison with nearby wells to estimate its geological depth. The lithology at the upper portion of Formation-5, as picked in Field-A, is actually limestone. In the crestal part of the Mother-Field, the segment between pre-Formation-5 unconformity and post-Formation-5 Sand Member is eroded and it may not be possible to pick Formation-5 from drill time. It is then followed by Formation-6 which is mainly detected by the common “E” shape signature[9].

Formation-7 (water aquifer) comes afterwards. Circulation is occasionally lost in this formation. If returns can not be gained by Loss Circulation Material (LCM) pills or cement plugs, then drilling from this point to the casing point must be executed with mud and mud cap across Formation-7. Circulation is commonly lost in the Dolomitic Limestone (Formation-8), and drilling from this point to the casing point is done with water and a mud cap across Formation-7. The upper portion of the greenish-gray shale is water sensitive, if exposed for more than a short period of time. Formation-9 bottoms the top mentioned zones and it is a good seating area for casing isolation[9].

Formation-10 is following the Formation-9 and it is a water bearing zone with moderately low pressure when compared to the lower formations. Formation-11 is typically anhydrite that contains a non-developed reservoir at this Mother-Field. After wards, Formation-12, 13 and 14 exist and could have water or oil or both but are not usually targeted as Formation-15 is more of a commercial value and quantity. Each of the formations 12 to 14 is bottomed with an anhydrite layer that caps the next formation. For example, Formation-12 has a Base of Formation-12 which acts as the cap rock for Formation-13 and so on. The distinct criteria of those cap rocks are their impermeability and zero-porosity.

Formation-15 (our main target) is an Upper Jurassic carbonate formation, sealed by the massive overlaying Base Formation-14 anhydrite cap rock. In the Mother-Field, Formation-15 is differentiated into four lithostratigraphic zones. From top to bottom, these zones are generally known as Zone 1 to 4, with Zones 2 and 3 being sub-divided into A and B sub-zones. The best reservoir quality is located in Zone 2 with respect to permeability and porosity[8].

1.2 Actual Mother-Field Casing Design of Single Lateral Wells:

1.2.1 26"-24" CONDUCTOR PIPE:

This is set at 100'± below the surface. It serves to keep the unconsolidated sand from washing out under the rig. Actual size of the casing used for this may vary, based on the well program and the final payzone hole size[9]. Unconsolidated sand usually exist in Field-A which is the northern part of the mother-Field. The more south of the mother-Field we go, the more firm surface hole is found like in Field-B and Field-C.

1.2.2 18-5/8" CASING POINT:

Standard casing point is the top of Formation-3. Actual setting depths have varied widely over the years. It has been set as high as the top of the Eocene. Most of the casing points are from 25' above to 50' below the top of this formation. The complete range is from 315' above to 201' below the top of Formation-3[9].

The main objective of this casing point is to isolate the fresh aquifers from Formation-4 that contains salty water, and to maintain the hole after losing circulation in Formation-4[9].

The casing point is easily identified by samples, at the first occurrence of a chalky white gypsiferous anhydrite. As mentioned earlier, this point may also be identified by the ROP[9].

1.2.3 13-3/8" CASING POINT:

Standard casing point for the string is 50' into Formation-5. Actual setting depths have ranged from 990' above Formation-5 (troublesome formation) to 375' below the top[9]. Over the years, the casing point has been shifted to be 50' into Formation-6 to confirm full isolation of Formation-5 that consists mainly of shale.

The main objective of this casing point is to case off the problematic lost circulation zone of Formation-4 from the water flow of Formation-7, and to allow drilling Formation-7 with mud to control the sensitive shale right above. Since this section is typically drilled with complete losses, the top of Formation-5 must be identified by the ROP. It is usually described by a steady decrease in ROP and may be approximated by nearby wells data. As mentioned earlier, the lithology at the upper part

Formation-5, as picked in the Field-A, is limestone[9]. The main reason of shifting this casing point to Formation-6 instead of Formation-5 is because of the distinct “E” signature seen in all wells.

1.2.4 9-5/8” CASING POINT:

Standard casing point is 300’ into Formation-9 which is greenish-gray shale. Actual setting depths have ranged from 290’ above to 525’ below the top, with most in the range of 250-350’ below the top[9].

The main objective of this casing point is to case off the problematic lost circulation of Formation-8, which is a Dolomitic Limestone, and to facilitate drilling with water for the section below, all the way to the top of Formation-15 (reservoir of inerest)[9].

The section between the 13-3/8” and 9-5/8” casing points is drilled with mud to have power over Formation-7’s water, and avoid Formation-7’s shale from sloughing. Returns of drilling fluid at surface are rarely lost in Formation-7. If 100% circulation can not be achieved by LCM pills or cement plugs, then the rest of the section to the casing point must be drilled with mud and mud cap across Formation-7. Circulation is generally lost in Formation-8, and drilling from this point to the casing point is carried out with water and a mud cap (mud being continuously pumped in the backside) across Formation-7. Doing so will eliminate the contact of the water sensitive shale streak at the top of Formation-7 and water. In order to drill the section below with water, the casing must cover this top part. 300' of penetration into Formation-9 is found to be adequate since the shale section length may be uneven[9].

1.2.5 7" CASING POINT:

Standard casing point is at 1' to 2' above top of Formation-15 (reservoir of interest). Going into the reservoir could cause loss of circulation and could greatly impact proper isolation between Formation-14 which is a highly pressured water bearing reservoir and Formation-15. On the other hand, setting it shallower will only expose more the cap rock that would be eventually wash out once the reservoir starts producing water[9].

The top of Formation-15 may be picked on cuttings or ROP. Offset wells data can give a proper estimation of when and where to expect the top of Formation-15[9].

Figure 1.1 shows the typical layout of the casing strings along with proper seating formations in the northern part of the mother-Field and figure 1.2 describes the same for the southern parts of the mother-Field.

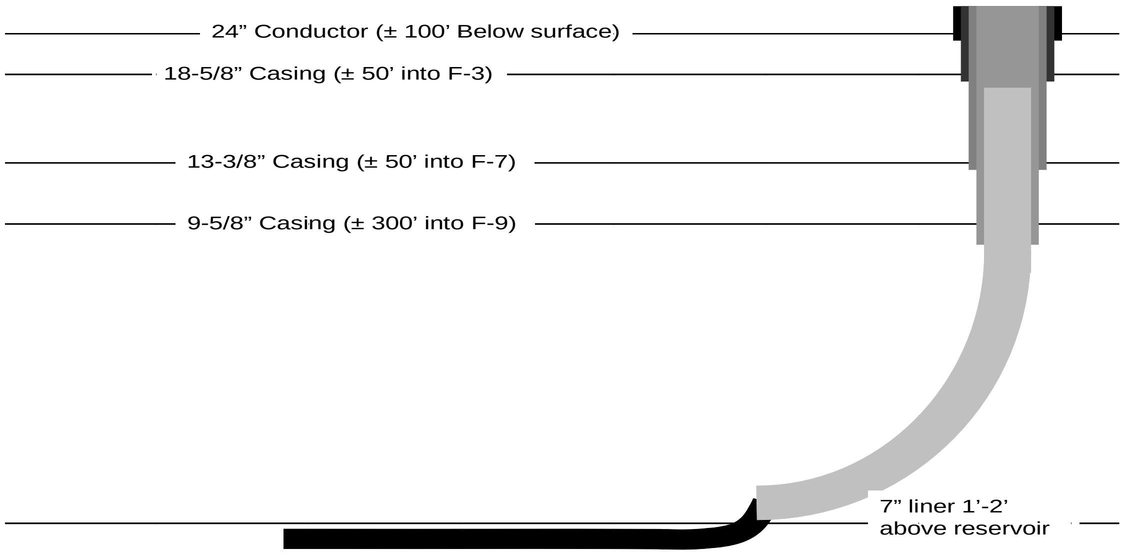

Figure 1.1

Field-A Conventional Horizontal Single Lateral Well Layout with Conductor Pipe

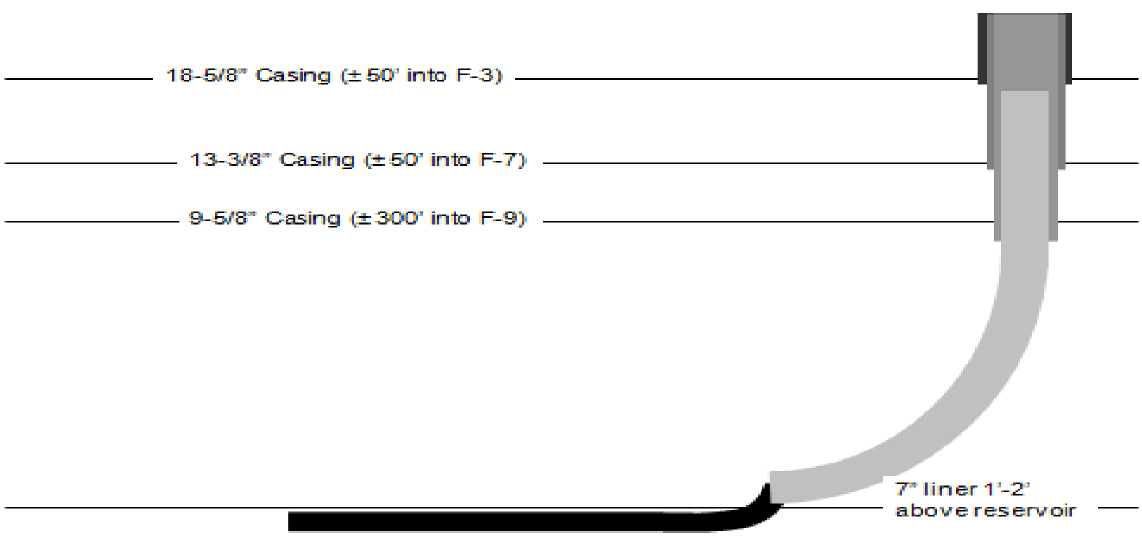

Figure 1.2

Field-B/Field-C Conventional Horizontal Single Lateral Well Layout

This study compares the two existing Smart MRC wells Saudi Aramco is applying nowadays against a proposed design that shall improve the quality of such wells to allow easier execution with high potential of long producing life of the well.

CHAPTER 2

BACKGROUND OF THE WORK

Wells' constructions have gone through intensive changes over the last two decades. Moving from vertical to slanted wells to target mainly offshore reserves and from slanted to horizontal wells for a lower and distributed drawdown pressure on the reservoir. Horizontal wells started to be more complex wells with dual, tri and quad laterals and started getting deeper with the concept of extended reach implementation.

2.1 Evolution of Smart MRC Wells:

Smart well technology is one of the most significant advancements in production technologies during latest years. It enables operators to actively observe, distantly choke or shut selected unwanted zones without manned interference. During early stages of development, electrical control systems and electronic sensors were applied. Recently, improvements in fiber optic sensors and hydraulic control systems have considerably improved the reliability, and the market satisfaction of this new technology is rapidly increasing[3].

2.1.1 REVIEW OF TECHNOLOGY:

A well completed with intelligent components can be called "smart" only when it maximizes its value over the life of the well. The classification of the level of intelligence is the result of a multidisciplinary analysis that concentrates on the well and reservoir management[1]. Wells prepared with permanent downhole measurement tools or control valves, and especially those with both, are at the moment known as smart wells or intelligent completions.

Early smart well systems, using permanently deployed downhole electronics, provided live pressure and temperature readings from gauges installed close to the wellbore. As these kits showed their benefits, the market developed follow-on systems for monitoring further properties, like flow rate and water-cut. These downhole sensors were complemented by the initial development of electro-hydraulically operated flow control systems. Since such systems are always unreachable once deployed, their true value is linked directly to their effective life. Those early systems were soon elapsed due to their low trustworthiness[1,3].

For an intelligent well to payback its true value, the permanent gauges must provide functionality for the life of the well. If downhole sensors fail too early, there is little point in having the possibility to use the hydraulically operated flow controls to adjust flow profiles and optimize reservoir recovery throughout the field life. Service providers would have to come up with a technology that targets increasing the market by lowering costs and improving reliability[1,3]. Figure 2.1 illustrates typical smart completion components that allow isolation between laterals through packers, flow from laterals through sliding sleeves or inflow control valves (ICV) and Pressure/Temperature gauges.

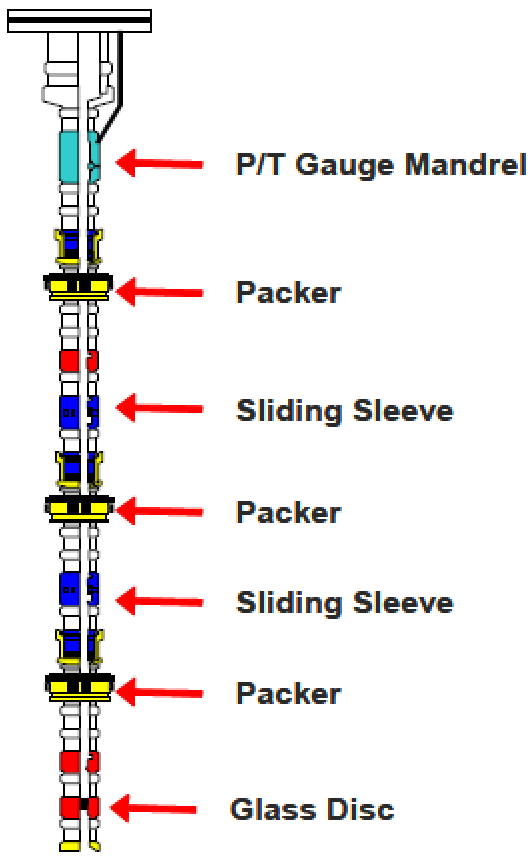

Figure 2.1

Smart Completion Components with Sliding Sleeve to Control Each Lateral

The use of smart completions fall in its best application if ran in Maximum Reservoir Contact wells (MRC). In which laterals are controlled from surface to choke or fully open each lateral's contribution toward the total production of the well[2].

2.1.2 MAXIMUM RESERVOIR CONTACT (MRC) WELLS:

An MRC well is known as having a cumulative reservoir contact (usually in the same reservoir) in the range of 5 km (or 16,000 ft) through a single or multilateral well design. The usual case, however, often refers to 3-laterals (trilateral) well due to its practicality and production tubing size allowable restriction[2].

An evaluation project consisting of 3 wells to test the MRC concept was initiated in 2001. The three pilot MRC wells with 5.8 km (fish bone), 8.5 km (fork) and 12.3 km (hybrid) reservoir contact length were drilled and put on production in 2002 at Field-X [2]. Figure 2.2 illustrates a fish bone and a fork MRC designs applied in Field-X.

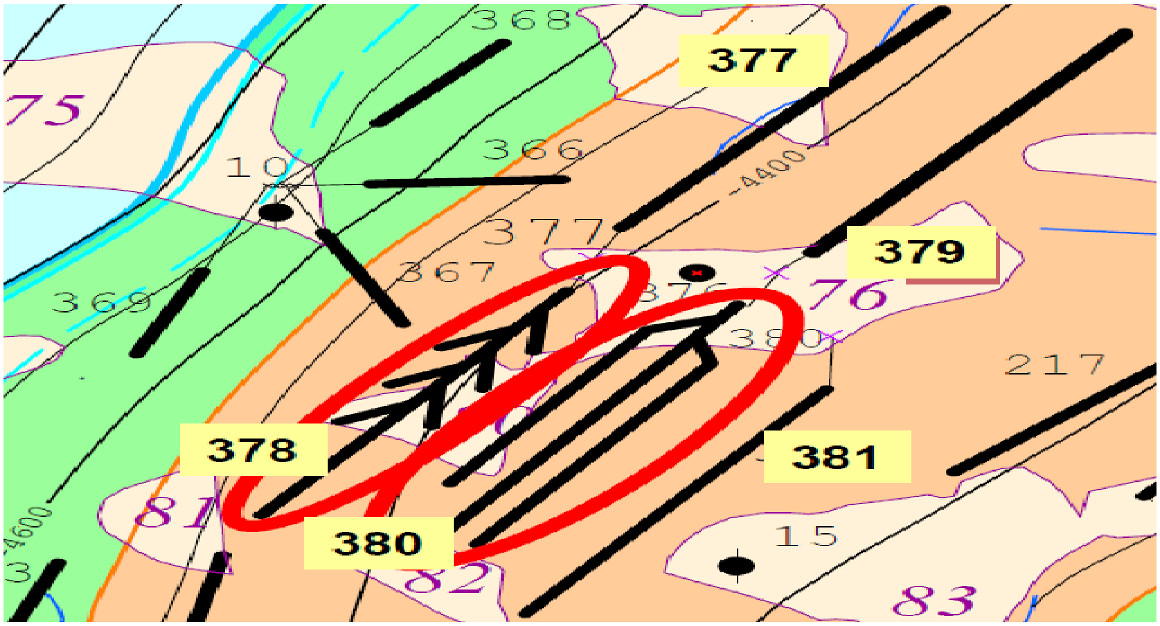

Figure 2.2

Two Examples of Field-X MRC Wells

Rates of production from these pilot wells were cross-checked against 1 km horizontal wells and one extended reach well with 3.7 km of reservoir contact. Great improvement in production rates were illustrated by multiple jumps in Production Index (PI) in the MRC wells. Moreover, other great benefits were also seen and they are: (a) Lower development cost if each lateral was treated as a single well, (b) Greater control and data collection on formation characterization due to increased contact area with reservoir, and (d) Lesser reservoir pressure drawdown. Since then, Field-X has been drilled using only the MRC well strategy together with re-drilling existing 1 km single lateral horizontal wells into MRC wells with the use of expandable liners[2].

2.1.3 SMART MRC WELLS:

Since reservoirs by nature are always heterogeneous, and the risk of early water production from pre-existing fractures or other undetected early water coning heavily exist, the flow control from each lateral becomes necessary from a reservoir management concept. The smart MRC well became the technology to target, where downhole flow control valves were installed across the motherbore lateral (main lateral) junctions to intentionally shut water production or choke production as an optimization process of minimizing pressure drawdown[2]. Figure 2.3 shows an example of a fish bone well design equipped with flow control valves to control the production of each lateral.

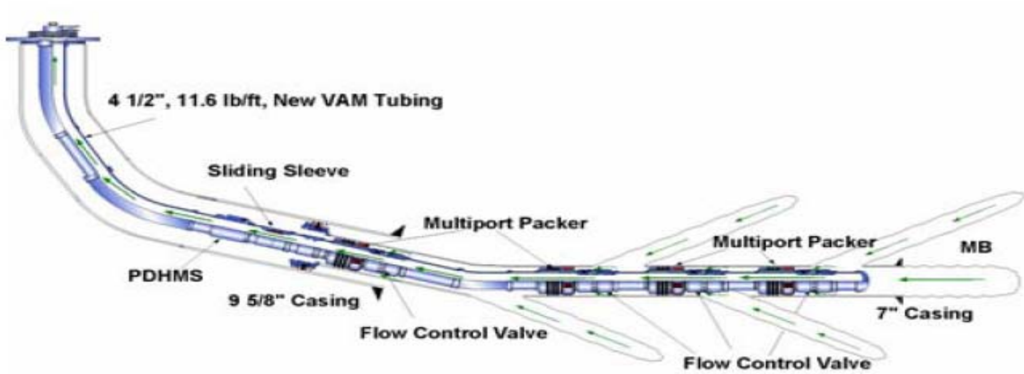

Figure 2.3

Fish Bone MRC Smart Well Design.

The use of MRC wells has also been given lot of attention in the Middle East during the past decade. The main advantages of a Smart MRC well are the following[1,2,3]:

- Fewer wells required to develop a field or higher production rate from wells.
- Avoid post-rig well intervention jobs.
- Assure swift changes to coop up with expected or unexpected changes in production or injection rates required by each well/lateral.
- More drainage area which allows less unswept reserves.
- Real-time data acquisition to understand better future infill wells.
- Identifies all reservior and fluid properties to help managing reservoirs.
- Unmanned operations which transelate into higher levels of Health, Saftey and Environment.
- Smaller footprints which leads to a reduction in the number of wells.

Therefore, this technology was applied with a great success rate in different mother-Field sub-fields, mainly in areas with thin oil column. This was done to reduce water production, by lowering the drawdown, avoiding water coning, and draining large areas; thus to minimize the number of wells to be drilled[7].

2.2 Statement of Problem:

For the sake of retaining a fixed scope of work, only the mother-Field represented in its subfields, that are Field-A, Field-B and Field-C, will be evaluated in this research. Some examples might be utilized from other fields in order to share the drilling practices in them. Other fields may have different reservoir type such as Field-X which has a gap cap drive type of reservoir and is not part of the mother-Field.

The first well design that was implemented in the mother-Field is the Big Cased Hole design. This design is extremely expensive when compared to conventional casing design utilized to deliver the single lateral wells. The high cost falls under two main categories. First is the lengths and the sizes of casings/liners used in such design. Second is the total drilling time compared to the Ultimate Drilling Curve benchmarking rate of penetrations at the conventional designs.

The second well design that was introduced to reduce cost associated with the first design is the Slim Open Hole design. Although the Slim Open Hole design is indeed a cheaper and faster option but the reduction of cost was performed on the expense of the well integrity, quality and assurance of safe deployment. This study is only focusing on the drilling and completion phase of the well and does not cover the production phase of the wells.

2.3 Objectives and Approach of the Study:

2.3.1 OBJECTIVE OF THE STUDY:

The primary objectives of this study are:

2.3.1.1 To evaluate thoroughly and compare the two existing designs Saudi Aramco is currently applying in the mother-Field and evaluate their pros and cons on the following features:

- Total end of well cost.
- Amount of time required to drill and complete both types.
- Quality, integrity and assurance during the drilling phase of a well.

2.3.1.2 Propose a new improved drilling design for Smart MRC Wells that will alleviate the drawbacks of the existing designs.

2.3.2 APPROACH OF THE STUDY:

The approach will depend on logical arguments and field experienced troubles. This research will be consisting on the following phases:

i. Conduct extensive and detailed study of the drilling designs of both types in every field this technology was applied to.

ii. Critically review the implementation of the designs in the sub-fields and the actual drilling and completion performance.

iii. Assess the advantages and disadvantages of both designs from field experience.

iv. Propose a new design that will overcome the disadvantages of both designs while maintaining their advantages.

CHAPTER 3

BIG CASED HOLE DESIGN

3.1 Application to the Mother-Field:

After the accomplishment of drilling MRC wells in Field-X, the strategy has been well thought-out for application to the whole of the mother-Field's sub-fields. The primary driving technologies that have accomplished such successes include: (a) more controlled 3-dimentional seismic data for improved reservoir development planning, (b) state-of-the-art geo-steering ability with live monitoring, and (c) great advancements in bit design, rotary steerable systems and a better measurement while drilling (MWD)/logging while drilling (LWD) systems. To get the intended outcome of a MRC well, a fully integrated plans by a dedicated multidisciplinary team from pre-drilling engineering analysis, rig operation, to geo-steering which provided real-time input for decision making has become a standard best practice[2].

Field-C/Formation-15 is part of the greater mother-Field. While most of the mother-Field wells were mainly drilled as vertical wells, improvement in technologies has given better options in developmental approach utilizing horizontal, and most recently, MRC wells to optimize the exploitation of the remaining producible oil. Field-C development represents a peak in this change in strategy. Original drilling at Field-C Increment-1 used mainly conventionally vertical wells, while Field-C Increment-2 was drilled and put on production with long horizontal wells and a limited number of MRC wells drilled as a proof of concept. Field-C Increment-3 was planned to be drilled completely with MRC producing wells[8].

Field-C Increment-III successfully installed 32 smart MRC (a combination of three lateral and four lateral) producing wells. Production from Field-C Increment-III started in early 2006 and field production performance went beyond expectations [4,5].

Installation of smart completion equipment was also carried out on bigger scale at Field-A. Maximum reservoir contact (MRC) oil wells with three to four laterals in Field-A started to be the norm in order to save some drilling pad due to the overcrowded surface area with pipelines and flowlines supporting the giant Oil Plant from all over the giant mother-Field wells. Those completions include downhole choke and control valves for each lateral, packer isolation for each lateral, and a permanent downhole monitoring system on the motherbore. Function test information has shown validity of such completions at this side of the field[5,7].

Recently, the Smart MRC wells were introduced to Field-B as the results from Field-A and Field-C were very encouraging. Few wells have been drilled and completed the same at the field however they have not been tied up to flow lines yet.

3.2 Justification of the Design:

The mother-Field standard horizontal oil producer wells are normally designed with three casing strings, landing the 7" liner on top of Formation-15 which is the reservoir, before drilling a horizontal single-lateral to finally complete the well as a 6-1/8" open-hole design. Designing Field-A, Field-B or Field-C Smart MRC wells, a liner has to be run across the reservoir for mainly two reasons: to provide the requested minimum inter-lateral separation interval of 300 meters of cement and steel isolation between cased-hole sidetracked laterals; and to be able to run a completion across the sidetracked lateral windows in the liner that can provide the required per-lateral flow control option[4]. Figure 3.1 shows the typical layout of a Big Cased Hole smart well design with final payzone of 6-1/8" in size.

For the Smart MRC wells, the casing design is enlarged to allow the smart completion to be deployed inside a casing. This condition forces the whole casing design to be bigger for example the 9-5/8" casing will be placed above Formation-15 instead of 300' inside Formation-9. Of course this leads to drilling the 12-1/4" hole across Formations 10 to 14 instead of drilling them at the normal practice of 8-1/2” hole size. This means starting off with bigger hole size to accommodate bigger casing size in order to lead to final pay zone of 6-1/8" open hole. A better understanding is derived by comparing Figure 3.1 to Figure 1.2.

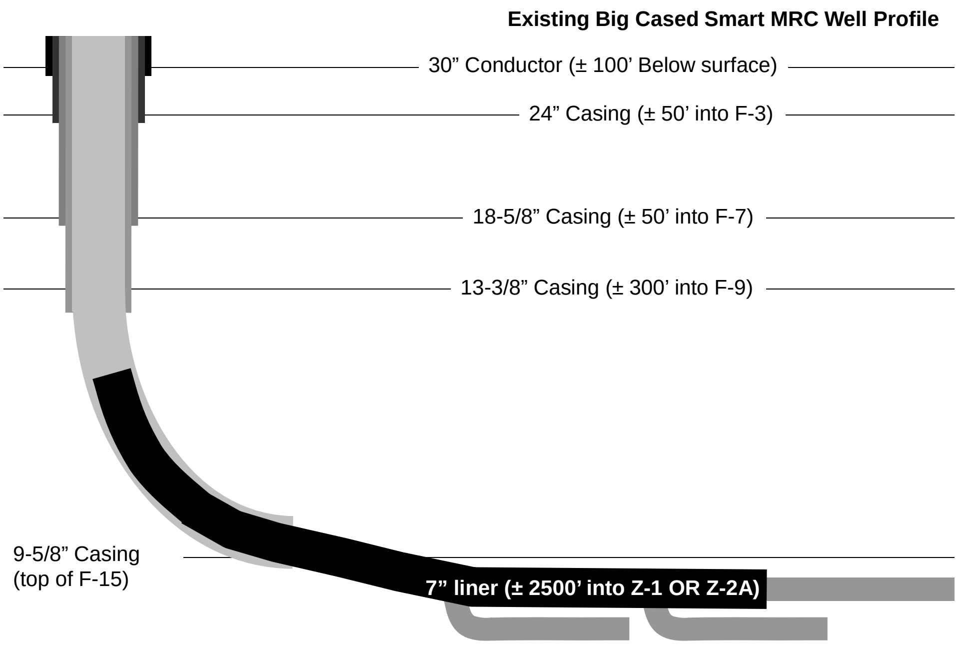

Figure 3.1

Existing Big Cased Hole Design Layout

3.3 Technical Problems and Challenges Related to the Design:

Many reservoir and drilling challenges are typically faced during the design and implementation phases of any Smart MRC well. Spacing laterals’ windows with the required minimum inter-lateral separation distance, estimated production rate, and allowing selective flow-control form each lateral were the main factors for the existing well design. Other challenges such as loss circulation, torque and drag limitations, well control, and formation damage are faced while drilling any well and must be minimized efficiently using various innovative means[4,5,6].

3.3.1 CASING DESIGN:

Just like mentioned earlier the standard well casing profile has to be altered. Overall, running a 4-1/2” liner was not practical. Pipe buckling will be very pronounced while running long 4-1/2” liners to be able to achieve the necessary inter-lateral separation target. Moreover, running such size will limit hole size to only 3-7/8” open hole size. Such final hole size will limit the lateral extension, increase the number of bit trips to be made, and lose the luxury of being able to utilize a Logging While Drilling (LWD) to geo-steer the open-hole laterals through the best reservoir porosities. In addition, having a 4-1/2” liner installed within the reservoir, will limit the completion size to 4-1/2” packers and 2-3/8” tubing completion string across the 4-1/2” liner, which will not meet the expected production rate according to previously done production tubing sizing simulation runs[4,5].

It was firm that 7” liner deployment is vital across the reservoir to meet the required objectives. An enlarged casing design was planned, with four casing strings, landing a 7” string across the reservoir pay zone, adding one more string to the original casing design. By doing so, wells end up with 6-1/8" hole size across the producing laterals. Consequently the conventional sizes will be upsized hence bigger size of holes will be drilled earlier. Drilling bigger holes is slower than smaller holes which consumes a great amount of time. Figure 3.2 shows the smart completion equipment deployment within the reservoir inside the installed for purpose 7" casing/liner.

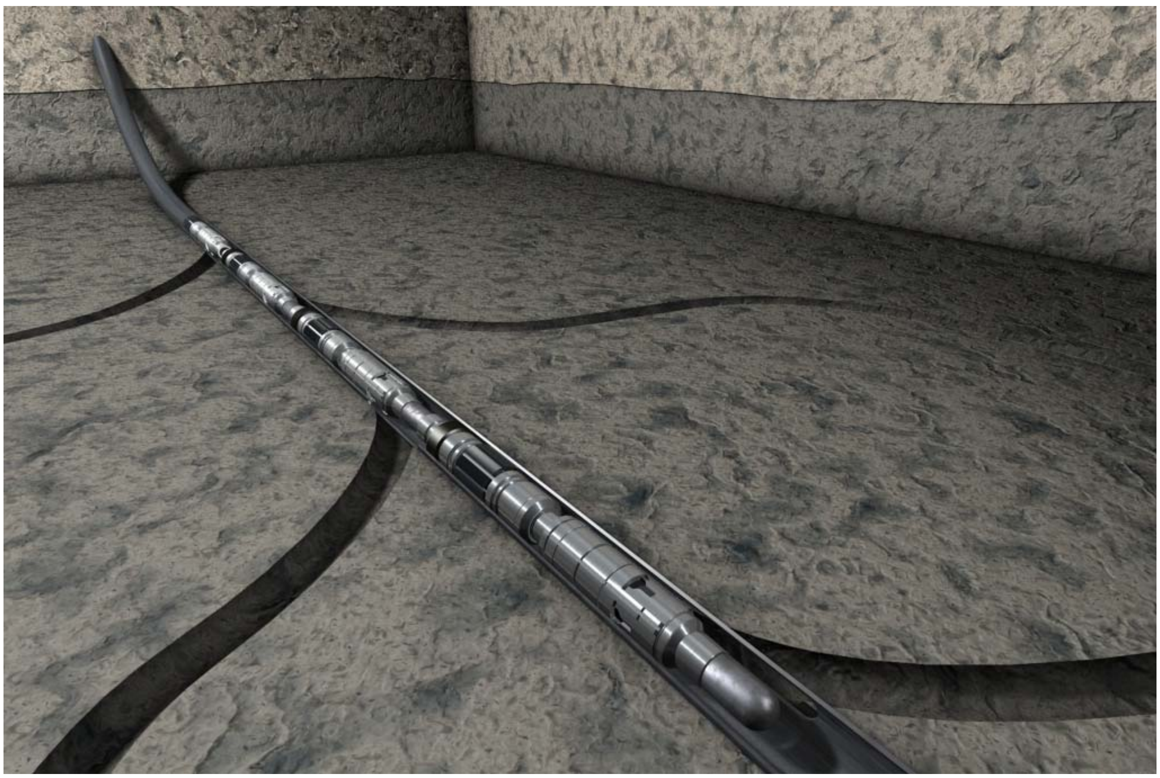

Figure 3.2

Smart Completion String Seated within a Casing within the Reservoir

3.3.2 LOSS OF CIRCULATION CHALLENGE:

With Formation-15 in Field-B and Field-C being a fractured reservoir, figure 3.3, loss circulation will always remain a challenge while drilling such wells in this area. In case loss circulation is encountered, the cement job quality will be a concern questioning the ability to provide the required effective minimum inter-lateral separation distance, as it is dependent on the 7” liner. In addition, drilling excessive reservoir contact footage with any losses can complicate any well control situation, if it starts[4,5]. Table 3.1 gives few of many wells that experienced loss of circulation that could not be regained and caused poor 7” liner cementing issues.

WELL	SIZE	TRBL	FROM	TO	LATERAL	DESC
Well-A	8 1/2	LCRC	11380	11885	0	ENCOUNTERED PARTIAL LOSS OF CIRCULATION
Well-B	8 1/2	LCRC	9956	9956	0	LOST 100% CIRCULATION AT 9956' WITH NO RETURNS.
Well-C	8 1/2	LCRC	9894	12067	0	TOTAL LOSSES @ 9894' DURING DRILLING 8 1/2"
Well-D	8 1/2	LCRC	7402	12600	0	LOST CIRCULATION WHILE DRILLING 8-1/2" HOLE AT 10,553 FT. UNABLE TO REGAIN CIRCULATION WITH CAC03 PILL.
Well-E	8 1/2	LCRC	12444	12801	0	HAD COMPLETE LOSS CIRCULATION WHILE DRILLING 8-1/2" HOLE
Well-F	8 1/2	LCRC	7646	11666	0	HAD COMPLETE LOSS CIRCULATION WHILE DRILLING 8-1/2" HOLE
Well-G	8 1/2	LCRC	7672	11550	0	WHILE DRILLING 8-1/2" HORIZONTAL SECTION, ENCOUNTERED TOTAL LOSSES AT 7672'.
Well-H	8 1/2	LCRC	8419	11798	0	HAD COMPLETE LOSS CIRCULATION WHILE DRILLING 8-1/2" HOLE WITH 67 PCF MUD @ 8419'
Well-I	8 1/2	LCRC	12070	12070	0	PERFORMED SQUEEZE JOB W/ 488 SKS OF CEMENT THROUGH TOL @ 7,204'.
Well-J	8 1/2	LCRC	9463	9463	0	LOST FULL RETURNS WHILE DRILLING 8-1/2" HOLE
Well-K	8 1/2	LCRC	7073	7073	0	AFTER CMTING 7" LINER, FLOW CHECK WAS DONE AND WELL LOSSES OF 30 BPH REGISTERED.
Well-L	8 1/2	LCRC	8100	11210	0	HAD COMPLETE LOSS CIRCULATION WHILE DRILLING 8-1/2" HOLE
Well-M	8 1/2	LCRC	9687	12710	0	TOTAL LOSSES @ 9687' DURING DRILLING 8-1/2" HOLE.
Well-N	8 1/2	LCRC	10200	12500	0	HAD PARTIAL LOST OF CIRCULATION AT 10200' WHILE DRILLING 8-1/2"
Well-O	8 1/2	LCRC	8419	11798	0	DURING DRILLING 8-1/2" HOLE WITH 66 PCF MUD HAD COMPLETE LOSS CIRCULATION @ 9054'
Well-P	8 1/2	LCRC	8712	10572	0	HAD COMPLETE LOST CIRC @ 8712' WHILE DRILLING 8-1/2" HOLE.
Well-Q	8 1/2	LCRC	8122	11476	0	DURING DRILING 8-1/2" HOLE SECTION WITH 69 PCF MUD HAD LOST COMPLETE CIRCULATION @ 8122'
Well-R	8 1/2	LCRC	8700	8700	0	WHILE DRILLING 8 1/2" HOLE WITH 66 PCF MUD LOST FULL RETURNS,
Well-S	8 1/2	LCRC	8185	8185	0	WHILE HORIZONTALLY DRILLING 8-1/2" HOLE WITH 65 PCF MUD. LOST COMPLETE RETURNS @ 8,185'.
Well-T	8 1/2	LCRC	10987	14050	0	HAD COMPLETE LOSS CIRCULATION WHILE DRILLING 8-1/2" HOLE WITH 68 PCF MUD @ 10987'

Table 3.1

Some of Wells that Encountered Loss of Circulation while Drilling 8-1/2” Hole.

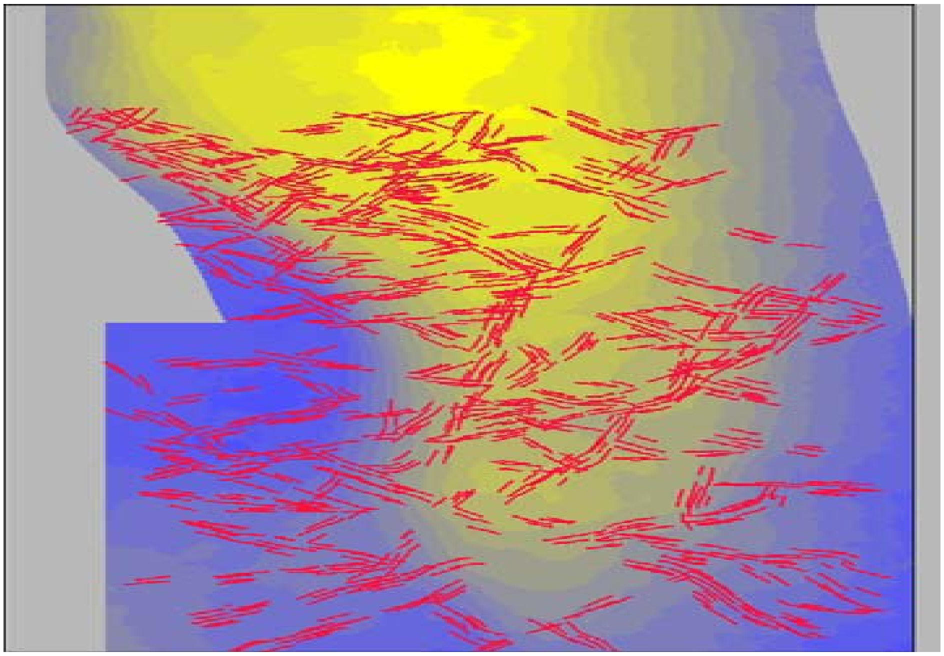

Figure 3.3

Simulation Map of Fractures Across Formation-15 (Reservoir)

3.3.3 LINER CEMENT JOB QUALITY:

In many Field-C Smart MRC wells, losses were encountered during drilling the motherbore due to fractures and super permeability layers within the reservior. During total losses, drilling was switched to water and gelled sweeps and continuously using heavier mud in the annulus as a mud cap for well control. In wells with total losses, image logs were used to locate the fractures and stage cementing was carried out. Cement with gas blocking additives was used to prevent gas upward migration. In some cases, cement evaluation logs were run to assure the quality of the cement and in selecting intervals with good cement for the lateral windows. Based on cement evaluation log data, remedial cement-squeeze jobs was carried out on some wells. Those extra runs and vigilant drilling is time-consuming[5]. Table 3.2 is a snapshot of few daily reports that explains what was described earlier.

The use of Annulus Casing Packer (ACP), if needed, to perform second cement job in the open-hole is highlighted as the best plan if loss circulation is faced while drilling the motherbore. Also, the use of Mica LCM pills will help reduce losses of drilling fluids, as the fear of damaging the reservoir is not critical anymore while drilling the motherbore, since it will end up being cased and cemented anyway[4]. Figure 3.4 the poor cementation between fractures in case encountered while drilling the motherbore inside the reservoir.

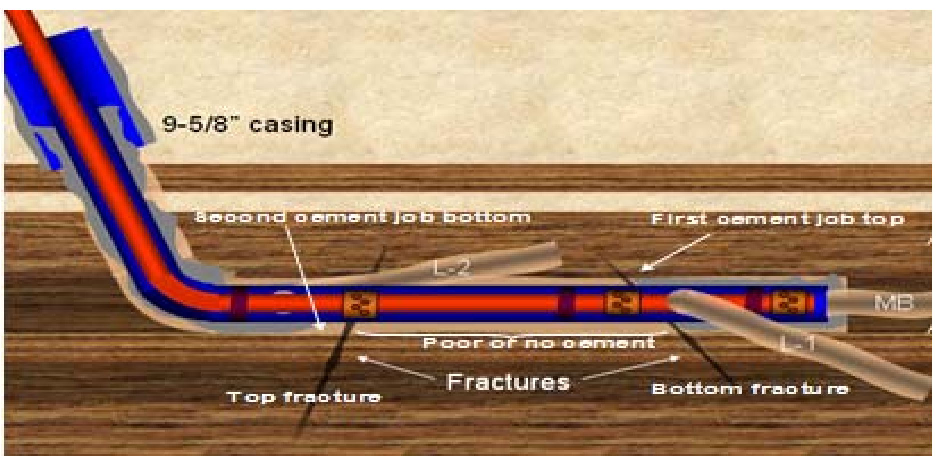

Figure 3.4

Big Cased Hole Laterals Hosting the 7" Casing and Smart Completion

Daily Onshore Drilling Report (0500-0500) Saudi Aramco	Date: FRIDAY 01/06/2006	Well No (Type): (HORIZONTAL TRI-LATERAL PRODUCER) Charge #: Wellbores: (0) HRDH_	Rig	Foreman(s) Engineer Superintendent

THURAYA	RIG FORMAN VSAT	OTHER VSAT	FAX VSAT	CONTRACTOR/CLERK VSAT

Depth	Summary of operation				Lost Hrs.	Rot. Hrs.	Dead Hrs	Location	
11666	RIH W/SCRAPER,POOH,RIH RTTS ,SET RTTS,P/T,INJ.TEST,POOH,RIH EZSV				24				
Prev. Depth	Last Csg Size	MD	TVD		Liner Size	TOL	MD	TVD	Circ %	Days Since Spud/Comm (Date)
11666	9 5/8	7322	6413		7	6812	11666	6598	0	36.4 (11/30/2005@2000)
Footage	Total Lost Time Hours: 128.5 for the well				Compl./Ev. Hrs	ROP Feet/Hrs	Target Days	Formation tops	
0	Total Z Time Hours: 0.0 for the well						76		
	Hrs	1.0	7.0	120.5					
	Lateral	0	0	0					
	Hole size	12 1/4	22	8 1/2					

Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
05.0	0500 - 1000	0	8 1/2	L	LCIR	PLUG	ARM			RIH,WITH 7"AND 9 5/8"SCRAPER
00.5	1000 - 1030	0	8 1/2	L	LCIR	PLUG	ARM			PUMP 30 BBLS HI-VIS CHC
06.5	1030 - 1700	0	8 1/2	L	LCIR	PLUG	ARM			POOH W/ 5"DP,9 5/8" SCRAPER,4"DP AND 7" SCRAPER ASSY
04.5	1700 - 2130	0	8 1/2	L	LCIR	PLUG	ARM			M/U 7" HOWCO RTTS ON 4" DP AND RUN IN HOLE T/7000'
01.0	2130 - 2230	0	8 1/2	L	LCIR	PLUG	ARM			HPJSM,SET 7"RTTS PKR AT 7,000'MD.CLOSE BOP.CHECK INJECTIVITY ON LINER LAP W/RIG PUMP @ 30 SPM.ANNULUS TAKING MUD WITHOUT ANY BACK PR.INCREASED SPM TO 90.NO BACK PRESSURE. HOLE TAKING MUD WITHOUT ANY BACK PRESSURE.INJECTIVITY @ 30SPM 167 BPH AND @ 90SPM 500 BPH AT ZERO PR.PRESSURE TEST 7" LINER THROUGH D/P @ 2500 PSI FOR 15 MIN.OK.
04.0	2230 - 0230	0	8 1/2	L	LCIR	PLUG	ARM			UNSEAT RTTS PKR & POOH.L/D RTTS PKR & 3'SAFETY JT.
00.5	0230 - 0300	0	8 1/2	L	LCIR	PLUG	ARM			M/U 9 5/8" EZ-SV & SETTING TOOL
02.0	0300 - 0500	0	8 1/2	L	LCIR	PLUG	ARM			HPJSM RIH 9 5/8" EZ-SV ON 5" D/P *** INC @ RPT ***
Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
03.0	0500 - 0800	0	8 1/2	L	LCIR	PLUG	ARM			CONT.RIH W/ 9 5/8" EZ-SV ON 5" DRILL PIPE
01.0	0800 - 0900	0	8 1/2	L	LCIR	PLUG	ARM			SET 9 5/8" EZ-SV P/U 190K,S/O 180K,40 TURNS TO RIGHT,P/U SLOWLY FROM 20K-50K AND SHEAR OUT STINGER AT 6665'MD,UNSTING P/T ANNULUS 500 PSI@ 15 MIN.(OK)HOOK UP DOWEL CMT LINES P/T AT 2000 PSI(OK)
01.5	0900 - 1030	0	8 1/2	L	LCIR	PLUG	ARM			HPJSM,MIX AND PUMP 50 BBLS SPACER 400 SX 122 PCF CEMENT,78 BBLS SLURRY,DISPL.W/118 BBLS WATER @5 BPM TO 1.5 BPM 350 PSI TO 116 PSI HOLDING 50 PSI
01.0	1030 - 1130	0	8 1/2	L	LCIR	PLUG	ARM			UNSTING FROM EZ-SV CHC.
01.5	1130 - 1300	0	8 1/2	L	LCIR	PLUG	ARM			POOH W/ 5"HWDP,HANG OFF 5"DRILL STRING 80,000
04.0	1300 - 1700	0	8 1/2	W	PTST	BOPE				CONDUCT FULL BOP TEST 300 PSI LOW 2500 PSI HIGH AS PER ARAMCO STANDARDS
07.0	1700 - 0000	0	8 1/2	L	LCIR	PLUG	ARM			P/U 4" XT-39 DRILL PIPE AND STAND IN DERRICK,WHILE WAITING ON CMT
00.5	0000 - 0030	0	8 1/2	D	SERV	RIG	ADC			SERVICE TOP DRIVE
01.5	0030 - 0200	0	8 1/2	L	LCIR	PLUG	ARM			RIH WITH 5"HWDP. STING IN TO EZ-SV. HOOK UP DOWEL CMT LINES & P/T @ 2000 PSI (OK).CARRY OUT INJECTIVITY TEST ON LINER LAP BY GRADUALLY INCREASEING PR. F/100 PSI T/ 800 PSI.NO INJECTIVITY @ 800 PSI.
03.0	0200 - 0500	0	8 1/2	L	LCIR	PLUG	ARM			L/D CMT LINES, UNSTING FROM EZ-SV & POOH *** INC @ RPT

Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
03.0	0500 - 0800	0	8 1/2	L	LCIR	PLUG	ARM			CONT.RIH W/ 9 5/8" EZ-SV ON 5" DRILL PIPE
01.0	0800 - 0900	0	8 1/2	L	LCIR	PLUG	ARM			SET 9 5/8" EZ-SV P/U 190K,S/O 180K,40 TURNS TO RIGHT,P/U SLOWLY FROM 20K-50K AND SHEAR OUT STINGER AT 6665'MD,UNSTING P/T ANNULUS 500 PSI@ 15 MIN.(OK)HOOK UP DOWEL CMT LINES P/T AT 2000 PSI(OK)
01.5	0900 - 1030	0	8 1/2	L	LCIR	PLUG	ARM			HPJSM,MIX AND PUMP 50 BBLS SPACER 400 SX 122 PCF CEMENT,78 BBLS SLURRY,DISPL.W/118 BBLS WATER @5 BPM TO 1.5 BPM 350 PSI TO 116 PSI HOLDING 50 PSI
01.0	1030 - 1130	0	8 1/2	L	LCIR	PLUG	ARM			UNSTING FROM EZ-SV CHC.
01.5	1130 - 1300	0	8 1/2	L	LCIR	PLUG	ARM			POOH W/ 5"HWDP,HANG OFF 5"DRILL STRING 80,000
04.0	1300 - 1700	0	8 1/2	W	PTST	BOPE				CONDUCT FULL BOP TEST 300 PSI LOW 2500 PSI HIGH AS PER ARAMCO STANDARDS
07.0	1700 - 0000	0	8 1/2	L	LCIR	PLUG	ARM			P/U 4" XT-39 DRILL PIPE AND STAND IN DERRICK,WHILE WAITING ON CMT
00.5	0000 - 0030	0	8 1/2	D	SERV	RIG	ADC			SERVICE TOP DRIVE
01.5	0030 - 0200	0	8 1/2	L	LCIR	PLUG	ARM			RIH WITH 5"HWDP. STING IN TO EZ-SV. HOOK UP DOWEL CMT LINES & P/T @ 2000 PSI (OK).CARRY OUT INJECTIVITY TEST ON LINER LAP BY GRADUALLY INCREASEING PR. F/100 PSI T/ 800 PSI.NO INJECTIVITY @ 800 PSI.
03.0	0200 - 0500	0	8 1/2	L	LCIR	PLUG	ARM			L/D CMT LINES, UNSTING FROM EZ-SV & POOH *** INC @ RPT

Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
00.5	0500 - 0530	0	8 1/2	L	LCIR	PLUG	ARM			POOH L/D EZ-SV SETTING TOOL.
01.5	0530 - 0700	0	8 1/2	L	LCIR	PLUG	ARM			M/U 8.5" BHA.
03.0	0700 - 1000	0	8 1/2	L	LCIR	PLUG	ARM			RIH TO TOP OF 9 5/8"EZ-SV @ 6665'.
04.5	1000 - 1430	0	8 1/2	L	LCIR	PLUG	ARM			DRILL OUT EZ-SV.
02.5	1430 - 1700	0	8 1/2	L	LCIR	PLUG	ARM			COC W/WATER TO TOL @ 6812'.
01.0	1700 - 1800	0	8 1/2	L	LCIR	PLUG	ARM			CIRC.ANNULUS CLEAN ,P/T LINER LAP AT 1000 PSI W/WATER @ 15 MIN.(OK)
04.0	1800 - 2200	0	8 1/2	L	LCIR	PLUG	ARM			POOH,L/D 5" HWDP AND 8.5"BHA.
01.5	2200 - 2330	0	8 1/2	D	MU	BHA				M/U 6 1/8" CLEAN OUT BHA.
03.5	2330 - 0300	0	8 1/2	D	TRIP	BHA				RIH W/CLEAN OUT ASSY.TAG CMT @ TOL 6812'.
02.0	0300 - 0500	0	8 1/2	D	CO	CSG				COC F/6812' T/6870'

Table 3.2: Morning Report Snap Shot for Cementing 7” Casing with Losses

CHAPTER 4

SLIM OPEN HOLE DESIGN

4.1 Application to the Mother-Field:

In a continued effort to save rig time and reduce end-of-well cost, a bold strategy was reviewed to consider a possible deployment of open hole smart completion in MRC wells. The idea was to set isolation packers and downhole hydraulically operated ICV's (interval or inflow control device) in open hole instead of in cased hole. A first trial test to implement open hole smart completion was scheduled to be carried out in one of the workover wells in August 2005. The key technology components to meet this objective consisted of open hole packers with feed-through control lines for zonal isolation in open hole, and hydraulically operated ICV[10].

4.2 Justification of the Design:

After few successful workover re-entries, the concept of open hole MRC Smart wells fell as the optimum slimming design of the "old-expensive" Cased Hole MRC Smart Wells as described in the previous section and figures. To visualize the "newly" adopted design, we simply look at the Conventional single lateral Arab-D well profile and execute multi-laterals within the open 6-1/8" hole. Of course, the lessons learned from the few workover re-entries were applied into this optimization move with adjusting the size of the hole drilled from 5-1/2" to 6-1/8". One key practice that led to the success of the "slimmed" design is the "top to bottom" sidetracking strategy[11]. It dictates drilling the upper lateral before middle and then middle before last which is called the "motherbore" lateral[10,11]. Figures 4.1 and 4.2 illustrate what was explained in this paragraph.

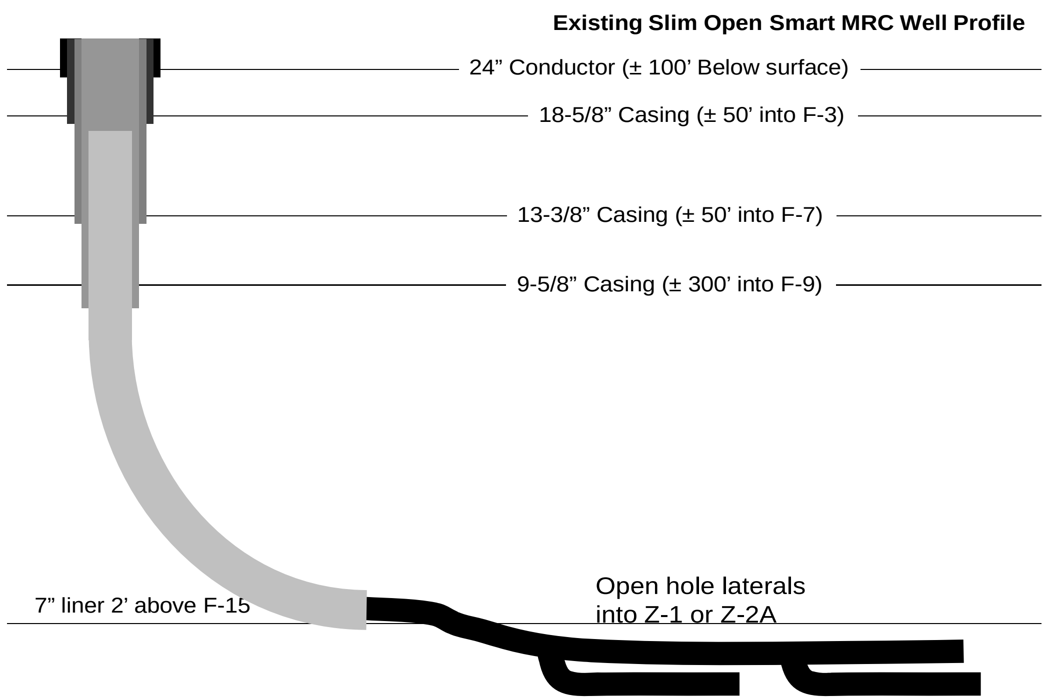

Figure 4.1

Slim Open Hole Well Design Layout

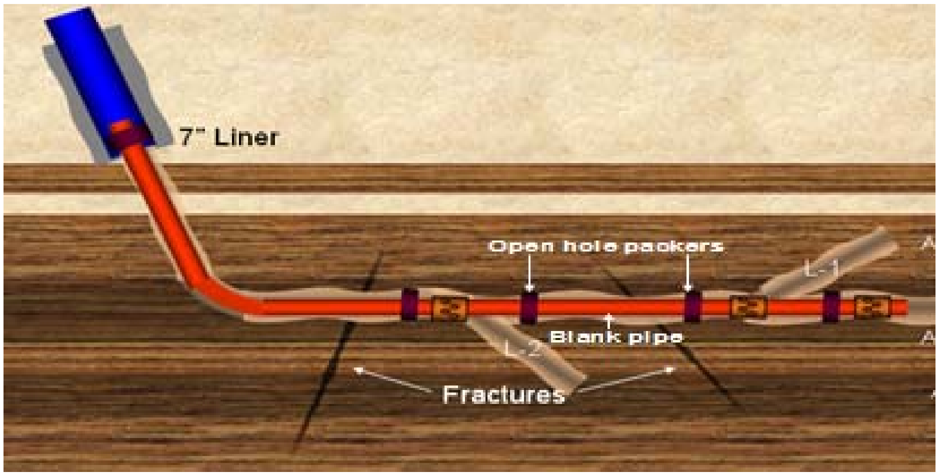

Figure 4.2

Slim Open Hole Laterals Hosting Smart Completion

4.3 Technical Problems and Challenges Related to the Design:

Just as noted previously regarding any Smart MRC project, this design requires the same amount of effort. However, other concerns arise specially when drilling the last footage of the MRC while the first foot is still exposed. Detailed and careful execution is required as fall-back plans vanish since the well is already slimmed to its extreme. Similar challenges are more pronounced at this design and the most out of all are the loss of circulation and torque and drag. Normally, pay zones are steered through geo-steering for the best producing streak. Added tortuousity will be present and eventually the drill pipe will experience it compared to if it was cased-off with a liner. Note that the stiff smart completion string will still have to undergo the induced tortuousity while being run in hole.

4.3.1 WELL CONTROL ISSUES:

The concern of loosing circulation while drilling could more substantial in the open hole design. As losses could start from the first lateral (upper one) and will never be isolated until the smart completion is deployed. This could take up to 3 weeks of drilling the well under well control situations. The practice in drilling any payzone is to have a ready-mixed kill fluid that is, at least, equal to the open hole volume in case a well control situation arises. This means the volume of all the open hole laterals that could be in the range of thousands of barrels must be ready in rig tanks. Moreover, once they are used, an equivalent volume must be build. For example, if a well has 3 laterals with a total length of 10,000' of reservoir contact that is drilled with a 6-1/8" bit the open hole volume equals:

$$\text{Volume} = \pi * r^2 * \text{Length} = 3.14*((6.125/12)/2)^2*10{,}000 = 11{,}480 \text{ ft}^3 = 2040 \text{ Bbls}$$

Aside from the safety issue at such drilling, the amount of drilling fluid that will be lost in the reservoir are a lot and it could take weeks to flow the well for clean up before the reservoir native fluids are out.

4.3.2 DIFFERENTIAL STICKING CONCERNS:

Smart completion string is big in outside diameter compared to simple completions. Smart completion requires a lot of complicated tools such as Open Hole Packers, Inflow Control Devices and Permanent Downhole Gauges. Each of those components is slightly less the open hole size by fraction of inches. As the string gets stiffer and bigger, chances of getting differentially stuck are more specially while making connections to run in hole to the desired depth or when cables and control lines are being spliced. Stopping for such jobs will keep the string stationary against the reservoir until the intended job is finished. The main cause of differential sticking is keeping the pipe against a porous zone for a relatively long time.

Unlike the cased hole design wells where the smart completion will be seated inside the installed-for-purpose liner that is seated within the reservoir. Throughout the experience of drilling industry, differential sticking could only be freed by reducing hydrostatic head pressure applied to the formation causing this suction to the pipe. Bare in mind when losses are evident, reducing hydrostatic head pressure could put the well into the verge of a kick. The morning report below shows a snap shot of stuck string that was only freed by lowering mud weight to water. Table 4.1 shows a snapshot of drilling report of stuck smart completion during the phase of completing the well.

Daily Onshore Drilling Report (0500-0500) Saudi Aramco

Date	Well No (Type) :	Rig
SATURDAY 10/13/2007		

Depth	Summary of operation	Lost Hrs.	Rot. Hrs.	Dead Hrs	Location
11067	RIH W/ BOT SMART COMPLEATION SYSTEM. FINAL DRIFT. WORK ON STUCK TUBING.	10		14	58 KM FROM DHAHRAN MAIN GATE.

Prev. Depth	Last Csg Size	MD	TVD	Liner Size	TOL	MD	TVD	Circ %	Days Since Spud/Comm (Date)
11067	7	7021	7021	5 1/2	5956	7563	7041	100	34.6 (08-SEP-07@1400)

Footage						Compl./Ev. Hrs	ROP Feet/Hrs	Target Days	Formation tops
0	Total Lost Time Hours: 50.5 for the well							44	
	Total Z Time Hours: 0.0 for the well								
	Hrs	21.0	2.0	17.5	10.0				
	Lateral	0	0-1	0-1	0-1				
	Hole size		5 1/2	6 1/8					

Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
10.5	0500 - 1530	0-1		C	RTBG					CONT. RIH W/ SMART COMPLETION ON 4 1/2" TUBING (TOTAL 142 JOINTS) TO 10365'. RUN ONE JOINT TO MAKE SURE TO LAND TBG HANGER, OK. PULL W/ ONE JOINT TBG & L/D.
01.5	1530 - 1700	0-1		C	WORK					BAKER SPLICE & ADD MORE ELECTRIC CABLE DUE TO LENGTH SHORTAGE. PT SAME TO 5000 PSI, OK.
01.0	1700 - 1800	0-1		C	RTBG					RUN ONE JOINT OF 4 1/2" TBG TO MAKE SURE THAT TBG HANGER CAN BE LANDED, OK. PULL W/ ONE JOINT OF TBG & L/D SAME.
01.0	1800 - 1900	0-1		C	WL					R/U MANSOORI W/L. RIH W/ FINAL DRIFT TO 5688'. OK.
10.0	1900 - 0500	0-1		L	HOLE	STKCG	ARM			M/U LANDING JOINT. ATTEMPT TO MOVE TBG GOT STUCK. CIRC. HOLE W/ 68 PCF LUBRICATED MUD. ATTEMPT TO FREE SAME W/ 135 KLBS OVER PULL & SLACK OFF TO 120 KLBS. PIPE MOVED 40' UPWARD.

Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
04.0	0500 - 0900	0-1		L	HOLE	STKCG	ARM			SPOT 50 BBLS WATER IN THE OPEN HOLE. WORK STUCK TUBING, NO SUCCESS. DISPLACE WATER OUT.
08.0	0900 - 1700	0-1		L	HOLE	STKCG	ARM			BAKER CONNECT VALVES (HCM) CONTROL LINES & OPEN MIDDLE VALVE. SPOT 50 BBLS WATER IN THE OPEN HOLE THRU MIDDLE VALVE. WORK STUCK TBG, NO SUCCESS. DISPLACE WATER OUT W/ 68 PCF MUD.
06.0	1700 - 2300	0-1		L	HOLE	STKCG	ARM			BAKER CUT CONTROL LINES (CHECKES GUAGES CABLE FOUND SHORT CIRCUT 800' BELOW). L/D DOWN TBG HANGER & JNT# 142. SPOT 130 BBLS GREASE PILL IN THE OPEN HOLE. WAIT 2 HOURS. WORK STUCK TBG FREE.
02.5	2300 - 0130	0-1		L	HOLE	STKCG	ARM			POH SLOWLY TO 9600' W/ BAKER SMART COMPLETION. FOUND GUAGE CABLE LINE WAS BROKEN. CONNECT & CHECK SAME, OK.
03.5	0130 - 0500	0-1		L	HOLE	STKCG	ARM			CONT. POH W/ BAKER SMART COMPLETION.

Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
01.5	0500 - 0630	0-1		L	HOLE	STKCG	ARM			CONT. POH W/ SMART COMPLETION INTO 5 1/2" LINER SHOE @ 7563' WHILE L/D 4 1/2" TBG.
01.5	0630 - 0800	0-1		L	HOLE	STKCG	ARM			BAKER FUNCTION TEST HCM-S VALVES FOUND CONTROL IS NOT HOLDING PRESSURE (LEAKING).
08.0	0800 - 1600	0-1		L	HOLE	STKCG	ARM			CONT. POH W/ SMART COMPLETION TO 5100' TOP OF PDHMS GUAGE.
01.5	1600 - 1730	0-1		L	HOLE	STKCG	ARM			DISCONNECT CABLES & CONTROL LINES FROM GUAGES, CMU & PREMIER PACKER ASSY. L/D SAME
06.5	1730 - 0000	0-1		L	HOLE	STKCG	ARM			POH W/ 3 1/2" TBG & SMART COMPLETION TO 2084'. FOUND CONTROL LINES DEFORMED & TWISTED. BAKER CUT CONTROL LINE & RECONNECT AGAIN.
05.0	0000 - 0500	0-1		L	HOLE	STKCG	ARM			CONT. POH TO 1383' TO FIRST FEED THRU M-PASS PACKER. DISCONNECT CONTROL LINES. L/D SAME

Table 4.1

Morning report snap shot showing stuck smart completion in open hole

4.3.3 EQUIPMENT MISS-PLACEMENT:

Any well to be drilled is an investment and it becomes a more substantial investment if the well is planned to be a Smart MRC well. Placing the laterals where the best rocks are and with the previously planned spacing is extremely crucial in mature fields. In the previous chapter, it was stated very boldly that the enlargement of casing design was done for the purpose of being able to hole the expensive completion in a smooth steel seat against each lateral for best performance.

Chances of miss-placement arises in open hole completions and there are no means of telling where the string is going unless the Total Depth (TD) of that lateral is tagged. With the fact that the smart completion in multi-lateral wells do not extend to TD, there is no 100% guarantee that the completion is properly placed. Any cutting beds could push the string to any lateral. Since the open hole windows are washed out by nature, chances of accumulating cuttings there is very high, hence the string may change direction and enter the upper lateral or the middle lateral by mistake.

Miss-deployment could easily blow away the investment plans as the ICVs will not be distributed on laterals evenly. The following figure demonstrates a true loss of investment in one of Field-X Slim Open Hole wells. The string entered the wrong lateral instead of following the motherbore got stuck 70’ below the window of the upper lateral. The string could not be freed by displacing mud to a lower weight due to a very high Gas Oil Ratio in this well and due to the fact that the open hole packers are swellable packers which set with time. Decision was made to leave completion where is and complete the well leaving the upper ICV inside casing, the middle ICV to control two laterals and the lower ICV to control the upper lateral. Figure 4.3 is an actual example of a stuck smart completion that was misplaced and could not be freed.

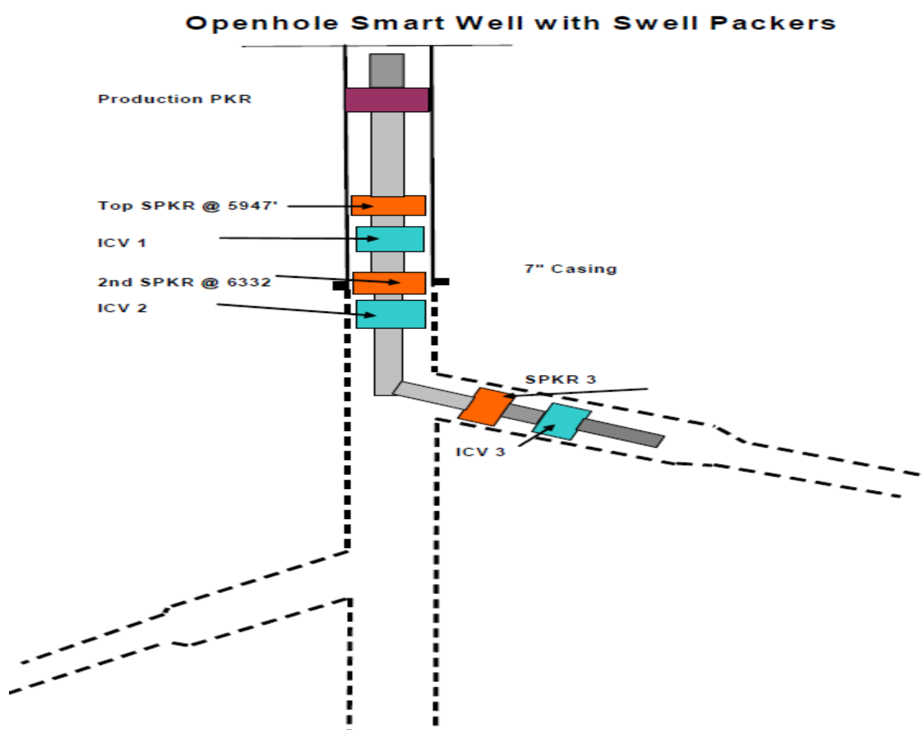

Figure 4.3

Actual miss-placement of smart completion in Field-X well

4.3.4 STEEL AND CEMENT SEPARATION:

One of the reasons why the Big Cased Hole design required a liner installed within the reservoir is to provide sufficient steel and cement separation between laterals. The main drive for such spacing is to avoid inter-lateral communication in case one lateral starts producing water or if the drilled fractures are communicating between each other. The Slim Open Hole design lacks such feature and replaces it with only open hole packers with blank pipe placed above and below the fractures as shown in figure 4.4.

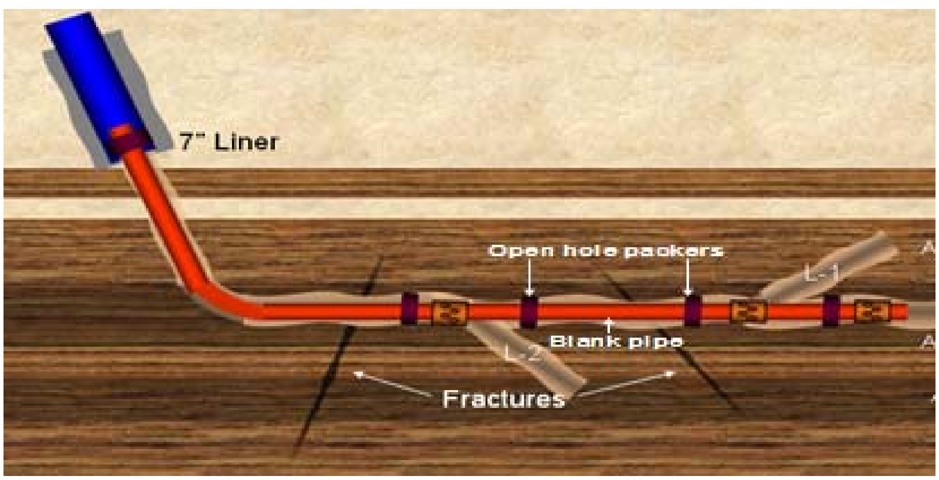

Figure 4.4

Lateral and fracture communication isolation means in the Slim Open Hole design

4.3.5 JUNCTIONS INTEGRITY AND LATERALS ACCESSIBILITY:

Since the open hole design dictates leaving the laterals open until the smart completion is deployed, the junction could be damaged easily while running in or pulling out of the hole. Continuous rotation of the drill pipe could also cause a severe damage to the junction integrity. Note that the condition of the open hole junction between each two laterals are the “only” means of production from that lateral. Whenever it is plugged or completely damaged, that lateral will never contribute to the flow through its Inflow Control Valve. In such scenario and both the lateral and its ICV will be useless in terms of contribution to the flow. The only assurance of good junction integrity is the steel junction or what is known as a casing window.

Laterals accessibility becomes an issue specially when all laterals are already drilled and it is time to clean laterals from mud cake if circulation was maintained at 100%. The only accessible lateral is the last lateral drilled which will be the only lateral that can be cleaned properly with mud-breaker fluids.

4.3.6 FUTURE WORKOVER:

The smart completion is run as a one string and it does not have any seals to allow sectioning of the string. It is full string from the end of completion all the way to the production tree and connected with hydraulic lines to control the ICV's and eclectic line to transmit pressure and temperature readings. Although smart wells were introduced to the market for the sake of eliminating well intervention and rig visits, it is a possibility that a smart well develops some unfavorable pressure between the last casing to surface and the production tubing. It could be even more serious if one or more of either the down hole packers or the ICV's stop functioning as it should. Such scenarios would dictate a workover rig arrival to the well in order to fix the malfunctioning tool. De-completing smart wells is a very challenging job to do, although it showed a good amount of success when it comes to de-completing cased hole smart completions. Even with such successful de-completions, the string had to be cut at different places in order to fish them section by section. It is known in the drilling industry that fishing in the open hole could take weeks if not months with very low chances of success.

The main reason why success diminishes in de-completing open hole completions is because the open hole packers that are sealing against the wall of the lateral takes the shape of that section which is definitely an irregular shape. If that packer is to be pulled, it could cause a huge drag while coming out of hole and could eventually be trapped at a relatively smaller or a different shape section. While in the cased hole design, once the packer is unset and/or pulled free, then it will only see a smooth steel surface to be dragged against.

CHAPTER 5

PROPOSED SLIM CASED HOLE DESIGN

It was clearly discussed in the previous two chapters that the old and the new Smart MRC design that are in use currently in Saudi Aramco have their pros and cons. The target of this research is to create a design that could bridge the gap between the two designs while maintaining their pros and avoid as many of their cons as possible.

5.1 Drive for the Proposed Design:

As Formation-15 reservoir in the mother-Field has been producing for tens of years, the water table had moved, has moved and will always move up. Almost all Formation-15 wells in the mother-Field target the top most zones, specifically Formation-15 Zone-1 or Zone-2A. The proposed design is based on retaining the same number of casings as the Slim Open Hole design which was the main intention for introducing the Slim Open Hole design. However instead of drilling the 8-1/2" to one or two feet above the targeted reservoir and then cement the 7" liner, the 8-1/2" hole is extended and drilled one or two feet above and parallel to Formation-15 within the cap rock. In other word, the hole will be geo-steered with Advanced Geo-Steering tools to allow the well path to cruise within a controlled window with the dip of the reservoir without entering the reservoir. The length of the drilled section of the anhydrate will depend on how many laterals need to be drilled with 300 meters spacing between each lateral. Since the two wells picked in this study are tri-laterals then the length to be drilled is going to be 600 meters or approximately 2000'. Then a longer 7" liner, by 2000', will be run and cemented. After that the laterals will be drilled bottom to top. The first one will be drilled from the shoe into the anhydrite and drops into the reservoir to its total depth. Then a whipstock with packer will placed at the middle lateral planned point to isolate the lower drilled lateral and allow exiting the installed 7" liner into the cap rock and then down to the reservoir and the same scenario gets repeated for the upper lateral. Of course with aid of packer-type whipstocks each lateral can be cleaned out from filter cake with any appropriate mud-breaker fluids and isolated without being damaged with the mud that will be used in drilling the next lateral.

Figure 5.1 explains best how casings' placements will be in the proposed design.

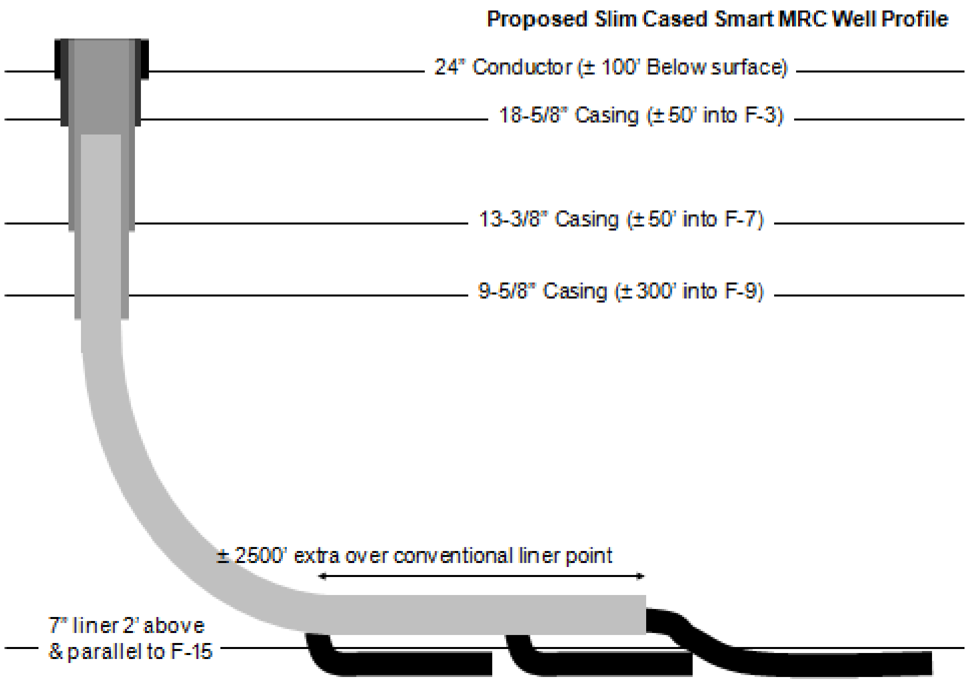

Figure 5.1

Proposed Slim Cased Hole well design layout.

5.1.1 <u>CAP-ROCK BUILT-IN FEATURE:</u>

The cap rock is zero porosity and zero permeability type of rock hence it is a competent rock that does not have fractures otherwise it will not act as a true seal of the reservoir below it. Fractures existence in such rocks is 0% and it will assist in achieving the best cement job quality and integrity.

5.1.2 RETAINING THE NORM IN HOLE SIZE VERSUS TYPE OF FORMATIONS:

It is important to know that for the last at least 50 years certain geological formations, as described in chapter 1, are drilled with certain bit sizes. Since this design does not enlarge the casing design like the Big Cased Hole design and retains the sizes used in conventional and Slim Open Hole designs, the number of variables in improving rate of penetration (ROP) is less and enhancement of performance is available. Moreover, bit vendors have gone through tremendous amount of research and modification until they came with the current designs that suit mother-Field wells.

5.1.3 PROBLEMATIC LARGE-EXPENSIVE OPEN HOLE COMPLETIONS:

The Slim Open Hole is indeed a cheaper option to drill those high investment wells however it is risky to be run in open hole. Getting stuck or miss-placing the string is no doubt ranked as a failure. The proposed design will utilize the 7" casing hosted by the slow-ROP drilled-for-purpose section to seat the smart completion at with zero chances of getting stuck or being miss-placed.

5.2 Technical Problems and Challenges Related to the Design:

Although the proposed design gives the best out of the two previously analyzed designs, it has to be done at a price. The cons are not associated with risks of deployment or execution as much as time and cost.

5.2.1 RATE OF PENETRATION:

The system should follow the same trend the ROP is in both the conventional and the Slim Open Hole designs except for the drilled-for-purpose section in the solid anhydrite. Typically the ROP slows down to around 25% as compared to drilling a porous zone. The best estimation of the ROP can be easily extracted from the re-entry wells drilled by combining Formation-14 and Formation-15 wells. The range of ROP recorded in such wells when approaching Formation-15 is between 10’ to 15’ per hour. For the sake of being prudent, the 10’/hour ROP will be considered. Thus, the 2000’ will require an additional 8.3 days over the Slim Open Hole Design. Table 5.1 shows a snapshot of an identical scenario of drilling the cap rock with a rotary steerable tool at rate of 11.2’/hour. Note that if 11.2’/hour is our assumption in drilling the required 2000’, then the total time will drop to 7.4 days.

Daily Onshore Drilling Report (0500-0500) Saudi Aramco

Date	Well No (Type) :	Rig
FRIDAY 05/07/2010		

Depth	Summary of operation	Lost Hrs.	Rot. Hrs.	Dead Hrs	Location
7575	POH, L/D TOOLS, RIH RSS, RE-LOG, DRILL 6-1/8" CURVE SEC.	1	6	17	115 KM FROM DMG, +/- 7 KM SOUTH ANDR WIP-1

Prev. Depth	Last Csg Size	MD	TVD	Liner Size	TOL	MD	TVD	Circ %	Days Since Spud/Comm (Date)
7508	9 5/8	4433	4433	7	2170	8963		100	13.8 (23-APR-10@0900)

Footage				Compl./Ev.	ROP	Target Days	Formation tops		
67	Total Lost Time Hours: 6.0 for the well			Hrs	11.2 Feet/Hrs	30	ARBC	6779	3' DEEPER
	Total Z Time Hours: 0.0 for the well						ARBD	6956	2' HIGHER
	Hrs	1.0	5.0						
	Lateral	0-2	0-2						
	Hole size	6 1/8							

Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
01.5	0500 -0630	0-2	6 1/8	D	TRIP	MMOT	RIG			CONT POH W/PES DIRECTIONAL TOOLS.
01.5	0630 -0800	0-2	6 1/8	D	TRIP	DP	RIG			DOWNLOAD MEMORY. L/DN PES DIRECTIONAL TOOLS.
01.0	0800 -0900	0-2	6 1/8	D	SERV	TDS	RIG			SERVICE TDS & BLOCK. C/OUT TDS X-OVER.
04.0	0900 -1300	0-2	6 1/8	D	MU	RSS	PES			PJSM, M/UP 6-1/8" HCM-406 RR BIT, PES RSS/LWD TOOLS, PROGRAM TOOLS, SHALLOW TEST - OK. LOAD RA SOURCE.
04.0	1300 -1700	0-2	6 1/8	D	TRIP	RSS	RIG			RIH WITH PES RSS BHA ON 4" DP.
00.5	1700 -1730	0-2	6 1/8	D	WORK	BOPE	RIG			CONDUCTED H2S DRILL & SAFETY MEETING.
02.0	1730 -1930	0-2	6 1/8	D	TRIP	RSS	RIG			RIH WITH PES RSS/LWD BHA ON 4" DP T/7358'.
01.0	1930 -2030	0-2	6 1/8	L	FAIL	LWD	PES			PES LWD TROUBLESHOOTING (DOWN TIME PES).
02.5	2030 -2300	0-2	6 1/8	E	LOG	HOLE	PES			PES RE-LOGGED F/7358' TO BTM @ 7508' AS PER GOC REQUEST.
06.0	2300 -0500	0-2	6 1/8	R	RSS	PSTRK	PES	7508	7575	SET DRLG PARAMETERS, RSS/LWD DRILL 6-1/8" CURVE SEC W/76 PCF MUD F/7508' T/7575 , 100% CIRC.

Table 5.1

Morning Report Snap Shot showing the ROP across Base of Formation-14 anhydrite

5.2.2 ADVANCED GEO-STEERING:

The only effective way of executing the proposed design is to utilize the market available tools that read deep resistivity contrast in the anhydrite extended section. Some tools can read as deep as 15' circle on 360 degrees. Such tools require 100% rotation and hence require utilization of Rotary Steer-able Systems to drill with instead of the normal mud motors which are costly. If, for any reason, the section was not placed properly above the reservoir within a reasonable separation then an additional amount of anhydrite will be drilled to correct for placing the well and would consume additional days. On the other hand, if the deep resistivity tools are not run, chances of penetrating the reservoir accidently are there.

An example of such advanced geo-steering tools is the Periscope which is always used in order to geo-steer in thin reservoir beds. One again, Formation-14/15 combined drilled re-entries proves that the tool can detect the boundary of the reservoir below it as shown in figure 5.2. The response from the tool indicates a conductive layer below the Formation-14 anhydrite with only 3' TVD away from reservoir.

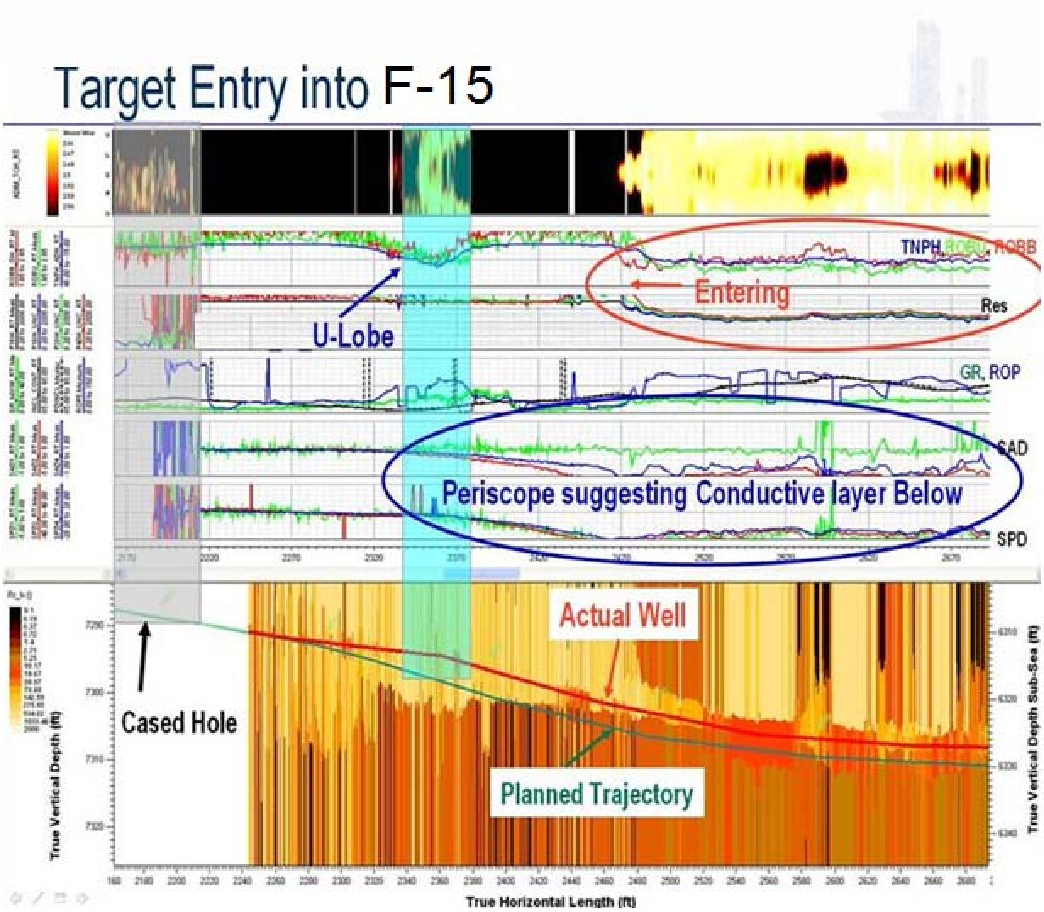

Figure 5.2

Periscope Log Helps to Detect Formation-15 Z-1 before Penetrating it

CHAPTER 6

RESULTS AND DISCUSSION

In this chapter, the comparison will be based on the pre-discussed technical challenges of the two existing design versus the proposed design. Each designs' deficiencies are going to be challenged in a common sense approach.

6.1 Big Cased Hole Design Technical Problems and Challenges Mitigation:

6.1.1 SLIM CASING DESIGN:

The proposed design clearly provides a slimmer option without altering the original requirements of the pre-determined smart MRC objectives that are set during the field development plans. As a matter of fact each lateral will represent a stand alone single lateral well. Figure 6.1 explains better the single well representation.

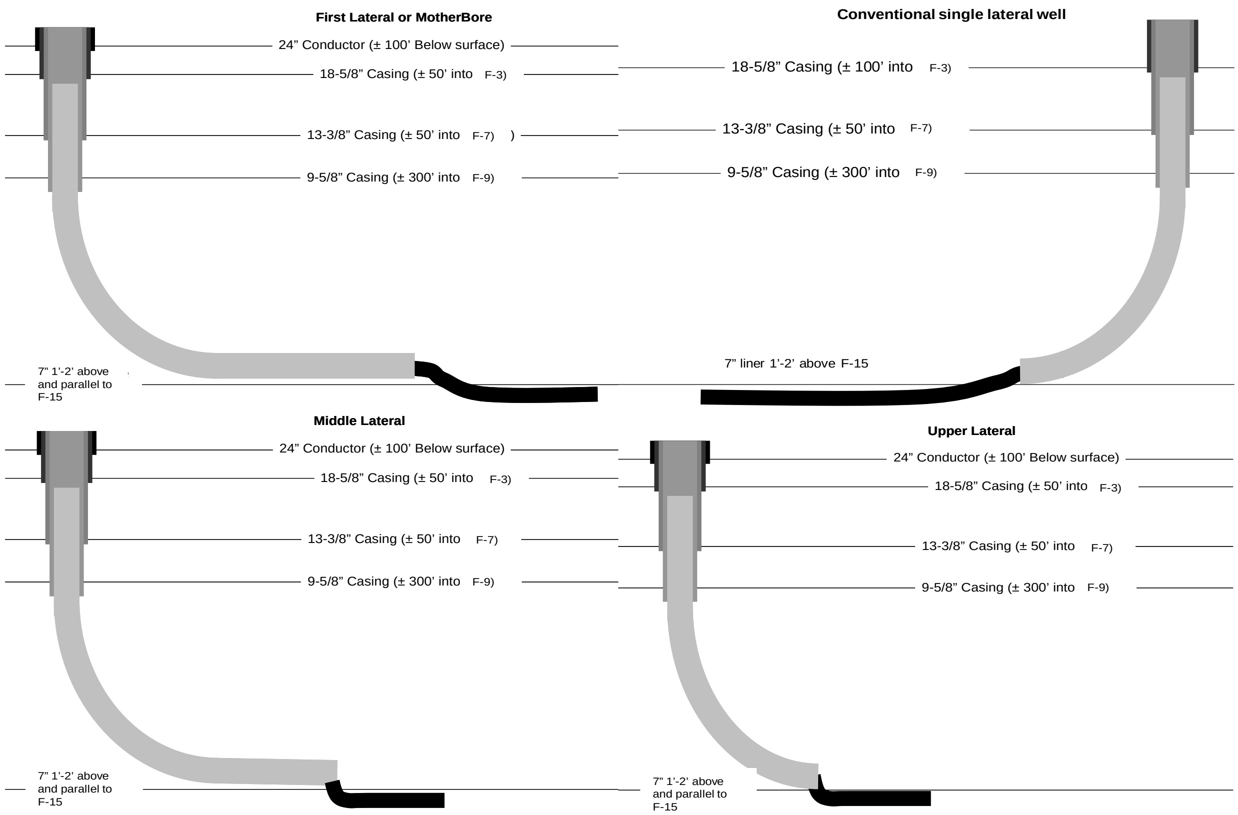

Figure 6.1

Each Lateral Represents a Unique Replacement of Single Lateral Wells

6.1.2 AVOIDING LOSS OF CIRCULATION:

Since the section that will host the smart completion is going to be drilled within the anhydrite, the operation will never encounter any loss of circulation. This provides a higher level of control on the well and will allow having a very gauged hole since it will be drilled with mud to the liner point.

6.1.3 ULTIMATE CEMENT JOB QUALITY:

The previous point is the most essential criteria in having a perfect and successful cement job. Since the circulation is going to be maintained across the anhydrite which is a very high compressive strength rocks, the cement job is surely successful. There will be completely no worries on where to set the whipstock and open the window to the middle or the upper lateral as seen in the Big Cased Hole design. In the Big Cased Hole design, a cement evaluation log must be run before opening any window to avoid poorly cemented sections. This is, of course, executed at an additional cost of tools and rig time delay.

Table 6.1 is snapshot of drilling report of the same well described in section 3.3.3 and shows the cement evaluation log run that precedes choosing the whipstock depth. Of course this log is only deployed if losses were encountered while cementing.

Daily Onshore Drilling Report (0500-0500) Saudi Aramco

Date	Well No (Type) :	Rig
MONDAY 01/16/2006	(HORIZONTAL TRI-LATERAL PRODUCER)	ADC-

Depth	Summary of operation			Lost Hrs.	Rot. Hrs.	Dead Hrs	Location
16134	POOH,RIH W/HAL LOGGING TOOL.POOH WITH HAL CCL/GR PIPE CON. LOGGING.					24	

Prev. Depth	Last Csg Size	MD	TVD	Liner Size	TOL	MD	TVD	Circ %	Days Since Spud/Comm (Date)
16134	9 5/8	7322	6413	7	6812	11666	6598	85	46.4 (30-NOV-05@2000)

Footage					Compl./Ev. Hrs	ROP Feet/Hrs	Target Days	Formation tops
0	Total Lost Time Hours: 165.0 for the well						76	
	Total Z Time Hours: 0.0 for the well							
	Hrs	1.0	7.0	157.0				
	Lateral	0	0	0				
	Hole size	12 1/4	22	8 1/2				

Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
08.0	0500 - 1300	0	6 1/8	D	TRIP	BHA				CONT. POOH W/68 PCF BRINE CAP.L/D BIT,STRING MILL,JAR & SPS C/O ASSY.HOLE TAKING @ 85 BPH
01.5	1300 - 1430	0	6 1/8	D	RU	HAL				HPJSM & R/U HALLIBURTON LOGGING TOOL & SURFACE TEST.OK.
05.5	1430 - 2000	0	6 1/8	D	WL	LOG				RIH W/TOOLS ON DRILL PIPE T/6986'. DRIFT ALL D/P.FILL D/P EVERY 10 STD.HOLE TAKING @ 85 BPH
01.5	2000 - 2130	0	6 1/8	D	RU	HAL				R/U WIRE LINE SHEAVE ON DERRICK.
02.5	2130 - 0000	0	6 1/8	D	CIRC	HOLE				M/U SIDE ENTRY SUB. CHC PRIOR TO LATCHING.PUMP DOWN & WET LATCH TOOL @ 6986'. TEST TOOL. OK.
03.5	0000 - 0330	0	6 1/8	D	WL	HAL				HPJSM.RIH W/HAL LOGGING TOOL T/10010'.
01.5	0330 - 0500	0	6 1/8	D	LD	HAL				FLOW CHECK. WELL STATIC. POOH LOGGING W/HAL TPL GR/CCL F/10,010' *** INC @ RPT****

Hrs	(From - To)	Lateral	Hole size	Cat.	Action	Object	Resp. Co	Start depth	End depth	Summary of Operations
01.0	0500 - 0600	0	6 1/8	D	LD	HAL				CONT. POOH W/LOGGIING F/10010' T/7500'.HOLE TAKING 68 PCF BRINE @ 85 BPH.
05.0	0600 - 1100	0	6 1/8	D	RD	HAL				UNLATCH & POOH WIRELINE.R/D HALIBERTON SHEAVES.POOH & L/D HALIBERTON TOOLS.
02.5	1100 - 1330	0	6 1/8	D	TRIP	WPSTK				M/U MWD & MCBPV TEST ASSY.SURFACE TEST MWD & MCBPV @ 3500 PSI.OK. L/D TIW VALVE.M/U WHIPSTOCK ASSY TO TRI-MILL.SCRIBE THE WHIPSTOCK BY DD.(HOLE TAKING 68 PCF BRINE @ 85 BPH.)
08.5	1330 - 2200	0	6 1/8	D	TRIP	WPSTK				HPJSM.RIH W/ WHIP STOCK ASSY 9746',WITH BRINE CAP OF 68 PCF IN ANNULUS.
02.0	2200 - 0000	0	6 1/8	D	SET	WPSTK				ORIENT WHIP STOCK TO 43 DEG HIGH RIGHT SIDE W/MWD.CLOSE MCBPV & SET WHIP STOCK @ 3500 PSI.CONFIRM WHIPSTOCK SET @ 20K DOWNLOAD.OK.W/S BOTTOM @ 9746'MD,TOP @ 9724.7'MD.(WELL STATIC AFTER PACKER SET.)
03.5	0000 - 0330	2	6 1/8	D	MILL	LINR				SHEAR BOLT,TUBE AND PLUGS.MILL LATERAL-1 WINDOW THROUGH 7"LINER F/9725' T/9745'MD WITH SMITH TRI MILL ASSY W/68 PCF MUD & HI VIS SWEEPS.100% CIR.POLISH WINDOW W/MILL ASSY TO ENSURE SMOOTH ENTRY.
01.0	0330 - 0430	2	6 1/8	D	CIRC	HOLE				PUMP 50 BBLS HI-VIS SWEEP AND CHC
00.5	0430 - 0500	2	6 1/8	D	TRIP	WPSTK				FLOW CHECK. WELL STATIC.NO LOSS. POOH *** INC @ RPT

Table 6.1

Morning Report Snap Shot Shows Additional Runs before Choosing the Window Depth

6.2 Slim Open Hole Design Technical Problems and Challenges Mitigation:

6.2.1 SAFE DRILLING CONDITIONS:

As shown earlier, Formation-15 reservoir in the mother-Field is extremely fractured. Moreover, the Slim Open Hole design does not allow isolation of laterals once they are completed until the smart completion is deployed. Having at least 10,000' of reservoir contact open to each other for weeks is serious concern but when losses becomes evident the situation turns into an emergency in which there are no chemicals or equipment available to keep with mixing and pumping the kill fluid. Loosing a tremendous amount of drilling fluid requires continues supply from town and could boost up the drilling fluid tickets easily to a higher than planned range. The proposed design allows isolation of each lateral, whether it had losses or not, before opening the window and drilling any other laterals. After all laterals are drilled, the isolation barriers are removed and the well is ready to accommodate the smart completion string.

6.2.2 ELIMINATION OF DIFFERENTIAL STICKING CONCERNS:

The proposed design completely erases the chances of getting differential stuck as the completion will only experience a smooth steel wall down to its seating point. Figure 6.2 shows where the completion will be set in both designs

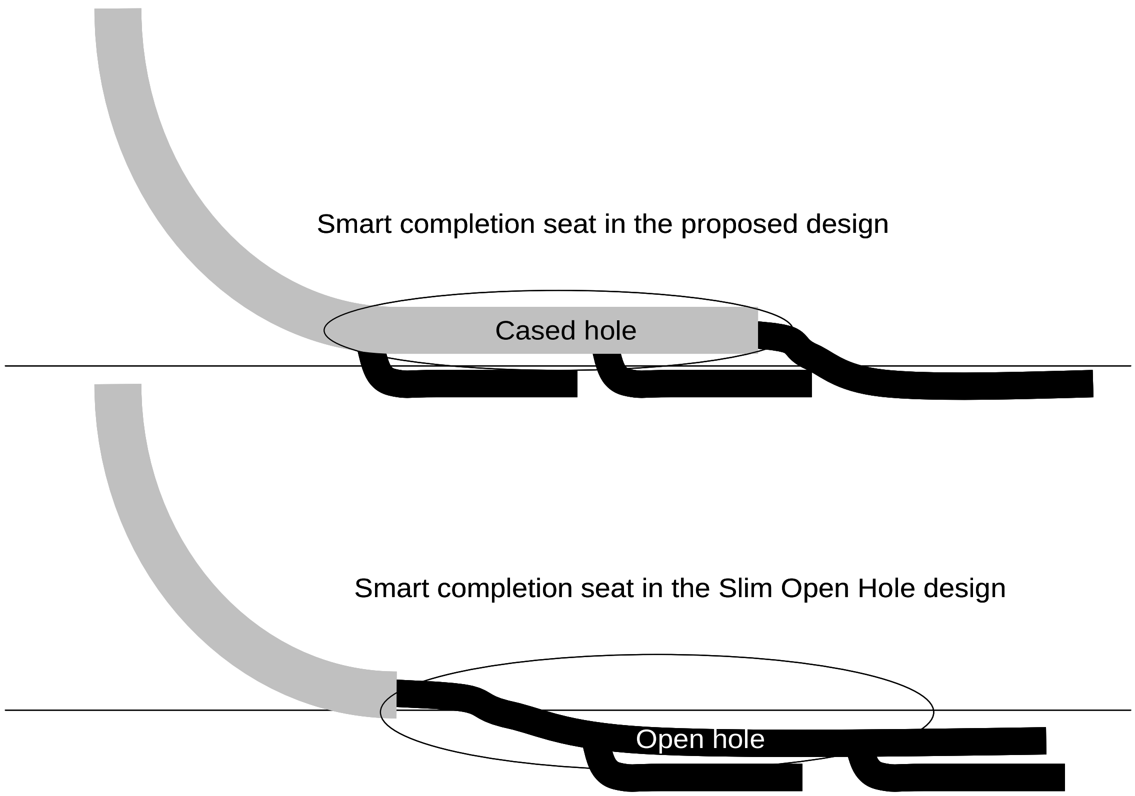

Figure 6.2

Smart Completion Seating Section on the Two Designs

6.2.3 INTACT STEEL JUNCTION AND SMOOTH LATERAL INTERVENTION:

The Slim Hole Design provides only open hole windows that could be damaged with the continuous rotation of drill pipe or while reaming the hole prior to running the smart completion or it could even be washed out. Not only that, the open hole junctions can never be detected by any magnetic deflection tools that are usually used to re-enter previously drilled laterals. Such steel windows are also provided by the Big Cased Hole design.

6.2.4 PROPER EQUIPMENT PLACEMENT:

The proposed design and the Big Cased Hole design provide a window that is milled at the right or left of high side wall of the casing. Such placement of windows allows the smart completion to follow the low side of the casing internal wall due to gravity. The completion string will never get in touch with the windows; hence proper string placement is always expected.

6.2.5 PROPER STEEL AND CEMENT SEPARATION:

The Slim Open Hole design only provides open hole packers to isolate laterals and/or fractures communication with each other. However the proposed design provides the proper firm isolation with casing and cement unlike some of the Big Cased Hole design.

6.2.6 POSSIBLE FUTURE WORKOVERS:

Planning for the future is a must, even if the investment was built on avoiding future rig visits. The Slim Open Hole design imposes that the smart completion is run across the open hole which always have irregular shapes even if the hole was drilled with mud and full circulation. Tortuousity induced by geo-steering the well while searching for the good rocks is the main reason behind the irregular shape if any section in the open hole. As discussed earlier, the string may not be freed and if it did, then there is a possibility that it jams into any other section while coming out of hole. Fall back positions or Plan-B diminishes and the well would be easily lost. Both the proposed and the Big Cased Hole design allow flexibility in pulling out the completion smoothly if it was freed. Even if the string could not be freed then it can be cut and then the rest as dealt with inside a smooth casing surface.

6.3 First in Class Features:

6.3.1 EXTRA ASSURANCE OF ELIMINATING LATERALS COMMUNICATION:

The proposed design does not only provide the ultimate steel and cement separation of laterals, it also provides a naturally existing means of separation which is the cap-rock below it. None of the two existing design can assure such elimination of communication. The Big Cased Hole design provides casing and cement that could be poor at times and it could be enhanced by installing Annulus Casing Packers. The Slim Open Hole design provides blank pipe and open hole packers that could leak with time.

6.3.2 FULL EQUALIZATION OF EACH LATERAL:

Equalizer systems are systems deployed into horizontal open hole in order to equalize the full lateral and assure uniform flow from all lateral sections. The primary goal of equalizing laterals is to allow proper sweep from the reservoir and delay water encroachment through highly permeable sections.

The proposed design allows full equalization of each lateral while the other two existing designs fail to provide. Although this advantage is never done before, it represent the ultimate dream of Smart Equalized MRC wells that are capable of producing all possible oil within the radius of investigation of each lateral.

The Big Cased Hole design can not provide such feature because the windows are already opened within the reservoir. Consequently, if the Equalizer system is to be deployed in the lateral it must be hung inside the 7” casing which will restrict the ID of casing and would not allow running the smart completion. If the Equalizer system is to be deployed in the open hole below the window, then the section of reservoir between the window and the top of the Equalizer system will contribute the most to the flow and allows early water encroachment for that lateral.

The Slim Open Hole design does not allow neither partial nor full equalization of laterals due to its full open hole design. It is completely impossible to hang the equalizers system in the casing because it does not exist. Moreover, it will be completely useless to install the equalizer system below open hole windows as more open hole will be exposed as compared to the Big Cased Hole design.

The following figures, 6.3, 6.4 and 6.5, demonstrate the above mentioned differences.

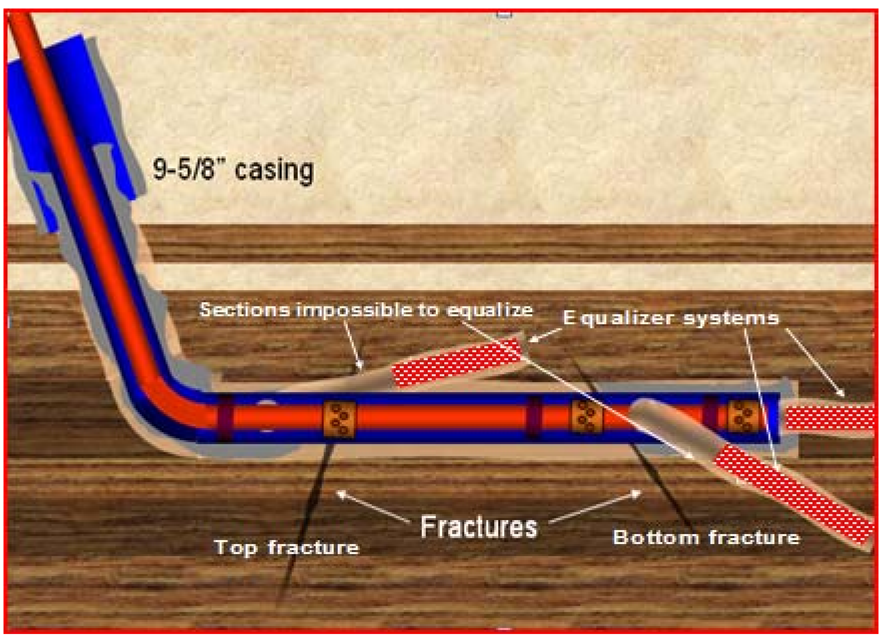

Figure 6.3

Deficiency in Full Equalization at the Big Cased Hole design

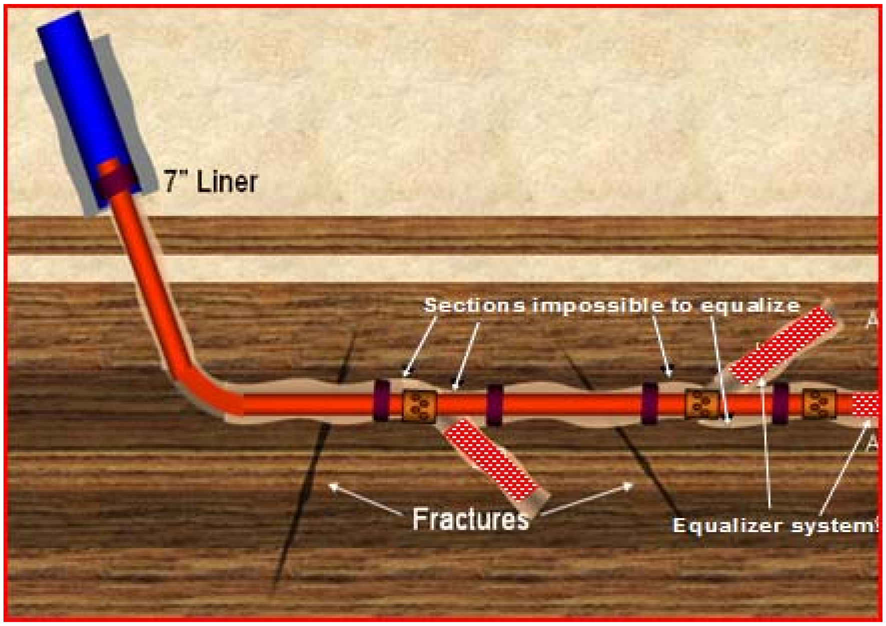

Figure 6.4

Deficiency in Full Equalization at the Slim Open Hole design

The proposed design will utilize the 1'-2' true vertical depth separation interval that will be represented in at least 100' measured depth to hang the equalizer system at. The biggest advantage is natural properties of zero porosity and zero permeability of the cap rock hence there will be a full equalization of the lateral.

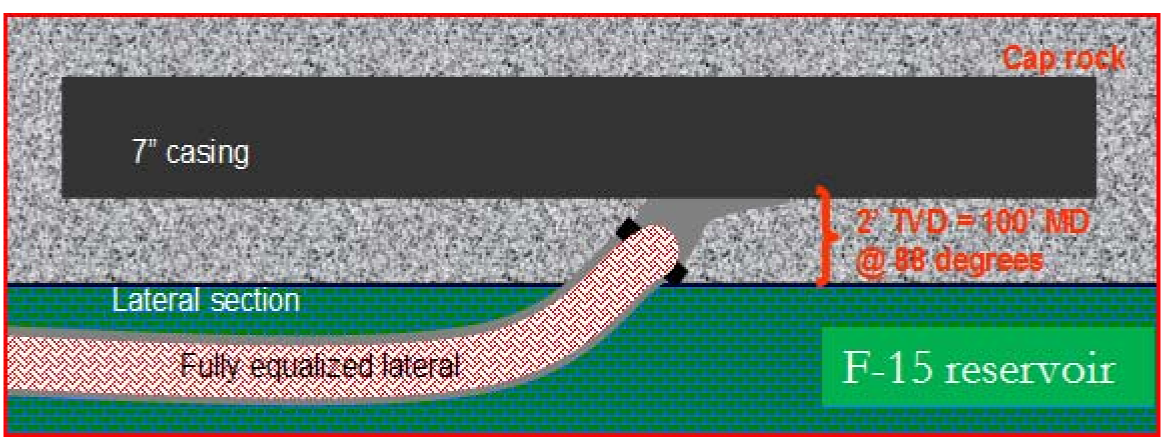

Figure 6.5

6.4 Total End of Well Time and Cost:

As mentioned in section 2.3.2, the confidentiality of prices and contracts of service providers and Saudi Aramco dictates showing the savings in increments. Small fractions of savings that are within the range of $100K or less will be ignored. The focus will be on mainly two categories. We will keep the cost of the most expensive design constant and show the savings relatively to it. Big Cased Hole tri-lateral smart wells cost around $9MM and it requires an average of 70 operational days to be completed per well. Two wells in Field-B are picked for this comparison because this field is the only field where the Slim Open Hole design was applied to.

There will be no conductor pipe installed at ± 100’ from surface with the assumption that the surface hole is a stable formation and will not collapse. The casing requirements for each design are shown table 6.2.

Casing size	BCH	SOH	SCH
24”	600’	NA	NA
18-5/8”	2500’	600’	600’
13-3/8”	4000’	2500’	2500’
9-5/8”	8000’	4000’	4000’
7”	5500’	5800’	7800’

Table 6.2

Casings’ Lengths Required for Each Design

All casing sizes mentioned above are extended to surface except for the 7” casing. BCH 7” casing will be extended to ±40º and as for SOH and SCH it will only extend to above the 13-3/8” casing shoe by 300’.

6.4.1 TARGET DAYS COMPARISON:

We will only here consider the time saved or spent by reducing casing design and by drilling the additional anhydrite footage. The following table shows the exact ROP recorded on both Field-B wells and the forecasted ROP by the proposed design.

Section	BCH				SOH				SCH			
	Hole size	section length	ROP	Time required	Hole Size	Section length	ROP	Time required	Hole Size	Section length	ROP	Time required
1	28	600	18.1	1.4	22	600	26.2	1.0	22	600	26.2	1.0
2	22	1900	31.1	2.5	16	1900	58.3	1.4	16	1900	58.3	1.4
3	16	1500	46	1.4	12.25	1500	60.4	1.0	12125	1500	60.4	1.0
4	12.25	4000	25.8	6.5	8.5	4000	37.3	4.5	8.5	4000	37.3	4.5
5	8.5*	2000	50	1.7	6.125*	2000	59.8	1.4	8.5*	2000	10	8.3
Total time	13.4				9.2				16.1			

Table 6.3

Time Required to Drill Each Section for all Designs

* The section that will host the smart completion.

Table 6.3 shows clearly that the Slim Open Hole design gives the fastest rotating time as compared to the Big Cased Hole design and the proposed design. Moreover the proposed design shows the slowest figure due to the prudent ROP assumption of 10'/hour across the anhydrite.

Poor cement and liner top squeeze jobs as well as cement evaluation logs witnessed in the Big Cased Hole design consumes an average of one week. Similarly pulling a stuck completion in Slim Open Hole design wells would consume that much amount of time if successful.

6.4.2 COST COMPARISON:

The cost of the enlarged and longer casings used in the Big Cased Hole design is the main drive for the high end of well cost. The bigger the casing size is the more expensive its price is. In the above example, the two Field-B wells casing sizes and lengths that will be saved are as follows:

- 600’ of 24” casing
- 1900’ of 18-5/8” casing
- 1500’ of 13-3/8” casing
- 4000’ of 9-5/8” casing

The proposed design will realize the same amount of steel savings but will require an additional 2000’ of 7” liner to be placed against the horizontal anhydrite section. The cost of the 2000’ of needed casing can be related easily to the cost of the saved casings above. The 7” casing has a weight of 26 pounds/foot and the whole 2000’ weigh 52,000 pounds. The 52K pounds become minor when compared to the 24” casing that has a weight of 174 pounds/foot. The weight of the saved 24” casing is equal to 105K pounds.

As for the proposed design, it was stated clearly that the added benefits are executed at a price but sometimes a sure perfect job is priceless. The high cost of the proposed design is still under the cost of the saved steel amount. The main points that would make the system more expensive as follows:

- Rig rate during drilling through the cap rock of around 8 days.
- Advanced Geo-steering logs cost.
- Rotary steerable cost.

The main points that could make the Slim Open Hole design price higher than calculated are:

- Excessive amount of mud and chemicals used in case of losses are encountered.
- Excessive amount of time required to pull stuck completion in case happened. Note that pulled completions are always damaged; hence the system will be partially replaced with new tools that will lead to an additional non-forecasted spending.

CHAPTER 7

CONCLUSION

To conclude this study, it is obvious that the Slim Open Hole design gives the lowest cost as compared to the proposed design which is less in cost as compared to the Big Cased Hole design. It is also quite clear that the Slim Open Hole wells are delivered faster than both the proposed and the Big Cased Hole design. However, improvement in ROP for the anhydrite section is achievable by adjusting the variables and it could eventually reduce the time required to drill the proposed design.

Sometimes it is very hard to quantify advantages or translate them into money such as those given by the proposed design unless the performance of the production life of the well is looked into. Unfortunately this is beyond the scope of this research and would be worth investigating if the proposed design is already implemented.

Table 7.1 shows a summary of the can do and cannot do by all types:

Feature	BCH	SOH	SCH
Time	Slow	Fast	In between
Money	High	Low	In between
Lateral communication	Average	Poor	Strong
Cement integrity	Questionable	Not available	Confirmed
Junction integrity	Confirmed	Weak	Confirmed
Well control	Low	High	Low
Lateral cleaning	Confirmed	Not available	Confirmed
Differential sticking risk	Zero	Possible	Zero
Equipment placement	Confirmed	Questionable	Confirmed
Future workovers	Achievable	Questionable	Achievable
Equalizers option	Not available	Not available	Achievable

Table 7.1

General Comparison between all Designs

At the end, the proposed design all along with the other designs can be applied to any reservoir in any field anywhere in the world. However, the proposed design will only provide its robust features only if the reservoir is capped with an impermeable and non-porous cap-rock and only the very top sections of the reservoir are targeted.

REFERENCES

1. Carlos A. Glandt, Shell Intl. E&P: **“Reservoir Management Employing Smart Wells: A Review”**, paper SPE 81107, SPE Latin American and Caribbean Petroleum Engineering Conference held in Trinidad, April 2004.

2. Dhafer A. Al-Shehri and Shaohua Zhou, “**Bionic Wells: Science Imitates Nature Again**”, Saudi Aramco Journal of Technology, Spring 2008, PP. 10-15.

3. Changhong Gao and T. Rajeswaran, Curtin U. of Technology, and Edson Nakagawa, CSIRO Petroleum Resources, “**A Literature Review on Smart-Well Technology**”, paper SPE 106011, SPE Production and Operations Symposium held in Oklahoma city, April 2007.

4. F. N. Nughaimish, SPE, Saudi Aramco; O. A. Faraj, SPE, Saudi Aramco; Nabeel Al-Afaleg, SPE, Saudi Aramco; Uthman Al-Otaibi, Saudi Aramco, “**First Lateral-Flow-Controlled Maximum Reservoir Contact (MRC) Well in Saudi Arabia: Drilling & Completion: Challenges & Achievements: Case Study**”, paper IADC/SPE 87959, IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition held in Kuala Lumpur, Malaysia, September 2004.

5. Fahad Al-Bani, SPE, and Ahmad Shah Baim, SPE, Saudi Aramco, and Suresh Jacob, SPE, WellDynamics Inc., "**Drilling and Completing Intelligent Multilateral MRC Wells in Haradh Inc-3**", paper SPE/IADC 105715, SPE/IADC Drilling Conference held in Amsterdam, The Netherlands, February 2007.

6. L. Vo and J.W. Styler, Saudi Aramco, "**An Assessment of Emerging Technologies for Production Optimization in Saudi Aramco-Southern Area Production Engineering**", paper SPE 93369, 14th SPE Middle East Oil & Gas Show and Conference held in Bahrain, March 2005.

7. Mohammed A Abduldayem, Nader D. Al Douhan, and Zulfiqar A. Baluch, Saudi Aramco, "**Technological Applications Redefining Mature Field Economic Limits**", paper SPE 110979, SPE Saudi Arabia Technical Symposium held in Dhahran, Saudi Arabia, May 2007.

8. N.I. Afaleg, T.R. Pham, U.F. Al-Otaibi, and S.W. Amos, Saudi Aramco, and S. Sarda, Beicip-Franlab, "**Design and Deployment of Maximum Reservoir Contact Wells With Smart Completions in the Development of a Carbonate Reservoir**", paper SPE 93138, 2005 Asia Pacific Oil & Gas Conference and Exhibition held in Jakarta, Indonesia, April 2005.

9. Saudi Aramco, Drilling & Workover Engineering Department, "**Drilling Manual**", June 2006, Chapter 2/Section B.

10. Khalifah M. Al-Amri, Abdulmohsin A. Al-Nassir, and Shaohua Zhou, SPE, Saudi Aramco, "**Successful Open Hole Smart Completion, Case History from Saudi Arabia**", paper SPE 114637, 2008 Asia Pacific Oil & Gas Conference and Exhibition held in Perth, Australia, October 2008.

11. Khalifah M. Al-Amri, SPE, Saudi Aramco, "**Case History – World's First Slim Open Hole Smart MRC Wells**", paper SPE 117050, 2009 SPE Middle East Oil & Gas Show and Conference, Kingdom of Bahrain, March 2009.

12. Paulo Tubel and Mark Hopmann, Baker Oil Tools, "**Intelligent Completion for Oil and Gas Production Control in Subsea Multi-lateral Well Applications**" paper SPE 36582, 1996 SPE Annual Technical Conference and Exhibition held in Denver, Colorado, U.S.A. October 1996.

13. Michael J. Tangedahl, SPE, RBOP Oil Tools International, Inc. "**Well Control: Issues of Under Balanced Drilling**", paper SPE 37329, 1996 SPE Eastern Regional Meeting held in Columbus, Ohio October 1996.

14. P. Head SPE and D. Turner SPE XL Technology Ltd, and T. Hanson SPE Enterprise Oil plc, and S. Al Rawahi SPE Shell International and G. Cameron SPE Amerada Hess, "**Slim Wells without the Pain**", paper SPE/IADC 52795, 1999 SPE/IADC Conference held in Amsterdam, Holland, 9-11 March 1999.

15. Graham Mensa-Wilmot, GeoDimond; Martyn J. Fear, BP, "**The Effects of Formation Hardness, Abrasiveness, Heterogeneity and Hole Size on PDC Bit Performance**", paper SPE/IADC 67698, 2001 SPE/IADC drilling conference held in Amsterdam, The Netherlands, February 2001.

16. Hector U. Caicedo, William M. Calhoun, and Russ T. Ewy, SPE, ChevronTexaco Energy Technology Company (ETC), "**Unique ROP Predictor Using Bit-Specific Coefficient of Sliding Frication and Mechanical Efficiency as a Function of Confined Compressive Strength Impacts Drilling Performance**", paper SPE/IADC 92576, 2005 SPE/IADC Drilling Conference held in Amsterdam, The Netherlands, February 2005.

17. Stig Lyngra, SPE, Abdulkareem M. Al-Sofi, SPE, Uthman F. Al-Otaibi, SPE, Mohammed J. Alshakhs, SPE and Ahmad A. Al-Alawi, SPE/ Saudi Aramco, "**New Technology Applications for Improved Attic Oil Recovery: The**

World's First Slim Smart Completions", paper IPTC 12365, 2008 International Petroleum Technology Conference held in Kuala Lumpur, Malaysia, December 2008.

18. Kenneth P. Malloy, Stress Engineering Services, and Vincent Roes, Shell, "**Improved Reliability of Drilling Operations Using Managed Pressure Drilling Technology: A Case Study in a Brownfield Environment**", paper OTC 18461, 2007 Offshore Technology Conference held in Houston, Texas, U.S.A., 30 April–3 May 2007.

19. A.M. Al-Jeffre, A.S. Al-Dossary, S. Zhou, A.A. Al-Hajji, N.M. Al-Khanferi, and S.M. Al-Jaafari, Saudi Aramco, "**World's First MRC Window Exits out of Solid Expandable Open-Hole Liner in The Shaybah Field, Saudi Arabia**", paper SPE/IADC 97514, 2005 Middle East Drilling Technology conference & exhibition held in Dubai, U.A.E., September 2005.

20. S.P. Salamy, H.K. Al-Mubarak, D.E. Hembling, and M.S. Al-Ghamdi, Saudi Aramco, "**Deployed Smart Technologies Enablers for Improving Well Performance in Tight Reservoirs-Case: Shaybah Field, Saudi Arabia**", paper SPE 99281, 2006 SPE intelligent energy conference and exhibition held in Amsterdam, the Netherlands, April 2006.

21. P.D. Howlett, SPE, M.T. Wardley, SPE, and C. Black, SPE, Caledus Ltd., and D. Reed, SPE, Senergy Ltd., "**Case Study of New Slender Well Construction Technology**", paper SPE 102580, 2006 SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, U.S.A. September 2006.

22. J.R.G. Jacobsen, W. Kharrat, J.V. Noya, SPE, Schlumberger, "**Changing the Game of Fluid Placement: Intelligent-Well Intervention on a Trilateral Horizontal Well**", paper SPE 130365, 2010 SPE/ICoTA Coiled Tubing and Well Intervention Conference and Exhibition held in The Woodlands, Texas, U.S.A. March, 2010.

23. Syed A. Ali, "**Mature Fields and Well Revitalization**", Journal of Petroleum Technology, January 2010, PP. 48-55.

VITAE

Name: Khalifah Mohammed Al-Amri

State of Origin: Saudi Arabia

Nationality: Saudi

E-mail: Khalifah.amri@aramco.com

Address: Saudi Aramco Box No. 9025, Dhahran 31311,
Eastern Province, Kingdom of Saudi Arabia

Education: **MS (Petroleum Engineering), January 2011**
King Fahd University of Petroleum & Minerals
Dhahran 31261, Saudi Arabia

BS (Petroleum Engineering), August/1998
King Fahd University of Petroleum & Minerals
Dhahran 31261, Saudi Arabia

Experience: Is a supervisor (position) in the Gas Development Drilling and Workover Department in Saudi Aramco, and a specialist in Oil and Gas well construction and workovers. He has been involved in the development, the design and implementation of many innovative drilling designs in both new and existing wells as well as with the Under Balanced Gas Drilling Rigs. He has more than 10 years of petroleum industry experience, and has written or co-written several technical and international publications.

In 2007, he received a recognition award for innovating and executing the Formation-14/15 Combined Drilling Technique that has proven savings in the range of hundreds of millions of dollars. He has been a very active SPE member and officer. Khalifah Al-Amri received a B.S. degree in Petroleum Engineering on August 1998 from King Fahd University of Petroleum & Minerals (KFUPM), Dhahran, Saudi Arabia.