CASE STUDY OF NITRIFIED ACID THAT ENABLE DEEPER PENETRATION OF ACID FOR MAXIMIZING PRODUCTION ENHANCEMENT IN SOUTHERN SARAWAK FIELD

By

Nurul Syafiqa Binti Abdul Wahab

DISSERTATION

Submitted to the Petroleum Engineering and Geoscience Programme

in partial fulfilment of the requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

APRIL 2011

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan.

CERTIFICATION OF APPROVAL

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Approved by,

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(Assoc. Prof. Aung Kyaw)

Associate Professor

Geoscience & Petroleum Engineering Department

Universiti Teknologi PETRONAS

Bandar Seri Iskandar, 31750 Tronoh

Perak Darul Ridzuan, Malaysia.

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

April 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Syafiqa

[NURUL SYAFIQA BINTI ABDUL WAHAB]

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ABSTRACT

With the increasing need for highly cost-effective well production enhancement applications, acid stimulation is becoming increasingly popular. To be successful, acidizing procedures require distribution of stimulation fluid across and within the desired treatment interval. Historically, this has been approached with mechanical placement or chemical or chemical diversion of treatment fluids. Method selection can be crucial to treatment success vary for matrix and fracture acidizing – in deviated wellbores, in sandstones and carbonates and in cased and perforated, gravel packed and open hole completions. Nitrified acid is the technique designed to remove well-bore formation damage which has occurred during the productive life of the well without causing additional damage with kill fluids. West Lutong and Tukau field are selected as the field of studies as this acid has shown several successful cases in Southern of Sarawak field. Tukau field has reduced watercut after using nitrified acid method for acidizing and currently this method is applied to West Lutong field with the combination of SAF MK II acid for high watercut wells. SAF MK II not reducing water cut but the chemical diverts the acid to oil zones and mostly stimulate oil zones only. Thus, more oil produce and water production maintained prior acid job. The project is also to determine the skin reduction for each field by using method used in PETRONAS Carigali Sdn. Bhd for acidizing treatment project. This project will be reviewed the production trend of both field as the determination of skin that reduced the production. The history of acid job and stimulation done for the fields will be analyzed to estimate the total reduction of skin and estimated the oil gained by using several simple mathematical equations before a simulation by using PROSPER will be done in order to confirm the calculations.

CHAPTER 1
INTRODUCTION

1.1 Background Study

With the increasing need for highly cost-effective well production enhancement applications, acid stimulation is becoming increasingly popular. To be successful, acidizing procedures require distribution of stimulation fluid across and within the desired treatment interval. Historically, this has been approached with mechanical placement or chemical or chemical diversion of treatment fluids. Method selection can be crucial to treatment success vary for matrix and fracture acidizing – in deviated wellbores, in sandstones and carbonates and in cased and perforated, gravel packed and open hole completions. Nitrified acid is the technique designed to remove well-bore formation damage which has occurred during the productive life of the well without causing additional damage with kill fluids. West Lutong and Tukau field are selected as the field of studies as this acid has shown several successful cases in Southern of Sarawak field. Tukau field has reduced watercut after using nitrified acid method for acidizing and currently this method is applied to West Lutong field with the combination of SAF MARK II acid for high watercut wells. SAF MARK II not reducing water cut but the chemical diverts the acid to oil zones and mostly stimulate oil zones only. Thus, more oil produce and water production maintained prior acid job. This project will be reviewed the production trend of both field as the determination of skin that reduced the production. The history of acid job and stimulation done for the fields will be analyzed to estimate the total reduction of skin and estimated the oil gained by using several simple mathematical equations before a simulation by using PROSPER will be done in order to confirm the calculations. In the next phase, the output from FYP1 will be use to estimate the expected post-acid skin and oil gain after acid job done. The actual post-acid result will be use in the end as the comparison between PROSPER well simulation and actual result.

1.2 Problem Statement

Acidizing is one of the method to enhance oil production of the well. A sudden and sharp decline in production is the strongest indicator of damage. Southern Sarawak field has increasing watercut since the field has been drilled for past 50 years. The presence of high watercut brings down the oil production of the field and also a difficulty for engineers in order to conduct acidizing job for oil production enhancement. Therefore, an effective acid which can maximize the reduction of the damage is needed in to obtain the optimum production for the field. Nitrified acid has been introduced to enable deep penetration of matrix for maximizing the oil production in Tukau and West Lutong field. West Lutong for example has been used nitrified acid with SAFMARK II for acidizing to optimize the deep penetration with high watercut formation.

1.2.1 Problem Identification

Before any modelling and simulation can be made using PROSPER, the needs of understanding the basic principle of the formation damage and nitrified acid is required. Besides having to understand the characteristic of the formation of the field, learning the method used in determining skin presence based on the production trend of the reservoir are also needed for the completion of the project. The history of acid job done in the field is also need to be reviewed and analyzed to determine the estimated percentage of skin reduction after each acidizing. Only then can the modeling and stimulation of the targeted wells take place.

1.2.2 Significant of Project

This project is importance in order to recognize the best method of acid stimulation in Sarawak field for production enhancement. Nitrified acid method has shown several successful jobs in Tukau field, therefore a study about this method is useful in order to propose nitrified acid method that enables deeper penetration of acid.

1.3 Objectives

The objective of this project is:

1. To determine total skin reduction for West Lutong and Tukau field based on acid job history
2. To find the total skin reduction for both fields by using PROSPER modeling and simulation
3. To compare and analyzed well models constructed in order to determine whether nitrified acidizing is suitable in maximizing production and optimization for both field.

1.4 Scope of Study

The scope of study will focus on the function of nitrified acid that enable deeper penetration of acid and maximize production enhancement in the oil wells. For this case study, two fields in Southern of Sarawak are selected as the field of interest; Tukau and West Lutong field in order to analyze the production trend. The focus of studies are a Tukau string that used nitrified acid only and a West Lutong string which applied combination of nitrified acid and SAF MARK II for high water cut. The SAF MARK II would be extended findings for high water cut applications. The geological history of the field will be studies in order to identify the type of formation of the field. Then, the reservoir production trend will be reviewed in order to determine the formation damage (skin). Formation damage means the reduced of current production. The method to identify the skin is by review the production trend of the field or the well by using OFM software. The skin is occurred when there is a decline in the production graph with a maintain watercut and no other well problem available. Acidizing is one of the method to enhance the oil production and removed the damage by dissolving the particles between the grains of formation. Then, the study expands on the history of acid job done in the field in order to determine the total of skin reduced and the oil gain for the job done. The targeted wells will be modeled and stimulate by using PROSPER software in order to analyze the oil gained after acid job done with sensitivities of watercut.

1.4.1 The Relevancy of Project

This project is relevant to the study of nitrified acid as it focuses on the calculation of skin reduction and the oil gain for the job done. This project is relevance as it is one of the ways to optimizing the oil production instead of hydraulic fracturing, adding perforations and workover. Nitrified acid has been widely used in oil and gas industry around the world. With cost-effective approaches to well stimulation and proven technologies for increasing productivity, nitrified acid method is useful to be used in most reservoirs in Malaysia. Therefore, it is useful in order to maximize the profits gained by optimizing the oil wells production.

1.4.2 Feasibility of the Project within the Scope and Time frame

The project will be conducted starting with the collection of related materials such books, journals and technical papers specifically on acidizing method with different type of acid used and PROSPER application. Research will be done from time to time as to get a better understanding on the subject. This project will then focus on the modelling a well based on the current scenario by using PROSPER software. Based on the activities stated above, given 5 months for the researches and studies to be done as well as experiment activities and for the other 5 months for the finalization the analysis and result, the author feels that the project can be completed within the given time frame.

CHAPTER 2

LITERATURE REVIEW / THEORY

2.1 SUMMARY OF WEST LUTONG AND TUKAU FIELD

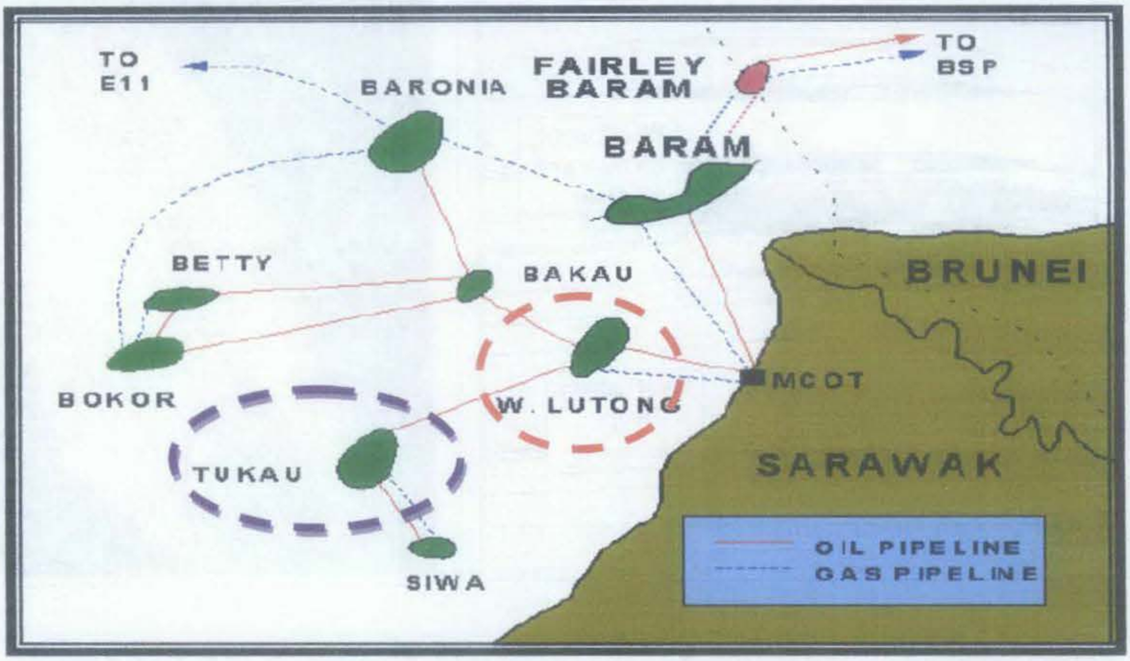


Figure 1: West Lutong and Tukau field

The West Lutong field was discovered by well WL-01 in 1966 and brought on production in mid 1968. It is located offshore Sarawak approximately 13Km north-west of Miri in water depth of 70 -100 ft. There are a total of 51 wells penetration (35 original holes and 16 sidetracks), which are distributed predominantly along the crest.

The reservoir sands are generally laterally correlatable over distances of 5000 to 10000 ft, suggesting limited stratigraphic complexity as well. Sands are loosely consolidated, fine to very fine and interbedded with layers of silts and clays. The porosity ranges from 14 to 26 % with a fieldwide mean of 20%. Permeabilities are in the order of 50 to 3000 mD while the average net-to-gross is 0.62. Net sand thickness is less than 30 ft, with most individual sands around 10 ft.

The reservoirs are subdivided into three groups; shallow reservoirs, main reservoirs and deep reservoirs. 'Shallow' reservoirs (A through J) at depths of 4000 to 5300 ft are generally unfaulted and characterised by large gas caps and thin oil rims. The main reservoirs (K through N) at depths of 5300 to 6000 ft are also generally unfaulted, have small or no gas caps and strong aquifer drive. Deep reservoirs (O through Z) at depths of 6000 to 9500 ft are dissected by a northwest-headed growth fault system.

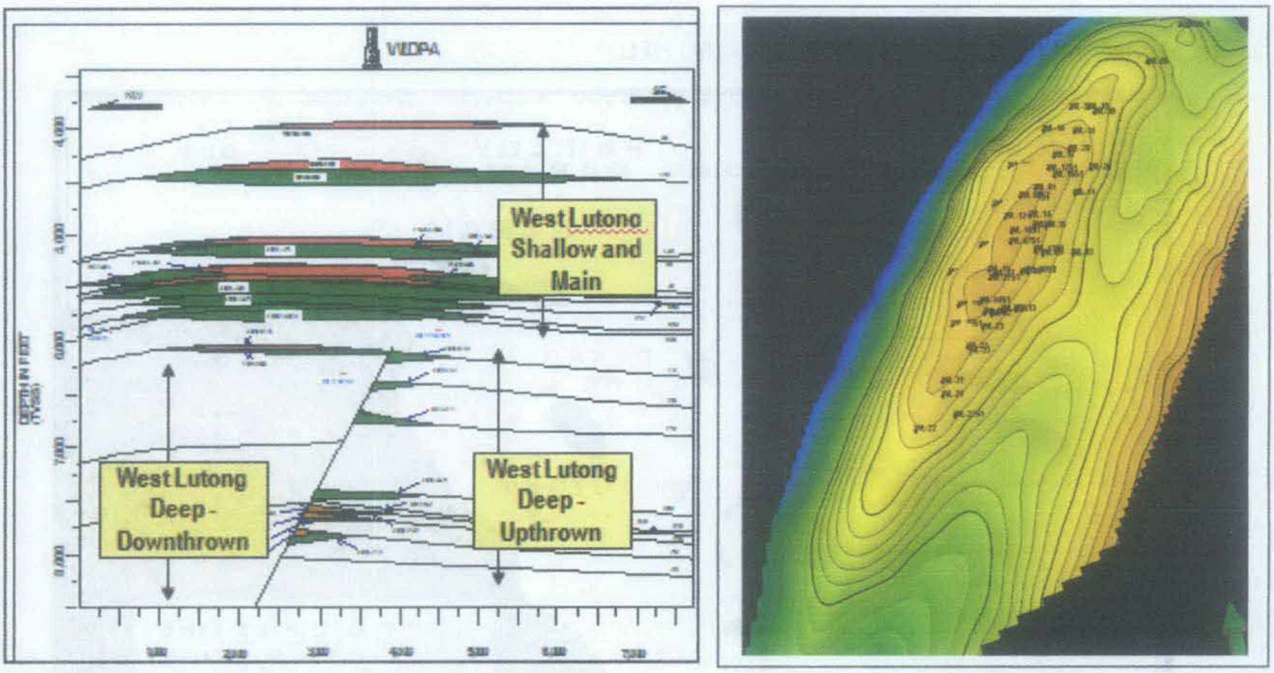


Figure 2: West Lutong field reservoir and depth structure map

Tukau field was discovered by TK-02 in 1966 and started to produce in August 1975. It is located 30km offshore Lutong, Sarawak with the water depth of 160 ft. There are 51 wells penetration. The structure of this field is a north to south elongated anticline, dissected by a system of WNW-ESE trending synthetic/antithetic normal faults at the shallow levels and complicated by growth faults at deeper levels.

The major upper reservoirs are Block 1 which is consist of E9-F5, H4-H9, I series, J1-J9 and N sands and Block 2 where D9-E9, F1-F5, F3-G3 and J2-J9 sands are located. N, M, O and K are the major lower reservoir. The major hydrocarbon accumulations are between 2400 ft ss and 7500 ft ss in the E, F, H, I, J and N sands. The oil columns range is from 10 to 150 ft. All the main reservoir have strong water drive mechanism except in 1-L5/N5 reservoir which has combination of depletion and gas cap drive.

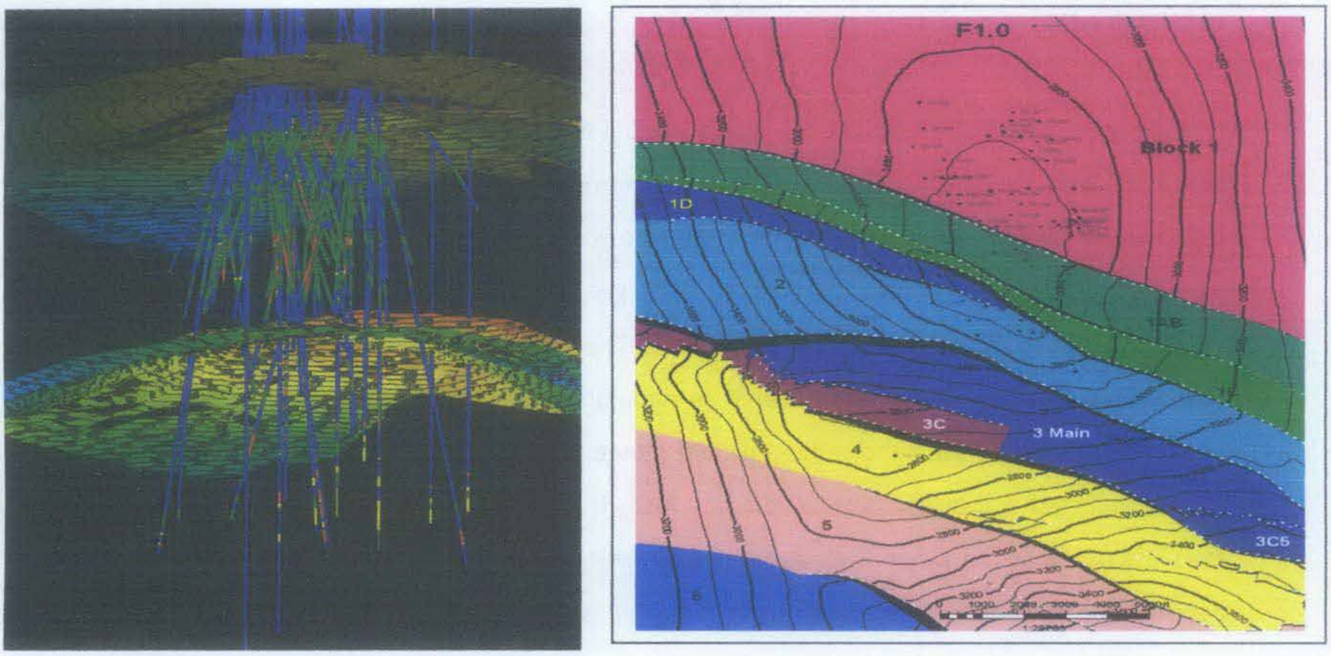


Figure 3: Tukau reservoir model and depth structure map

2.2 ACID RECIPE REVIEW

NITROGEN

Nitrogen is an odorless, colorless, nontoxic gas, which makes up about 78 percent of the earth's atmosphere. Gaseous nitrogen is taken from the atmosphere and processed into a liquid that can be easily transported and pumped. Upon reaching location, this liquid nitrogen can then be heated and pumped as a gas.

PHYSICAL CHARACTERISTICS

Liquid Nitrogen

- Weight -6.8 pounds per gallon
- Specific Gravity -0.809
- Boiling Point - (-320 °F)
- Critical Pressure -492.2 psia
- Critical Temperature - (-232.8 °F)

Gaseous Nitrogen

- Density 0.0724 pounds per SCF (Standard Cubic Foot)
- One gallon liquid converts to 93.11 SCF gas

NITRIFIED ACID

Nitrogen can be effectively and economically used in acid stimulation because it alleviates the need for swabbing. Because of its low solubility in fluids, nitrogen commingled with acid assumes the state of compressed gas bubbles. These bubbles serve as a source of energy inside the fluids injected into the formation. When the well pressure is relieved the gas bubbles expand, greatly aiding the forcing of the fluids to the wellbore and up to the surface. This added force will also help remove insoluble precipitates and formation fines. It should be remembered that the nitrogen adds volume to the fluid. This is significant because the radius of fluid penetration away from the wellbore is relative to the volume injected at bottom hole conditions. Also, the volume of the nitrogen in the fluid must be calculated so that the proper amount of flush may be determined. In order to obtain the maximum benefit from using nitrogen commingled with fluids it is important to consider each job individually.

SAF MK 11

Earlier sandstone acid stimulation stimulate entire zonal interval with Half Strength BJ Sandstone Acid. The water zone is stimulated simultaneously with oil zone and the damages occur on water zone is removed. As the result, there will be some increase in not only oil production but water production as well. SAF MK 11 is a new sandstone acid stimulation technique which is act as water control diverter. This method will divert acid from the water zone to the oil zone. Hence, only the oil zone will be stimulate which results in high oil water ratio.

SAF MK II will precipitate when in contact with calcium ions. This precipitation is soluble in oil but insoluble in water. Therefore, it will divert acid from water zone to oil zone. The oil will dissolve the precipitates whereas water will not. Thus, acid stimulates the oil zone only and results high oil water ratio. This technique is applicable in high watercut formation for better penetration and higher oil production after acid job done.

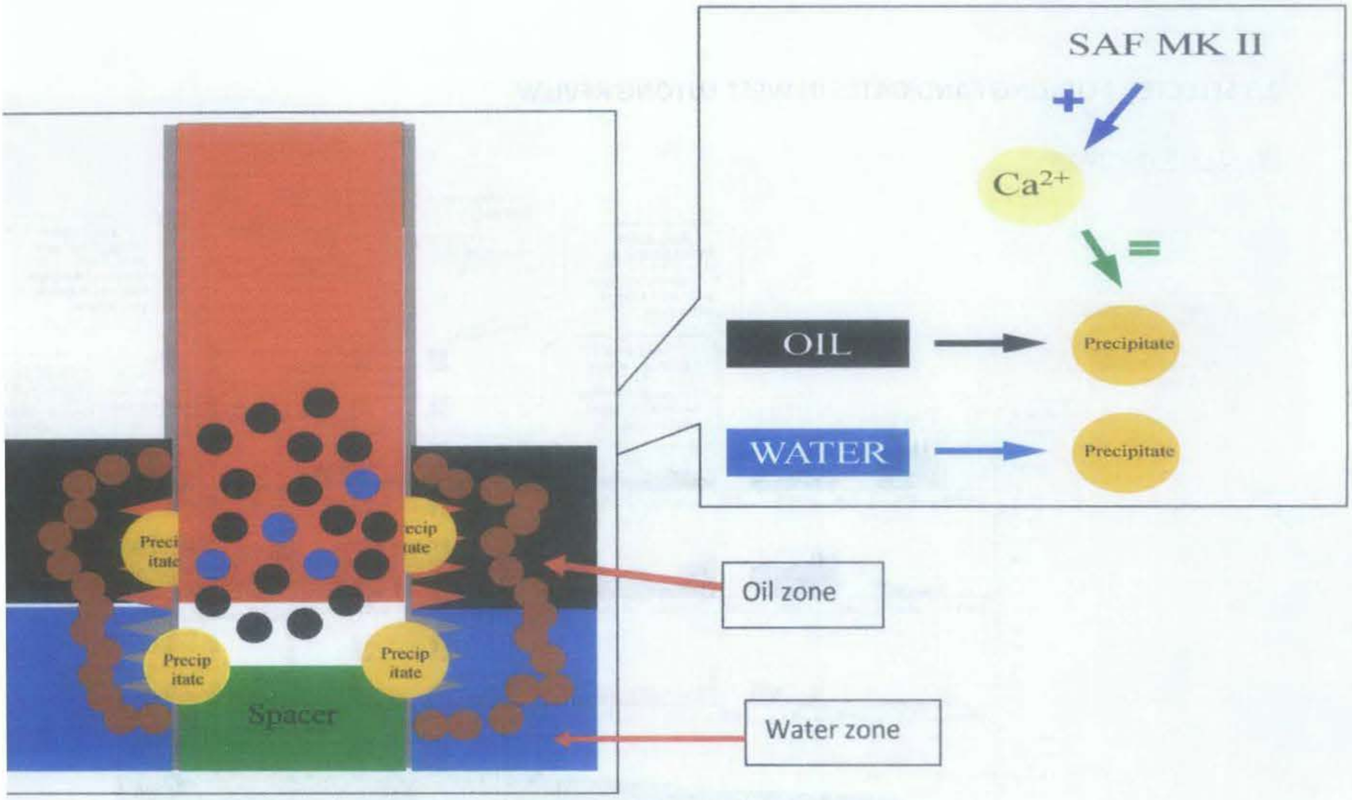


Figure 4: SAF MK 11 will precipitate with calcium ions and form soluble precipitates in oil but insoluble precipitates in water.

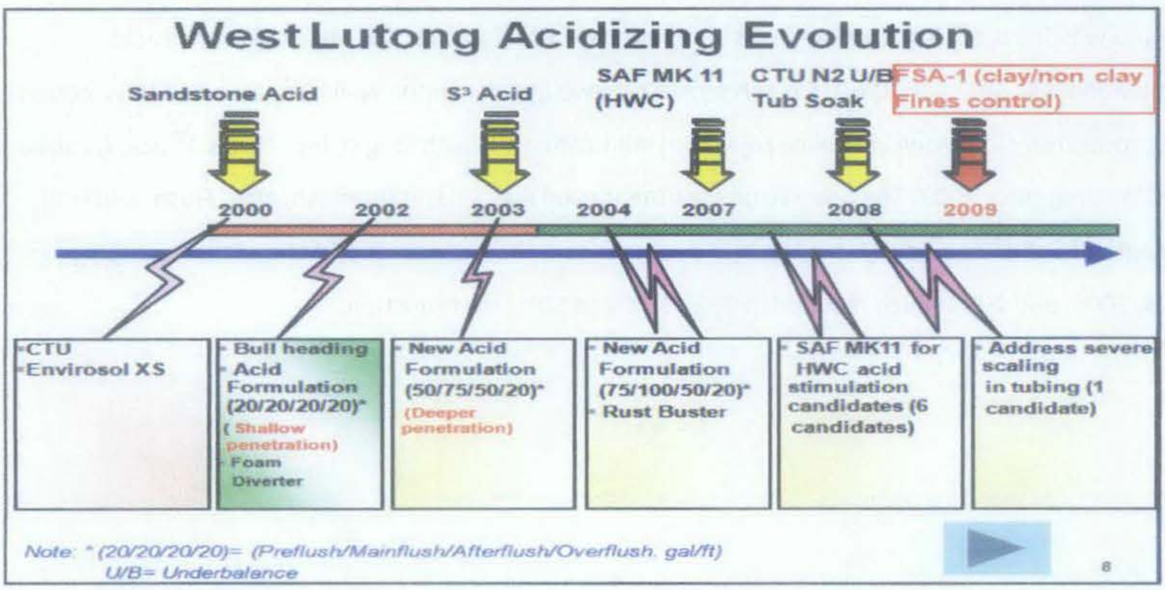


Figure 5: West Lutong Acidizing Evolution

2.3 SELECTED ACIDIZING CANDIDATES IN WEST LUTONG REVIEW

<u>WL-07S: K reservoir</u>

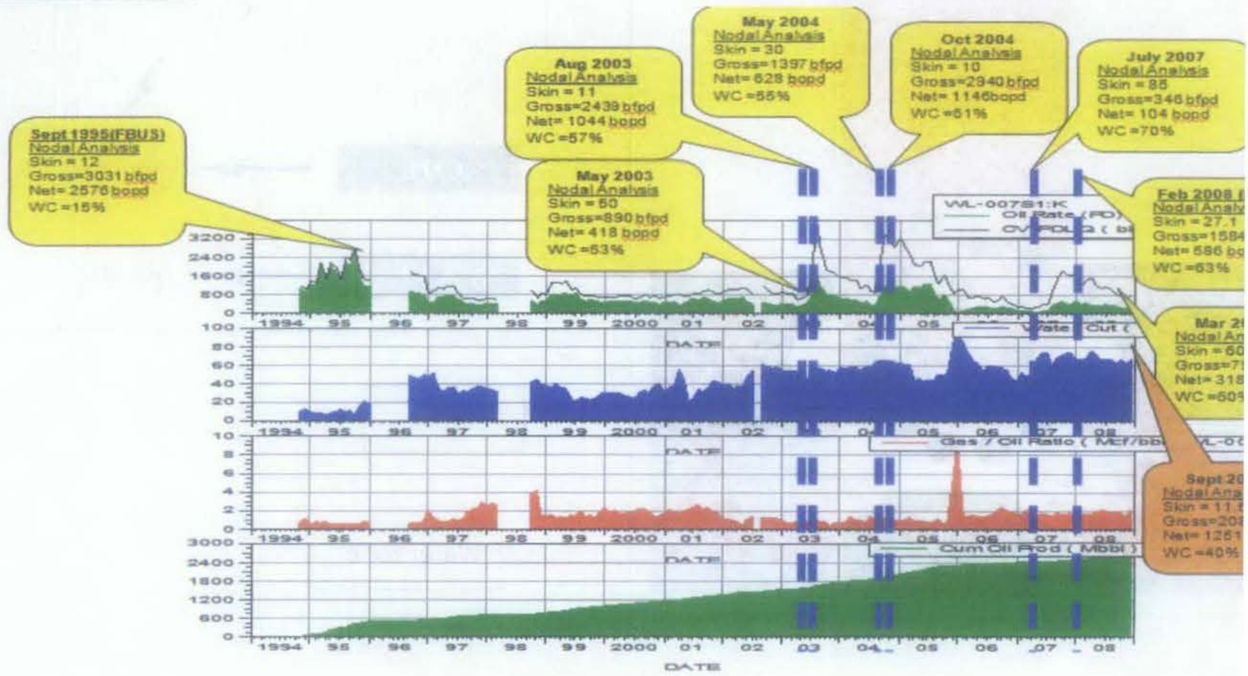


Figure 6: WL-07S in K reservoir production data by OFM software

The job was started 7 July 2009 and was completed on 12 July 2009. The objective of this acid stimulation is to stimulate the 1-K reservoirs to remove the skin in the well bore area and thus increase the production of the well via bullheading acid stimulation through long string. This is 4th acid treatment on this string since 2003. The acid recipe treatment used was S3 acid (Preflush/After Flush) and Half Strength BJ Sandstone Acid (Main Flush). As comparison, the previous 3 acid stimulation campaign in 2003, 2004, and 2007 which resulted in 78%, 66% and 68% skin reduction.

WL-08S: H reservoir

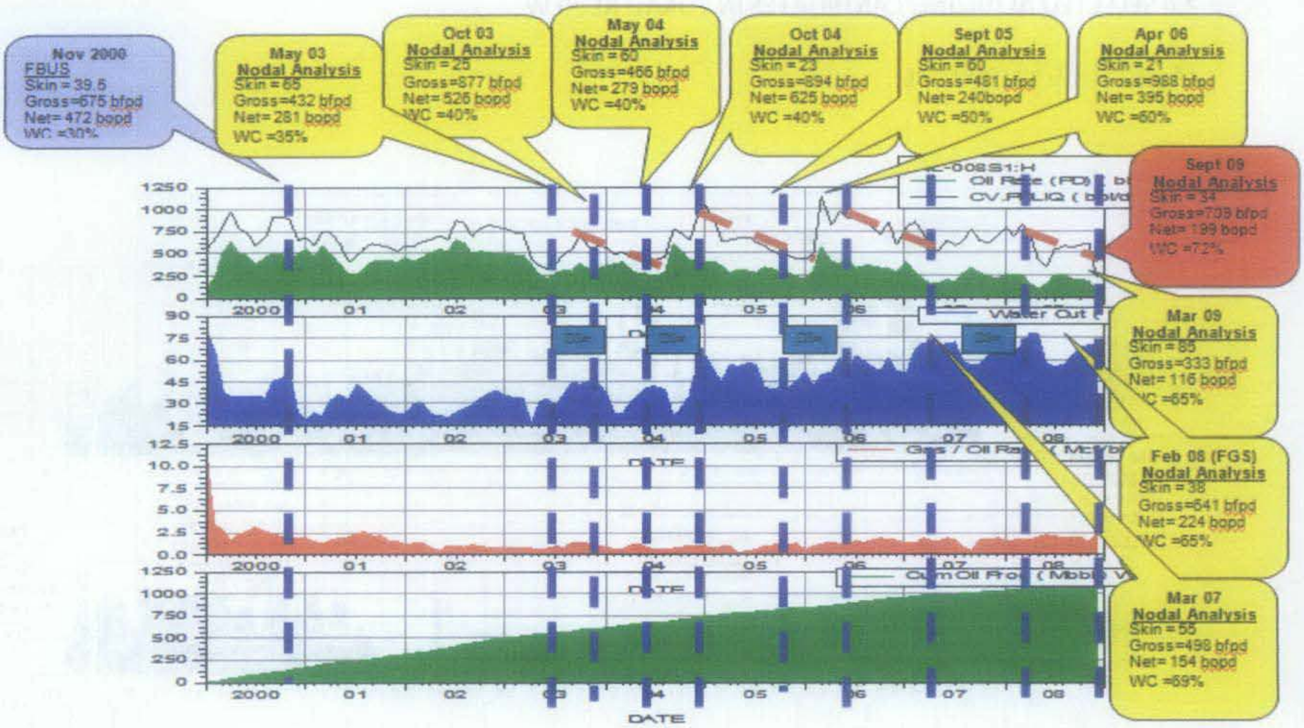


Figure 7: WL-08S1 in H reservoir production data by OFM software

The job was started 17 July 2009 and was completed on 20 July 2009. The objective of this acid stimulation is to stimulate the 1-H reservoirs to remove the skin in the well bore area and thus increase the production of the well via bullheading acid stimulation through long string. This is 5th acid treatment on this string since 2003. The acid recipe treatment used was S3 acid (Preflush/After Flush) and Half Strength BJ Sandstone Acid (Main Flush).

2.4 SELECTED ACIDIZING CANDIDATES IN TUKAU REVIEW

TK-44S: 2-F1/F6 reservoir

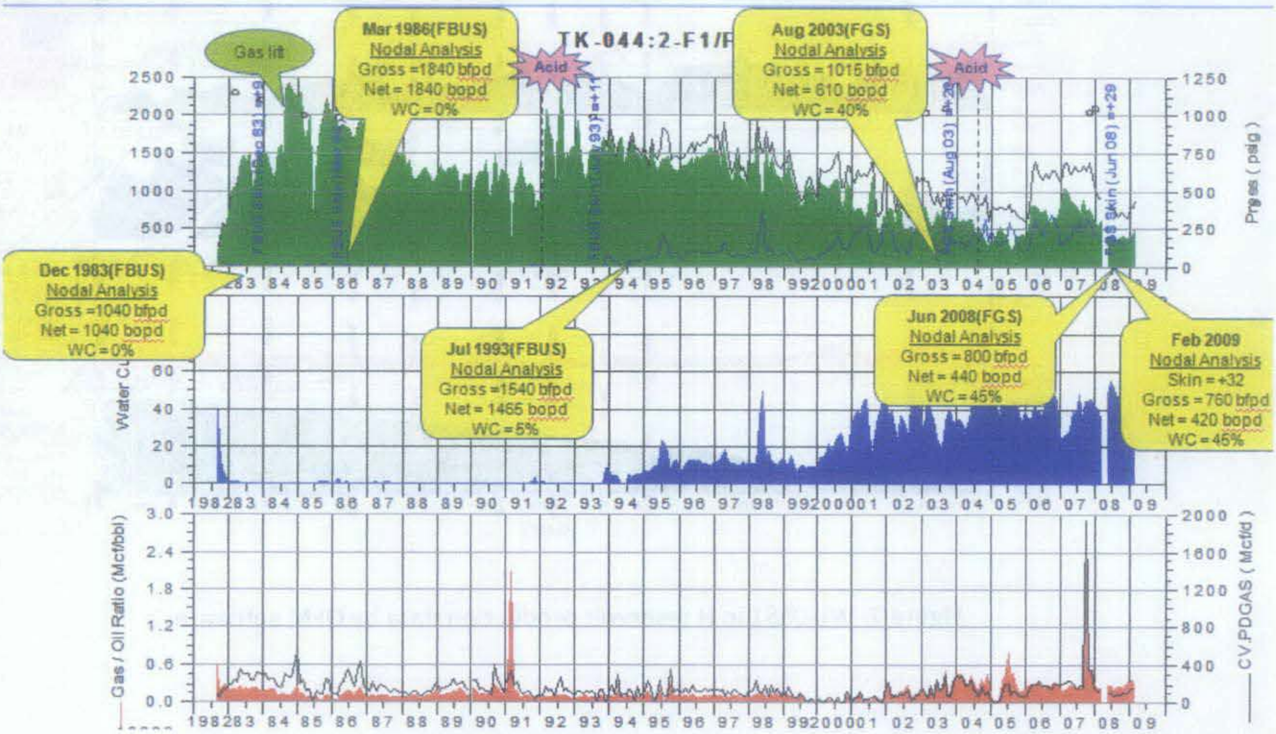


Figure 8: TK-44 in 2-F1/F6 reservoir production data by OFM software

- ☐ This well was completed in August 1982
- ☐ Stimulation history:
  - ■ Jan 1992: 1000 bopd gain (Preflush: 15% HCL, Mainflush: 12% / 3% HCL-HF, Postflush: 3% HCL)
  - ■ June 2004: minimal gain with 10% WC increased (Mainflush: Half strength SSA+Evirosol)

TK-45S: 2-E3/E9 reservoir

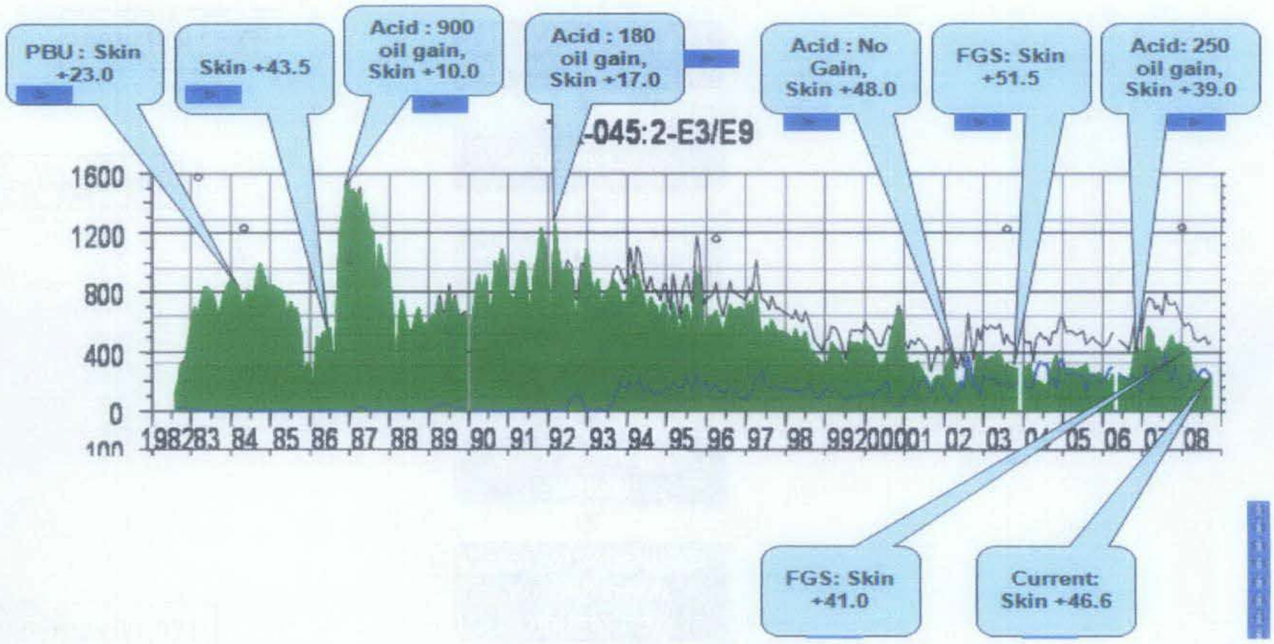


Figure 9: TK-45S in 2-E3/E9 reservoir production data by OFM software

- This well was completed in Aug 1982.
- Stimulation history:
  - July 1986 : 900 bopd gain (Preflush: 15% HCL, Mainflush: 12% / 3% HCL-HF, Postflush: 3% HCL)
  - Jan 1992 : 180 bopd gain (Preflush: 15% HCL, Mainflush: 12% / 3% HCL-HF, Postflush: 3% HCL)
  - Aug 2002 : No gain (Preflush: 10% HCL, Mainflush: BJSSA, Postflush: 10% HCL, Overflush: 3% NH_4Cl)
  - Nov 2006 : 250 bopd gain (Preflush: S^3 acid, Mainflush: HalfStrength BJSSA, Postflush: S^3 acid, Overflush: 3% NH_4Cl)

CHAPTER 3

METHODOLOGY

3.1PROJECT ACTIVITY FLOW

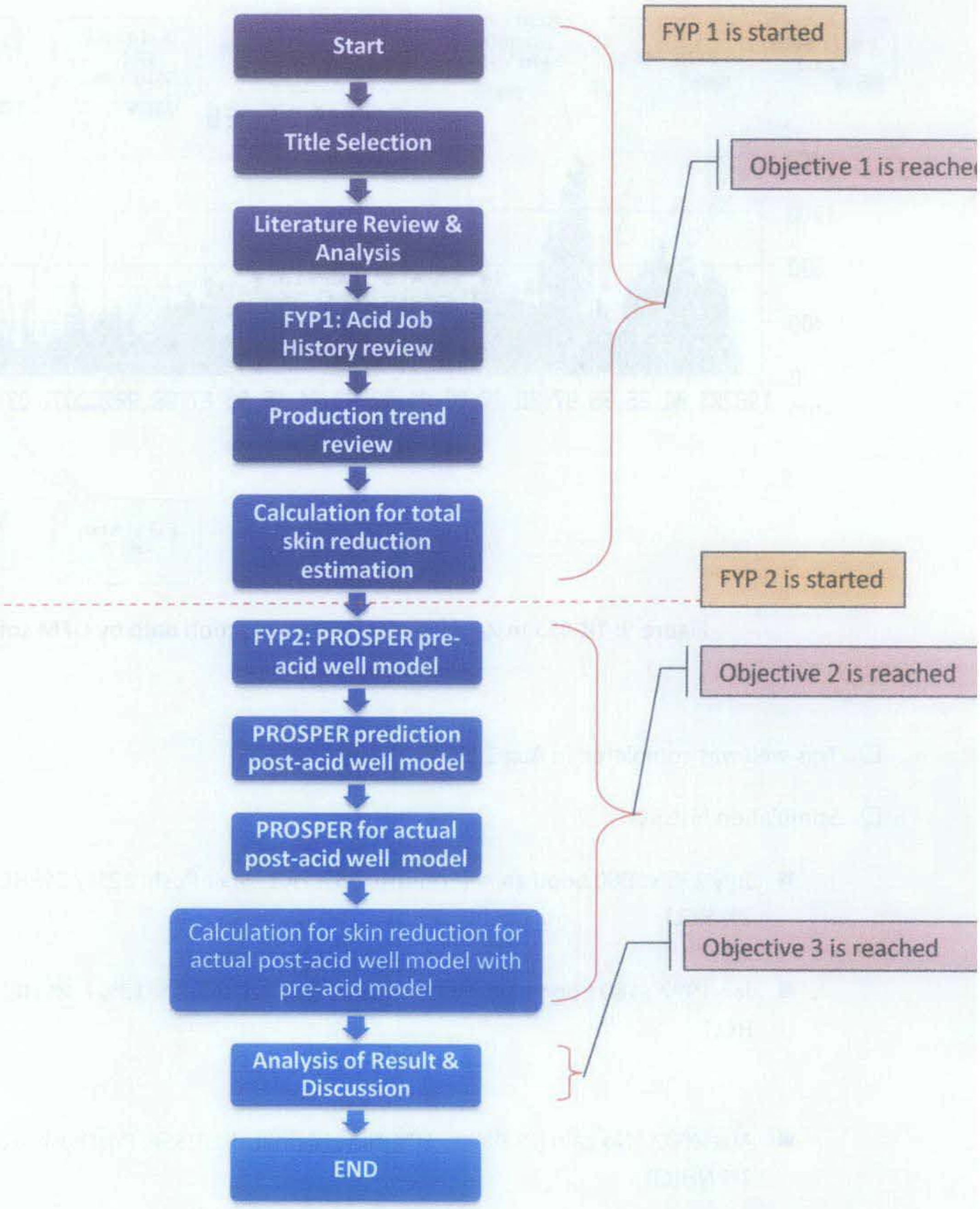
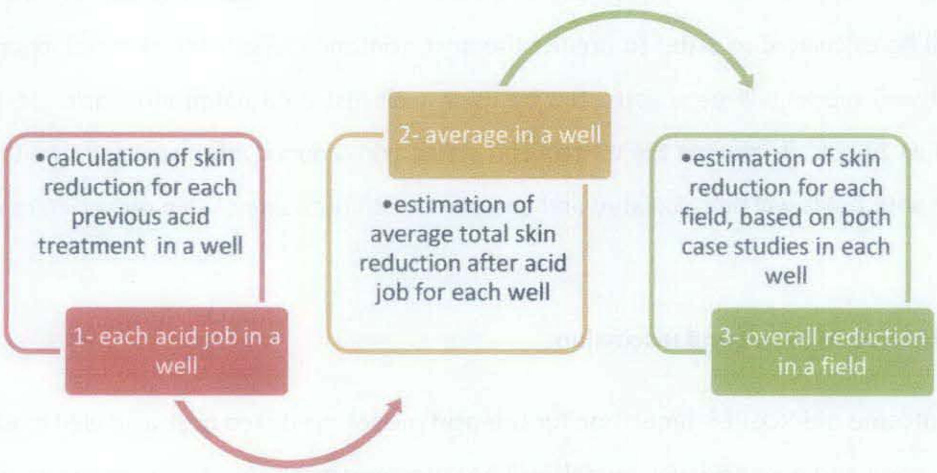


Figure 10: Project Work flow

3.2 RESEARCH METHODOLOGY

3.21. Determination of skin reduction:

Firstly, gathering of information is made on the geological view of the field, type of damage in the formation, production trend of the reservoirs, acid job history and type of acid used for the field. Each one of the well in West Lutong and Tukau field is reviewed in order to understand the production trend throughout years of production. Some of the well has stimulated with acidizing treatment in the past, therefore the average of skin reduction for each acidizing job done for each well is reviewed to understand the total skin reduced after each acid treatment done. The workflow for skin reduction estimation is:



The percentage of estimated skin reduction for each acid job done in a well will be predicted by using this formula.

% skin reduction = [(Skin before acid job) – (Skin after acid job)]/ Skin before acid job * 100%

Based on the calculation of skin reduction for each acidizing treatment done, the average of skin reduction for the well is calculated in order to get the total reduction of skin after all the acidizing treatment.

Average well skin reduction = sum of % skin reductions / total of acid treatment done

Next, the average skin reduction for both wells in West Lutong and Tukau will be calculated in order to estimate the total skin reduction for both fields.

Average field skin reduction = sum of average well skin reductions / total of wells calculated

The average skin reduction will be use as the outcome for this project and the input for well modeling by using PROSPER software in FYP 2.

3.2.2 PROSPER well model and simulations:

Secondly, the outcome of objective 1, which is 50% of skin reduction expected after acidizing job done is used in the simulation stage to model the well and to analyze the oil gained based on the acid job reduction skin theoretically. Pre-acid well model will be constructed based on well test data before acid job is done to determine current well skin. Then, sensitivities with 10% to 70% of skin reduction will be calculated in order to predict the post-acidizing oil gain and skin reduction. Next, the post-acid well model will be constructed by using well test data dated after acid job is done which is on July 2009 to determine the oil gain and actual skin reduced after acidizing. The total skin reduction for both fields will be calculated and compared with outcome of skin reduction calculated in FYP 1.

3.2.3 Analysis of Result and Discussion

Finally, the outcome of PROSPER simulation for pre-acid model, predicted post-acid well model with 50% skin reduction and post-acid well models will be compared and analyzed to determine whether nitrified acidizing method is suitable and effective for West Lutong and Tukau field.

3.3 TOOLS REQUIRED

For the accomplishment of the project, there are needs for a certain software application especially for Modelling and Simulation process to analyze the result of skin reduction based on the acid job done. This project needs to do modelling and simulation using PROSPER software based on the production data by using OFM software. The i-handbook by Schlumberger software is also used in order to construct well model based on the well diagram.

3.3 PROJECT ACTIVITIES:

No	Action Item	Action By	Date	Note
1	Briefing & update on students progress	Coordinator / Students / Supervisors	8 February 2011	Week 3
2	Project work commences	Students		Week 1 -8
3.	Submission of Progress Report	Students	16 March 2011	Week 8
4.	PRE-EDX combined with seminar/ Poster Exhibition/ Submission of Final Report (CD Softcopy & Softbound)	Students / Supervisor / Internal Examiner / Coordinator	4 April 2011	Week 11
5.	EDX	Supervisors / FYP Committee	11 April 2011	Week 12
6.	Final Oral Presentation	Students / Supervisors	20 April 2011	Week 13
7.	Delivery of Final Report to External Examiner / Marking by External Examiner	FYP Committee / Coordinator	20-27 April 2011	Week 14
8.	Submission of hardbound copies	Students	04 May 2011	Week 16

Table 1: Key milestone for the whole activities conducted throughout FYP 2.

No	Activities	Week/Month																																			
		Year 2010 (FYP 1)																				Year 2011 (FYP 2)															
		August				September				October				November				December				January				February				March				April			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Introduction to FYP																																				
2	Selection of FYP Topic																																				
3	Preliminary Research Work																																				
4	Submit Prelim Report																																				
5	Literature Review – Research Work																																				
6	Progress Report																																				
7	Interim Report / Final Draft																																				
8	Presentation																																				
9	Preparation for PROSPER simulation																																				
10	Data gathering for PROSPER software																																				
11	Familiarize with PROSPER software																																				
12	Well modeling with PROSPER																																				
14	Post-acid model and simulation analysis																																				
15	Result Analysis																																				
16	Pre EDX																																				
17	EDX																																				
18	Final oral presentation																																				
19	Delivery of final report																																				

Note: **Green Box** = completed project, **yellow box** = work in progress

Table 2: Gantt Chart for the whole FYP.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 PRE-ACID MODELS AND PREDICTION: WEST LUTONG

WL-07L Pre-acid well model : K reservoir

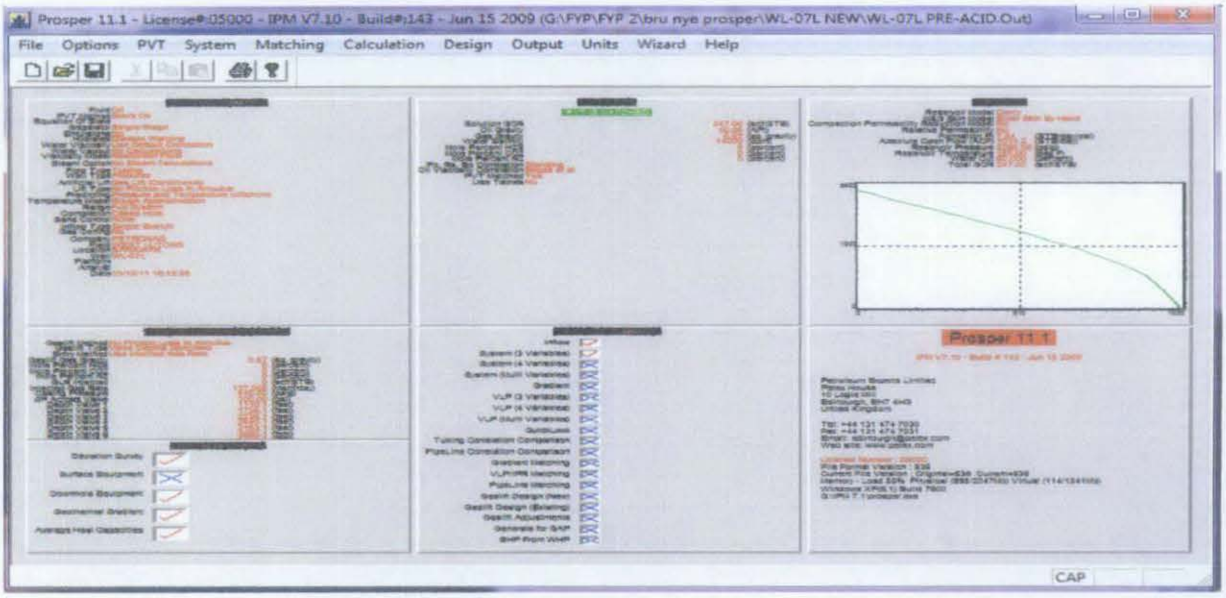


Figure11: WL-07L PROSPER well model

In order to construct WL-07L well model, these data are needed as the input for this analysis:

- Well diagram for equipment input
- Well deviation data
- Geothermal gradient
- PVT data of WL-07L

Input	Value	Unit
GOR	247	scf/STB
Oil gravity	40	API
Gas specific gravity	0.67	
Pb	1950	psi
Bo	1.133	RB/STB
μ	1.5	cp
Water salinity	14000	ppm

Table 3: PVT data for WL-07L

- K reservoir rock and fluid properties

Input	Value	Unit
Pr	2250	psi
Tr	157	F
k	180	mD
thickness	47	ft
drainage area	3.14E6	ft^2
dietz shape factor	31.62	
wellbore radius	4.4	ft

Table 4: Reservoir rock and properties of WL-07L

- Well test data

ACT. DATE	BEAN	GROSS (stb/d)	W/C (%)	NET (stb/d)	GAS OUTPUT (Mscf/d)	FORM GAS (Mscf/d)	GASLIFT (Mscf/d)	FGOR (scf /stb)	FGLR (scf/st b)	Wp (stb/ d)	FTHP (psig)	CHP (psig)	FLP (psig)
4-May-09	64	**897**	**58**	**377**	669	565.00	104	1501	630	520	120	540	70

Table5: WL-07L well test

After all data required was entered to construct WL-07L well model, the base skin input was set to 10 as the initial input of skin. Sensitivity to skin will be construct in order to search the pre-acid job skin based on the chosen West Lutong 2009 well test data for pre-acid skin. Well test data dated of 4th July 2009 is chosen as the reference for pre-acid job well model. The input for sensitivity to skin was generated from 10 to 90 to find out the best skin that represents the well test data.

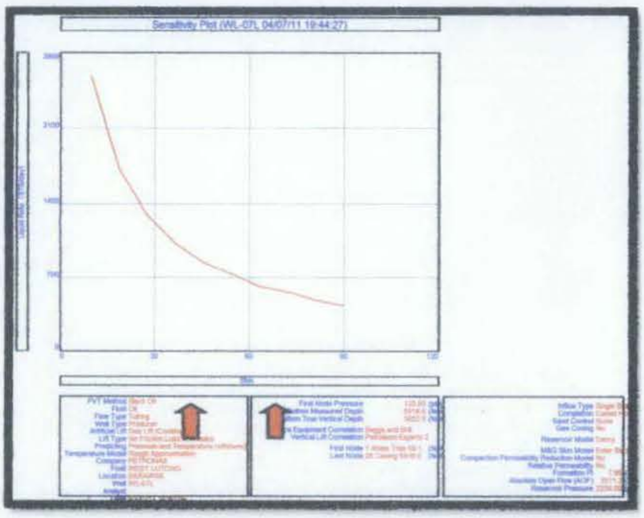


Figure 12: Sensitivity Plot WL-07L, Liquid rate versus Skin

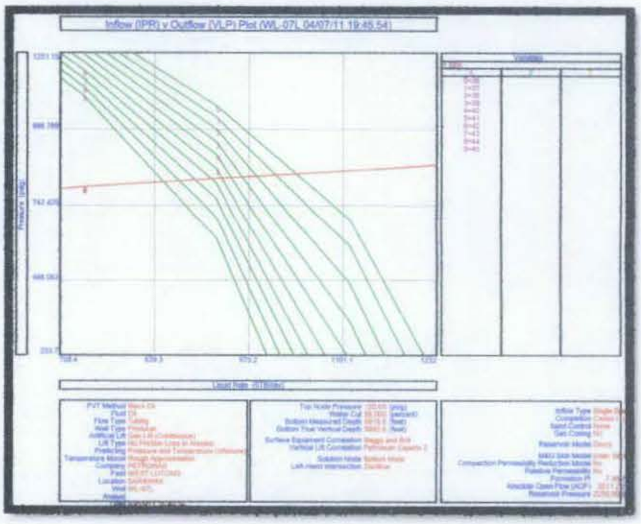


Figure13: Inflow and Outflow Plot with sensitivity of skin from 36 to 45

Figure12 shows that the higher skin of the well, the lower liquid rate will be produced. According to the graph of Liquid rate versus Skin (Figure13), it shows that the skin of WL-07L must be in between 36 to 45 in order to match with well test data which is Q_{gross}= 897 bopd and Q_{net} =377 bopd at WC=58%. The value of skin sensitivity was setting again from 36 to 45 and the graph is plotted. Based on the graph, we can conclude that the matching skin for WL-07L is 43.2. Thus, the value of skin in IPR column is changed to 43.2.

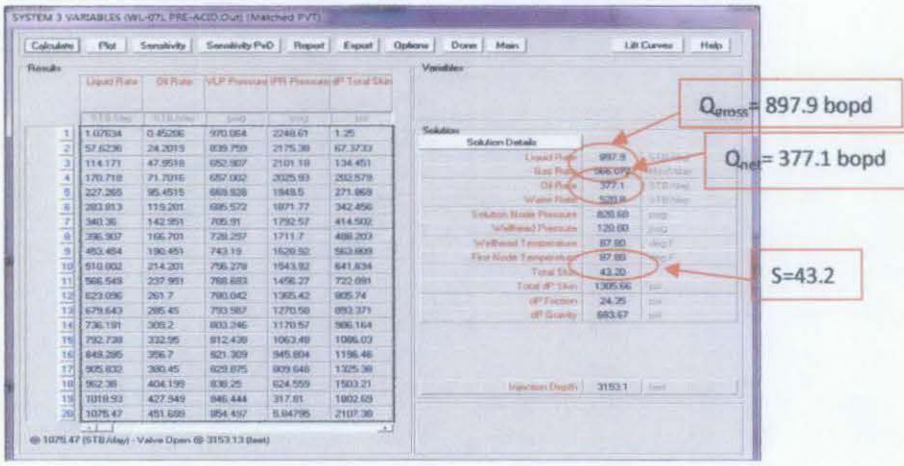


Figure 14: System 3 variable output of WL-07L

Based on figure 14, the pre-acid skin for WL-07L is matching at:

- S=43.2
- Q_{gross}= 897.9 bopd
- Q_{net}= 377.1 bopd

Error calculation: [(377.1-377)/ 377] *100% = 0.03%. The error is less then 5%, therefore, the output is approved.

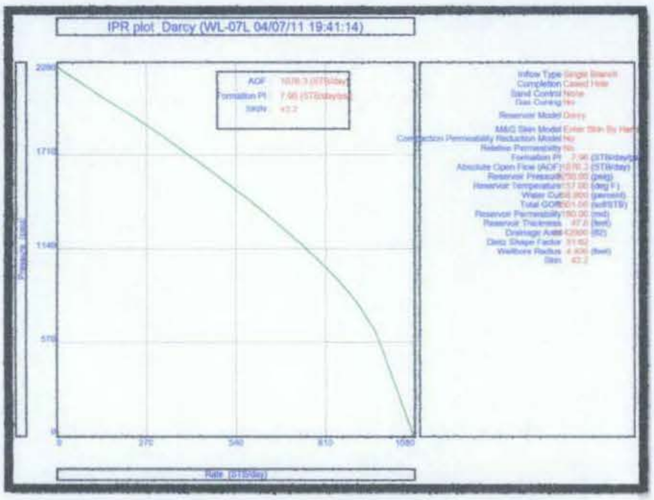


Figure15: IPR plot for pre-acid WL-07L well model

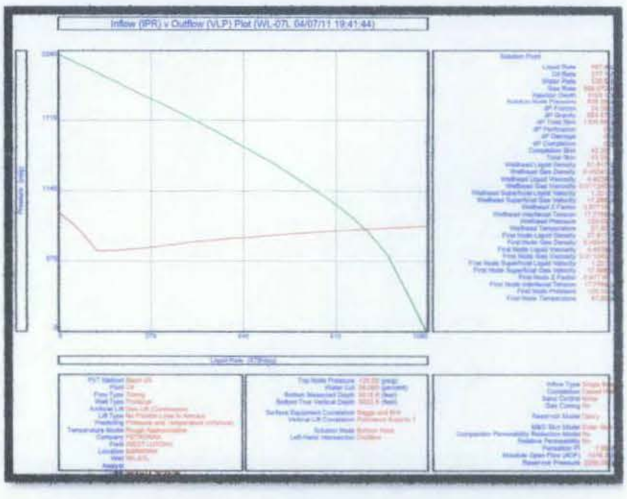


Figure16: Inflow vs. Outflow plot of pre-acid WL-07L well model

Analysis of expected post-acid skin for WL-07L:

Referring to the output of Final Year Project 1, the expected skin reduction for nitrified acidizing based on the history acid job done for both field is 50%. In order to determine the oil gain for each percentage of skin reduction, the skin reduced for each 10%, 20%, 30%, 40%, 50%, 60% and 70% are calculated. After that, the sensitivity to skin reduced is constructed by using PROSPER software to determine the oil gain for each skin. The oil gains for each case are calculated by using:

$$Q_{gain} = Q_{post\text{-}acid} - Q_{pre\text{-}acid}$$

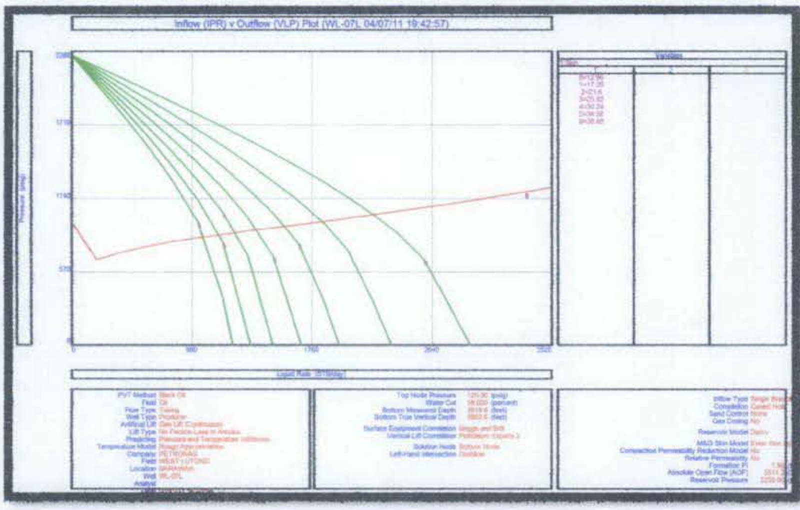


Figure17: Inflow versus Outflow plot with each WL-07L skin reduction case

%Skin reduction	Skin reduced	Qoil (bopd)	Q gain (bopd)
10	38.88	404.8	27.7
20	34.56	453.1	76
30	30.24	502.7	125.6
40	25.92	569	191.9
50	21.6	655.1	278
60	17.28	771.2	394.1
70	12.96	931.3	554.2

Table6: Oil gain for WL-07L expected %skin reduction

50% skin reduction is chosen as the base case for this acid job. The determination of Q gain when skin reduced to 50% is:

$$\begin{aligned} Q_{gain} &= Q_{post\text{-}acid} - Q_{pre\text{-}acid} \\ &= Q_{of\ skin+23.9} - Q_{of\ skin\ +47.78} \\ &= 655.1\ \text{bopd} - 377.1\ \text{bopd} \\ &= 278\ \text{bopd} \end{aligned}$$

Therefore, the expected Q_{gain} after acid job is 278 bopd if the WC is maintained. WC tends to increase or decrease after acid job done. Thus, sensitivity for WC needs to be done in order to compare the Q_{gain} for each WC case. Sensitivities to WC of 50%, 55%, 60%, 65% and 70% is run for skin of 21.6.

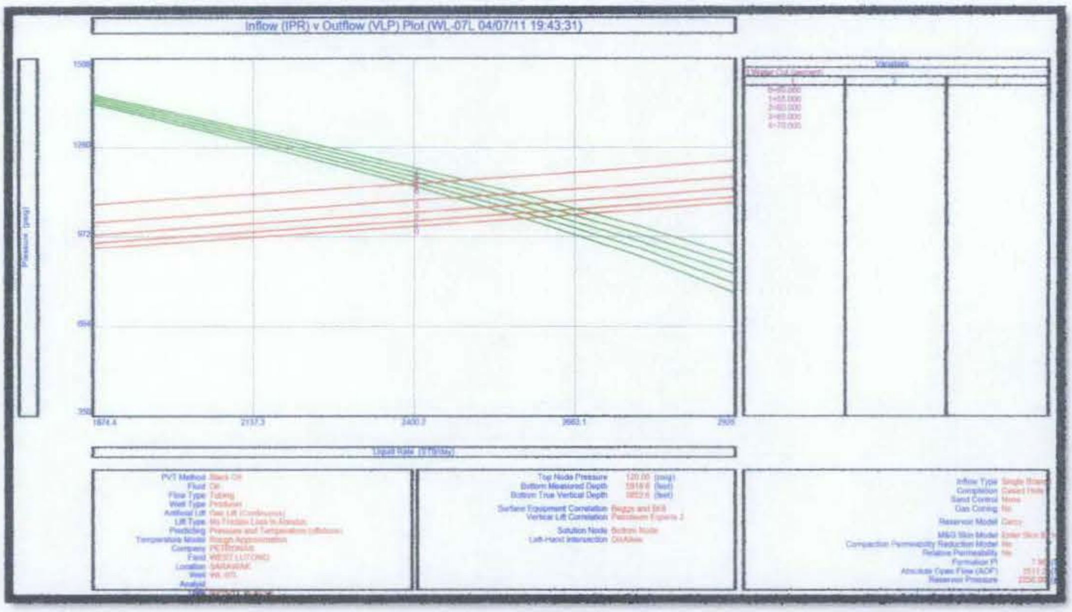


Figure18: Inflow versus Outflow plot with WC sensitivities for WL-07L

%Skin reduction	%WC	Qoil (bopd)	Q gain (bopd)
50	50	779.4	402.3
50	55	701.8	324.7
50	60	625.2	248.1
50	65	543	165.9
50	70	456	78.9

Table7: Oil gain for each WC in WL-07L

60% of WC is chosen as the base case for WL-07L by assuming the WC is maintained after acidizing.

WL-08S Pre-acid well model: H reservoir

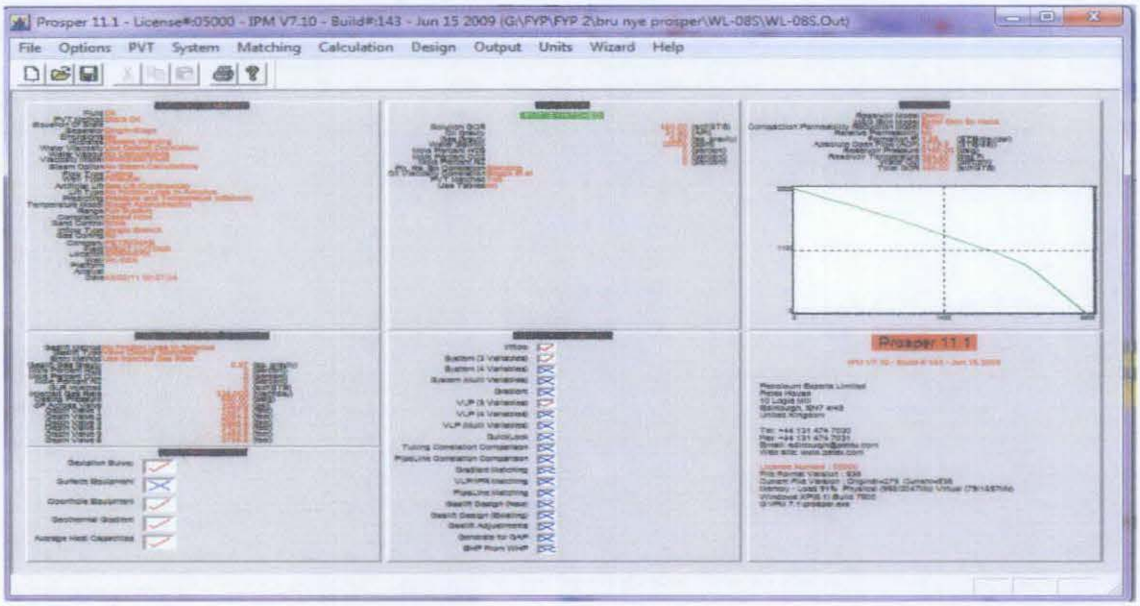


Figure19: WL-08S PROSPER well model

In order to construct WL-08S well model, these data are needed as the input for this analysis:

- Well diagram for equipment input
- Well deviation data
- Geothermal gradient
- PVT data of WL-08S

Input	Value	Unit
GOR	485	scf/STB
Oil gravity	31.5	API
Gas specific gravity	0.67	
Pb	2252	psi
Bo	1.26	RB/STB
μ	1	cp
Water salinity	20000	ppm

Table8: PVT data for WL-08S

- H reservoir rock and fluid properties

Input	Value	Unit
Pr	2160	psi
Tr	164	F
k	90	mD
thickness	56	ft

drainage area	3.14E6	ft^2
dietz shape factor	31.62	
wellbore radius	3.1	ft

Table9: Reservoir rock and properties of WL-08S

- Well test data

ACT. DATE	BEAN	GROSS (stb/d)	W/C (%)	NET (stb/d)	GAS OUTPUT (Mscf/d)	FORM GAS (Mscf/d)	GASLIFT (Mscf/d)	FGOR (scf/stb)	FGLR (scf/stb)	Wp (stb/d)	FTHP (psig)	CHP (psig)	FLP (psig
8-May-09	64	**416**	**75**	**104**	490	155.00	335	1490	373	312	95	580	80

Table10: WL-08S well test

After all data required was entered to construct WL-08S well model, the base skin input was set to 10 as the initial input of skin. Sensitivity to skin will be construct in order to search the pre-acid job skin based on the chosen West Lutong 2009 well test data for pre-acid skin. Well test data dated of 8th May 2009 is chosen as the reference for pre-acid job well model. The input for sensitivity to skin was generated from 10 to 90 to find out the best skin that represents the well test data.

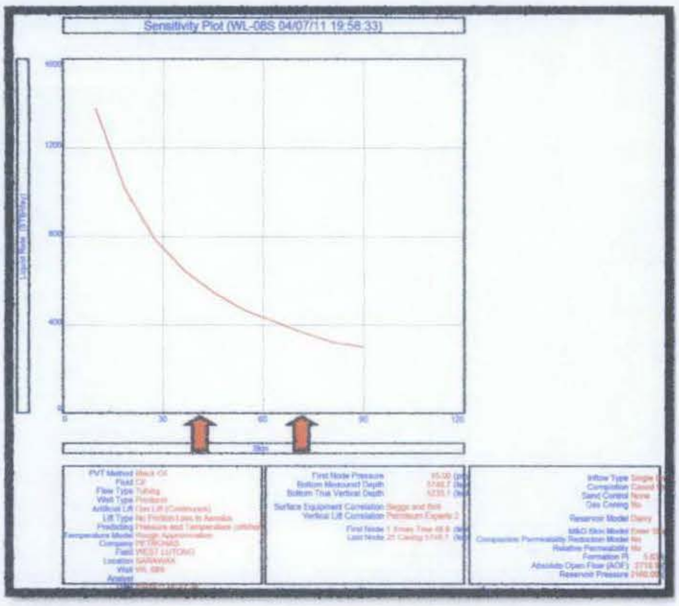


Figure20: Sensitivity Plot WL-08S, Liquid rate versus Skin

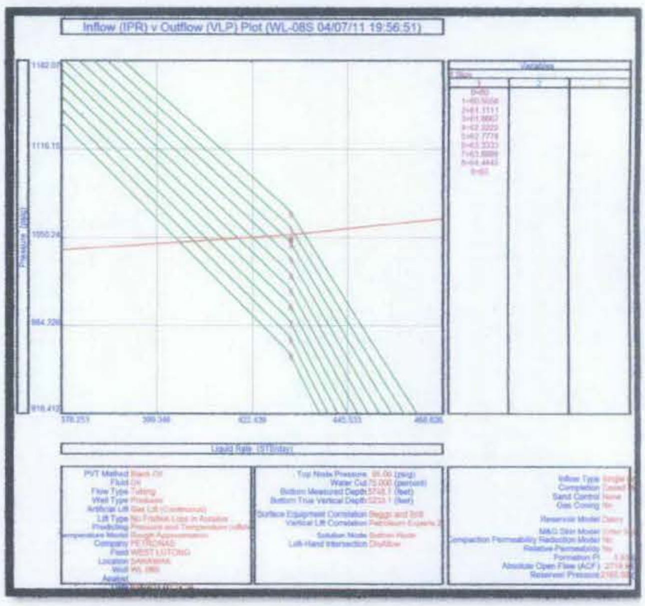


Figure21: Inflow and Outflow Plot with sensitivity of skin from 60 to 65

Figure20 shows that at the higher skin of the well, the lower liquid rate will be produced. According to the graph of Liquid rate versus Skin (Figure20), it shows that the skin of WL-08Smust be between 40 to 70 in order to match with well test data which is Q_{gross}= 416 bopd and Q_{net} = 104 bopd at WC=75%. The value of skin sensitivity was setting again from 60 to 65 and the graph is plotted. Based on the graph, we can conclude that the matching skin for WL-08S is 63.33. Thus, the value of skin in IPR column is changed to 63.33.

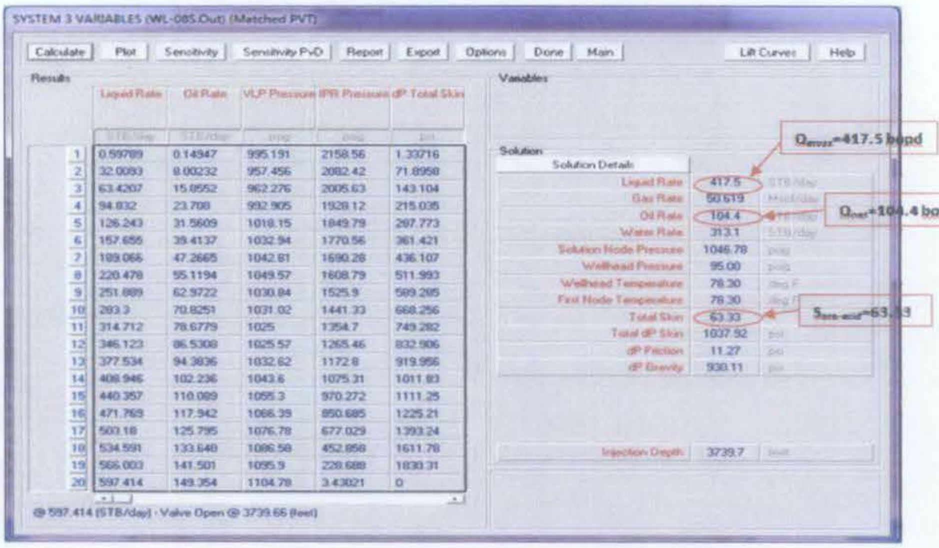


Figure 22: System 3 variable output of WL-08S

Based on figure 22, the pre-acid skin for WL-08S is matching at:

- S=63.33,
- Q_{gross}= 417.5 bopd
- Q_{net}= 104.4 bopd

Error calculation: [(417.5-416) /416]*100% = 0.36%.. The error is less then 5%, therefore, it is approved.

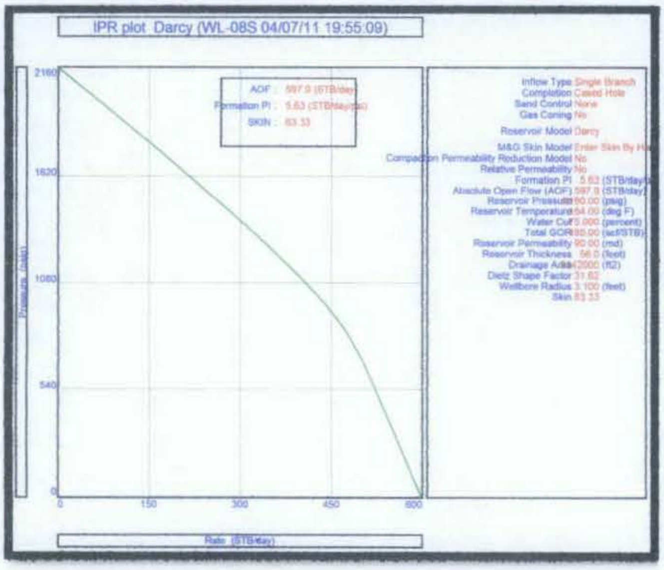


Figure23: IPR plot for pre-acid WL-08S well model

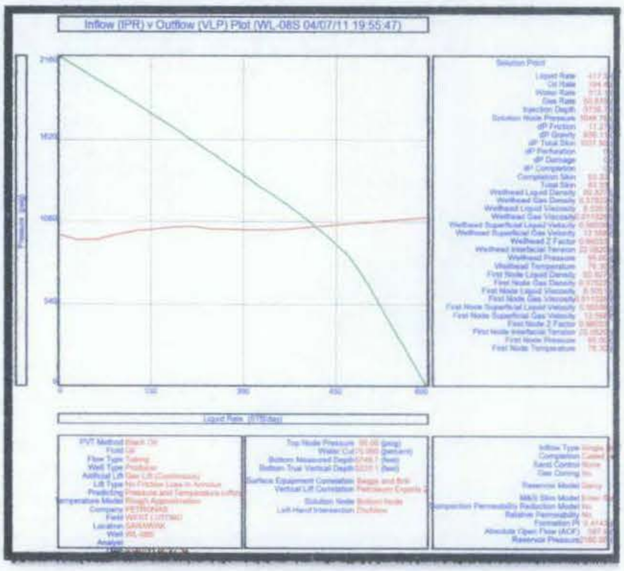


Figure24: Inflow vs. Outflow plot of pre-acid WL-08S we

Analysis of expected post-acid skin for WL-08S:

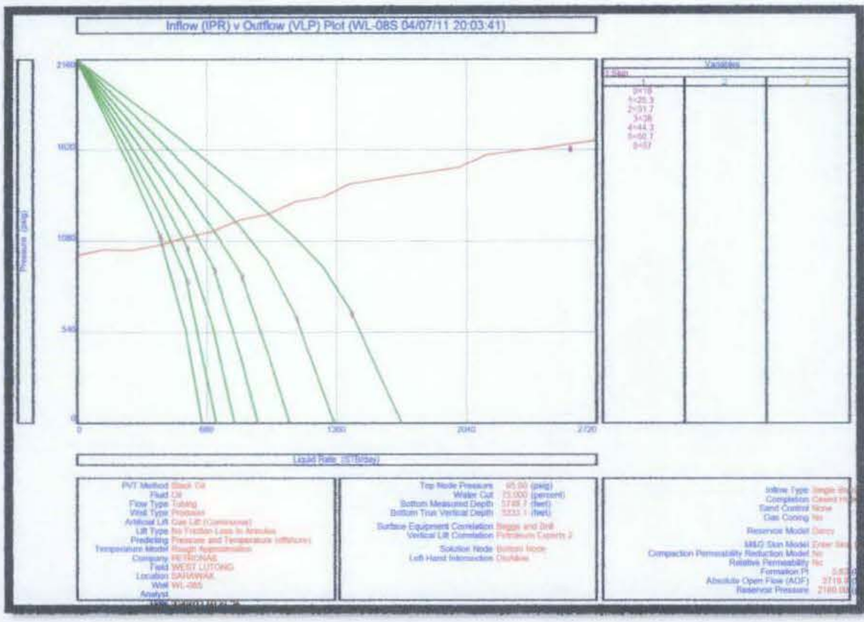


Figure25: Inflow versus Outflow plot with each WL-08S skin reduction case

%Skin reduction	Skin reduced	Qoil (bopd)	Q ga (bop
10	57	112.3	
20	50.7	124.2	1
30	44.3	139.5	3.
40	38	156.9	5.
50	31.7	180.8	7
60	25.3	208.6	10
70	19	252.6	14

Table11: Oil gain for W-08S expected %skin reduction

50% skin reduction is chosen as the base case for this acid job. The determination of Q gain when skin reduced to 50% is:

$Q_{gain} = Q_{post\text{-}acid} - Q_{pre\text{-}acid}$

$= Q_{of\ skin+31.7} - Q_{of\ skin\ +63.33}$

$=180.8$ bopd $-$ 104.4 bopd

$=76.4$ bopd

Therefore, the expected Q_{gain} after acid job is 76.4 bopd if the WC is maintained. WC tends to increase or decrease after acid job done. Thus, sensitivity for WC needs to be done in order to compare the Q_{gain} for each WC case. Sensitivities to WC of 65%, 70%, 75%, 80% and 85% is run for skin of 31.7.

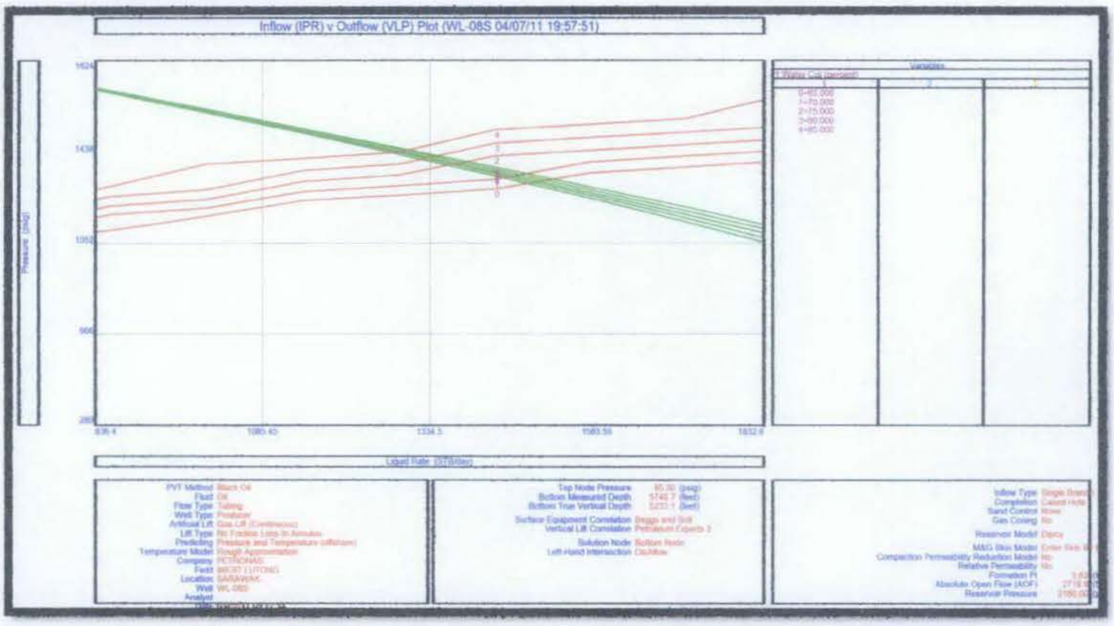


Figure26: Inflow versus Outflow plot with WC sensitivities for WL-08S

%Skin reduction	%WC	Qoil (bopd)	Q gain (bopd)
50	65	258.1	153.7
50	70	219.5	115.1
50	75	181	76.6
50	80	142.7	38.3
50	85	104.9	0.5

Table12: Oil gain for each WC in WL-08S

75% of watercut is chosen as the base case for WL-08S acidizing as there is high possibility SAFMAK does not reduce the WC but maintain it after acidizing.

4.2 PRE-ACID MODEL AND PREDICTION: TUKAU

TK-44S Pre-acid well model: 2-F1/F6 reservoir

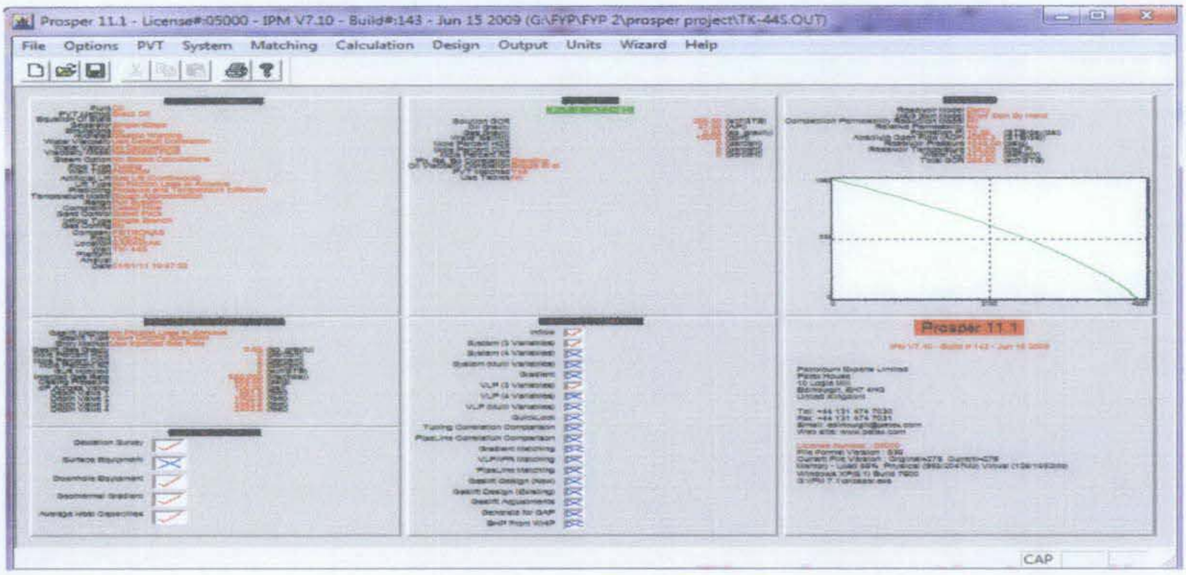


Figure27: TK-44S PROSPER well model

In order to construct TK-44S well model, these data are needed as the input for this analysis:

- Well diagram for equipment input
- Well deviation data
- Geothermal gradient
- Gravel pack properties

Input	Value	Unit
GP permeability	25000	mD
Perf. diameter	0.43	
GP length	3	inches
Shot density	6	
Perf. efficiency	0.7	
Overall heat transfer coefficient	8	cp
Perf. interval	35	ft

Table13: Gravel pack properties of TK-44S

- PVT data of TK-44S

DEVELOPMENT UNIT	DATUM FT.SS	FORMATION TEMPERATUR DEG. F	INITIAL PRESSURE PSIG	OIL GRAVITY DEG. API	BOI RB/STB	RSI SCF/STB	BGI RB/MSCF	OIL VISCOSITY CP
2 - F1/F5	2790	145	1214	27.5	1.104	183	2.226	1.6

Table14: PVT data for TK-44S

- F1/F6 reservoir rock and fluid properties

Input	Value	Unit
Pr	1045	psi
Tr	138	F
k	350	mD
thickness	58.9	ft
drainage area	1.131E6	ft^2
dietz shape factor	31.6	
wellbore radius	0.345	ft

Table15: Reservoir rock and properties of TK-44S

- Well test data

DATE	ZONE	STT	BEAN	GROSS	WC	NET	GASOUT	FORMATION GAS	GASLIFT	TGLR	GOR	FTHP	CHP	FL
9-Aug-08	2-F2/F5	GLI	64/128	787	47	417	1086	105	981	1380	251	140	440	12
4-Nov-08	2-F2/F5	GLI	64/64	783	40	470	643	118	525	821	251	130	440	12
10-Dec-08	2-F2/F5	GLI	64/128	660	45	363	559	112	447	847	309	170	570	14
6-Jan-09	2-F2/F5	GLI	64/64	861	45	474	952	166	786	1105	251	185	570	12
AVERAGE				773	44	431	[redacted]	[redacted]	685	[redacted]	266	156	[redacted]	[redacted]

Table16: TK-44S well test

After all data required was entered to construct TK-44S well model, the base skin input was set to 10 as the initial input of skin. Sensitivity to skin will be constructed in order to search the pre-acid job skin based on the chosen Tukau 2009 well test data for pre-acid skin. The average well test data is chosen as the reference for pre-acid job well model. The input for sensitivity to skin was generated from 10 to 90 to find out the best skin that represents the well test data.

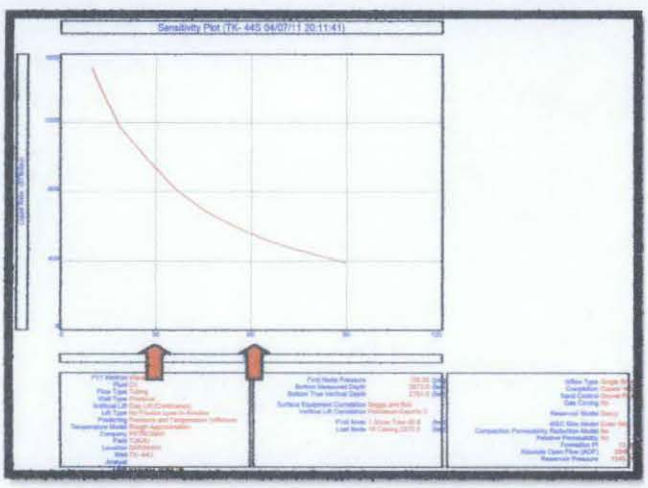


Figure28: Sensitivity Plot TK-44S, Liquid rate versus Skin

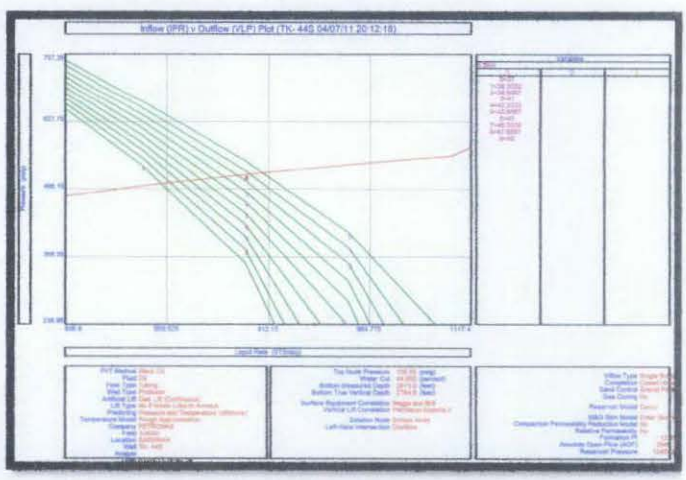


Figure29: Inflow and Outflow Plot with sensitivity of skin from 37 to 49

It shows that at the higher skin of the well, the lower liquid rate will be produced. According to the graph of Liquid rate versus Skin (Figure28), it shows that the skin of TK-44Smust be between 30 to 60 in order to match with well test data which is Q_{gross}= 773 bopd and Q_{net} = 431 bopd at WC=44%. . Based on the graph of liquid rate versus skin, we can conclude that the pre-acid skin of TK-44S is 39 which is matching with gross=771 bopd and net=431.7 bopd. Therefore,the input skin in IPR column will be changed to 39.

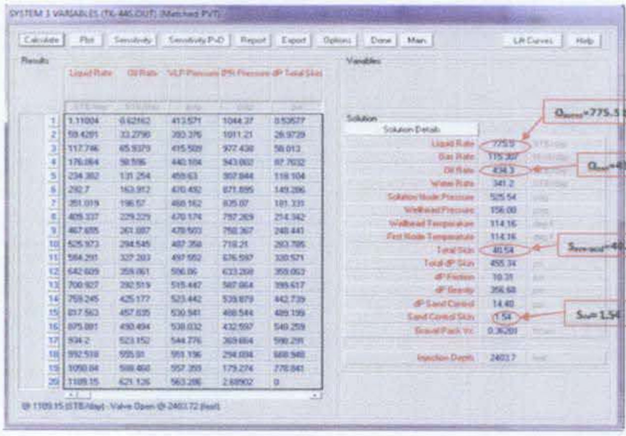


Figure30: System 3 variable output of TK-44S

Based on figure30, the pre-acid skin for TK-44S is matching at:

- Pre-acid Skin = Total skin – Sand Control skin
  = 40.54 – 1.54
  =39
- Q_{gross}= 775.5 bopd
- Q_{net}= 434.3 bopd

Error calculation: (434.3 – 431)/ 431 = 0.77%. The error is less then 5%, therefore, it is approved.

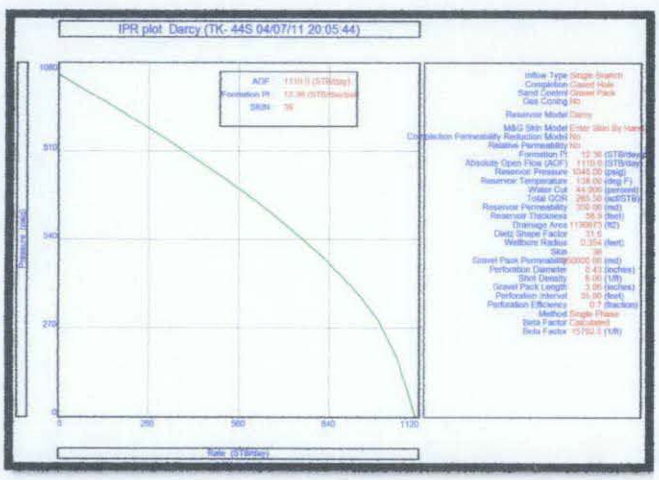


Figure31: IPR plot for pre-acid TK-44S well model

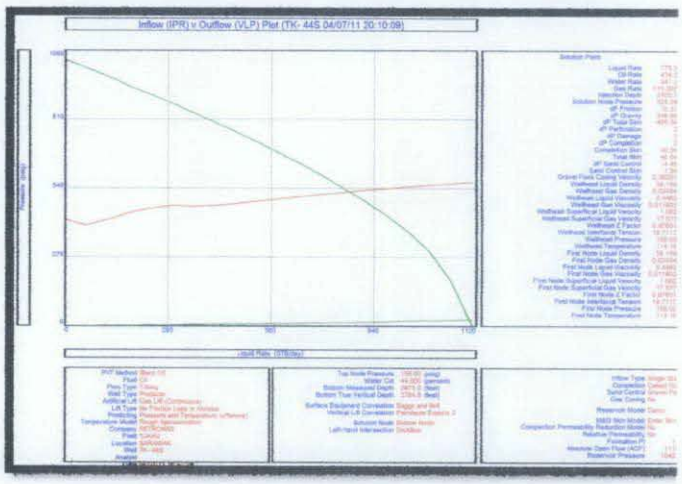


Figure32: Inflow vs. Outflow plot of pre-acid TK-44S well model

Analysis of expected post-acid skin for TK-44S:

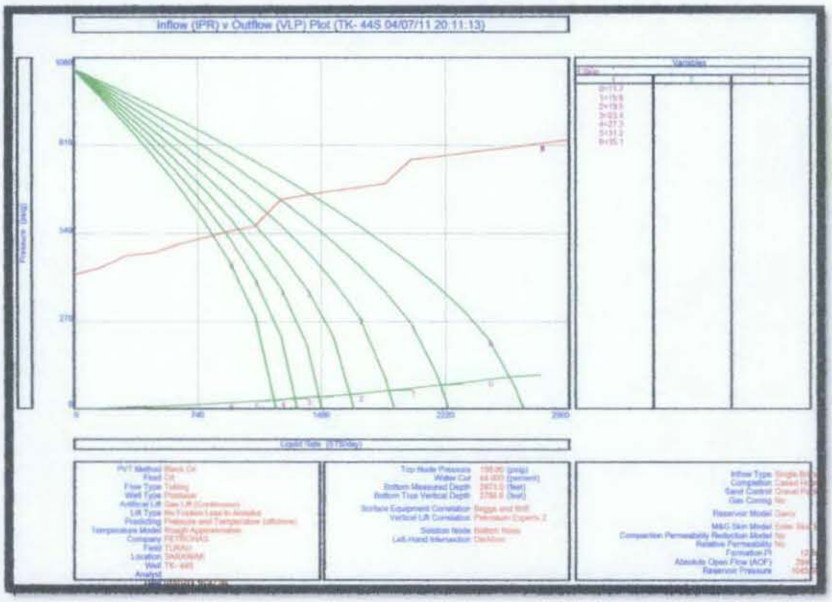


Figure33: Inflow versus Outflow plot with each TK-44S skin reduction case

%Skin reduction	Skin reduced	Qoil (bopd)	Q gain (bopd)
10	35.1	467.3	33
20	31.2	506.1	71.8
30	27.3	553.3	119
40	23.4	609	174.7
50	19.5	653.6	219.3
60	15.6	705.2	270.9
70	11.7	795.7	361.4

Table17: Oil gain for TK-44S expected %sk reduction

50% skin reduction is chosen as the base case for this acid job. The determination of Q gain when skin reduced to 50% is:

$Q_{gain} = Q_{post\text{-}acid} - Q_{pre\text{-}acid}$

$= Q_{of\ skin+19.5} - Q_{of\ skin\ 39}$

=653.6 bopd – 434.3 bopd

=219.3 bopd

Therefore, the expected Q_{gain} after acid job is 219.3 **bopd** if the WC is maintained. WC tends to increase or decrease after acid job done. Thus, sensitivity for WC needs to be done in order to compare the Q_{gain} for each WC case. Sensitivities to WC of 35%, 40%, 45%, 50% and 55% is run for skin of 19.5.

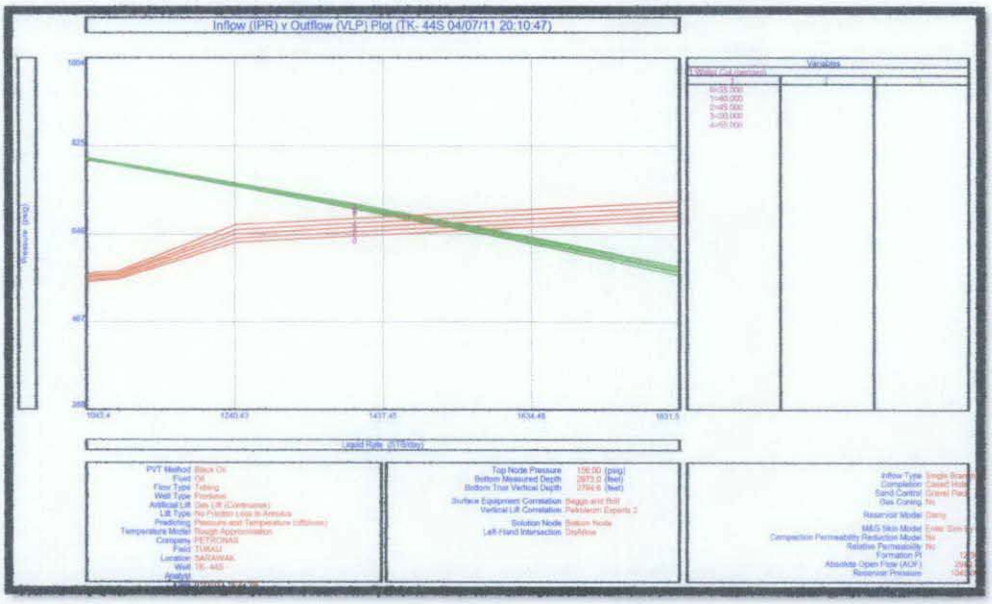


Figure34: Inflow versus Outflow plot with WC sensitivities for TK-44S

%Skin reduction	%WC	Qoil (bopd)	Q gain (bopd)
50	35	755.1	320.8
50	40	696.2	261.9
50	45	637.4	203.1
50	50	578.6	144.3
50	55	520	85.7

Table18: Oil gain for each WC in TK-44S

45% of watercut is chosen as the base case for TK-44S acidizing.

TK-45S Pre-acid well model: 2-E3/E9 reservoir

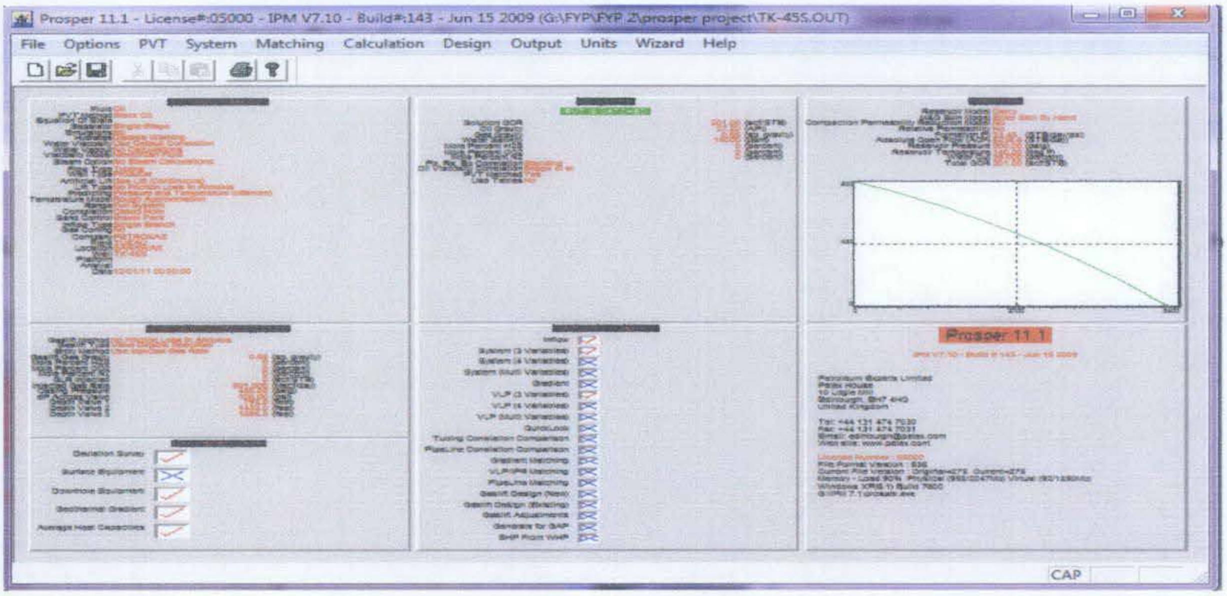


Figure35: TK-45S PROSPER well model

In order to construct TK-45S well model, these data are needed as the input for this analysis:

- Well diagram for equipment input
- Well deviation data
- Geothermal gradient
- Gravel pack properties

Input	Value	Unit
GP permeability	15500	mD
Perf. diameter	0.4	inches
GP length	0.5	inches
Shot density	4	
Perf. efficiency	1	
Overall heat transfer coeefficient	8	cp
Perf. interval	39	ft

Table19: Gravel pack properties of TK-45S

- PVT data of TK-45S

DEVELOPMENT UNIT	DATUM FT.SS	FORMATION TEMPERATUR DEG. F	INITIAL PRESSURE PSIG	OIL GRAVITY DEG. API	BOI RB/STB	RSI SCF/STB	BGI RB/MSCF	OIL VISCOSITY CP
2 - D9/E9	2570	142	1118	27	1.1	166	2.41	1.8

Table20: PVT data for TK-45S

- Reservoir rock and fluid properties

Input	Value	Unit
Pr	900	psi
Tr	140	F
k	400	mD
thickness	162	ft
drainage area	3.146E6	ft^2
dietz shape factor	31.6	
wellbore radius	0.452	ft

Table21: Reservoir rock and properties of TK-45S

- Well test data

DATE	ZONE	STT	BEAN	GROSS	WC	NET	GASOUT	FORMATION GAS	GASLIFT	TGLR	GOR	FTHP	CHP
24-Feb-09	2-E3/E9	GLI	64	604	38	374	743	75	668	1231	201	150	610
26-Mar-09	2-E3/E9	GLI	64	606	40	364	407	73	334	671.7	201	110	350
AVERAGE				605	39	369			501		201	130	480

Table22: TK-45S well test

After all data required was entered to construct TK-45S well model, the base skin input was set to 10 as the initial input of skin. Sensitivity to skin will be construct in order to search the pre-acid job skin based on the chosen Tukau 2009 well test data for pre-acid skin. The average well test data is chosen as the reference for pre-acid job well model. The input for sensitivity to skin was generated from 10 to 90 to find out the best skin that represents the well test data.

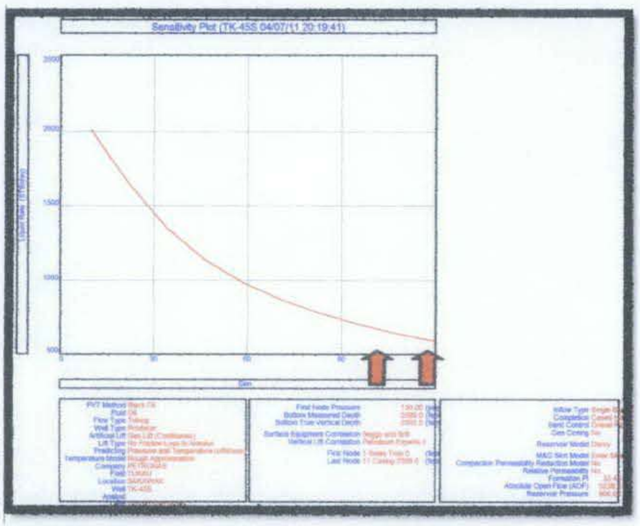


Figure36: Sensitivity Plot TK-45S, Liquid rate versus Skin

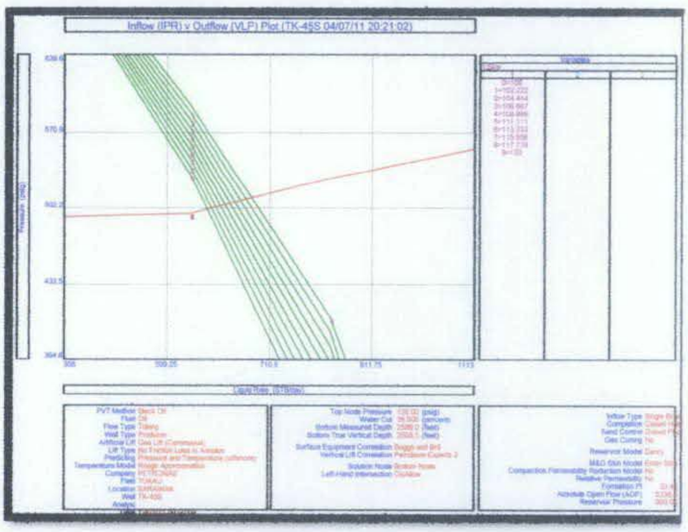


Figure37: Inflow and Outflow Plot with sensitivity of skin from 100 to 120

It shows that at the higher skin of the well, the lower liquid rate will be produced. According to the graph of Liquid rate versus Skin (Figure36), it shows that the skin of TK-45S must be between 100 to 120 in order to match with well test data which is Q_{gross}= 605 bopd and Q_{net} = 369 bopd at WC=39%. After setting the skin sensitivity from 100 to 120, the graph of figure is obtain. Based on the graph of Liquid rate versus skin, the matching skin with the well test data is 116. Thus, the input data in IPR column will be changed to 116.

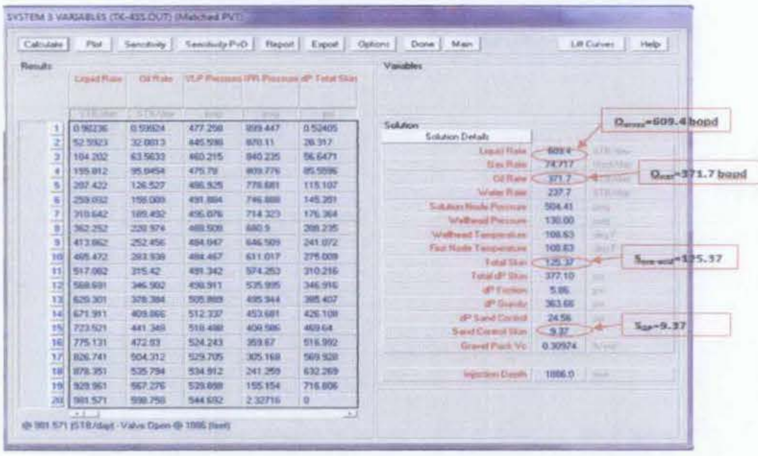


Figure38: System 3 variable output of TK-45S

Based on figure38, the pre-acid skin for TK-44S is matching at:

- Pre-acid Skin = Total skin – Sand Control skin
  = 125.37 – 9.37
  =116
- Q_{gross}= 609.4 bopd
- Q_{net}= 371.7 bopd

Error calculation: [(609.4-605) /605]* 100% = 0.73 %. The error is less then 5%, therefore, it is approved.

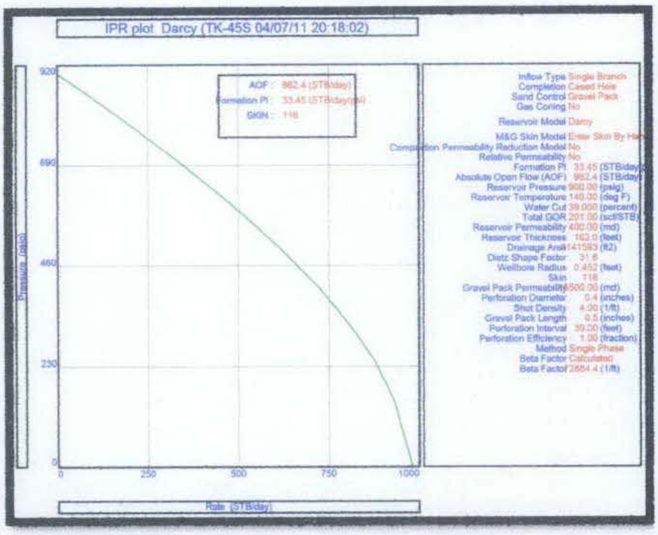


Figure39: IPR plot for pre-acid TK-45S well model

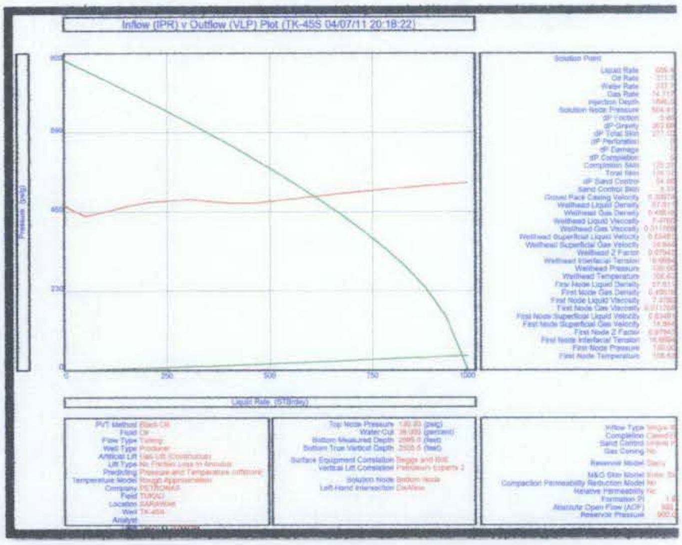


Figure40: Inflow vs. Outflow plot of pre-acid TK-45S well model

Analysis of expected post-acid skin for TK-45S:

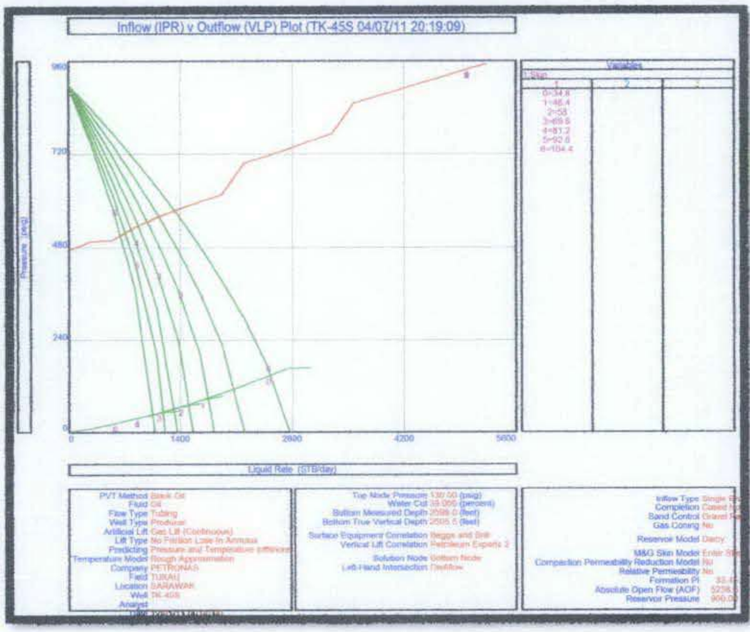


Figure41: Inflow versus Outflow plot with each TK-45S skin reduction case

%Skin reduction	Skin reduced	Qoil (bopd)	Q gain (bopd)
10	104.4	399	27.3
20	92.8	436.6	64.9
30	81.2	482.3	110.6
40	69.6	536.2	164.5
50	58	604.8	233.1
60	46.4	694.6	322.9
70	34.8	814.7	443

Table23: Oil gain for TK-45S expected %skin reduction

50% skin reduction is chosen as the base case for this acid job. The determination of Q gain when skin reduced to 50% is:

$Q_{gain} = Q_{post\text{-}acid} - Q_{pre\text{-}acid}$

$= Q_{of\ skin58} - Q_{of\ skin\ 116}$

=604.8 bopd – 371.7 bopd

=233.1 bopd

Therefore, the expected Qgain after acid job is 233.1 bopd if the WC is maintained. WC tends to increase or decrease after acid job done. Thus, sensitivity for WC needs to be done in order to compare the Qgain for each WC case. Sensitivities to WC of 30%, 35%, 40%, 45% and 50% is run for skin of 58.

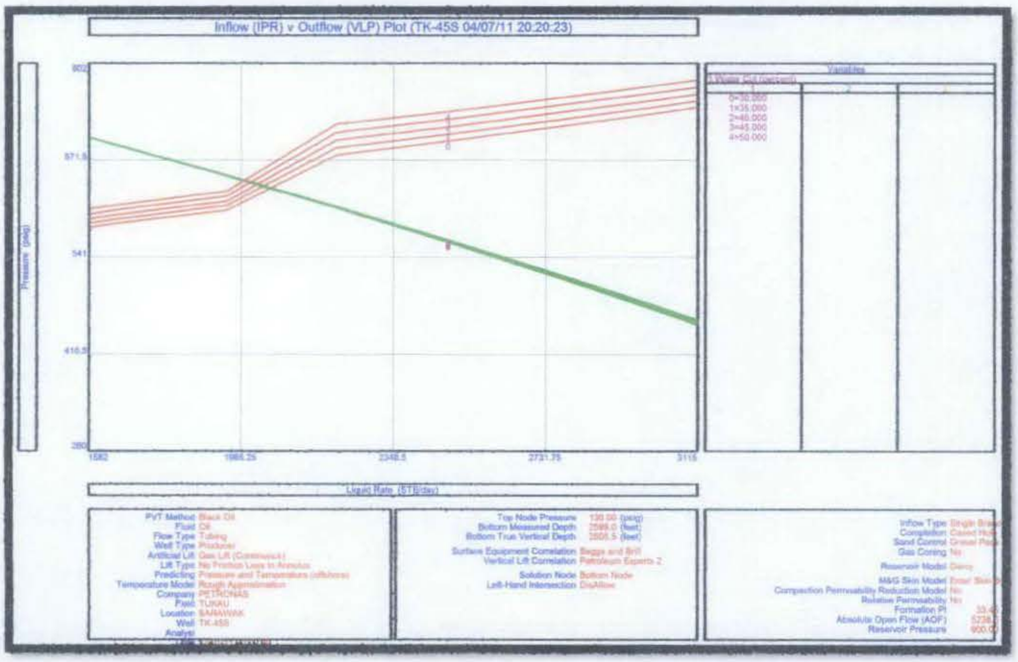


Figure42: Inflow versus Outflow plot with WC sensitivities for TK-45S

%Skin reduction	%WC	Qoil (bopd)	Q gain (bopd)
50	30	702.2	330.5
50	35	648.6	276.9
50	40	595.2	223.5
50	45	542	170.3
50	50	489.2	117.5

Table24: Oil gain for each WC in TK-45S

40% of watercut is chosen as the base case for this acid job.

4.3 ACTUAL POST-ACID JOB WELL MODEL: WEST LUTONG

WL-07L post-acid model: K reservoir

ACT. DATE	BEAN	GROSS (stb/d)	W/C (%)	NET (stb/d)	GAS OUTPUT (Mscf/d)	FORM GAS (Mscf/d)	GASLIFT (Mscf/d)	FGOR (scf /stb)	FGLR (scf/stb)	Wp (stb/d)	FTHP (psig)	CHP (psig)	FLP (psig)
1-Feb-09	64	**2378**	**55**	**1070**	2000	1800	200	1177	757	1308	120	500	80

Table25: WL-07L post-acid well test

Well test data dated of 1st February 2010 is chosen as the reference for post-acid job well model. The input for sensitivity to skin was generated from 10 to 50 to find out the best skin that represents the well test data.

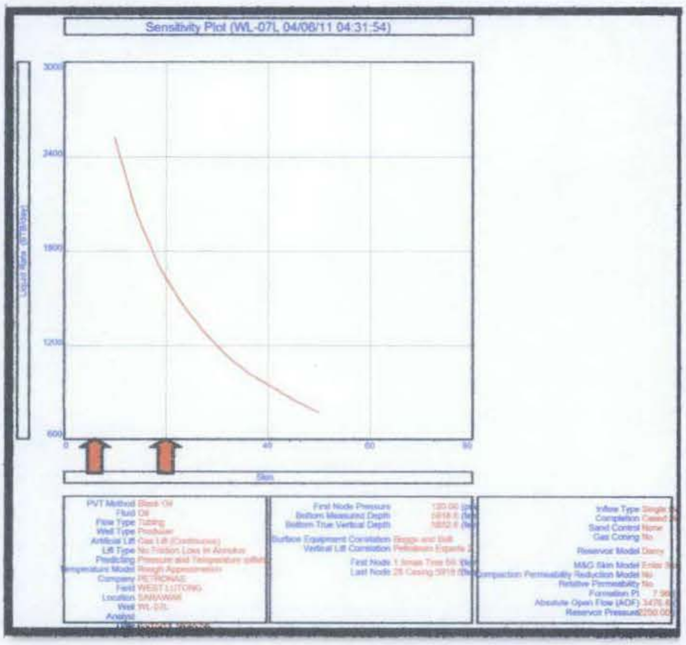


Figure43: Sensitivity Plot WL-07L, Liquid rate versus Skin

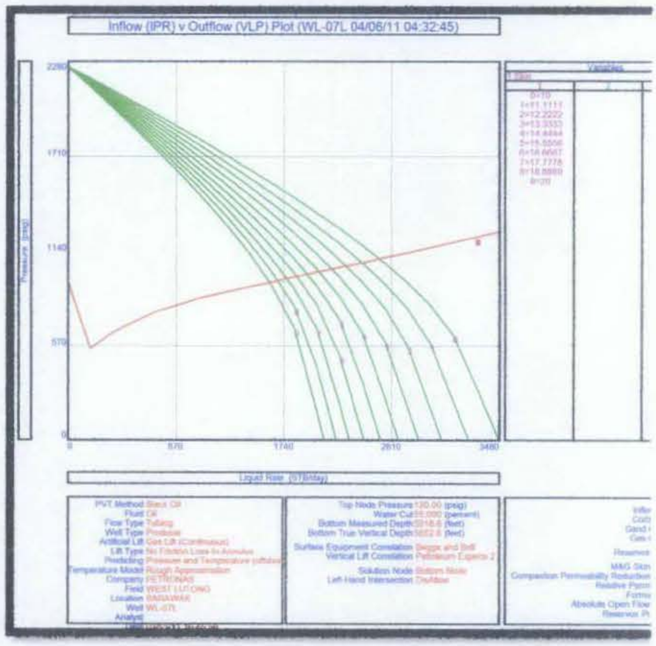


Figure44: Inflow and Outflow Plot with sensitivity of skin from 10 to 20

According to the graph of Liquid rate versus Skin (Figure20), it shows that the skin of WL-07L must be between 10 to 20 in order to match with well test data which is Q_{gross}= 2378 bopd and Q_{net} = 1070 bopd at WC=55%. Based on figure 44, we can conclude that the matching skin for WL-07L is 11.11.

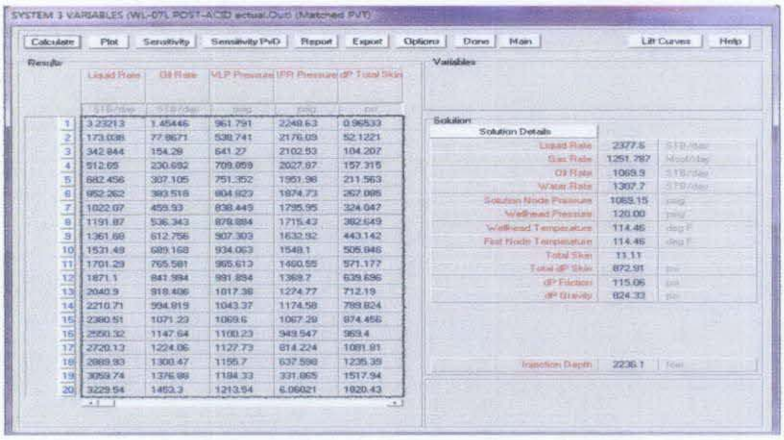


Figure 45: System 3 variable output of WL-07L

Based on figure 45, the post-acid skin for WL-07L is matching at:

- S=11.11,
- Q_{gross}= 2377.6 bopd
- Q_{net}= 1069.9 bopd

Error calculation: [(1069.9-1070) /1070]*100% = 0.01%. The error is less then 5%, therefore, it is approved.

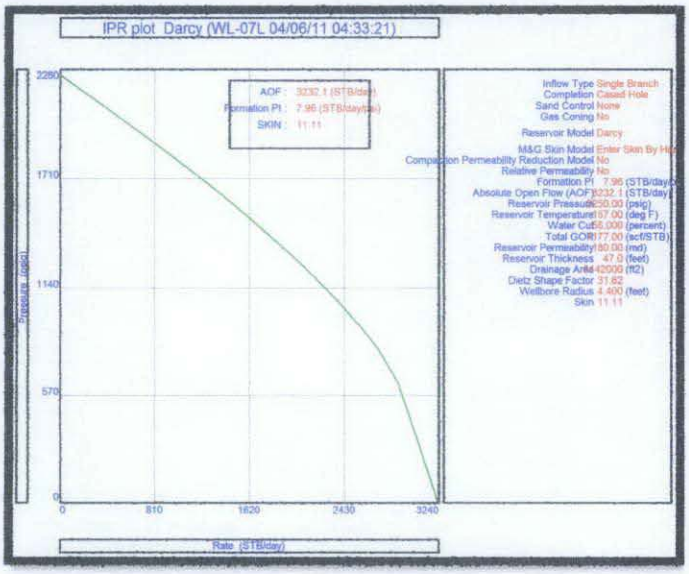


Figure46: IPR plot for post-acid WL-07L well model

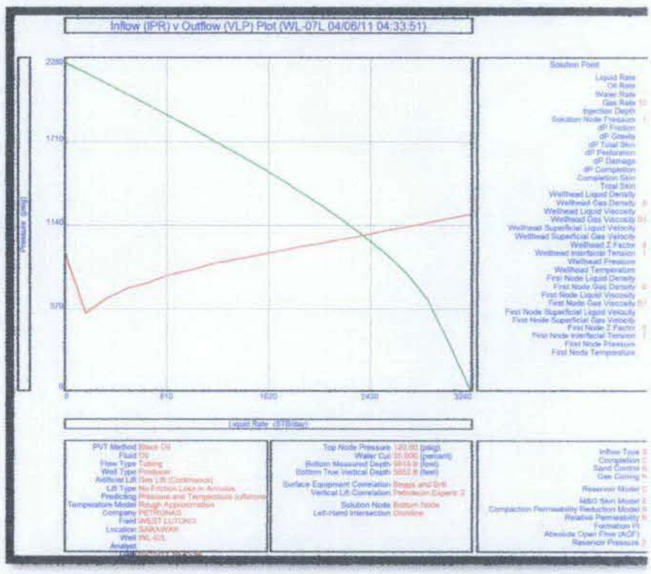


Figure47: Inflow vs. Outflow plot of post-acid WL-07L well model

WL-08S post-acid model: H reservoir

ACT. DATE	BEAN	GROSS (stb/d)	W/C (%)	NET (stb/d)	GAS OUTPUT (Mscf/d)	FORM GAS (Mscf/d)	GASLIFT (Mscf/d)	FGOR (scf/stb)	FGLR (scf/stb)	Wp (stb/d)	FTHP (psig)	CHP (psig)	FLP (psig)
3-Oct-09	64	**1098**	**72**	**307**	546	458.00	88	1490	417	790.6	120	650	80

Table26: WL-08S post-acid well test

Well test data dated of 3rd October 2009 is chosen as the reference for post-acid job well model. The input for sensitivity to skin was generated from 10 to 50 to find out the best skin that represents the well test data.

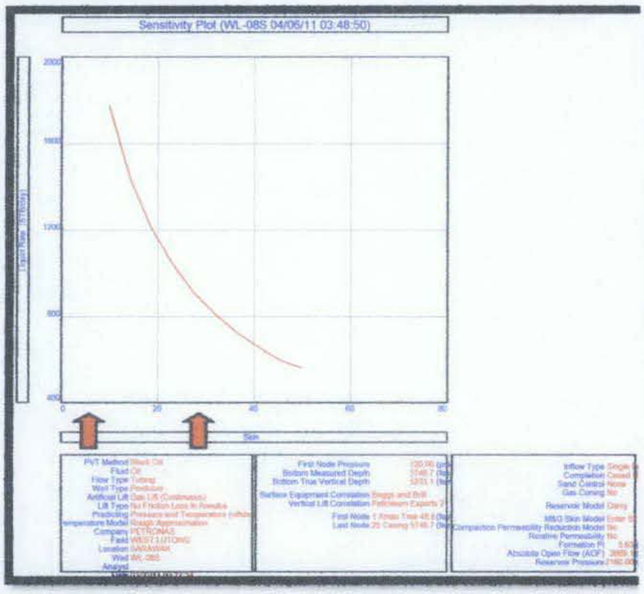


Figure48: Sensitivity Plot WL-08S, Liquid rate versus Skin

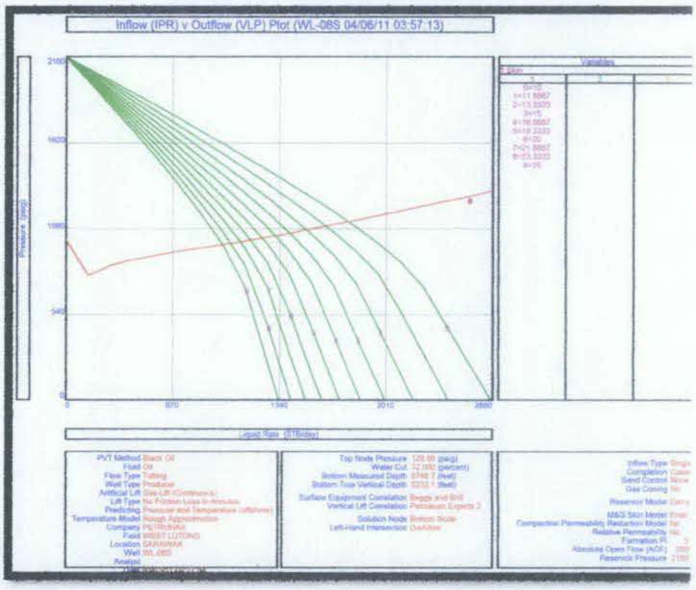
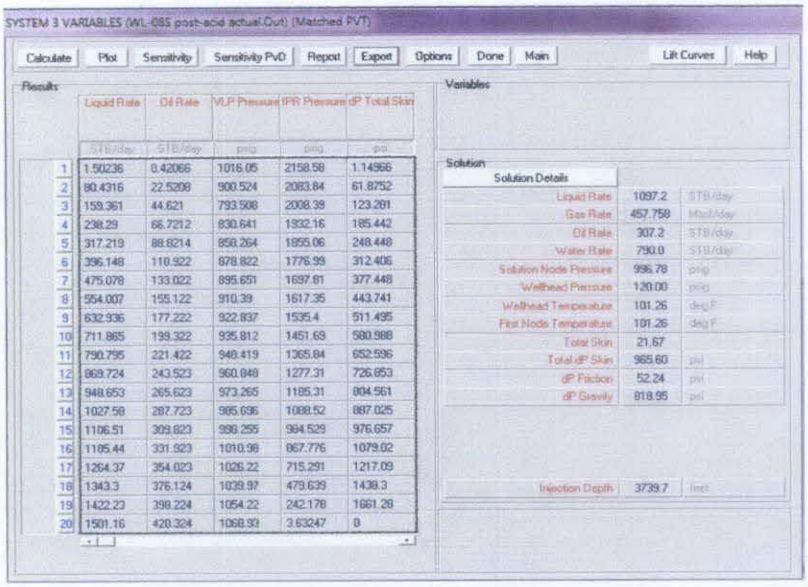


Figure49: Inflow and Outflow Plot with sensitivity of skin from 10 to 25

According to the graph of Liquid rate versus Skin (Figure48), it shows that the skin of WL-08Smust be between 10 to 25 in order to match with well test data which is Q_{gross}= 1097.8 bopd and Q_{net} = 307.2 bopd at WC=72%. Based on figure 49, we can conclude that the matching skin for WL-08S is 21.67.



	Liquid Rate	Oil Rate	VLP Pressure	IPR Pressure	dP Total Skin
	STB/day	STB/day	psig	psig	psi
1	1.50236	0.42066	1016.05	2158.58	1.14966
2	80.4316	22.5208	900.524	2083.84	61.8752
3	159.361	44.621	793.508	2008.39	123.281
4	238.29	66.7212	830.641	1932.16	185.442
5	317.219	88.8214	858.264	1855.06	248.448
6	396.148	110.922	878.822	1776.99	312.406
7	475.078	133.022	895.651	1697.81	377.448
8	554.007	155.122	910.39	1617.35	443.741
9	632.936	177.222	922.837	1535.4	511.495
10	711.865	199.322	935.812	1451.69	580.988
11	790.795	221.422	948.419	1365.84	652.596
12	869.724	243.523	960.848	1277.31	726.853
13	948.653	265.623	973.265	1185.31	804.561
14	1027.58	287.723	985.696	1088.52	887.025
15	1106.51	309.823	998.255	984.529	976.657
16	1185.44	331.923	1010.98	867.776	1079.02
17	1264.37	354.023	1026.22	715.291	1217.09
18	1343.3	376.124	1039.97	479.639	1438.3
19	1422.23	398.224	1054.22	242.178	1661.28
20	1501.16	420.324	1068.93	3.63247	0

Solution Details		
Liquid Rate	1097.2	STB/day
Gas Rate	457.758	Mscf/day
Oil Rate	307.2	STB/day
Water Rate	790.0	STB/day
Solution Node Pressure	996.78	psig
Wellhead Pressure	120.00	psig
Wellhead Temperature	101.26	deg F
First Node Temperature	101.26	deg F
Total Skin	21.67	
Total dP Skin	965.60	psi
dP Friction	52.24	psi
dP Gravity	818.95	psi
Injection Depth	3739.7	feet

Figure 50: System 3 variable output of WL-08S

Based on figure50, the post-acid skin for WL-08S is matching at:

- S=21.67,
- Q_{gross}= 1097.2 bopd
- Q_{net}= 307.2 bopd

Error calculation: [(307.2-307) /307]*100% = 0.07%. The error is less then 5%, therefore, it is approved.

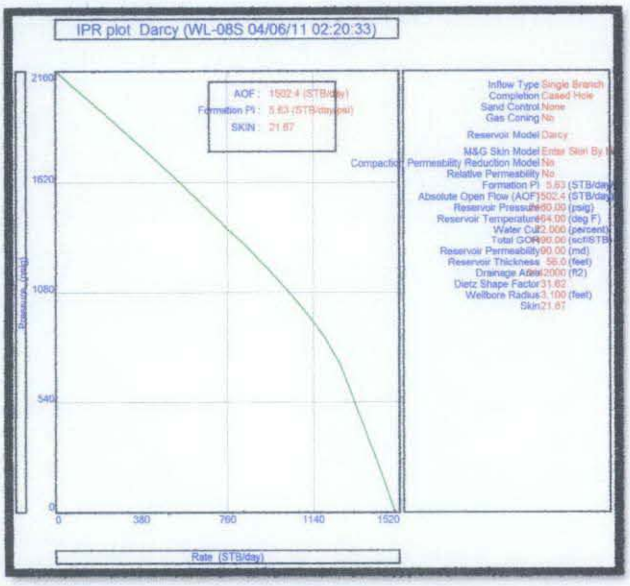


Figure51: IPR plot for post-acid WL-08S well model

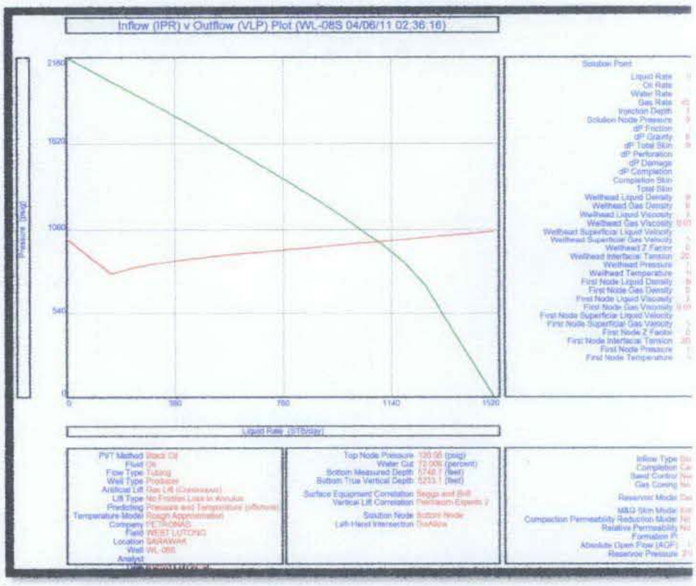


Figure52: Inflow vs. Outflow plot of post-acid WL-08S well model

4.4 ACTUAL POST-ACID JOB WELL MODEL: TUKAU

TK-44S post-acid model: 2-F1/F6 reservoir

DATE	ZONE	STT	BEAN	GROSS	WC	NET	GASOUT	FORMATION GAS	GASLIFT	TGLR	GOR	FTHP	CHP
11-Jan-11	2-E3/E9	GLI	64	660	44	374	743	75	959	1231	309	200	520

Table27: TK-44S well test

Sensitivity to skin will be construct in order to search the post-acid job skin based on the chosen Tukau 2009 well test data for pre-acid skin. The input for sensitivity to skin was generated from 10 to 50 to find out the best skin that represents the well test data.

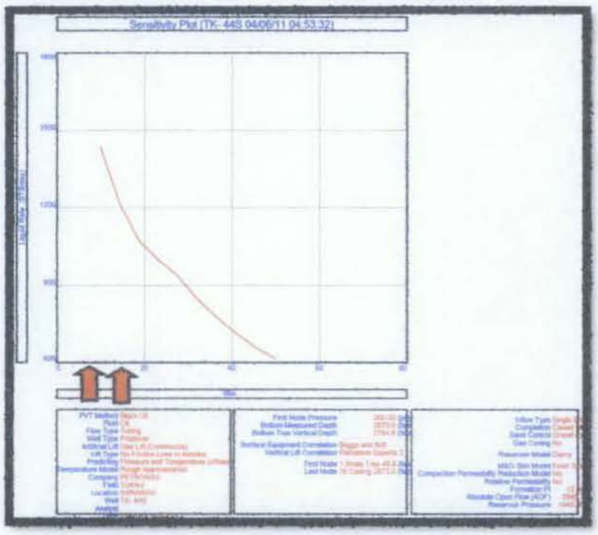


Figure53: Sensitivity Plot TK-44S, Liquid rate versus Skin

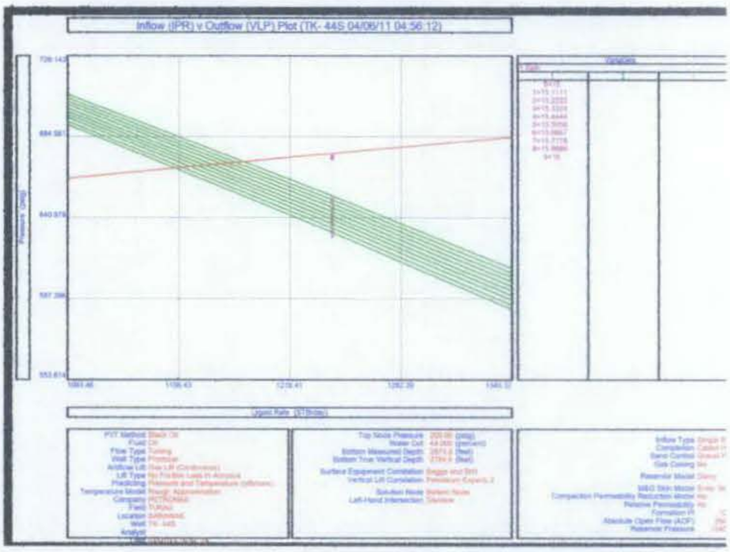
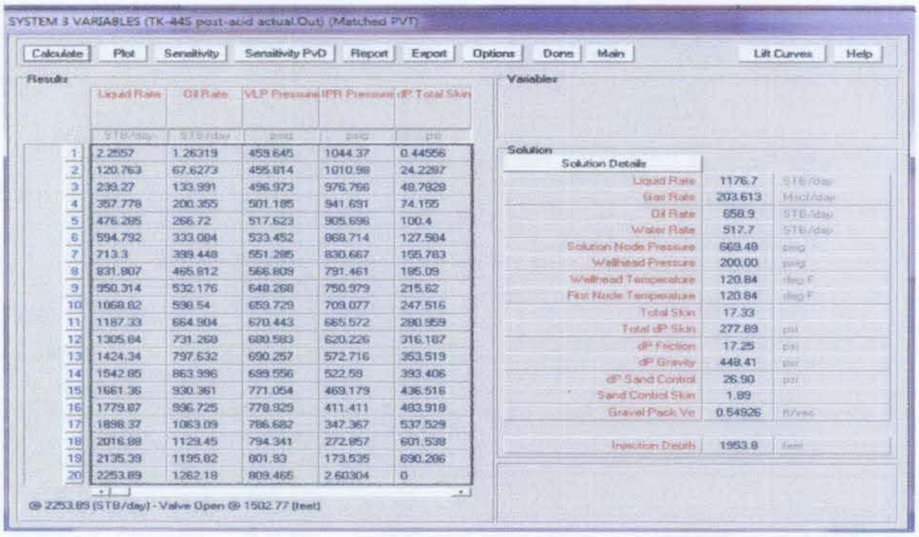


Figure54: Inflow and Outflow Plot with sensitivity of skin from 15 to 16

According to the graph of Liquid rate versus Skin (Figure53), it shows that the skin of TK-44S must be between 10 to 18 in order to match with well test data which is Q_{gross}= 1178 bopd and Q_{net} = 660 bopd at WC=44%. Based on the graph of Liquid rate versus skin (figure54), the matching skin with the well test data is 15.44.



SYSTEM 3 VARIABLES (TK-44S post-acid actual.Out) (Matched PVT)

Results

	Liquid Rate	Oil Rate	VLP Pressure	IPR Pressure	dP Total Skin
	STB/day	STB/day	psig	psig	psi
1	2.2557	1.26319	459.645	1044.37	0.44556
2	120.763	67.6273	455.814	1010.98	24.2287
3	239.27	133.991	496.973	976.766	48.7828
4	357.778	200.355	501.185	941.691	74.155
5	476.285	266.72	517.623	905.696	100.4
6	594.792	333.084	533.452	868.714	127.584
7	713.3	399.448	551.285	830.667	155.783
8	831.807	465.812	566.809	791.461	185.09
9	950.314	532.176	648.268	750.979	215.62
10	1068.82	598.54	659.729	709.077	247.516
11	1187.33	664.904	670.443	665.572	280.959
12	1305.84	731.268	680.583	620.226	316.187
13	1424.34	797.632	690.257	572.716	353.519
14	1542.85	863.996	699.556	522.58	393.406
15	1661.36	930.361	771.054	469.179	436.516
16	1779.87	996.725	778.929	411.411	483.918
17	1898.37	1063.09	786.682	347.367	537.529
18	2016.88	1129.45	794.341	272.857	601.538
19	2135.39	1195.82	801.93	173.535	690.286
20	2253.89	1262.18	809.465	2.60304	0

@ 2253.89 (STB/day) - Valve Open @ 1502.77 (feet)

Solution

Solution Details		
Liquid Rate	1176.7	STB/day
Gas Rate	203.613	Mscf/day
Oil Rate	658.9	STB/day
Water Rate	517.7	STB/day
Solution Node Pressure	669.49	psig
Wellhead Pressure	200.00	psig
Wellhead Temperature	120.84	deg F
First Node Temperature	120.84	deg F
Total Skin	17.33	
Total dP Skin	277.89	psi
dP Friction	17.25	psi
dP Gravity	448.41	psi
dP Sand Control	26.90	psi
Sand Control Skin	1.89	
Gravel Pack Vc	0.54926	ft/sec
Injection Depth	1953.8	feet

Figure55: System 3 variable output of TK-44S

Based on figure55, the pre-acid skin for TK-44S is matching at:

- Pre-acid Skin = Total skin – Sand Control skin
  = 17.33 – 1.89
  =15.44
- Q_{gross}= 1176.7 bopd
- Q_{net}= 658.9 bopd

Error calculation: [(658.9-660) /660]* 100% = 0.16 %. The error is less then 5%, therefore, it is approved.

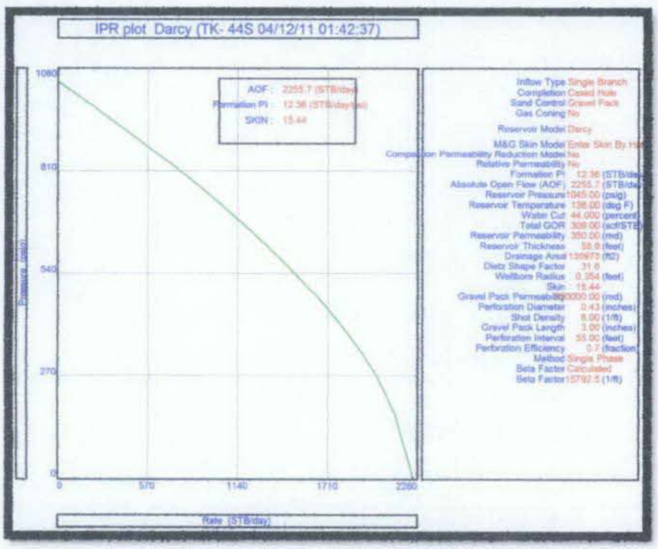


Figure 56: IPR plot for TK-44S post-acid model

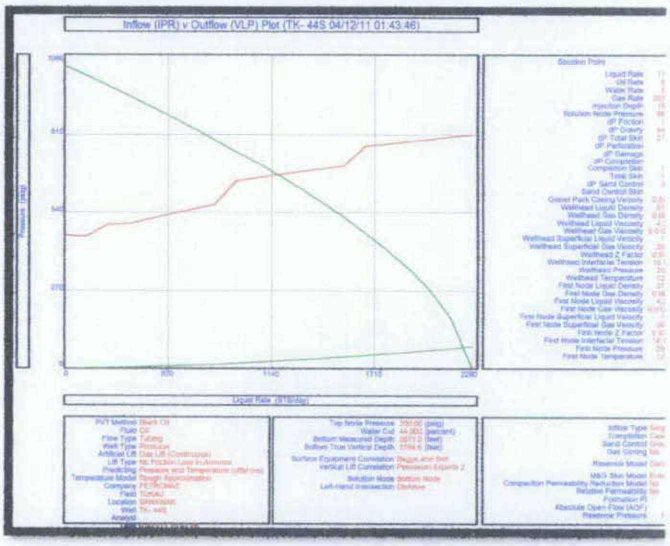


Figure 57: Inflow vs. Outflow plot of TK-44S post-acid we model

TK-45S post-acid model: 2-E3/E9 reservoir

DATE	ZONE	STT	BEAN	GROSS	WC	NET	GASOUT	FORMATION GAS	GASLIFT	TGLR	GOR	FTHP	CHP	FLP
24-Feb-09	2-E3/E9	GLI	64	1052	40	631	743	75	437	1231	286	160	620	110

Table28: TK-45S well test

Sensitivity to skin will be construct in order to search the post-acid job skin based on the chosen Tukau 2009 well test data for pre-acid skin. The average well test data is chosen as the reference for pre-acid job well model. The input for sensitivity to skin was generated from 10 to 70 to find out the best skin that represents the well test data.

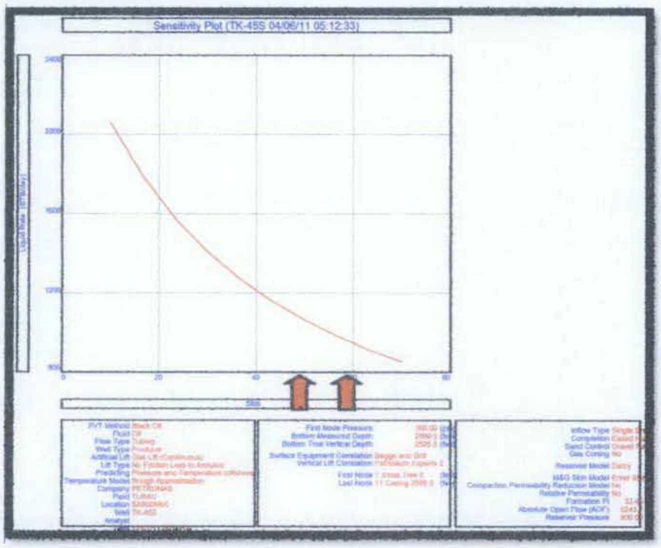


Figure58: Sensitivity Plot TK-45S, Liquid rate versus Skin

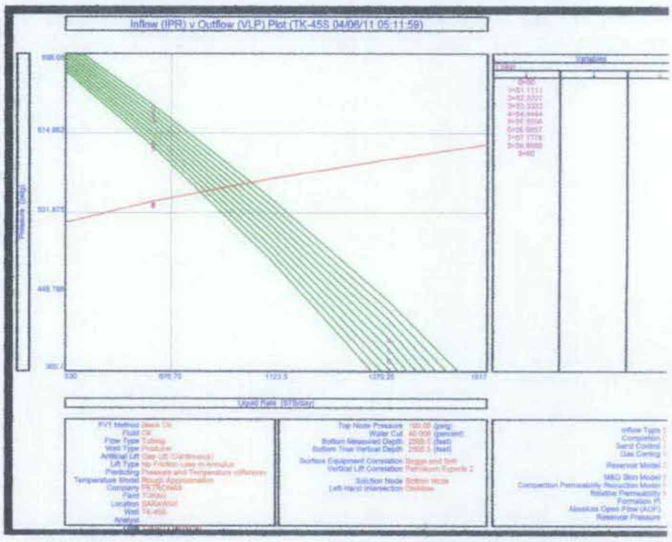


Figure59: Inflow and Outflow Plot with sensitivity of skin from 50 to 60

According to the graph of Liquid rate versus Skin (Figure56), it shows that the skin of TK-45S must be between 50 to 60 in order to match with well test data which is Q_{gross}= 1052 bopd and Q_{net} = 631 bopd at WC=40%. Based on the graph of Liquid rate versus skin (figure 57), the matching skin with the well test data is 51.

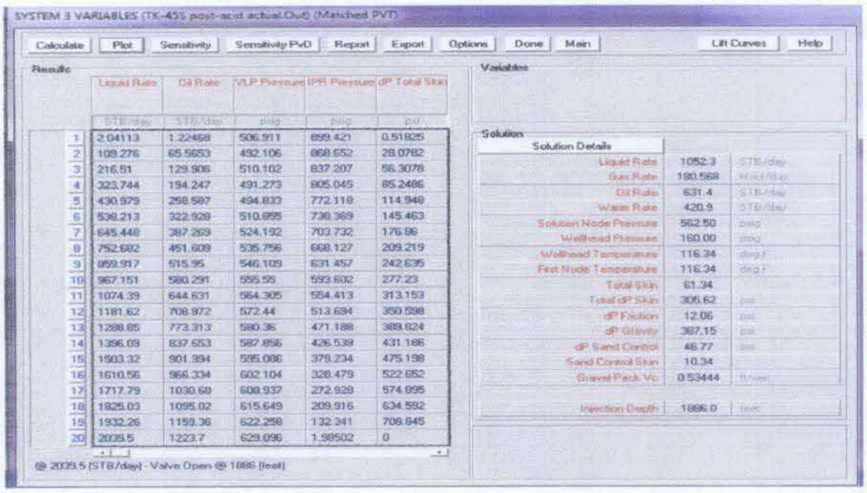


Figure60: System 3 variable output of TK-45S

Based on figure58, the pre-acid skin for TK-45S is matching at:

- Pre-acid Skin = Total skin – Sand Control skin
  = 61.34 – 10.34
  =51
- Q_{gross}= 1052 bopd
- Q_{net}= 631.4 bopd

Error calculation: [(631.4-631) /631]* 100% = 0.06 %.The error is less then 5%, therefore, it is approved.

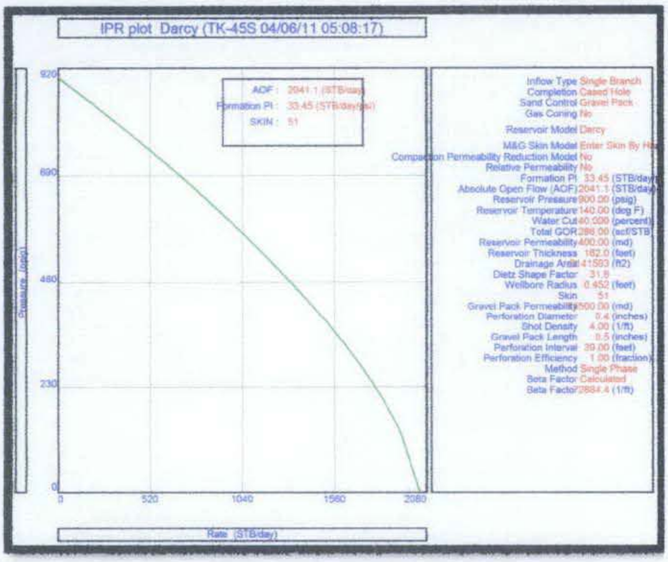


Figure61: IPR plot for post-acid TK-45S well model

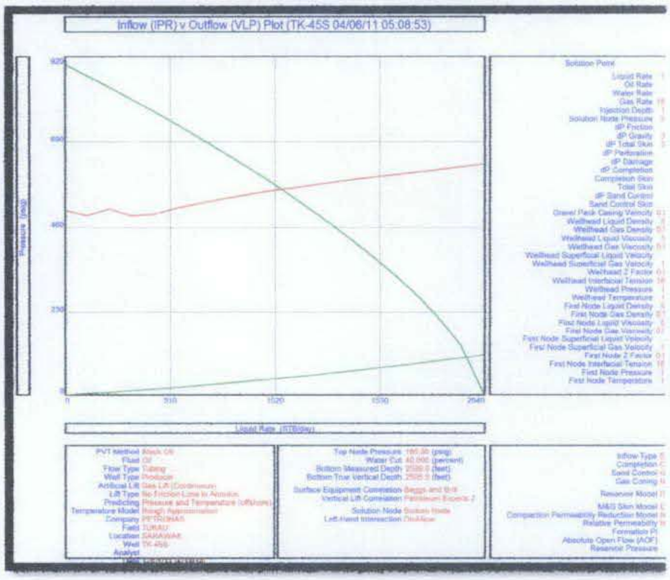


Figure62: Inflow vs. Outflow plot of post-acid TK-45S we
model

4.5 DISCUSSIONS

On skin reduction calculations, at least two cases will be compared in order to predict the possible skin reduces after acid treatment in the particular well. The particular candidate historical skin reduction will be reviewed to predict the average of skin reduction for previous acid job done. This method is used to find the estimation of skin reduction for each acidizing job done for the field. Both field has strong to moderate water drive mechanism, therefore, the reservoir pressure for both field is maintain even though it has been produced since 1966. Both West Lutong and Tukau field is situated near to each other; therefore, the lithology and reservoir properties are almost the same. This is the reason why this particular method is applied for skin reduction estimation in order to stimulate the well with nitrified acidizing method.

There will be a decrease in skin reduction after each acid job is done. It is because during early production years, the reserves for the well were high and the watercut was low or no watercut occured. Thus, any acid treatment would result in higher skin reduction. The varying skin reduction trend was also due to the acid recipe imposed for each candidate. Nitrified preflush/main flush/afterflush is also believed to contribute to deeper penetration of main flush in the near well bore area as evident in higher skin reduction/ gross/net oil. This method has been conducted in both field in 14 July 2009 and the result of well test data after the date has been used for post-acid simulation by PROSPER.

Referring to the output of Final Year Project 1, the expected skin reduction for nitrified acidizing based on the history acid job done for both field is 50%. After that, the sensitivity to skin reduced is construct by using PROSPER software to determine the oil gain for each skin. The oil gains for each case are calculated by using:

$$Q_{gain} = Q_{post\text{-}acid} - Q_{pre\text{-}acid}$$

The skin reduction percentage for each well will be calculated by using this equation:

% Skin reduction = **[(Skin before acid job) – (Skin after acid job)/ Skin before acid job]* 100%**

$$= [(S_{pre\text{-}acid} - S_{post\text{-}acid})/\ S_{pre\text{-}acid}] * 100\%$$

By comparing both cases in WL-07L, the skin reduction in WL-07L is:

% Skin reduction (WL-07L) $= [(S_{pre\text{-}acid} - S_{post\text{-}acid}) / S_{pre\text{-}acid}] * 100\%$

$= [43.2 - 11.11) / 43.2] * 100\%$

$= 74.3\% \approx 74\%$

The oil gain after acidizing for WL-07L is:

Oil gain (WL-07L) $= Q_{post\text{-}acid} - Q_{pre\text{-}acid}$

$= Q_{11.11} - Q_{43.2}$

$= 1069.9 - 377.1$ **bopd**

$= 692.8$ **bopd**

The percentage of oil gain after acidizing for WL-07L is:

%Oil gain (WL-07L) $= [(Q_{post\text{-}acid} - Q_{pre\text{-}acid}) / Q_{pre\text{-}acid}] * 100\%$

$= [692.8 / 377.1] * 100\%$

$= 183\%$ **of oil gain**

Based on the calculation, it can be concluded that the skin reduced almost 74% with nitrified acidizing method and SAFMAK II, which exceeding the predicted skin reduced for WL-08S which is 50%. The watercut for WL-07L is reduced from 58% to 55% after acid job done. The watercut has reduced due to increasing amount of oil after acid job. The oil gain is increasing 183% from pre-acid job. Therefore, we can conclude that this method is suitable and effective to be use in West Lutong with the additional usage of SAF MAK II. SAF MAK II has shown good stimulation and deeper penetration of acid in high watercut formation.

Next is the result discussion for WL-08S. By comparing both cases in WL-08S, the skin reduction in WL-08S is:

% Skin reduction (WL-08S) $= [(S_{pre\text{-}acid} - S_{post\text{-}acid}) / S_{pre\text{-}acid}] * 100\%$

$= [63.33 - 21.67) / 63.33] * 100\%$

$= 65.8\% \approx 66\%$

The oil gain after acidizing for WL-08S is:

Oil gain (WL-08S) $= Q_{post\text{-}acid} - Q_{pre\text{-}acid}$

$= Q_{21.67} - Q_{63.33}$

$= 307.2 - 104.4$ **bopd**

$= 202.8$ **bopd**

The percentage of oil gain after acidizing for WL-08S is:

%Oil gain (WL-08S) $= [(Q_{post\text{-}acid} - Q_{pre\text{-}acid}) / Q_{pre\text{-}acid}] * 100\%$

$= [202.8 / 104.4] * 100\%$

$= 194\%$ **of oil gain**

WL-08S skin reduced from 63.33 to 21.67 after nitrified acidizing with additional SAF MAK II has done in 14 July 2009. Total of 66% of skin reduction is exceeding the predicted skin reduced for WL-08S which is 50%. Based on the simulation done by using PROSPER software, the oil rate for post acid job in WL-08S is increasing from 104.4 bopd to 307.2 bopd. The total percentage of oil gain by calculation is 194%. The watercut in WL-08S also has been reduced from 75% to 72% after acidizing job is done. Thus, we can conclude that SAFMAK II is effective in stimulate oil zone in high watercut formation and reduce or maintaining the watercut after acidizing done. Nitrified aciding is suitable and contributed a lot for deeper penetration of acid in stimulating the well.

Both wells in West Lutong has skin reduction more than 50% predicted earlier in the project,thus it is concluded that SAFMAK II and nitrified acidizing method is effective for stimulate high watercut formation.

Tukau field aciding campaign was done in the middle of July 2009 by using nitrified acidizing method with no SAFMAK II added. The well test data dated later by July 2009 has been reviewed in order to construct well model for post acid job. TK-44S result is reviewed and by comparing both cases in TK-44S, the skin reduction in TK-44S is:

% Skin reduction (TK-44S) $= [(S_{pre\text{-}acid} - S_{post\text{-}acid}) / S_{pre\text{-}acid}] * 100\%$

$= [39 - 15.44) / 39] * 100\%$

$= 60.4\% \approx 60\%$

The oil gain after acidizing for TK-44S is:

Oil gain (TK-44S) $= Q_{post\text{-}acid} - Q_{pre\text{-}acid}$

$= Q_{15.44} - Q_{39}$

$= 658.9 - 434.3$ **bopd**

$= \mathbf{224.6\ bopd}$

The percentage of oil gain after acidizing for TK-44S is:

%Oil gain (TK-44S) $= \mathbf{[(Q_{post\text{-}acid} - Q_{pre\text{-}acid}) / Q_{pre\text{-}acid}] * 100\%}$

$= \mathbf{[224.6 / 434.3] * 100\%}$

$= \mathbf{52\%}$ **of oil gain**

The skin reduction for TK-44S is 60% which is exceeding 50% of skin reduction predicted before acid job done. The oil gain is increasing from 434.3 bopd to 658.9 bopd which is increasing 52% from pre-acid oil rate. The watercut for this well is maintaining 44% after acid job. Based on the result, we can conclude that nitrified acidizing method is suitable and effective in Tukau field but recommended to use SAF MAK II in the future for better stimulation.

Next is the result discussion of TK-45S. By comparing both cases in TK-45S, the skin reduction in TK-45S :

% Skin reduction (TK-45S) $= \mathbf{[(S_{pre\text{-}acid} - S_{post\text{-}acid}) / S_{pre\text{-}acid}] * 100\%}$

$= \mathbf{[116 - 51.1) / 116] * 100\%}$

$= \mathbf{55.9\% \approx 56\%}$

The oil gain after acidizing for TK-45S is:

Oil gain (TK-45S) $= \mathbf{Q_{post\text{-}acid} - Q_{pre\text{-}acid}}$

$= \mathbf{Q_{51.1} - Q_{116}}$

$= \mathbf{631.4 - 371.7\ bopd}$

$= \mathbf{259.7\ bopd}$

The percentage of oil gain after acidizing for TK-45S is:

Oil gain (TK-45S) $= \mathbf{[(Q_{post\text{-}acid} - Q_{pre\text{-}acid}) / Q_{pre\text{-}acid}] * 100\%}$

$= \mathbf{[259.7 / 371.7] * 100\%}$

$= \mathbf{70\%}$ **of oil gain**

TK-45S skin reduced from 116 to 51.1 after nitrified acidizing with no additional SAF MAK II done. Total of 56% of skin reduction is exceeding the predicted skin reduced for TK-45S which is 50%. Based on the simulation done by using PROSPER software, the oil rate for post acid job in TK-45S is increasing from 371.7 bopd to 631.4 bopd. The total percentage of oil gain by calculation is 70%. The watercut in TK-45S is increasing from 39% to 40% after acidizing job is done. The increasing of watercut after acid job is normal and predicted earlier as the watercut tends to increase or decrease after stimulation done. Based on the result, we can conclude that nitrified acidizing method is suitable and effective in Tukau field but recommended to use SAF MAK II in the future for better stimulation.

CHAPTER 5
CONCLUSION

As for the conclusion, the total skin reduction for both West Lutong and Tukau field is about 55% to 70% which indicates that the theory of 50% of skin reduction will be expected after nitrified acidizing done in Tukau and West Lutong in FYP 1 is confirmed.

Nitrified Preflush/Main Flush/Afterflush is believed to contribute to deeper penetration of main flush in the near well bore area as evident in higher skin reduction/ gross/net oillt can also be concluded that acidizing in high water cut is viable with SAF MK11 and current BJ Half Strength Sandstone Acid and S3 acid recipe. SAF MK11 diverter had proven its application to divert acidizing treatment fluid to damaged formation by sealing off water zone temporarily as evident in water cut reduction in both cases in West Lutong. Tukau field is recommended to use SAFMAK II for better stimulation in the future as the usage of SAF MAK II is effective in reducing/maintaining watercut after acidizing in high watercut formation.

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