Formation Damage Removal Through Acidizing of an Oil Well After Drilling and Completion

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Abstract

This paper discusses a real case study on how formation damage can be removed after finishing all operations in drilling and completing a well that is used vertically for producing commercial hydrocarbons using Over Balanced Drilling (OBD) techniques. Formation damage happens in every drilled well during field operations. It is an undesirable and complicated situation usually caused by solids invasion, fines movements, organic precipitation and deposition, and collapse and swelling formations (clay formations).

The production performance of drilled well is significantly affected by the scale of damage in the invaded formation of the pay zone. The process of finding ways to solve this problem and the mechanism of preventing formation damages are the most important efforts faced by oil and gas industries. Formation damage is even a difficult problem to diagnose, but there are still some steps used for indicating it. For instance, this includes; well testing, well history reports, and well logging analysis. However, these techniques can only carry out diagnosis and an overall measure of the damage. Also, the results can apply suitable mechanisms for minimizing the risks and reducing the causes. After drilling and completing a well in Field A in Kurdistan region-north of Iraq, acid job is performed for the well considering the other wells potential and productivity. This is because the level was not enough for oil to be delivered to degassing station with the request pressure as shown in the appendix figures of pressure versus depth and tables of surface well testing results.

Acidizing is a mean of production optimization for naturally flowing wells, whereby a designed acid volume is pumped to remove the damaged interval. Hence, it aims to increase the flow of oil to the surface. The type of acid used

was Hydrochloric acid (HCL) with a concentration of 15%. In choosing the acid concentration, historical stimulation operation and lab tests were considered as the field is been developed a long-time ago. Here, enough programming data were made available for proposing operation of which one of them is acidizing.
In the mentioned Field A, wells with high pressure drop between the well that was shut in and flowing pressure are required to be stimulated through acidizing. In this case, the pressure difference was about 300 psig before performing the job. Thus, the aim of this job was to obtain the optimum pressure difference between Bottom hole flowing pressure Pwf and Sand face well pressure Pws which yields to the maximum oil production rate.
The objectives of the job were achieved after obtaining a high flow rate of 8000 bbl/day at the surface and from the slickline data measurement. This recorded too much lesser draw down pressure of 11 psig between Pwf & Pws.

Keywords: Over Balanced Drilling (OBD), Hydrochloric acid (HCL), Bottom hole flowing pressure (Pwf), Sand face well pressure (Pws)

Background

Formation damage is a term used to describe a formation when its permeability impair due to every field operations. This situation usually occurs after doing some subsurface oil field procedures. For example, the processes that are applied on a well starting from drilling until producing oil in the well include: drilling, work over, and stimulation procedures. This situation is undesirable because it has a negative impact on the well and it will reduce the production capacity of the well. For instance, Amaelule *et al.* (1988) stated that “Formation damage is an expensive headache to the oil and gas industries.”

However, any destroyed section inside the formation is due to the restriction to the flow of the hydrocarbons during the production process in a well. For example, it reduces the permeability of the reservoir that is known as impairment of permeability. To recapitulate, the processes of producing oil which start by drilling will have a significant effect on the formation, especially against the well bore. This, however, causes formation damage and consequences in the skin factor.

Common Formation Damage Problems

a. Sudden changing in the formation properties because of the varieties of down hole situations. For example, permeability reduction, change in wettability, lithology alteration, and particles appearing of minerals.

b. Variation in the fluid properties which includes change in the fluid viscosity that is created by emulsion block and mobility change.
c. The contact between drilling fluids and the formation fluids causes fluid instability that leads to incompatibility between these two fluids. This is because the invaded zone by drilling fluids that have bacterial agents will touch formation. Also, this will affect permeability and would have a negative impact on the well productivity and will also reduce the well performance (Amaelule *et al*., 1988).
d. As it is known during the drilling operation of a well, there will be falling of drilling solids while drilling a hole and/or from the solids that was added to the drilling mud. This will cause formation damage because as these solids invade the formation face, blocking will happen (Civan, 2000).
e. Fines migration, the movement of fines affects the on production performance of a well, especially in the sandstone formation reservoirs, because the existing of fines inside the well bore and their migration towards the formation will block pore throats (Clegg, 2007).

Main Causes and Mechanisms of Formation Damage

Formation Damage Caused by Drilling Fluids (Water-Based Mud)

The components of drilling fluids vary, which contains Bentonite, Barite, and Polymers that gave the drilling fluid some required specification. These specifications, however, include cutting carrying capacity, losses controlling capacity and dissolving with salts, and maintaining PH of the mud. The existence of these components inside drilling fluids leads clearly to formation damage. For instance, solids when they invade the formation will cause formation damage resulting in the lowering of the well productivity performance. Furthermore, filtrates, fresh water, can also create formation damage. In addition, the existence of polymers inside drilling mud has negative impact on formation. Consequently, the formation damage occurs especially during the mixing of the polymer products with brines water from the invaded formation.

Formation Damage Caused by Drilling Fluids (Oil Based Mud)

Oil based mud that contains water droplets will resulted in formation damage. This status will happen, because water droplets are stabilized by emulsified and organopheric clays. The invasion of solids and water droplets inside oil-based mud affect filter cake. As a result, there will be a significant lowering in production which means that formation damage occurred.

Formation Damage Caused By Completion and Work Over Fluids

When a well is drilled and it reached its required total depth, it will be followed by perforation, gravel packing, and acidizing. In each of these operations, there is circulating of drilling fluids especially during completion. This occurs when the component of the drilling fluids is brine. The brine does not quite clear because it contains corrosion products and debris. The existing of these particles inside brines leads to increase of the hydrostatic pressure. As a result, the effected formation will damage and follow the reduction of its production as well as lower the well performance (Clegg, 2007).

Formation Damage Caused by Cementing and Perforation

During the pumping of cement into the annulus between the production casing, the well bore usually causes a differential pressure between the cement pumping pressure and formation pressure. In this case, the probability of formation damage will increase. As perforation processes follow the cementing process, this will also result to formation damage.

Fines Migration Causes Formation Damage

Some formations of oil reservoirs have been affected by formation damage due to the migration of fines. Evidences have shown that this usually happen in sandstone formations. The characteristic of sandstone results due to the instability of formation during production. The accumulation of fines adjusted the formation which will precipitate sands. Also, this will result in the blocking of the pore throats and reduce the production capacity of the well due to impairment in formation permeability (Jiaojiao *et al*., 2010).

Formation Damage Caused by Paraffins And Asphaltenes

Crude oil, which mainly contains organic compounds (Table 1), are mainly composed of Paraffins and Asphaltenes which are the bigger problems of oil production. Paraffins are high-molecular-weight types of Alkanes which can create a burial adjust to the wellbore because they can easily be deposited during production. The mechanism of formation damage by Paraffins is due to the change in temperature, pressure, and the components of crude oil especially because of dissolved gases. Consequently, paraffins are easily separated from crude oil because they have higher melting point as a result of their high molecular weight. For example, C^{60} Alkane will deposit when the temperature of the mature region reaches to 250 ºF. Asphaltenes are compounds that contain high molecular weight of inorganic compounds, such as Nitrogen, Oxygen and Sulfer. In addition, the existence of these compounds will create resins and formation damage.

The way of occurrence of formation damage through Asphaltenes is due to change in the crude oil parameters and the compounds. For example, when a reservoir pressure is depleted, the bubble point will result in Asphaltenes depositing into the wellbore.

CROSS COMPOSITION OF CRUDE OIL

Average Value	Normal Producible Crude Oil (n=517)*	All crude Oil (n=636)*	Disseminated Bitumen (n=1057)*
Saturated HC	57.2	53.3	29.2
Aromatic HC	28.6	28.2	19.7
Resins +	14.2	18.5	51.1
Asphaltenes	2.07		1.86
Aromatic Sulfur			
% Aromatic			
Fraction			

Values are wt% of the fraction boiling>210 °C
*n means number of samples.
** Number of samples for aromatic sulfur: 230 and 88 respectively

Figure 12. Cross Compositions of Crude Oil (Clegg, 2007)

Diagnosis of Formation Damage

The step to address this problem and to put a remedy program for the well varies according to the way of dealing with the problem and also the mechanism which could be implemented. In most cases, diagnosing the formation damage usually relies on well testing, history of the well, well logging tests, and analyzing of the extracted fluid. In terms of standard, there are three main steps by which the formation damage can be indicated (Figure 1):

i. Quantifying the degree of existing formation damage.
ii. Indicating the down-hole damage mechanisms.
iii. Performing laboratory study skills to apply an accurate and specific mechanism.

During testing to indicate the types of formation damage, there will be some special experiments. These includes; well-test analysis to scale the quantities of the damage, down hole video to monitor the damaged area and well bore, and taking samples inside well bore in both fluids and solids/or taking core samples when the well is drilled with open hole completion through using side well coring tool.

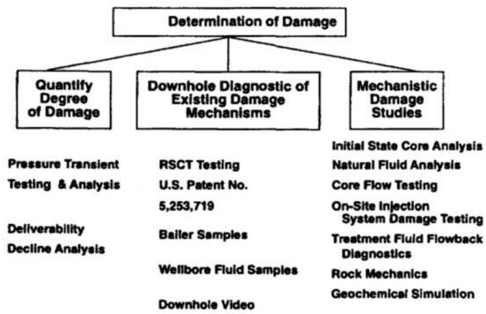

Figure 13. Determinations and diagnosis of formation damage (Civan, 2000)

Formation Damage Impacts on Well Production

Evaluations and diagnosis for formation damage minimizing were conducted to reduce the scale of risks during sensitive operations, such as, well drilling, completion, and production. Basically, there are two main impacts of formation damage on well production:

Volume Reduction (Reduction in Pore Sizes of the Pay Zone)

This situation occurs when fillings inter the pore space of the formation and when it interacts with other materials. For instance, circulating fluids in both the drilling and the completion processes create solid invasion. Furthermore, cement procedure, mineral and paraffinic precipitations, and the debris that accumulated due to the perforation process also result to formation damage and volume reduction. Another reason which may cause formation damage and consequences in reduction in the well production is the production of reservoir fluids and destruction in fractures resulting to formation compaction (Baker Hughes INTEQ, 1994).

Flow Reduction

The presence of oil and gas inside the reservoirs has their permeability in different categories. Thus, the existing of other fluids such as formation water will alter the permeability to relative permeability. Due to the interaction between fluids inside the well bore, there will be a reduction in relative permeability. This is because the existing of brines will create emulsion. Also, an increase in the formation water will cause water conning.

Due to interaction, these fluids will result to the blocking of pore throats and will impair the permeability. The dehydration and swelling of clay dispersion and the movement of these particles with the fluids that came from drilling fluid or the formation water or from injected water will damage the permeability (Tiab & Donaldson, 2004).

Therefore, change in the parameters of down hole such as pressure reduction results in the gas break out and water conning. Consequently, fluid saturation will occur and will reduce the flow of hydrocarbons from the well (Baker Hughes INTEQ, 1994).

Case Study

Damaged Formation Indication through Flow Efficiency

Standing (1970) essentially extended the application of Vogel's (Vogel did not consider formation damage) who proposed a companion chart to account for conditions where the flow efficiency was not equal to 1.00. This is as shown in the figure below.

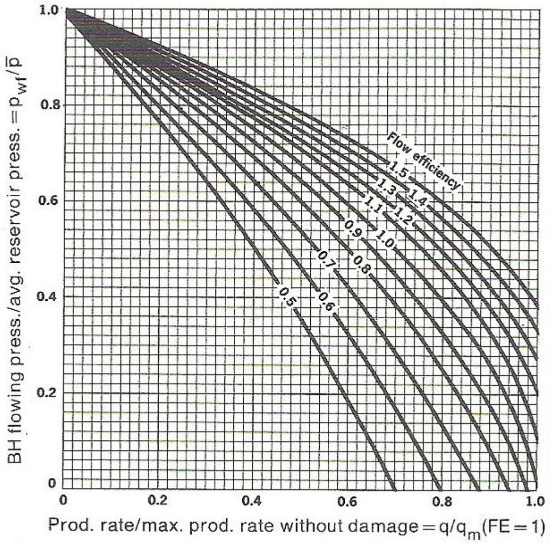

Figure 14. Inflow performance relation modified by standing

The figure above shows IPR curves for flow efficiencies between 0.5 and 1.5. Thus, several things can be obtained from this plot:

- The maximum rate possible for a well with damage.
- The maximum rate possible if the damage is removed and FE = 1.0.
- The rate possible if the well is stimulated and improved.
- The determination of the flow rate possible for any following pressure for different values of FE.
- The construction of IPR curves to show rate versus flowing pressure for damaged and improved wells.

Furthermore, Standing proposed a companion chart to account for conditions where the flow efficiency is not 1.0.

As shown in figure 4.0, the flow efficiency is defined as:

$$\mathrm{FE} = \frac{\text{Ideal drawdown}}{\text{Actual drawdown}} = \frac{\overline{\mathrm{P}}_{\mathrm{R}} - \mathrm{P'}_{\mathrm{wf}}}{\overline{\mathrm{P}}_{\mathrm{R}} - \mathrm{P}_{\mathrm{wf}}} \quad \text{... Eq. 2.1}$$

– $\mathrm{P'}_{\mathrm{wf}} = P_{wf} + \Delta P_{skin}$

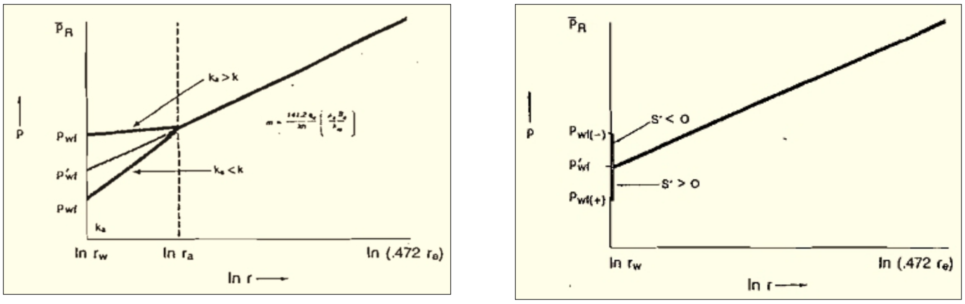

Figure 15. Effect of Skin Factor (Damagity) on Near Wellbore Paramters

The above standard sketch is used to measure the damages of the formation followed by measuring the bottom-hole pressure at two different well conditions. One of the figure shows when the well is a closed (build-up) pressure test, while the other shows when the well is a flowing (draw-down) pressure test.

Additionally, one datum line for measuring the bottom-hole pressure for both situation (flow and close) is 630 meter AMSL. This datum line was assumed to be the measured point for reservoir pressure for the whole field. Consequently, at this level, the following pressure data were recorded for the studied well under two different situations:

A. Before Acidizing

BHCIP (P_{ws}) = 1206 psig & BHFP (P_{wf}) = 914 psig

$\text{Pressure Difference (Drawdown)} = P_{ws} - P_{wf} = 1206 - 914 = 293 \text{ psig}$

The above data shows that the drawdown pressure is too high. Hence, there is damage in the pay-zone which is caused by drilling operation.

B. After Acidizing Treatment

BHCIP (P_{ws}) = 1206 psig & BHFP (P_{wf}) = 914 psig

$\text{Pressure Difference (Drawdown)} = P_{ws} - P_{wf} = 1206 - 1194 = 11 \text{ psig}$

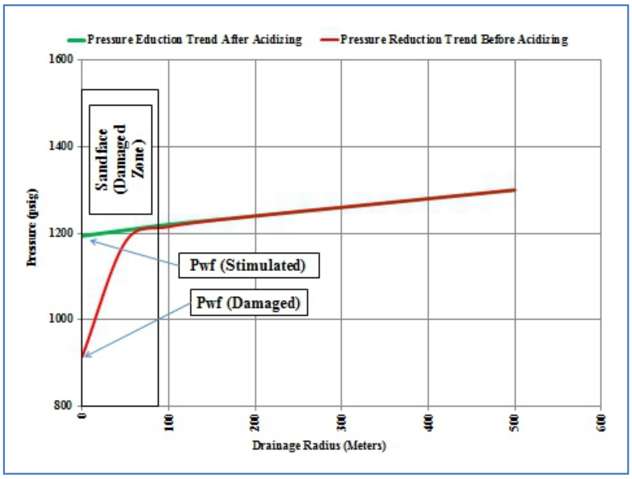

Figure 16. Effect of Acid on Pwf

Results and Analysis

The overall results show that the well before acidizing had damaged zone. Thus, this resulted to high pressure difference between Bottom-Hole Closing In Pressure and Bottom-Hole Flowing.

Conclusion & Recommendations

Conclusion

- Formation damage is a common problem in oil and gas fields, which yield reducing production rate.
- The stimulation technique, which can be used to reduce damaged section in the invaded zone due to participating scales and organic compound, is acidizing technique.
- HCL acid for Acidizing is a proper stimulation technique for this described field based on historical stimulation data.
- The process achieved the purpose by reducing draw down pressure between $\boldsymbol{Pwf}$ & $\boldsymbol{Pws}$ from 300 psi to 11 psi with high production rate.
- Based on the final test point after acidizing process, the result showed that the production rate increases to approximately 74% of the oil production rate.

Recommendations

- Selecting the stimulation process requires some historical and lab test data.
- For further stimulation technique, hydraulic fracturing can be used to increase formation permeability in the cleaned zone to increase production rate and reduce pressure differences between $\boldsymbol{Pwf}$ & $\boldsymbol{Pws}$.

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Appendices

Bottom-Hole Field Measurement Data

Table 2. Field Measurement Data Before Acidizing

Field M easurment Data / Before Acidizing								
Press. Survey (Close)			Depth, m G.L.	G.L. m ASL	Press. Survey (Flow)			BHT, C
Depth ft G.L.	BHCIPres sure, Psia	Gard. (psi/ft)			Depth, m MSL	BHFPressure, Psia	Gard. (psi/ft)	
0	425.36					245.103		49
500	432.403	0.014086	152.401853	324.45	-172.048147	309.355	0.128504	
1000	463.426	0.062046	304.803706	324.45	-19.6462936	388.117	0.157524	
1500	639.853	0.352854	457.20556	324.45	132.7555596	483.619	0.191004	
2000	815.778	0.35185	609.607413	324.45	285.1574128	596.988	0.226738	
2500	990.348	0.34914	762.009266	324.45	437.559266	729.558	0.26514	
3000	1162.437	0.344178	914.411119	324.45	589.9611192	872.823	0.28653	
3032	1173.41	0.34290625	924.164838	324.45	599.7148378	882.474	0.30159375	
3064	1184.398	0.343375				891.615	0.28565625	
3096	1195.256	0.3393125				900.713	0.2843125	
3128	1206.304	0.34525				909.552		
3160	1217.239	0.34171875				917.295		
3190	1228.746	0.38356667				927.48		

Table 3. Field Measurement Data After Acidizing

Field Measurment Data / After Acidizing								
Press. Survey (Close)			Depth, m G.L.	G.L. m ASL	Press. Survey (Flow)			BHT, C
Depth ft G.L.	BHCIPres sure, Psia	Gard. (psi/ft)			Depth, m MSL	BHFPressure, Psia	Gard. (psi/ft)	
0	434.942					350.45		41.287
500	455.115	0.040346	152.401853	324.45	-172.048147	444.115	0.18733	43.541
1000	568.716	0.227202	304.803706	324.45	-19.6462936	557.716	0.227202	45.134
1500	697.27	0.257108	457.20556	324.45	132.7555596	686.27	0.257108	46.499
2000	837.543	0.280546	609.607413	324.45	285.1574128	826.543	0.280546	47.677
2500	994.618	0.31415	762.009266	324.45	437.559266	983.618	0.31415	48.736
3000	1161.159	0.333082	914.411119	324.45	589.9611192	1150.159	0.333082	49.67
3032	1171.503	0.32325	924.164838	324.45	599.7148378	1160.503	0.32325	49.758
3064	1182.791	0.35275				1171.791	0.35275	49.794
3096	1195.256	0.3895313				1183.539	0.367125	49.815
3128	1205.028	0.305375				1193.959	0.325625	49.831
3160	1215.986	0.3424375				1204.633	0.3335625	49.863
3192	1227.748	0.3675625				1215.552	0.34121875	50.101

Table 4. SWT Result Before Acidizing

			Oil Production Rate	3113	bbls/day
			Gas flow rate	318038	cf/day
			Gas flow rate	1161163	scf/day
Choke Opening	30	%	GOR	373	scf/bbl
			Water	Trace	D1796
Length of test	7	Hours	Sediment	Trace	D1796
			Bitumen	Trace	D1796

Time	Wellhead		Manifold	Test Separator								
	WHFP Swab Valve	FLP at Wellhead	Manifold Pressure	Test Sep. Pressure	Oil Level	Water Level	Oil Temp.	Gas Temp.	Oil Flow Rate	Oil Meter Totaliser	Gas Flow Rate	Gas Meter Totaliser
	BAR	BAR	BAR	BAR	%	%	°C	°C	BBL/Min	BBLs	CF/Hr	CF
8:10	16.0	15.8	13.5	3.0	40.0	0	26	31	5.5	94522.0	7889.30	9153928.89
9:10	13.0	12.8	10.5	3.0	40.0	0	27	34	2.2	94660.0	3358.42	9167479.12
10:10	13.0	12.8	10.5	3.0	44.0	0	30	37	2.1	94783.0	7543.21	9180361.91
11:10	13.0	12.8	10.5	3.0	45.0	0	33	40	2.1	94915.0	18130.55	9193294.15
12:10	13.0	12.8	10.5	3.0	40.0	0	36	43	2.3	95051.0	12342.48	9206360.57
13:10	13.0	12.8	10.5	3.0	40.0	0	39	44	2.1	95174.0	17639.68	9219751.89
14:10	13.0	12.8	10.5	3.0	43.0	0	40	45	2.1	95300.0	3676.26	9233217.38
15:10	13.0	12.8	10.5	3.0	40.0	0	40	46	2.1	95430.0	20108.17	9246689.92

Table 5. SWT Result After Acidizing

			Oil Production Rate	5417	bbls/day
			Gas flow rate	286666	cf/day
			Gas flow rate	1139066	scf/day
Choke Opening	30	%	GOR	210	scf/bbl
			Water	0	D1796
Length of test	7	Hours	Sediment	Trace	D1796
			Bitumen	Trace	D1796

Time	Wellhead		Manifold	Test Separator								
	WHFP Swab Valve	FLP at Wellhead	Manifold Pressure	Test Sep. Pressure	Oil Level	Water Level	Oil Temp.	Gas Temp.	Oil Flow Rate	Oil Meter Totaliser	Gas Flow Rate	Gas Meter Totaliser
	BAR	BAR	BAR	BAR	%	%	°C	°C	BBL/Min	BBLs	CF/Hr	CF
8:15	23.0	22.8	20.5	3.0	36.0	0	5	4	1.5	171694.0	9436.08	16121918.75
9:15	22.5	22.3	20.0	3.0	45.0	0	10	13	3.5	171918.0	9665.62	16133805.67
10:15	22.5	22.3	20.0	3.0	45.0	0	12	16	5.1	172132.0	8839.26	16145752.62
11:15	22.5	22.3	20.0	3.0	40.0	0	15	18	3.5	172363.0	13762.13	16157643.07
12:15	22.5	22.3	20.0	3.0	40.0	0	15	18	3.6	172581.0	9619.72	16169724.21
13:15	22.5	22.3	20.0	3.0	36.0	0	15	17	3.6	172829.0	19857.44	16181649.98
14:15	22.5	22.3	20.0	3.0	38.0	0	15	16	3.6	173049.0	16082.30	16193596.93
15:15	22.5	22.3	20.0	3.0	38.0	0	14	15	3.6	173274.0	13476.08	16205529.75

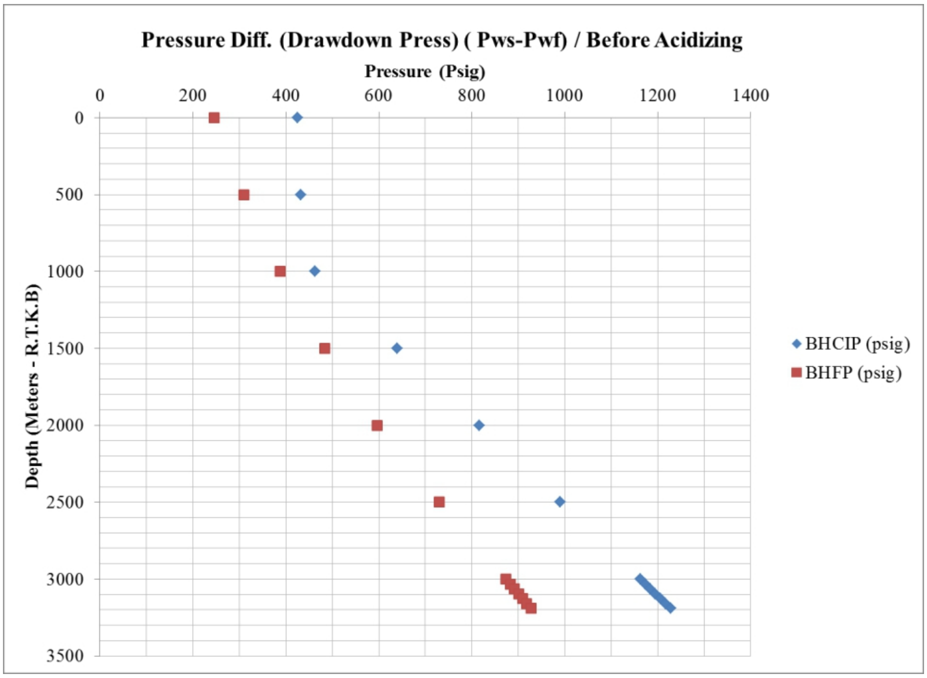

Figure 17: Pressure Diff. (Drawdown Press) (Pws-Pwf) / Before Acidizing

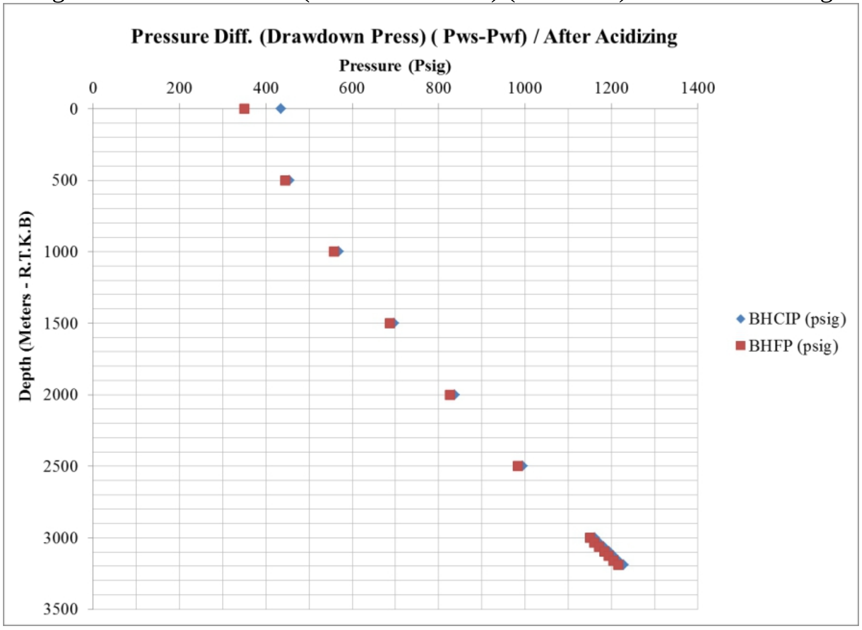

Figure 18: Pressure Diff. (Drawdown Press) (Pws-Pwf) / After Acidizing

Table 6: Acidizing Procedure Detail

Job Description	Transistion Zones Stimulation		Do you use diversion ?		No
Acidizing technique	Squeezing		Type of diversion		
Operation Design steps	Pressure test - Pickling - Main treatment - Soaking time				
Treatment design					
Pressure test (psi)	2000		Pickling volume (bbl)		10
Pickling additives					
32 % HCl (bbl)	8.25		Surfactant (%)		____
Corrosion inhibitor (bbl)	1		Iron control		____
Implemeted Acidizing Detail					
Date of Stimulation:	7/21/2015		Stimulated Formation		Transtion bed
Top of Formation (m)	911		Bottom of Formation (m)		918.8
Stimulation Stages	1	Vol	10	Vol Unit:	bbl
Type of treatment	Squeezing	Acid %	28	Max Treatment Pressure (Psi)	