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A Method for Stimulation Candidate Well Selection

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ABSTRACT

Production enhancement can be achieved by bridging the gap between the maximum flow rate and the operating point of a well. This can be done by stimulating the well either by matrix acidization or hydraulic fracturing. However, Fracture stimulation is used to overcome the adverse effects of formation damage and low permeability, accelerate production, increase reserves and control formation solids. These fracturing applications require different fracture stimulation designs to achieve their objectives; therefore a means of evaluating treatment designs is important to determine which of well is the optimum approach. In a field that has multiple wells to stimulate, the ones of adverse effect need to be rank first. Thus, this study was carried out to develop a model for stimulation candidate well selection base on skin due to damage, production increase, economics, payback period and the R-factor. Seven wells were used and the results obtained after the candidate well selection for stimulation job will help the company to prioritize the wells based on the model they choose.

Keywords; *Formation Damage, Stimulation, Candidate Well Selection, Well Productivity, Skin, Production Increase, Payback Period, Economics And Fracturing.*

1. INTRODUCTION

Stimulation is a term used to describe different operation carried out in an oil well to get optimum productivity. This technique is very vital to the production operation and is employed to encourage production to flow from the reservoir rocks to the wellbore since the hydrocarbons are located in the spaces between pores of reservoir rock. The ease out which the hydrocarbons flow from the reservoir rock to the wellbore is known as the permeability and it is achieved when the pore spaces are connected. Besides, well productivity can be adversely affected by formation damage in the near wellbore or by low natural permeability of the reservoir rock. The damage may be caused by drilling operations or the effects of long-term production and the severity of damage on the production depends on the location, extent and type of damage.

In an oil field, there are always more than one well producing from a reservoir and if these wells are not producing optimally, there is need to select the wells that are candidate for stimulation in other to increase productivity. Thus, candidate selection for matrix stimulation is based on finding wells with impaired productivity and diagnosing the cause of the impairment. The process of candidate selection consists of identifying wells with low productivity relative to what they are capable of producing and then evaluating possible mechanical problems in these wells (Thomas and Milne, 1995).

Candidate selection requires an accurate assessment of what a well can produce without impairment and the current productivity of the well. Techniques for making the assessments rely heavily on knowledge of the formation geology and reservoir properties. Methods for assessment of production system performance have been developed and are in wide use. The methods which help the engineers to quantify the extent of formation damage and the potential for productivity improvement were published by Earlougher, (1977). These are pressure transient analysis of reservoirs and well performance. The methods developed in this paper are based on skin due to damage, production increase, economics, payback period and the R-factor.

Well screening should be based on the potential production increase and incremental economics. Obviously, wells with the greatest potential should be selected as candidates. This process should include determination of the maximum allowable drawdown pressure before formation or sand production occurs (i.e., critical drawdown). The critical drawdown is used to predict expected production and is important in evaluating the economic potential of the treatment (Weingarten and Perkins, 1992).

Various investigations show that the success of hydraulic fracture operation mainly acquired by better candidate-well selection (Vincent, 2011; Malik *et al.*, 2006; Conway *et al.*, 1985). It could be said that candidate-well selection is the process of choosing or recognizing wells that have potential for higher production and better return of investment after stimulation job. In order to successfully performing hydraulic fracture treatment, the selection of the first well through well-defined methodology is of particular importance. This objective not only saves money and time but also will establish this technology as a proper stimulation method in carbonate/limestone reservoirs. So, the need for accurate hydraulic fracture candidate-well selection to eliminate possible failures becomes very important.

Guoynes *et al.* (2000) showed that success attributed to custom treatments based on accurate identification of damage mechanisms, using new testing methods and candidate selection. In fact, one of the current typical issues related to hydraulic fracture is selection of candidate-wells. Smith (2006) best describes hydraulic fracture as “The Multi-Disciplinary Technology.” If any single issue within fracturing most accurately epitomizes this, it would be the complex and multifaceted subject area of candidate-well selection. Martin, (2010) described the process of selecting candidate-wells for hydraulic fracture treatment for the increase of their productivity, as a challenging task. Although a common practice, researchers (Martin and Raylance; 2010; Martin and Economides, 2008; Mohaghegh, 2001) have a common view about candidate-well selection; there is not a straightforward process and up to now, there has not been a well-defined and unified approach to address this process. However, Moore and Ramakrishnan (2006) believed that it is possible to formulate a framework for proceeding with the candidate-well selection for a certain field.

2. THE CAUSES OF FORMATION DAMAGE

Formation damage is an impairment of reservoir permeability around the well bore, leading to low or no well production or injection. It simply refers to the decrease in permeability that occurs in the near wellbore region of a reservoir and this represents a positive skin effect. Formation damage is often quantified by "Skin" factor. Skin is strictly a measure of an additional pressure drop in the producing formation as fluids flow into a well. This excess pressure drop can occur from one or several of a wide variety of causes such as drilling mud, cement and completion fluid filtrate invasion, solids invasion, perforating damage, fines migration, formation compaction, swelling clays, asphaltenes/paraffin deposition, scale precipitation, emulsions, reservoir compaction, relative permeability effects, effects of stimulation treatments, etc. Therefore, it is evident that formation damage problems are caused by the nature of our activities during the process of interactions with our wells.

3. WHAT ARE THE TECHNIQUES AVAILABLE TO REMOVE THE DAMAGE FROM THE FORMATION

Basically, there are two methods of stimulating a well to remove the damage due to skin; these are matrix acidization and hydraulic fracturing. We have to note at this point that among the types of skin, it is only the skin due to damage that can be stimulated. Matrix acidization involves the placement of acid within the wellbore at rates and pressures designed to attack an impediment to production without fracturing or damaging the reservoir. In this treatment, the acid is injected into the pores and flow channels of carbonate rocks at a bottom-hole pressure considerably less than the fracturing pressure the purpose being to increase uniformly. On the other hand, hydraulic fracturing, which includes acid fracturing, involves the injection of a variety of fluids and other materials into the well at rates that actually cause the cracking or fracturing of the reservoir formation. These techniques usually cause a highly conductive flow path between the reservoir and the wellbore.

4. WHAT ARE THE PROBLEMS?

Since the oil and gas industry is a high risk and challenging venture, every operating company wants to get to the reservoir as fast as they can, but nobody wants to cause impairment to the ease at which the fluid gets to the wellbore. Now, the key to successful operation is how they could avoid the fluid-related causes of formation damage such as: foreign particle invasion and plugging, formation clay dispersion and migration, chemically incompatible fluids, oil wetting of reservoir rock, emulsion and water blocking and fluid invasion etc. it also noted the problem, however, is that the highest permeability zones are the easiest to damage, and that can have a major impact on productivity. Furthermore, the assortment of chemicals pumped down the well during drilling and completion can often cause damage to the surrounding formation by entering the reservoir rock and blocking the pore throats (the channels in the rock throughout which the reservoir fluids flow). Similarly, the act of perforating can have similar effect by jetting debris into the perforation channels. Both of these situations reduce the permeability in the near wellbore are and so reduce the flow of fluids into the wellbore.

5. OBJECTIVES OF STUDY

The aim of this paper is to develop a simple tool for candidate well selection based on skin due to damage, production increase, economics, payback period and the R-factor to enhance oil well production performance. This will aim at the following:

- To increase a well's productivity by restoring oil production to original rates less normal decline, or to boost production above normal predictions
- Develop an analytical and a computer base application for candidate well selection for stimulation and racking of the wells since acidizing and fracturing will only work when selecting the right well and conducting the correct design.
- Estimation of the well performance after stimulation operation to justify its successes.

6. MODEL DEVELOPMENT

The success of every stimulation operation such as acidizing and hydraulic fracturing is of vital importance to the oil and gas industry, therefore an in-situ stress analysis will be a key to the stimulation operation despite the wells have been selected and rank in the order that they should be acidized during the planned well stimulation campaign. Thus, the internal pressure must be higher than the minimum horizontal stress, to prevent the fracture being closed. Minimum horizontal stress can be calculated, based on the Eaton equation:

$$\sigma_h = \frac{v}{1-v}(\sigma_{v-}p_P) + p_p \quad \ldots \ldots (1)$$

$$FG = \sigma_h - p_n \quad \ldots \ldots (2)$$

The mathematical equations used in developing the tool for candidate well selection are given in appendix A.

7. WELL AND RESERVOIR DESCRIPTION OF THE FIELD

The model developed in excel is required to rank the 7 wells in the field in the order that they should be acidized during the planned well stimulation campaign. It is required to justify its selection in terms of the potential production increase and treatment cost efficiency (US $ per additional BPD oil production capacity). The artificial lift installations in each well and the surface production facilities have sufficient capacity to cope with the production increases. The completions installed for the 7 wells are similar with a wellbore radius of (r_w) 0.3592ft and a drainage radius (r_e) of 1630ft. the formation height is fully perforated with an interval height (h) of 100ft. the reservoir oil has a viscosity of 0.42cp under downhole conditions and the volume shrinkage value during production (B_o) is 1.325 bbl/stb. The formation porosity is 35% and is independent of permeability.

The wells are all damaged during the completion phase due to lack of fluid loss control which implies that greater volume of (damaging) completion fluid were lost into the higher permeability wells. The fluid loss caused smaller (percentage) damage in the higher permeability, more productive wells. One pore volume of acid to be injected into each well to remove this formation damage. The cost charged for the stimulation fluid pumped is 2800US$/ft^3 and the revenue from the produced fluid is $8/bbl. It is important to note that the company's requirement is a 2 months payback time in its stimulation campaign. The table below is an additional data for analysis;

8. FRACTURE GRADIENT ANALYSIS

Table 1: Fracture gradient determination

Well	Depth (ft)	Poisson ratio	σv (psi/ft)	σh (psi/ft)	Pn	Gn	FG (psi/ft)
1	11808	0.19	1.01	0.6342	6452.6	0.5465	0.0877
2	11843.8	0.16	1.00	0.6106	7015.7	0.5924	0.0183
3	11920.3	0.20	1.02	0.6443	5967.2	0.5006	0.1437
4	12944.2	0.16	1.05	0.6201	6016.9	0.4648	0.1553
5	12652.2	0.30	1.00	0.7251	8005.4	0.6327	0.0924
6	12799.5	0.33	1.01	0.7554	7245.8	0.5661	0.1893
7	12988.2	0.27	1.03	0.7080	7812.3	0.6015	0.1065

In a successful hydraulic fracturing, the internal pressure must be higher than the minimum horizontal stress, to prevent the fracture being closed. Therefore, a proper analysis on the pore pressure and fracture gradient is required prior to the hydraulic fracturing job in other for it to be successful. This is to know the pressure at which the fracture fluid will be pumped above the determined formation fracture pressure to cause a crack or create a drainage area in the formation. Hence, figure 1, shows the fracture gradients of the seven wells.

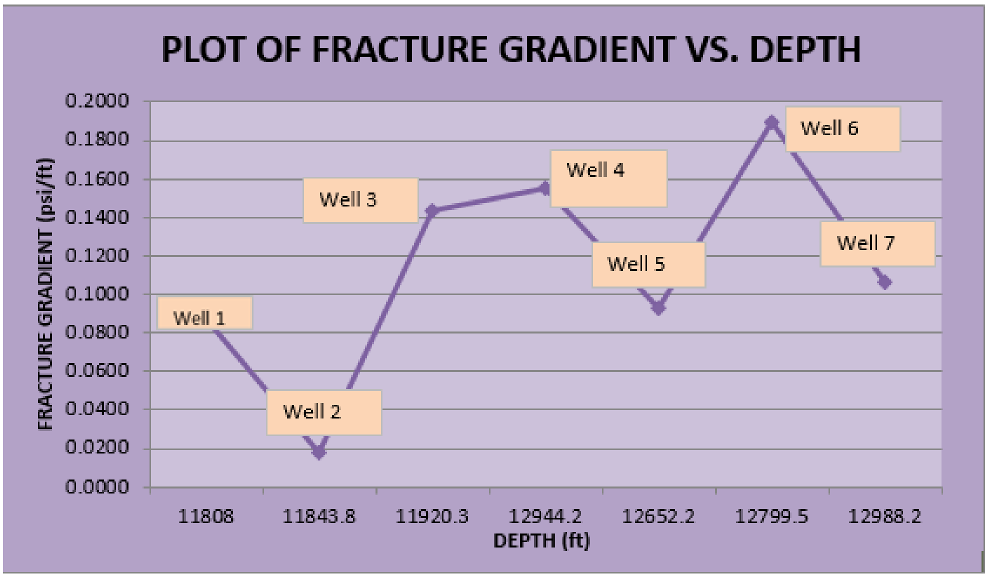

Figure 1: Fracture gradient versus depth plot

9. RESULTS FROM THE WELLS BASED ON SKIN DUE TO DAMAGE

Table 2: Results of skin due to damage

PARAMETERS	UNITS	WELL 1	WELL 2	WELL 3	WELL 4	WELL 5	WELL 6	WELL 7
Undamaged (k)	mD	998.00	786.00	629.00	500.00	382.00	707.00	680.00
% of k damaged	%	20.00	35.00	64.00	75.00	80.00	48.00	52.00
% of undamaged k	mD	199.60	275.10	402.56	375.00	305.60	339.36	353.60
Damage premeability (K_d)	mD	798.40	510.90	226.44	125.00	76.40	367.64	326.40
Permeability ratio (K/K_d)		1.25	1.54	2.78	4.00	5.00	1.92	2.08
Depth of damaged	in	22.00	17.00	11.00	9.00	8.00	16.00	14.00
Damage radius (r_i)	ft	2.19	1.78	1.28	1.11	1.03	1.69	1.53
skin (S)		0.45	0.86	2.25	3.38	4.20	1.43	1.57
RANK ORDER		7	6	3	2	1	5	4

From figure 2, well 5 is the well with the highest skin, which is heavily damaged and is ranked first. But that is not a yardstick to determine if it is a candidate well for hydraulic fracturing. However, this ranking by skin factor does not take into account that the well shows wide formation permeability range. Hence the R factor model to determine which well that will be recommended for stimulation. The figure 2 below shows the ranking of the seven wells according to pseudo skin due to damage.

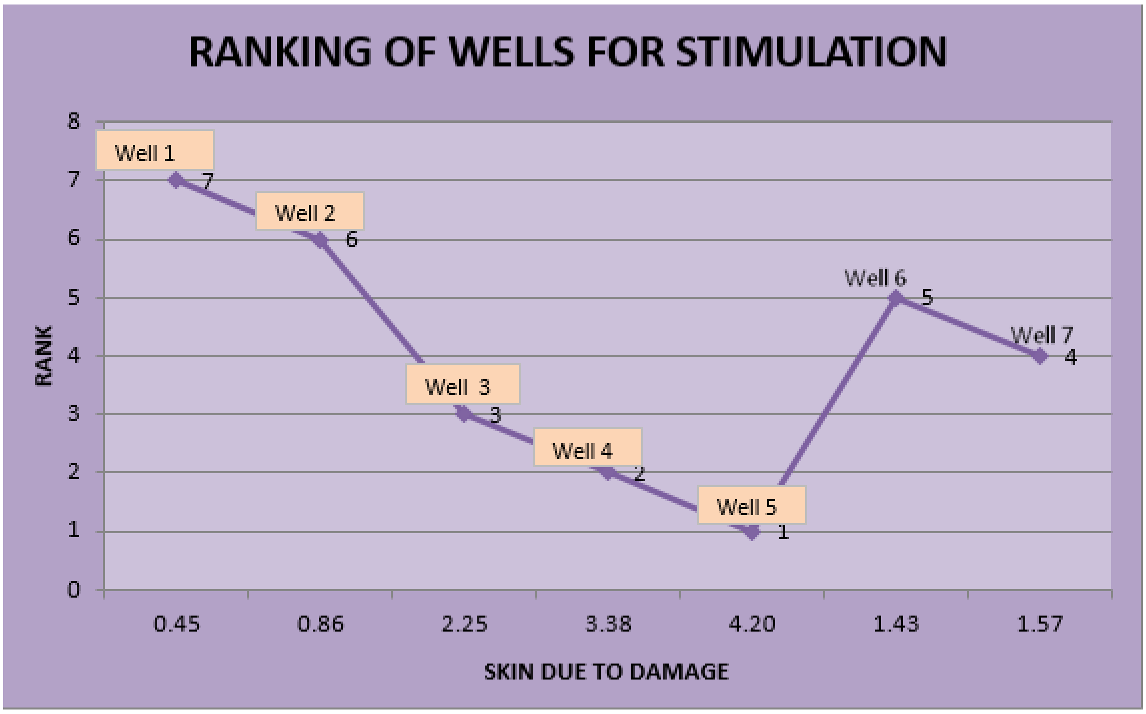

Figure 2: Ranking of well based on skin due to damage

10. RANKING AND CANDIDATE WELL SELECTION FOR STIMULATION BASED ON POTENTIAL GAIN

Table 3: Results of increase in production

PARAMETERS	UNITS	WELL 1	WELL 2	WELL 3	WELL 4	WELL 5	WELL 6	WELL 7
skin (S)		0.45	0.86	2.25	3.38	4.20	1.43	1.57
Productivity ratio (j_o/j_i)		0.95	0.91	0.79	0.71	0.67	0.85	0.84
Damage production rate (Q_i)	BPD	17177.84	12933.63	8999.60	6469.46	4623.37	10960.17	10397.94
Undamage production rate (Q_o)	BPD	18100.43	14255.45	11407.99	9068.35	6928.22	12822.65	12332.96
Increase in production (Q_o-Q_i)	BPD	922.59	1321.82	2408.39	2598.89	2304.85	1862.48	1935.02
RANK ORDER		7	6	2	1	3	5	4

From the result of table 3, it can be seen that the stimulation candidate criteria is different from that of skin due to damage. The graph below indicates that well 4 has the largest increase in production and should be rank first with the least as well 1 which was also the least in ranking based on skin due to damage. A different picture results if we base the ranking criteria on economics; based on the fact that we know the depth of the formation damage and can thus alter the acid treatment size depending on the volume of the rock to be treated.

Figure 3: Production increase

11. RANKING AND CANDIDATE WELL SELECTION FOR STIMULATION BASED ON ECONOMICS

Table 4: Economic analysis

PARAMETERS	UNITS	WELL 1	WELL 2	WELL 3	WELL 4	WELL 5	WELL 6	WELL 7
Increase in production	BPD	922.59	1321.82	2408.39	2598.89	2304.85	1862.48	1935.02
Formation pore volume	ft^3	514.46	332.62	164.82	121.11	101.54	300.84	241.85
Cost of treatment	US$	1440485.79	931346.68	461507.92	339107.89	284322.79	842348.69	677182.55
US$ per BPD added production	US$/BPD	1561.35	704.59	191.63	130.48	123.36	452.27	349.96
RANK ORDER		7	6	3	2	1	5	4

From table 4, well 5 is now the most attractive stimulation candidate since it minimizes the investment required for the gain in production capacity. The results based on production increase are almost the same with the results from economic analysis with except of well 3, 4 & 5 respectively.

12. RANKING AND CANDIDATE WELL SELECTION FOR STIMULATION BASED ON PAYBACK TIME

The two months payback criteria can now be used to determine if the treatments are economical.

Table 5: payback time

PARAMETERS	UNITS	WELL 1	WELL 2	WELL 3	WELL 4	WELL 5	WELL 6	WELL 7
US$ per BPD added production	US$/BPD	1561.35	704.59	191.63	130.48	123.36	452.27	349.96
Payback time	days	195.1689	78.28803	21.2917	14.49796	13.7065	50.2524	38.8845
Payback time	months	6.420031	2.575264	0.70038	0.476907	0.45087	1.65304	1.2791
Economic to carryout		no	no	yes	yes	yes	yes	yes
Payment order				3	2	1	5	4
% of total production	%	6.90868	9.89883	18.03488	19.46145	17.25955	13.9469	14.4902

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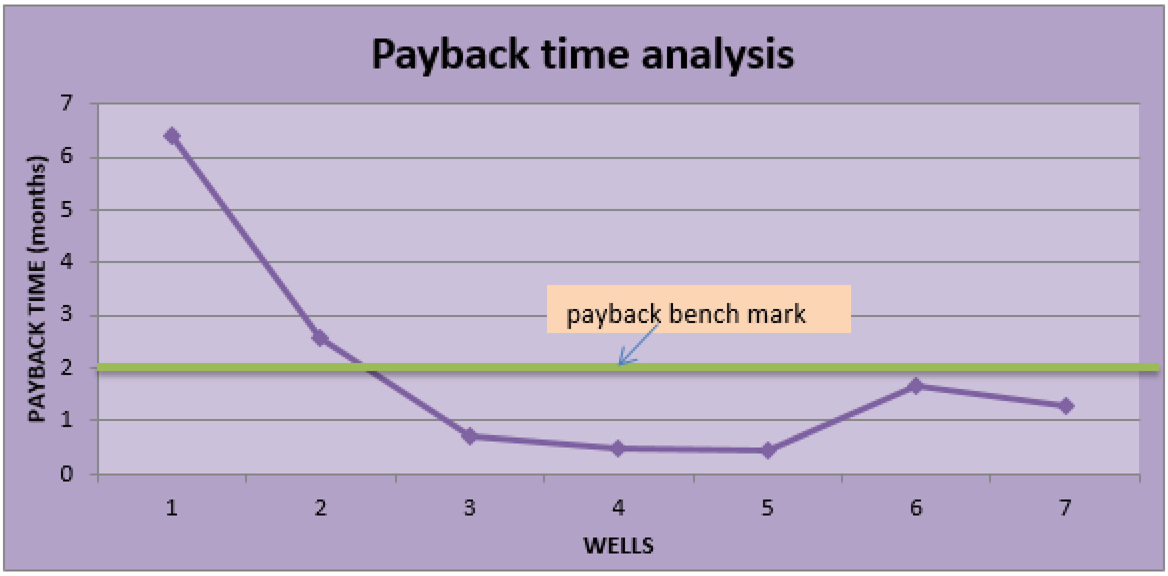

Figure 5: payback time analysis

Based on the percentage of total production for the seven wells and 2 months payback time criteria by the company, well 1 & 2 are not candidate wells for stimulation because the exceed the bench mark and with little contribution to total production in the field and as such, well 5 with the third highest production contribution is ranked first ahead of well 4, the highest production contribution based on payback time.

13. R FACTOR

All the seven wells used in this analysis of candidate wells for stimulation are not recommended based on R-factor since all of them are less than 0.6. This implies that the wells might not lead to a large increase in revenue

Table 6: R-factor

PARAMETERS	UNITS	WELL 1	WELL 2	WELL 3	WELL 4	WELL 5	WELL 6	WELL 7
skin (S)		0.45	0.86	2.25	3.38	4.20	1.43	1.57
Undamage production rate (Qo)	BPD	18100.43	14255.45	11407.99	9068.35	6928.22	12822.65	12332.96
pressure drop due to skin (ΔP_s)	psi	6.4449	12.2641	32.1132	48.2061	59.8226	20.3918	22.3316
pressure drop	psi	120	120	120	120	120	120	120
R-factor		0.05370	0.10220	0.26761	0.4017	0.4985	0.16993	0.18609

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14. SUMMARY OF RESULTS

Criteria	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
Pseudo skin due to damage	7	6	3	2	1	5	4
Production Increase	7	6	2	1	3	5	4
Economics	7	6	3	2	1	5	4
Pay Back Period			3	2	1	5	4

15. CONCLUSION

Based on the analysis of the various wells to determine which well will be a candidate for stimulation using skin due to damage, production increase, economics, payback period and R factor criteria of less than 0.6, it therefore means that all the wells will be recommended for stimulation based on skin due to damage, production increase and economics and these are ranked accordingly. On the contrary, well 1 & 2 will not be recommended based on the company's criteria of two months payback period and also, R-factor model indicating that none will be recommended based on the available date. Hence, ranking of the wells will be based on the other models except the R factor to determine which well comes first in the stimulation job. The results obtained after the candidate well selection for stimulation job will help the company to prioritize the wells based on the model they choose. Finally, the determination or obtaining the pore pressure and fracture gradient is very important to know the rate to inject the fracture fluid into the formation.

16. RECOMMENDATIONS

From the results obtained, the following recommendations are draw:

- Wells with positive skin are often recommended for stimulation.
- The total skin may not be a good yardstick for determining stimulation candidates. It is better to used pseudoskin due to damage, but preferably uses the R factor, this is because the total skin might be very high but the amount of skin due to damage in it will be low.
- An importance should be placed on the determination of fracture gradient before the fracturing job for it to be successful.
- In our next paper an estimation of the well performance after stimulation operation to justify its successes will be presented.

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