Assessment of Scale Removal by Chemical and Underbalance Mechanical Treatments

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Abstract

Scale in oil and gas wells is a major problem leading to significant losses in production and therefrom potential revenue. Scale limits oil and gas production by plugging oil-producing matrix, perforations, tubing, flowlines and other production facilities. Most common scale deposits are calcium carbonate, calcium sulfate and barium sulfate. Scale problems cost the petroleum industry hundreds of millions of dollars per year in both scale removal operations and lost production. Chemical scale removal is often the first lowest cost option especially when mechanical removal methods are unemployable. The aim of this paper is to review and assess the effectiveness of both treatments. Chemical treatments involve the injection of chemicals such as hydraulic acid, while the mechanical method utilizes pressure difference between the reservoir and wellbore in order to remove scale. Five wells were considered that were first chemically treated and then were, after some prolonged time, mechanically treated. The results indicate that the mechanical treatment does not always efficiently remove scale from perforations compared to the chemical treatments. The efficiency of each treatment showed increase and sometimes decrease of oil production. The scale source plays a significant role on the treatment type that must be considered to minimize cost.

Keywords

Underbalance scale removal, chemical scale treatment, mechanical scale treatment, oil and gas production.

1. Introduction

Scale deposition across perforation tunnels is an ongoing and serious problem encountered during the lifetime of an oil or gas wells. However, the perforation tunnels create a flow path between the formation and wellbore. The pressure difference between them can drive surge flow, either from the formation into the wellbore or from the wellbore into the formation. Deposited particles in the perforation tunnels hinder the flow of oil and/or gas leading to significant increase in pressure drop and therefrom dwindled production. If the well is not treated by removing, or at least reducing, the deposited scale, the production rate could ultimately become zero. Scale deposits usually form due to the crystallization and precipitation of minerals dissolved in water. In general, scale is deposited in formation, wellbore, down-hole pumps, tubing, casing and flow-line. The direct cause of scaling is frequently the pressure drop, temperature changes, mixing of two incompatible waters or exceeding solubility products. On the other hand, common scale removal treatments include chemical scale removal (CSR) and mechanical scale removal (MSR). Several factors affect the type of treatment to be considered such as the amount of precipitation and costs. Harive et al (2011) reported that CSR is more costly than MSR, however, the present study found that the cost of MSR treatment is one-and-half more than the cost of CSR treatment.

This paper reviews and assesses the effectiveness of both CSR and MSR treatments. Five oil producing wells from a Libyan oilfield were considered in this study. The scale types found in these wells are sulfates and carbonates salts.

Since MSR is relatively new, the wells had first been chemically treated and later mechanically treated. The technical efficiency shows both treatments do not always lead to an increase in in oil production.

2. Oilfield Scales Types

Generally, water is primary important in oilfield scaling as most scale deposits occur if water is produced. Water is a good solvent for many materials and can carry large qualities of scaling minerals. Some oilfield scale deposits are pH independent and others are pH sensitive; scaling tendency of sulfates (calcium sulfate, barite and celestite) and halite scales are not a strong function of brine pH. The carbonates (calcite, dolomite and siderite) and sulfide scales are acid soluble and their scaling tendencies are strongly influenced by brine pH. For pH sensitive scales, scale prediction is more complicated since issues that control the brine pH also affect their scaling tendencies, (Olajire, 2015). Most common oilfield scales in Libya are sulfates such as calcium sulfate (anhydrite, gypsum), barium sulfate (barite), strontium sulfate (celestite) and calcium carbonate.

Common scale found in oil producing wells of the present study is mainly calcium sulfate or gypsum/$CaSO_4$ due to incompatibilities between injection water and formation water. The sources of different ions are Barium and Calcium ions for formation water and Sulfates ions for injection water. The precipitation of $CaSO_4$ might be caused by either heating of injected water due to high reservoir temperature, which is around 300 ^{o}F, or/and mixing of water with different salinities which creates incompatibilities. The deposits of $CaSO_4$ particles might occur close to the wellbore due to different velocities between reservoir section and perforation zone. Further, friction pressures and temperature variations in the wellbore induce local deposits of anhydrite. As a result, scale deposits affect the productivity index of the well in different ways: (1) plugging perforation tunnels; (2) creating restrictions in casings and production tubing; and (3) causing malfunctioning of safety valves. Different treatments can be performed for the different mentioned scale segments. Scale removal techniques must be quick and effective to restore production rate. Best scale removal technique depends on knowing the quantity and scale type; a poor choice can promote rapid return of scale.

The simplest method of physically detecting scale in the wellbore is to run productivity log tool (PLT), shown in Fig. 1, down the wellbore. Generally, PLT consists of caliper, gamma ray, spinner, density identifier, and pressure and temperature sensors. Scale precipitation can be detected in the tubing and casing by measuring any decrease in the tubing and casing inner diameters. Gamma ray log interpretation has been used to indicate scale precipitates in perforations. The spinner can measure flow rates and the density identifier is used to derive type of produced fluids. Thus, PLT is an essential tool for monitoring or for candidate well/interval selections. Moreover, PLT consists of running logging tool in a well under dynamic or static conditions. Production type, production intervals and flow rates can be determined using proper interpretation of PLT data. Accordingly, PLT information is used to distinguish between perforation intervals that flow oil and that flow water. Crabtree in 1999 offered an example of this technology as illustrated in Fig. 2. The figure shows that the 1997 gamma ray buildup on the lower side-pocket mandrel one year before treatment, while the 1998 log was measured after the scale was removed from the zone between X872 and X894 m (region of scale removal).

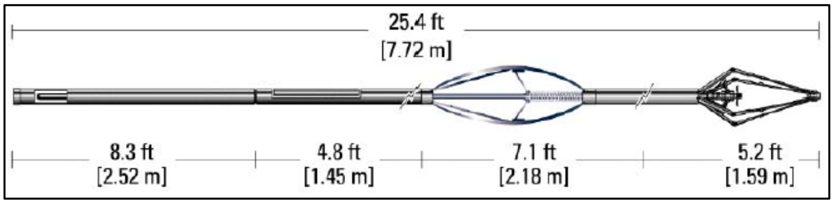

Fig. 1 - Production log tool (PLT)

Since scale deposits plug the producing perforation intervals, it is not possible to identify the real potential of a specific interval if the scale deposition has already occurred at the moment of first PLT. Ideally, PLT should be carried out immediately after the first perforation job in each layer. This is important for two reasons; (a) to be compared with the open-hole log based performance prediction, (b) as baseline of all single level key parameters to be compared with PLT recorded in future production life of the layer.

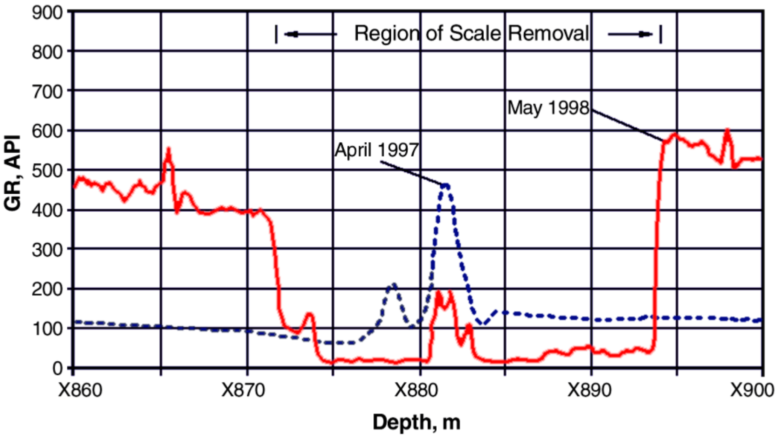

Fig. 2- Gamma ray log interpretation (after Crabtree, 1999)

2.1 Chemical Scale Removal, CSR

In CSR, the chemical washes are used to attack soluble deposits across perforations; however, normally fresh water is pumped first before the designated chemical is injected. Water jetting cleans out soft scale such as halite and debris and also maintains the concentration of injected chemical unchanged. Various chemical solvents dissolve hard scales, depending on their mineralogy. The most common chemical solvents are: 1) *Hydrochloric acid* (HCl); it used to dissolve all carbonate scales such as $CaCO_3$ and $FeCO_3$ and iron scales such as iron sulfide (FeS) or iron oxide (Fe2O3). HCl is also efficient with hydroxide scales such as magnesium (Mg(OH)2) or calcium (Ca(OH)2) hydroxides. Weak acidic (HCl, acetic) solutions are also used to remove sodium chloride (NaCl) scale. 2) *Chemical compounds*; they are used to remove gypsum ($CaSO_4 \cdot 2H_2O$) or anhydrite ($CaSO_4$). These compounds convert the sulfate to a hydroxide or other ion form followed by acid or by direct dissolvers such as ethylenediamenetetraacetic acid (EDTA) or other types of agents. EDTA can also be used to dissolve barite ($BaSO_4$) or celestite ($SrSO_4$) scales but at higher temperature and longer contact times. 3) *Hydrofluoric acid* (HF); it is used to dissolve silica scales.

The typical procedure of pumping steps involved in squeezing inhibitors for a chemical scale removal job, acid cleans the scale and debris out of the wellbore to “pickle” the tubing. It should not be pushed into the formation. To effectively remove scale, the chemical must be in contact with deposits for a period of time (soaking time). This soaking time, however, is an important factor in designing a scale removal treatment. The major concern in treating scale deposits is allowing sufficient time for the treating fluid to reach and effectively dissolve the bulk of the scale material. Treating fluid must dissolve most of the scale for the treatment to be successful (Hill et al., 2000 and Tyler et al., 1985). Usually, time required for treating scale deposits is determined experimentally. After allowing sufficient time for scale to convert, the sludge is washed or pumped from the well or dissolved by an acid.

2.2 Mechanical Scale Removal, MSR

The MSR is essentially based on creating a dynamic underbalance in which the wellbore pressure is less than formation pressure. The underbalance surge is created when surge chamber is allowed to accept wellbore fluid and debris. This creates a low pressure and is propagated throughout the wellbore. The underbalance surge can clean the perforation in two main ways (Bolchover and Walton, 2006). First, the debris can be transported out of the perforation tunnel. Second, the damaged zone can be cleaned up either by mobilization of fines or by additional failure of the damaged rock. The tool, similar to that assessed by Harive et al. (2011) containing surge vents and chambers, is utilized to create and optimize dynamic underbalance conditions. Thus, in a few hundred milliseconds after the tool detonates its perforating gun; the wellbore pressure is dropped significantly below static formation pressure, creating a dynamic underbalance. The created differential pressure flushes back perforating debris and crushed rock to clean the perforations. The perforating assembly can also be modified with increased gun volume and addition of specially designed vents and surge chambers to optimize pressure surge behavior. As a result, MSR treatment creates a dynamic underbalance regardless of initial pressure conditions. It is normally compatible with or can be performed by tubing-conveyed perforating, slick-line, wire-line or coiled tubing.

3. Scale Removal Results and Discussion

CSR treatment used to remove down-hole sulfate deposits, from wells selected for the present study, was first performed in 1996. Coil tubing is normally used to perform CSR jobs after a washing operation by HCl acid. The wells have a five inch liner at approximately 12,000 to 15,000 ft with high pressure and temperature around 6500 psi and 300 ˚F, respectively. Salinities of produced and injected waters are 160,000 and 7,000 ppm, respectively. Scale occurred below packer and dispersed inside and outside the 3½ inch tubing leading to plugged perforation tunnels. Chemical analysis showed that the scale was a mixture of CaCo4, CaCo3 and FeCo3 in various proportions. On the other hand, first MSR treatment was conducted in 2009 for the wells considered in the present study. Production test data, before and after the scale removal jobs, was calculated considering the same flowing tubing head pressure. The calculations are summarized in Table 3 for the five selected wells. Results of production tests are compared at equal conditions.

3.1 CSR Treatment

Chemical, used for the selected wells, was diluted 50% by water and pumped into the wells. Coil tubing is reciprocating up and down from around 150 ft above top perforation and 30 ft below bottom perforation. Then a portion of the chemical was squeezed into perforations and left to soak for 36 hrs. Thus, the pumped chemical converted the calcium sulfate scale to soluble sludge dissolvable by acid or washable out by water.

For instance, CSR treatment was conducted on well #2 that has a total depth of 14612 ft including four perforated intervals in E2 and E1 layers (P1; 11,3862 – 13,872 ft, P2; 13,882 – 13,892 ft, P3; 13,900 – 13,960 ft, and P4; 13,980 – 14,014 ft). The well was completed with a five-inch liner and tubing shoe was set at seven ft above the top perforations. The first PLT and baseline was logged in February 2009 prior to scale inhibitor operation to determine the down-hole flow profile following a scale inhibitor squeeze operation performed. The well was logged in both shut in and flowing conditions. However, it was decided to log only the two bottom-perforated intervals (P3 and P4) to avoid pulling the tool string in the tubing (risk of pulling out the tool). The second run was logged in March 2009 around one month after the first run. The tool string was 36 ft length included a full suite of sensors. Since the top interval was not logged, it was not possible to directly compare the total down-hole measured flow rate with the surface flow rate. The evaluation was only made to correspond logged intervals. Comparison of the first and second run is presented in Fig. 3. The solid green line denotes the baseline gamma ray (first run) while the dotted green line represents the second run. Generally, increasing gamma ray reading compared to the baseline log indicates presence of scale deposits. This, however, might plug the perforation tunnels and reduce inside casing diameter. It is interesting to note that, as shown in Fig. 3, the increased gamma ray peaks across the perforations which suggests more radioactive scale than in first run. Evaluation of scale treatment is summarized in Table 1. It shows that before treatment, perforation interval P4 accounts for most produced oil and water. It can be observed from the table that after the scale was removed, oil production almost doubled and water production increased by around one-quarter.

Table 1 - Flow rates before and after the CSR treatment

Perforation	Before UB MSR			After UB MSR		
	Oil bpd	Gas Mscf/d	Water bpd	Oil bpd	Gas Mscf/d	Water bpd
P1	Not Logged			Not Logged		
P2						
P3	189	265	391	343	0	915
P4	408	596	1858	752	0	1972
Total	597	861	2249	1095	0	2887

3.2 Underbalance MSR Treatment

In MSR, before underbalance surge is created, the designated well is washed by acid to remove scale deposits in the tubing and casing. Then PLT is run down to cross the perforation interval at static and flowing conditions. PLT data are then interpreted in order to select the perforations that require scale removal. The required pressure difference for the underbalance surge is then calculated by software for each candidate perforation interval. Finally, PLT is rerun to obtain flow profile of the well so that comparison with previous results is made to evaluate the treatment job.

Well #5 underwent an MCR treatment and used as an example in the present study. The well was drilled to a total depth of 14,549 ft and completed with nine perforation intervals in five layers (P1; 14,148 – 14,158 ft, P2; 14,166 – 14,232 ft, P3; 14,241 – 14,280ft, P4; 14,283 – 14,293 ft, P5; 14,320 – 14,337 ft, P6; 14,343 – 14,346 ft, P7; 14,352 – 14,359 ft, P8; 14,371 – 14,375 ft, P9; 14,383 – 14,390 ft). PLT was run before MSR treatment across interval 14,033 – 14,442 ft. PLT interpretation shows the well was producing 769 bpd at 83% water cut. Perforations P2, P3 and P5 were the main water and oil contribution zones while perforation P4 was not contributing to flow. Perforations P6, P8 and P9 were mainly producing water with limited oil. As a result, the three top perforations (P1, P2 and P3) were candidate for an underbalance MSR (UB MSR) treatment. The PLT interpretation results, after UB MSR treatment, showed that the well was producing at an oil rate of 2293 bpd at 62% water cut. The candidate perforations showed good improvement as illustrated in Table 2 and Fig. 4.

Table 2 - Flow rates before and after the UB MSR treatment

Perforation	Before UB MSR			After UB MSR		
	Oil bpd	Gas Mscf/d	Water bpd	Oil bpd	Gas Mscf/d	Water bpd
P1	23	68	24	350	534	403
P2	327	780	738	1084	1650	1045
P3	300	733	1448	567	892	1879
P4	0	0	0	0	0	0
P5	98	165	821	183	280	224
P6	4	9	132	0	0	0
P7	6	10	29	0	0	0
P8	10	19	199	97	145	0
P9	2	9	293	12	22	170
Total	770	1793	3684	2293	3523	3721

The overall scale removal treatment results for the five wells are summarized in Table 3. Generally, for CSR, PLT log interpretation, scale type, and soaking time all affect the assessment of scale removal treatment effectiveness. Similarly, for MSR, assessment of a treatment mainly relies on differential pressure calculation accuracy PLT log interpretation that was adopted to select the targeted perforation interval. Thus MSR reliance on PLT log interpretation is stronger than that of CSR. The following are separate discussions for all wells considered:

- First and second CSR treatments for well #1 were performed during 1999 and 2004. Treatments were successful leading to increase in oil production by 25% and 73.3%, respectively. However, CSR treatment performed in 2005 yielded negative results as oil production rate decreased from 5558 to 5421 bpd. UB MSR treatment was performed in 2009 that resulted in an increase in oil production from 627 to 1784 bpd. Thus, MSR treatment was fully justifiable as it yielded almost three times the production rate.

- Well #2 had the heaviest scale deposition problems among wells considered in the present study. Scale precipitation consisted of mainly calcium sulfate deposits and lower concentrations of barium and strontium. Seven CSR treatment jobs were conducted in this well during the period from February 2003 to March 2009. Each job had different improvement on oil production rates by various percentages ranging from 13.2% to 156.8%. The treatment during February 2004 yielded best results among them. It shows oil production increased by 156.8% and water cut decreased by 21%. On the other hand, only one MSR was conducted in July 2010 resulting in an increase in oil production by 3.5% and a decrease in water cut by 3.7%.

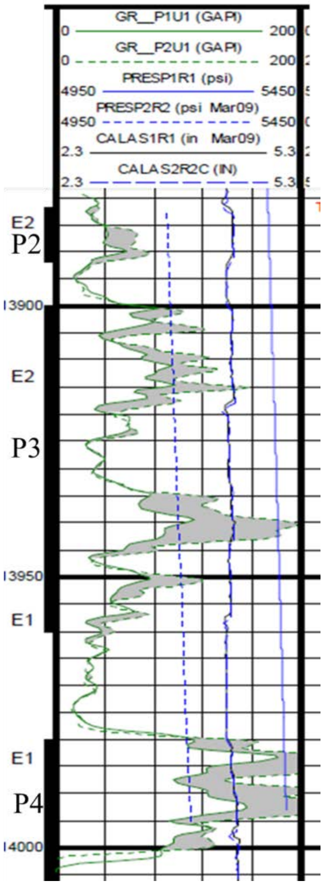

Fig. 3 – well flowing first run (sold green line) vs. second run comparison (dotted green line)

- Five CSR jobs were performed on well #3 from June 1998 to May 2003 and one UB MSR performed in June 2010. CSR treatment conducted in November 2000 had contributed to an increase in oil production by 106.6%. However, subsequent CSR treatments in December 2001 and May 2003 had led to decrease in oil production by 5.3% and 0.4%, respectively. Water cut was also increased by 140.9% and 68.4% respectively. UB MSR treatment was performed in June 2010 resulted in increase in oil production rate and water cut by 40.1% and 791.1% respectively.

- Well #4 was producing in May 1996 at low oil flow rate of 458 bpd and high water cut of 72%. Thus, the well was a candidate to CSR treatment that was performed in May 1996; however, the job was unsuccessful. Oil flow rate decreased to 381 bpd and water cut increased by 6.9%. Subsequent CSR treatments performed in June 2003 and February 2004, however, were successful leading to increase in oil production rates by 359.8% and 258.1%, respectively. In January 2010, the well was subjected to UB MSR treatment that yielded good improvement in oil production; oil rate increased from 478 bpd to 1234 bpd; whereas, water cut decreased from 76.19% to 53.7%.

- Two UB MSR jobs were performed to well #5 in June 2009 and June 2010. In June 2009, PLT interpretation results showed that the well was producing 874 bpd of oil at 78.18 % water cut. After the UB MSR treatment, PLT interpretation results showed an improvement in oil production rate by 67.7% along with a drop in water cut by 20.7%.

4. Conclusion and Recommendation

This work assessed the effectiveness of both chemical and underbalance mechanical treatments. Five wells were selected from a Libyan oilfield. Wells had first been treated by chemical scale removal (CSR) technique then later were treated by an underbalance mechanical scale removal (MSR) technique. Overall results indicate that MSR does not always efficiently remove scale from perforations compared to CSR treatments. On the other hand, both treatments vary in their efficiency. Treatments mostly result in increase in oil production; however, in few cases the treatments resulted in decrease in oil production. For MSR, assessments of the treatment mainly rely on the differential pressure calculation accuracy and PLT log interpretation that is the base for selecting the perforation interval. Therefore, MSR reliance on PLT log interpretation is stronger than that of CSR. Moreover, scale source and type have significant roles on the treatment type selection.

The authors highly recommend further deeper investigation on the reasons behind the varying effectiveness of MSR and CSR.

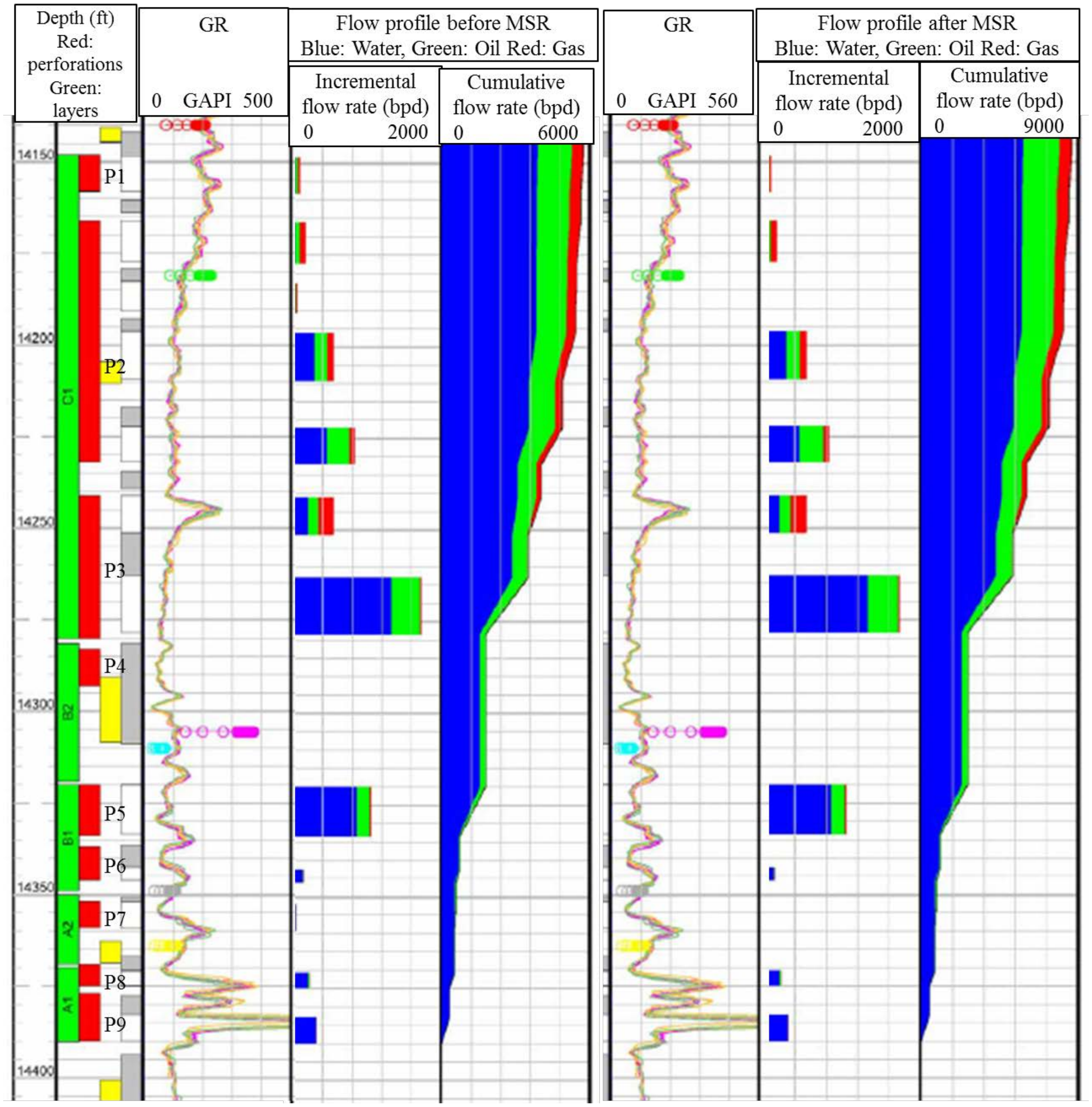

Fig. 4 – Flow profile before and after UB MSR treatment

Table 3- Treatment history of the wells

Well#1

Date	Treatment	Before Treatment			After Treatment			Improvement %		
		Oil bpd	GOR scf/stb	WC %	Oil bpd	GOR scf/stb	WC %	Oil bpd	GOR scf/stb	WC %
Jan-99	CSR	9389	1665	34	11738	1690	26	25.0	1.5	-23.5
Jun-04	CSR	4274	2044	65.9	7407	1930	50.2	73.3	-5.6	-23.8
Jun-05	CSR	5558	1747	63	5421	1836	66	-2.5	5.1	4.8
Dec-09	MSR	627	3306	91	1784	3400	80	184.5	2.8	-12.1

Well #2

Feb-03	CSR	965	2412	54.3	1773	1960	37.4	83.7	-18.7	-31.1
Feb-04	CSR	1422	1579	50.9	3652	1795	40.2	156.8	13.7	-21.0
Sep-04	CSR	2076	2189	51.1	2923	2222	46.5	40.8	1.5	-9.0
Jul-05	CSR	1758	2728	55.1	2846	2274	46.3	61.9	-16.6	-16.0
Jun-06	CSR	1590	1415	59.6	2364	1957	49.7	48.7	38.3	-16.6
Aug-07	CSR	1584	1492	62.6	1793	2115	60.9	13.2	41.8	-2.7
Feb 09	CSR	702	4563	78	866	2020	79	23.4	-55.7	1.3
Jul-10	MSR	944	2114	75.2	977	2800	78	3.5	32.5	3.7

Well#3

Jan-98	CSR	2401	1827	16	2791	1773	17	16.2	-3.0	6.3
Aug-99	CSR	1516	1886	25	1625	1839	32	7.2	-2.5	28.0
Nov-00	CSR	452	1809	37	934	1844	50	106.6	1.9	35.1
Dec-01	CSR	527	1300	22	499	1516	53	-5.3	16.6	140.9
May-03	CSR	241	1650	43.7	240	1730	73.6	-0.4	4.8	68.4
Jun-10	MSR	1487	2267	7.16	2084	2158	63.8	40.1	-4.8	791.1

Well#4

May-96	CSR	458	1830	72	381	1790	77	-16.8	-2.2	6.9
Jun-03	CSR	929	2014	0	4272	2204	0	359.8	9.4	_
Feb-04	CSR	1409	1951	0	5045	1255	28	258.1	-35.7	_
Jan-10	MSR	478	2340	76.19	1234	2525	53.7	158.2	7.9	-29.5

Well#5

Jun-09	MSR	874	1892	78.18	1466	1567	62	67.7	-17.2	-20.7
Jun-10	MSR	489	1820	74.76	696	2029	65.5	42.3	11.5	-12.4

5. Acknowledgements

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