9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-107

Innovative Stimulation Approach in a Mature Field with Special Reference to Multilayered, Horizontal and Multilateral Wells

Dilip Kumar Sarma*, Y R L Rao, B Mandal, B Deuri, *ONGC*

Summary

Mumbai High is one of the major offshore oil fields in India. The field was discovered in 1974 and consists of multilayered carbonate reservoirs, with substantial heterogeneities among the layers. As the field is maturing, the reservoir pressure is depleting, water production is increasing and hence, the recovery of the remaining reserves becomes more challenging. Most of the wells are either multilayered or horizontal/multilateral wells completed barefoot or with un-cemented perforated liners. Matrix acidization is the dominant stimulation technique for improving/maintaining production. However, preferential stimulation of high permeable streaks is a common issue in multilayered wells. Stimulation of horizontal and multilateral wells, especially not accessible to Coiled Tubing is another concern with respect to the exposure of stimulation fluids in entire horizontal section. Wettability alteration also suspected to be the potential problem in few wells.

To address these issues, methodical stimulation approaches have been adopted for effective stimulation of multilayered as well as horizontal/multilateral wells. Three stimulation techniques viz. a polymer based self-diverting acid; a multistage stimulation with deep penetrating retarded acid system (DPRAS) and a VES based self-diverting acid (VSDA) were conceptualized with increased pump rate and acid volume. A chemical formulation for wettability alteration also customized for application.

The SDA technique was implemented in 25 multilayered wells and DPRAS and VSDA were implemented in 30 horizontal/multilateral wells. Three wells were treated for addressing the wettability issues. All the candidates were selected with MDT approach. Well specific treatment designs were carried out considering the damage mechanism, reservoir properties and well completions. Preconditioning of formation was carried out in low pressure wells. Post treatment analysis indicated significant oil gain with better sustenance.

This paper will cover the critical areas for stimulation in multilayered, horizontal and multilateral wells, details of techniques, treatment methodology, design and post treatment evaluation.

***Key words**: Stimulation, DPRAS, VSDA, SDA*

Introduction

Mumbai High field is situated Offshore Western India in the Mumbai Offshore Basin, about 160 Km west of Mumbai city. The Middle Miocene formation comprises low-energy carbonate bank and lagoonal limestone and shale. The main lithology consists of Mudstone, Wackestone & rarely Packstone with patchy dolomatisation. The broad mineralogy is calcite & dolomite with traces of pyrites and aluminite. The reservoirs of the field consist of multi-layered complex limestone reservoir, having around 50% of the reserves below large gas cap. The reservoir is highly heterogeneous with ten sequential pay sands, covering a large areal extent. The reservoir permeability ranges from 5 to 500 mD, with the higher values associated with vugs, channels and moulds enlarged by strong leaching and the reservoir temperature is about 116oC (240oF). As the field is getting matured, reservoir pressure is declined and most of wells have become sub-hydrostatic.

About 50% of the wells of Mumbai High field are conventional completion and rests are horizontal or multilateral, mostly to exploit a single layer. The conventional wells are generally deviated and completed in multiple layers having significant permeability and saturation contrast. Stimulation of multilayered wells in

Email: sarma_dilip@ongc.co.in

such environment is highly challenging, because, most of the treatments get diverted to least resistant areas 1, 10, chances of high water production and difficulties in post treatment flow back.

During acid stimulation, transporting acids to the far end of the horizontal well becomes critical. Entry of Coiled Tubing is limited in most of the horizontal/multilateral wells due to surface or/and completion constrains. Moreover, generation of wormholes is the preferred dissolution process in carbonate acidization, which requires high pumping rate. Low injection rate leads to compact dissolution, poor acid penetration into the reservoir and poor zonal coverage. The conventional jobs with plain and emulsified acid resulted limited success may be due to inadequate placement of acids in multiple layers or in long horizontal laterals.

The techniques

The details of innovative techniques viz. SDA, DPRAS and VSDA are discussed below:

Self-diverting acid system (SDA)

During acidization of multilayered wells, most of the reactive fluids preferably enter into more permeable zones, leaving less permeable zones untreated10. To combat the challenge, the self-diverting acid (SDA) has been developed with conventional chemicals for effective stimulation of all the layers. The technique involves two suitable acid systems and a viscous gel diversion system. Two polymers viz. hydroxyethyle cellulose (HEC) and Xanthan gum Biopolymer was evaluated in the laboratory for customization of diversion gel befitting the reservoir conditions. The concentration of polymer was optimized to achieve the optimum viscosity required to divert the acid based on the reservoir properties and the flow back after the treatment. The viscosity at different shear and temperature of HEC and XC polymer gel used for the system are shown in the figure-1 and figure-2 respectively.

The treatments were designed in multiple stages of retarded emulsified acid, viscous gel and plain acid with compatible additives. Each acid stage was followed by a diversion gel pad. Typically, one acid diverter combination was planned for every 5–8 m11. The viscous gel pad temporarily blocks the treated layer and automatically diverts the remaining acids to the next low permeable or more damaged zones. In high water producing wells a preflush of Isopropyl alcohol, mutual solvent and surfactant was applied for better cleanup of wellbore, reducing the surface and interfacial tension. The system does not require any mechanical diversion system or CT and all the treatments were carried out by bull-heading through tubing. The number of stages and volume of acid and diversion pad in stage was optimized based on the properties of completion layers.

Deep penetrating retarded acid system (DPRAS)

To address the issues of acid exposure in the entire horizontal lateral and deep penetration of acids into the reservoir a multistage stimulation technique using DPRAS, a gelled acid and a nonreactive gel with different viscosities was formulated. Different viscosities and retardation of reaction of acid formulations enhances the diversion efficiency and acid penetration into the formation.

DPRAS is an acid formulation with adequate retardation of reaction and increased viscosity. It overcomes the problem of high reaction rate and compact dissolution especially at high formation temperature and provides effective stimulation by penetration of acids deep into the reservoir. DPRAS is an emulsified acid consists of 15% hydrochloric acid, a hydrocarbon (normally diesel) and two emulsifiers with acid to diesel ratio of 70:30. The acid in DPRAS is the internal phase of the system, while diesel is in external phase. Viscosity created by emulsification of acid and diesel retards the mass transfer rate of acid molecules to the rock surface as well as improves the zonal coverage. This reduction in mass transfer rate and its corresponding reduction in acid reaction rate increases the depth of acid penetration into the formation before spending.

The degree of retardation of reaction depends on the emulsion stability. Stability of emulsion at reservoir temperature and its separation into two phases after the treatment mainly depends on the Hydrophilic-Lipophilic balance (HLB) of emulsifiers (surfactants)2. The DPRAS system is customized with two non-ionic emulsifiers (esters of sorbitan oleates) with HLB 4.3 and 15 respectively.

The phase behavior of DPRAS formulation i.e. 15% HCl + 3%ACI + 0.5% EDTA + 1.5 – 3% surfactant (70:30 acid and diesel ratio) are shown in the figure-3.

Viscoelastic surfactant based self-diverting acid (VSDA)

In-situ generation of viscosity during acid spending process can be established either by in-situ cross-linking of water-soluble polymer mixed with acid or reaction of a specific surfactant added to the treatment fluid to the reaction products generated during acid spending process4. The VSDA is formulated by modifying the acid solution with a viscoelastic surfactant (VES). VES belong to a class of compounds that form micelles in an aqueous system containing certain anions8. The micelle structures of VES in brine appear rod-shaped or worm-like as the micelle elongated. When the viscoelastic surfactants fluid breaks, the micelles become spherical, with a diameter roughly equal to the diameter of the rod-shaped micelles. The viscosity and degree of viscoelasticity obtained is dependent upon the conditions employed i.e. surfactant concentration, brine concentration and temperature.

This self-diverting acid system is a residue free fluid system applicable in temperature greater than 1200C. Depending on the reservoir characteristics, the acid concentration may be varied. The HCl present in the system reacts with carbonate rock and generates CaCl2. The calcium salt (CaCl2) produced during the reaction further reacts with the viscoelastic surfactant present in the system, transforms the spherical micelle structures to worm like structures and gains viscosity in-situ3. The viscous spent acid diverts the remaining acids towards low permeable layer of a multilayered well or far end of the horizontal laterals. Breaking of the thick gel takes place in contact with formation hydrocarbon during flow back or dilution with formation/injection fluid.

The major advantages of VES gel fluid are:

- Ease of preparation.
- Enters into the rock matrix without forming any filter cake on the face of the rock.
- Efficient diversion.
- High retained permeability.
- Easy flow back.

However, the acid spending rate should be considerably high in this process for gaining the viscosity of spent acid in-situ and divert the remaining live acids to the other zones of interest. The additional pressure drop created by the VSDA depends on the viscosity and radius of penetration of the viscous fluid into the rock matrix. The formulation was customized by modifying the acid system with a suitable viscoelastic surfactant. Extensive laboratory studies were conducted for optimization of the formulation and evaluation of its performance. The formulation has been optimized based on the reservoir temperature of the field (~1160C). The rheological behavior of VSDA formulation consisting of 15% HCl, 3% VES and standard additives in different shear rate is given in figure-4.

Candidate Well Selection

Candidate selection for matrix stimulation is based on the identification of wells with impaired productivity and diagnosing the cause of impairment10. Matrix stimulation is the right option for improving productivity, if the cause of low productivity is due to the impaired permeability (near wellbore damage). Wells with impaired productivity were analyzed based on the structural location, reservoir properties, production performance, completion, stimulation histories, performance of lift system and that of offset wells. Accordingly, conventional wells were identified for SDA and horizontal/multilateral wells were identified for DPRAS treatments. Subsequently, both conventional and horizontal wells located in highly heterogeneous areas and better productive potential were identified for VSDA treatments.

Treatment design and implementation

SDA treatments

The treatments were designed in three main stages viz. tubing pickling, main squeeze treatment and flow back of spent acids. Tubing pickling has been carried out by plain acid (15% HCl with additives) for removing inorganic scales (mainly calcium carbonate) and any kind of debris from tubing to avoid impairment of formation during the squeeze treatment. The main squeeze treatment consists of many stages of emulsified acid, plain acid and viscous diversion gel. Stages were designed based on the interval length and properties. An after flush followed by displacement with nitrogen has been carried out for pushing the entire fluids into the reservoir. Nitrogen preconditioning has also been carried out in low pressure wells for effective flow back of spent acids. The acid volume was normally maintained in the range of 400-600 gal/ft. Considering the requirement of maximum acid diversion and fracture pressure of the formation, pump rate was maintained in the range of 15-20 bpm. Some low pressure and high water cut wells were treated by using a preflush of isopropyl alcohol (IPA), mutual solvent and surfactant.

SDA treatments have been implemented in more than 25 multilayered wells so far. The wells are completed in two to five producing layers with different degree of permeability and saturation among the layers. The real time treatment plots were recorded for each job and analyzed critically. The treatment plots indicate effective acid exposure and uniform stimulation among the layers. The treatment plots of jobs carried out in wells A1 and A2 are shown in figure-5 and figure-6 respectively. Evaluation production performance indicates encouraging responses in most of the wells with better sustenance. The pre and post treatment production performance of well A2 is shown in figure-7. The production performances of 25 wells are shown in table-1.

DPRAS treatments

DPRAS jobs have been carried out in horizontal and multilateral wells. The treatments were designed in three main stages viz. pre treatment tubing pickling, main squeeze treatment and flow back of spent acids. The sequence of treatment is as shown below:

- Tubing pickling with plain acid (15% HCl and additives) followed by flow back.
- Nitrogen preconditioning in low pressure wells.
- Main Treatment:
    - A solvent stage for removal of organic deposits.
    - Stages of DPRAS, gelled acid, plain acid and viscous gel diverter.
    - After flush with mutual solvent.
    - Displacement wellbore volume with nitrogen.
- Flow back of the spent acids by operating GLVs.

The acid volume was normally maintained in the range of 20–30 gal/ft of the horizontal length. Considering the average fracture pressure of the formation, reservoir pore pressure, fluid friction and requirement of deeper acid penetration, pump rate was maintained in the range of 10–15 bpm in initial jobs. However, in few jobs, while the acid was pumped in 10–15 bpm, the surface pressure was observed in the range of less than 2000 psi. It indicates low reservoir pressure and indicates the scope of increasing pumping rate without fracturing the formation with better diversion of acids towards far end of the horizontal laterals. Therefore, treatments in remaining wells were carried out with increased pumping rate of 20–30 bpm.

DPRAS treatments have been implemented in 16 horizontal/multilateral wells so far. The horizontal length ranges from 500m to more than 1000m. The real time treatment plots were recorded for each job, which indicates effective acid diversion towards far end of the horizontal section and effective stimulation. The treatment plots of DPRAS jobs carried out in wells B7 and B8 are shown in figure-8 and figure-9 respectively. The pressure plots indicate good acid coverage in the long horizontal laterals. The evaluation of production performance indicates encouraging response in most of the wells. The pre and post treatment production performance of well B8 is shown in figure-10. The production performances of all the 16 wells are shown in table-2.

VSDA treatments

The VSDA system has been implemented in 15 conventional as well as horizontal/multilateral wells. The conventional wells are completed either in multiple layers or in long perforation intervals. The horizontal wells are either 6” or 8 ½” diameter holes with lateral length ranging from 300m to more than 1000m. The treatments were designed in following sequences:

- Tubing pickling with plain acid (15% HCl and additives) followed by flow back.
- Nitrogen preconditioning in low pressure wells.
- Main Treatment:
    - Multiple stages of VSDA.
    - 15-20 minutes gelation time after each VSDA stage.
    - Emulsified acid and/or gelled acid.
    - After flush with mutual solvent.
    - Displacement wellbore volume with nitrogen.
- Flow back.

Usually, three- four stages of VSDA for high permeable areas and three-four stages of emulsified acid or gelled acid for low permeable areas were applied depending on the well completion. A lag-time of 15–20 minutes was allowed between two VSDA stages to spend the acids and gain the viscosity of the spent acid in-situ. The real time treatment plots were recorded for each job.

The treatment plots of VSDA job carried out in wells C3 is shown in figure-11. The well is completed in three pay intervals with considerable permeability contrast. Real time treatment plot clearly indicates the elevation of treating pressure after injection of VSDA, which shows effective diversion of live acids from high perm to the low perm streaks. The post treatment production analysis indicates significant oil gain in most of the wells with better sustenance. The pre and post treatment production performance of well C3 is shown in figure-12. The production performances of all 15 wells are shown in table-3.

Conclusions

- Mumbai High field consists of multilayered carbonate reservoirs, with substantial heterogeneities among the layers. Matrix acidization is the dominant stimulation technique for improving/maintaining production.

- Preferential stimulation of high permeable streaks in multilayered wells and heel areas of horizontal and multilateral wells is a common issue.

- CT accessibility is also a critical concern in long horizontal sections. Lower size of CT restricts the pump rate, leads to compact dissolution and inadequate acid penetration into the reservoir.

- Three stimulation techniques viz. an SDA, a DPRAS and a VSDA were customized and widely applied in the field.

- Preconditioning of formation with nitrogen, use of IPA, mutual solvent and surfactant as preflush in low pressure wells improves efficiency of flow back, leads to effective stimulation.

- The real time treatment plots of most of the jobs show effective acid diversion towards low permeable areas or far end of the horizontal laterals.

- The post treatment production analysis indicates significant oil gain in most of the wells treated with these techniques.

Acknowledgement

The authors would like to thank management of Oil and Natural Gas Corporation Ltd. for the permission to publish this paper. Authors would also like to thank Shri C P Singhal, General Manager, ONGC; Shri A K Srivastava, General Manager, ONGC; Shri Ajit Kumar, Executive Director, ONGC and Shri Apurba Saha, Executive Director, ONGC for their constant guidance and valuable advises during the entire work.

Nomenclature

Blpd	= barrel of liquid per day
Bopd	= barrel of oil per day
Bpm	= barrel per minute
GLV	= gas lift valve
HCl	= hydrochloric acid
SDA	= self-diverting acid
VES	= viscoelastic surfactant
VSDA	= VES based self-diverting acid

References

A.D. Hill et. al. SPE-27982 "Fluid placement and diversion in Matrix Acidizing" presented at the University of Tulsa Centennial Petroleum Engineering Symposium, held in Tulsa, 23-31 Aug-1994.

Paul Becher, Emulsions: Theory and Practice, Second Edition, published by Robert E. Krieger Publishing Company, Huntington, New York 1977.

Abdul Wahab et al. SPE 89418, "Impact of Acid Additives on the Rheological Properties of Viscoelastic Surfactants and Their Influence on Field Application".

Taylor K. C et. al. SPE 87331, "Laboratory Evaluation of In-Situ Gelled Acids for Carbonate Reservoirs", presented at 2001 SPE Annual Technical Conference and Exhibition, New Orlands, 30-Sept- 03 Oct.

Nasr-El-Din et. al. SPE 90385, "A Novel Technique to Acidize Horizontal Wells with Extended Reach".

Valdo Ferreira Rodrigues et al. SPE 108075, "Horizontal Well Completion and Stimulation Techniques – A Review with Emphasis on Low-Permeability Carbonates".

Subero D at. al. "Design Execution and Evaluation of Matrix Stimulation Treatments Using Chemical Diversion and Bullheading", presented at the fourth Latin American and Caribbean Petroleum Engineering Conference, Trinidad 23 – 26 April 1996.

Bernhard Lungwitz et. al. SPE-86504, "Diversion and cleanup studies of Viscoelastic surfactant- Based self-Diverting Acid",.

Charles Wiley et al. SPE 90697, "Improved Horizontal Well Stimulation in the Bakken Formation, Williston Basin".

Economides Michael J. and Nolte Kenneth G. "Reservoir Stimulation" 3rd edition, published by John Wiley & Sons Ltd. Baffins Lane, Chichester, England.

Curtis Crow et. al. "Trends of matrix acidizing", published in Oilfield review, October1992

Tables

Wells	Date of job	Intervals length	Pre job production			Post job production			Liq. gain blpd	Oil gain bopd
			blpd	bopd	w/c, %	blpd	bopd	w/c, %		
A1	25/09/10	4 layers 20 m	586	117	80	1617	436	73	1031	**319**
A2	15/11/10	2 layers 10 m	381	102	73	556	289	48	175	**187**
A3	29/9/10	2 layers 10 m	1352	330	76	1444	365	75	92	**35**
A4	20/10/10	3 layers 10.5 m	426	175	59	538	203	62	112	**28**
A5	02/11/10	3 layers 9 m	318	156	51	590	247	58	272	**91**
A6	05/11/10	3 layers 12.5 m	324	229	29	611	288	53	287	**59**
A7	25/11/10	2 layers 11.5 m	645	354	44	880	396	55	235	**42**
A8	28/11/10	4 layers 37 m	146	111	24	258	175	32	112	**64**
A9	05/12/10	2 layers 11 m	202	80	60	958	143	85	756	**63**
A10	06/12/10	4 layers 11 m	338	152	55	650	195	70	312	**43**
A11	09/12/10	3 layers 50 m	289	151	48	464	242	48	175	**91**
A12	21/12/10	3 layers 13 m	302	151	50	906	317	65	604	**166**
A13	09/04/11	3 layers 9 m	610	164	73	816	285	65	206	**121**
A14	15/04/11	2 layers 16 m	800	471	41	1215	644	47	415	**173**
A15	24/04/11	4 layers 12.5 m	664	219	67	1486	357	76	822	**138**
A16	25/04/11	4 layers 19 m	402	269	33	741	459	38	339	**190**
A17	29/04/11	2 layers 8 m	896	298	67	561	342	39	-335	**44**
A18	10/05/11	5 layers 48 m	795	151	81	1254	225	82	459	**74**
A19	26/05/11	2 layers 5.5 m	647	194	70	982	343	65	335	**149**
A20	29/05/11	3 layers 8.5 m	479	40	92	409	156	62	-70	**116**
A21	04/06/11	4 layers 19.5 m	511	225	56	826	323	61	315	**98**
A22H	05/06/11	336 m	240	178	26	543	358	34	303	**180**
A23	31/05/11	2 layers 15 m	0.6	0.6	0	1187	99	91.7	1186.4	**98**
A24	20/06/11	2 layers 8 m	173	101	42	419	227	46	246	**126**
A25	08/07/11	2 layers 4.5 m	354	116	67	460	244	47	106	**128**

Table-1: Production performances of 25 wells treated with SDA jobs

Wells	Date of job	DH length	Pre job production			Post job production			Liq gain blpd	Oil gain bopd
			blpd	bopd	w/c, %	blpd	bopd	w/c, %		
B1ML	25/05/09	2 laterals 1288 m	337	307	9	462	416	10	125	**109**
B2H	27/05/09	705 m	200	172	14	330	280	15	130	**108**
B3ML	25/11/09	2 laterals 1299 m	413	334	19	614	436	29	201	**102**
B4H	06/11/09	1011 m	293	281	4	330	297	10	37	**16**
B5ML	02/12/09	2 laterals 891 m	75	66	12	272	190	30	197	**124**
B6H	8/8/2010	502 m	1.5	1.2	20	773	742	4	772	**741**
B7ML	29/08/10	2 laterals 936 m	253	207	18	336	282	16	83	**75**
B8H	22/09/10	422 m	131	117	11	335	294	12	203	**177**
B10H	19/10/10	502 m	275	264	4	324	304	6	49	**40**
B11H	29/10/10	500 m	431	388	10	801	321	60	412	**-67**
B12ML	08/11/10	1106 m	3	2	25	291	195	33	287	**192**
B13H	06/12/10	670 m	4	3	10	171	154	10	167	**151**
B14	03/11/10	26 m	477	462	3	576	552	4	99	**90**
B-15H	21/07/11	823 m	285	158	44	478	287	40	193	**129**
B-16H	31/07/11	530 m	327	289	12	510	357	30	183	**68**

Table-2: Production performances of 16 wells treated with DPRAS jobs

Wells	Date of job	Interval/DH length	Pre job production			Post job production			Liq. gain blpd	Oil gain bopd
			blpd	bopd	w/c, %	blpd	bopd	w/c, %		
C1	22/05/07	63 m	340	255	20	414	310	20	74	55
C2	23/05/07	39.5 m	320	311	3	562	558	0.8	242	**247**
C3	21/09/07	26 m	598	342	42	652	611	6.3	13	**269**
C4	22/09/07	24 m	712	155	78.2	639	227	64.4	723	**72**
C5	24/09/07	19.5 m	584	440	24.7	589	558	5.3	05	**118**
C6	03/02/08	43 m	1028	280	72.7	1182	346	70.7	154	**66**
C7H	08/08/10	439 m	938	370	60	1523	857	43.7	585	**487**
C8H	17/08/10	622 m	950	272	71.4	1514	286	81	564	**14**
C9	22/08/10	37 m	926	630	32	1375	1033	24.9	449	**403**
C10	27/08/10	12 m	419	139	66.9	364	91	73.6	-55	**-48**
C11	07/09/10	15 m	544	286	47.4	1393	857	38.5	849	**571**
C12	21/09/10	20 m	217	211	2.6	308	294	4.5	91	**83**
C13ML	06/09/10	3 laterals 1637 m	481	360	25	730	511	30	249	**151**
C14ML	23/09/10	2 laterals 1395 m	490	431	12	590	501	15	100	**70**
C15	01/11/10	17 m	465	209	55	611	305	50	146	**96**

Table-3: Production performances of 15 wells treated with VSDA jobs

Figures

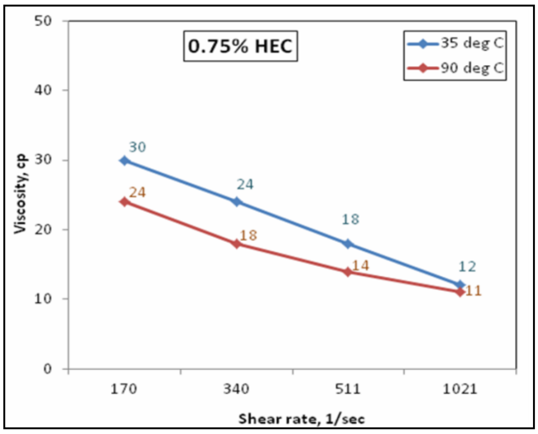

Fig-1: viscosity of HEC gel

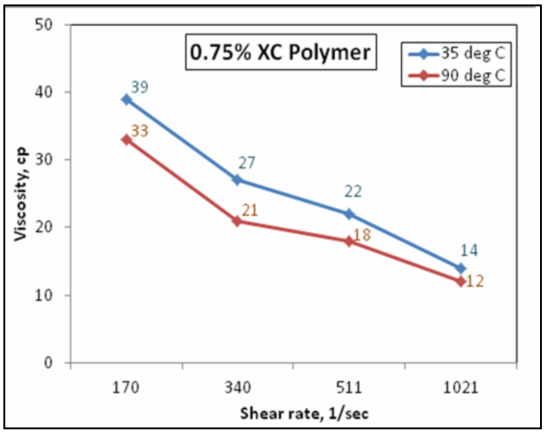

Fig-2: viscosity of XC polymer gel

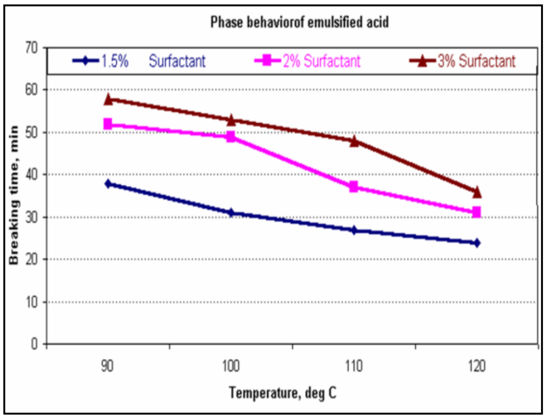

Fig-3: Phase behavior of DPRAS system

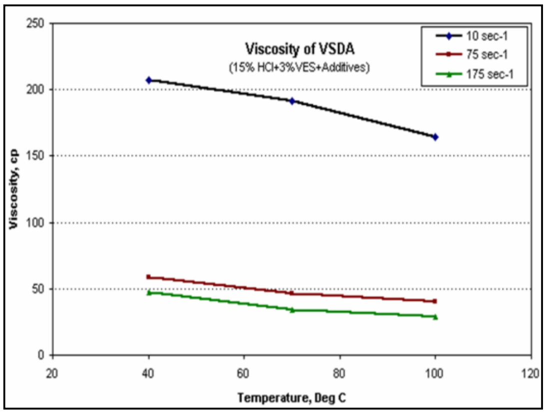

Fig-4: Rheology of VSDA at various shear rates

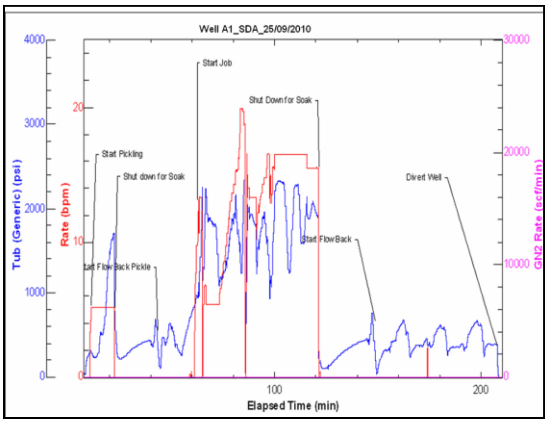

Fig-5: SDA treatment plot of well A1

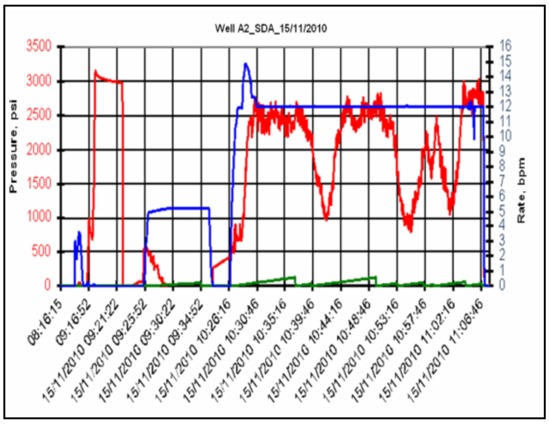

Fig-6: SDA treatment plot of well A2

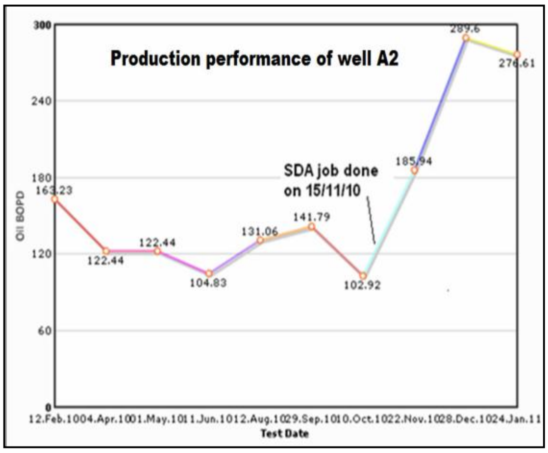

Fig-7: Production performance of well A2

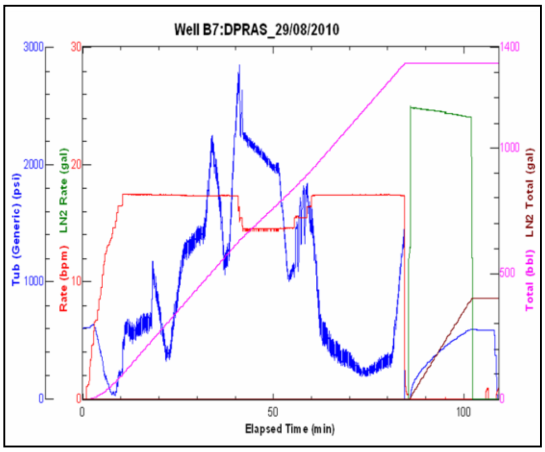

Fig-8: DPRAS treatment plot of well B7

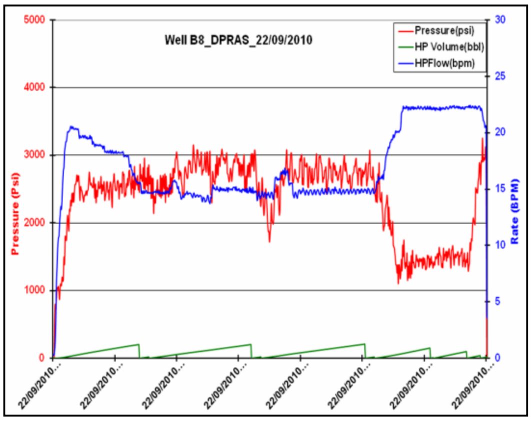

Fig-9 DPRAS treatment plot of well B8

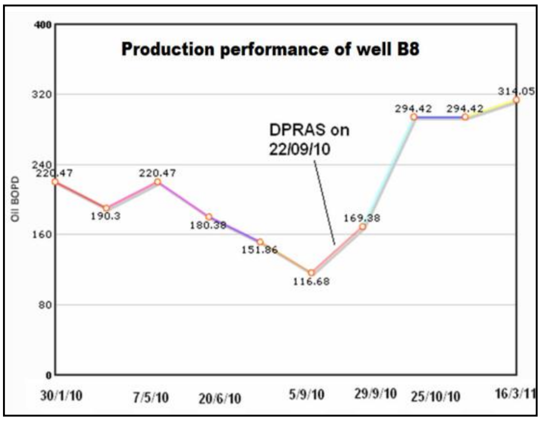

Fig-10: Production performance of well B8

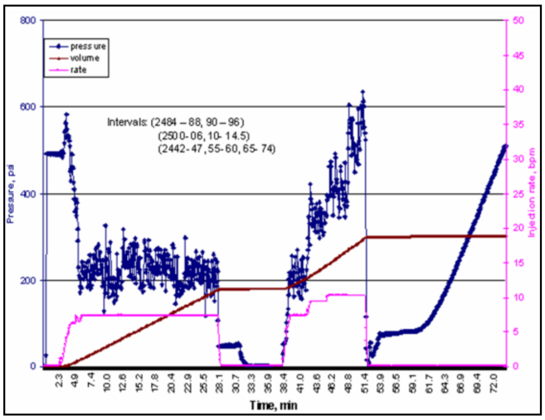

Fig-11: VSDA treatment plot of well C3

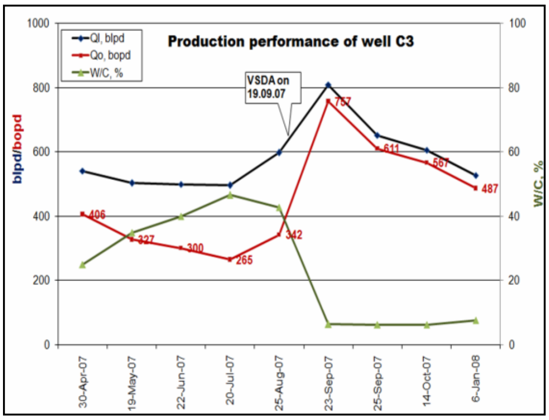

Fig-12: Production performance of well C3