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Water Injection Surveillance in large off shore carbonate reservoir of Mumbai High – A Case study

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Mumbai High South field was put on production in October 1980 and has undergone several rounds of development in order to improve oil recovery from the field. Although development of Mumbai High South field started in 1980, the western peripheral area has been a subsequent development. This area comprising of 7 platforms is producing mainly from 'A1' sub-layer of L-III reservoir. It lies west of the injection platforms WIX1, WIX2, WIX3 and WIX4, initially thought to be on the western producible limit of Mumbai High South field.

Platforms A1 and A2 (1990) indicated extension of the western boundary due to flattening of structure and established the oil production potential of the peripheral area. Platforms A3, A4 and A5 (1993-94) indicated development of 'A1' sub-layer but the initial conventional wells had limited productivity/ injectivity. The area was further developed with horizontal/ multilateral wells from A6 and A7 platforms (2002-05). These horizontal wells came initially with very good production rates, which declined sharply, especially of the wells towards west, away from the injection platforms. The high decline could be attributed to negligible pressure support from western natural aquifer influx and tight reservoir characteristics leading to poor pressure transmissibility from the eastern injection platforms.

A pilot water injection project aimed at enhancing water injection through additional line of injectors was initiated in Nov.'07 by converting two existing producers into water injector from platform A6 in an E-W line pattern. The regular monitoring of the project in terms of oil rate, water-cut, salinity and ionic concentration have been effectively used as water injection performance monitoring tools.

The paper presents the application of these inexpensive techniques in this successful project in the peripheral sector of Mumbai High South (L-III) field.

Introduction

Mumbai High field is located in offshore, 165 km west of Mumbai city. This is one of the most complex carbonate reservoir covering about 1500 sq km area. The structure is a doubly plunging anticline with gently dipping limbs on its three sides and is bounded by a NNW-SSE trending fault on its eastern side. LII and LIII are the two main limestone oil reservoirs of Miocene age. Main pay zone L-III reservoir holding about 94% of the total initial oil in place of the field is a multilayered limestone reservoir with a gas cap & partial water drive. On the basis of an E-W trending shale channel in L-III reservoir the field is divided into two blocks: Mumbai High North (MHN) and Mumbai High South (MHS). The western most part of the Mumbai High South namely peripheral sector is the area of discussion in the present paper.

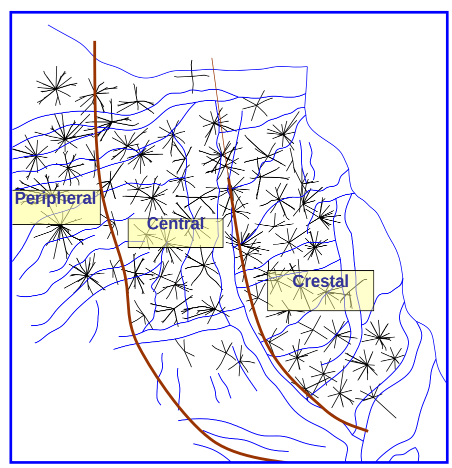


Fig 1: Location Map of Mumbai High South

It lies west of the injection platforms WIX1, WIX2, WIX3 and WIX4 which were initially thought to be on the western producible limit of Mumbai High South field. The geological structure in this area is gently dipping towards West with local variations. The 3D seismic data interpretation has brought out a number of ENE-WSW trending faults in the western periphery. These faults have minor throw and generally non-sealing in nature. In this area, A1 is the only oil bearing layer. All other layers are either tight or poor in hydrocarbon saturation. The adjacent aquifer was considered to be limited and partially active in providing pressure support. The effective thickness across the peripheral area varies in the range 5-10 m with porosity 20-28 %. The reservoir permeability across the peripheral area is estimated to be in the range 5.0 to 125 mD.

Development History

Although development of Mumbai High South field started in 1980, the western peripheral area has been a subsequent development. Platforms X1 and X2, installed in 1990, indicted extension of the western boundary due to flattening of the geological structure and established the oil production potential of the peripheral area west of the water injection platforms. Platforms A3, A4 and A5 installed during 1993-94 installed during 1993-94 indicated development of ‘A1’ sub-layer but the initial conventional wells had limited productivity/ injectivity. Use of horizontal/ multilateral well technology provided the means to develop the outer most area. The area has been developed with horizontal/ multilateral wells from A6 and A7 platforms installed in 2002 and 2005 respectively as part of MH South redevelopment. Additional horizontal wells were also drilled from clamp-on installed on A3, A4, A1 and A2 platforms to drain oil from the peripheral area. All the horizontal wells drilled in this area came initially with very good production rates. However, the productivity of the wells declined sharply, especially of the wells towards west, away from the injection platforms. The high decline is attributed to negligible pressure support from western natural aquifer influx and tight reservoir characteristics leading to poor pressure transmissibility from the eastern injection platforms. The support from existing injectors at the production platforms) was confined to these platforms only. The higher fluid withdrawal from newly drilled horizontal wells from platforms A6 and A7 increased the gap between fluid withdrawal and its compensation through water injection. In order to bridge this gap, a need for more water injection in the peripheral area was felt. As such, a pilot water injection project was initiated in Nov.’07 by converting two existing producers, A6-6H and A6-9zH, as water injector from platform A6 in an E-W line pattern. Based on the positive response from this pilot, 6 more injectors from different platforms spread over the peripheral area, namely A5-4 (Aug.’08), A1-7zH (Dec.’08), A3-8zH (Jan.’09), A6-11H (Apr.’09), A7-5H (Jul.’09) and A2-7zH (Sep.’09) have been added.

The impact of the increased water injection through added water injectors in the nearby producers is being monitored through periodical measurements/ estimation of liquid rate (ql), oil rate (qo), water cut, salinity data and ionic concentration (analysis of produced water sample).

Surveillance Programme

The water injection monitoring has been executed through regular measurements of key production performance parameter (liquid rate, oil rate & water cut), salinity and ionic concentration **(Natural Tracer Technique)** of produced water sample in identified 26 key monitoring wells. The salinity and ionic concentration study has been conducted on 135 number of produced water samples at Regional Chemical Laboratory, Panvel, Mumbai. The Natural Tracer Technique is based on significant difference in the concentration of certain common ions in the formation water and the injection water, as shown in Figure 2. It is clear from the data that salinity of injection water is higher than the formation water;

NATURAL TRACER TECHNIQUE

Natural tracer technique makes use of:

- **Ions commonly present both in the formation water and injection water.**
- **The vast difference in the ionic concentration of these common ions in both the waters.**
- **Salinity (Cl^-), sulphate (SO_4^{--}), magnesium (Mg^{++}), strontium (Sr^{++}), & bicarbonate ($HCO3^-$) have got significant difference in IW & FW.**
- **Mixing of these waters reflect the signatures of change in concentration of these ions in produced waters.**

NATURAL TRACERS	FORMATION WATER (mg/l)	INJECTION WATER(mg/l)
SALINITY	22000 (LII) 25000 (LIII)	35000
MAGNESIUM	100 – 120	1400
SULPHATE	300	2800
BICARBONATE	1300-1500	150
STRONTIUM	150 – 180	8

Figure 2: Ionic concentration in formation and Injection water of MHS (L-III)

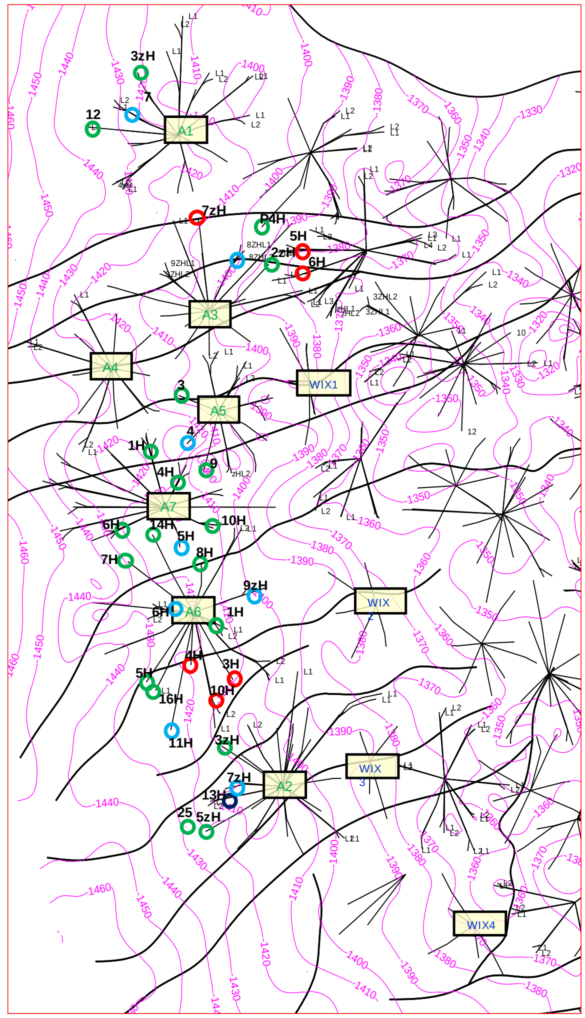
the salinity (Cl^- ions) of the produced water tends to increase, as the injection water component increases in the produced water of any producer. Similarly the concentration of Mg^{++} and $SO4^{--}$ions, being higher in the Injection water, tend to follow same trend in the produced water sample from their base value of 100-130 ppm and 300 ppm respectively. However the concentration of Sr^{++} and $HCO3^{--}$ tends to decrease as their values are lower in injection water. The salinity and ionic concentrations data for about 135 samples have been analysed on this basis.

Results and Discussions

The acquired data on 26 oil producers, spread across peripheral area, have been analysed in terms of its variation with time. Based on the analysis of the response shown by the 26 monitoring wells to the corresponding water injectors, could be grouped in three categories as follows,

- First category represents the producers, wherein there was a gradual change in production parameter i.e. ql, qo, water cut, salinity and ionic concentration with time.
- Second category producers showed immediate negative response to injection water, resulting in premature injection water breakthrough. Only one well has shown such behaviour.
- Third category producers are yet to response to on-going water injection.

The location map of injectors and the corresponding monitoring wells are shown in Figure 3. The brief account of production behaviour, one producer each from the three categories, during ongoing WI project is given below.

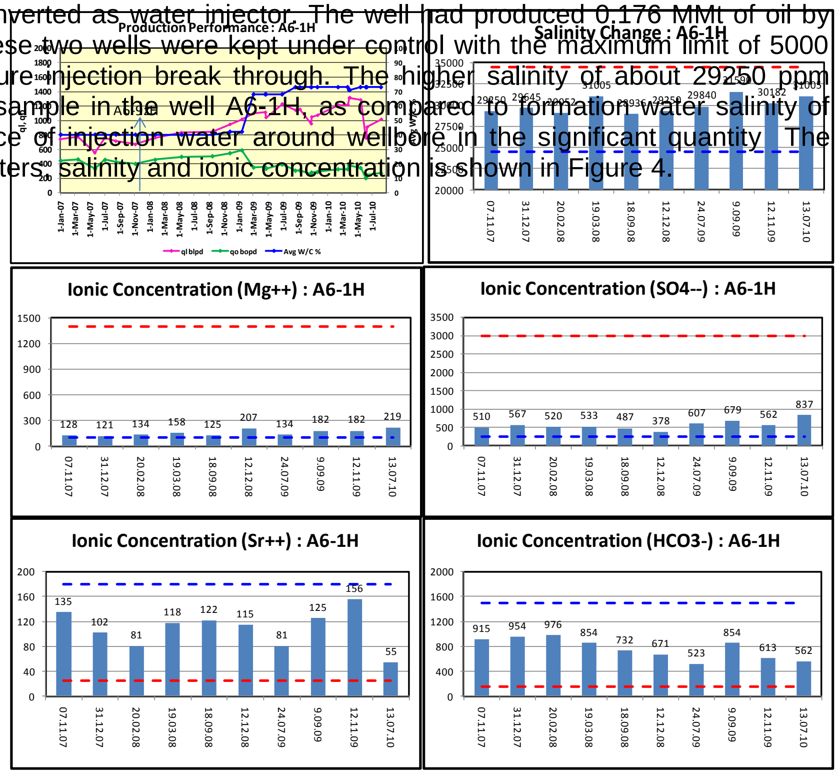


Converted water injector
Gradual change in ql, qo, water cut, salinity and ionic concentration.
Immediate response resulting in premature water injection break through
No response so far

Figure 3: Location map of monitoring wells

Category I: 19 strings namely, A1-3zH, 12H, 25; A2-3zH, 5zH; A3-2zH; A5-3, 9H; A6-1H, 5H, 7H, 8H, 14H, 15H, 16H; A7-1H, 4H, 6H; and P4H are falling in this Category. In these producers, positive response in terms of gradual increase in production parameters with time, is observed**.** Such behaviour represents the Buckley and Leverett's leaky piston type movement of the water front. The production behaviour for this category is explained with the performance of well A6-1H.

The well A6-1H, is the nearest well to E-W line drive injectors. The well is structurally lower by 14m with respect to injector A6-9zH and structurally higher by 10m with respect to injector A6-6H. The well was put on production in Nov.'02. It was producing 402 bopd oil with 40% water cut in Nov.'07, when the wells A6-6H and A6-9zH were converted as water injector. The well had produced 0.176 MMt of oil by this time. The injection rates in these two wells were kept under control with the maximum limit of 5000 bwpd so far to avoid any premature injection break through. The higher salinity of about 29250 ppm (Nov.'07) for the produced water sample in the well A6-1H, as compared to formation water salinity of 24500 ppm, indicated the presence of injection water around wellbore in the significant quantity. The variation of key production parameters, salinity and ionic concentration is shown in Figure 4.



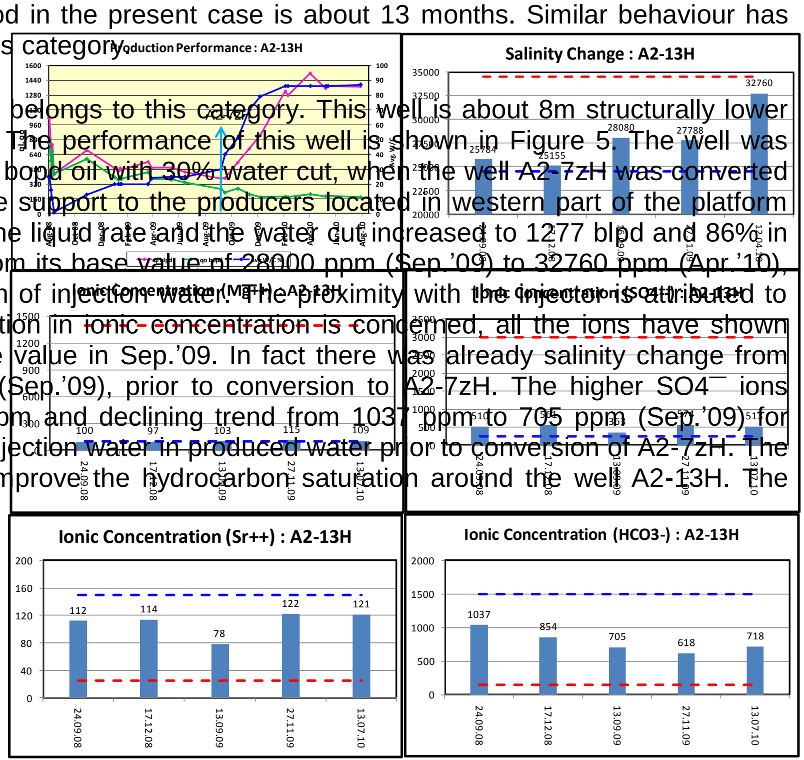
It is clear that there has been a gradual increase in ql from 500 blpd to 1300 blpd by Mar.'10. The oil rate also showed increasing trend from 400 bopd to 600 bopd till Jan.'09. The water cut remained stable around 40% during this period. It was followed by an increase in water cut resulting in decrease in oil rate. The salinity remained stable in the range 29250-29840 ppm until Sep.'09. It has increased to 31000 ppm in Jul.'10. The variation in ionic concentration data for four ions during the period from Nov.'07 till date is as follows:

Figure 4: Production performance of A6-1H

- The Mg^{++} remained stable in the range 128-134 ppm till Sep.'09 before increasing to 219 ppm in Jul.'10.
- The concentration of $SO4^{--}$, was in range 510-533 ppm during same period before increasing to 837 ppm in Jul.'10.
- Sr^{++} ions varied in the range 135-115 ppm till Sep.'09 prior to decrease significantly to 55 ppm in Jul.'10.
- The variation in concentration of $HCO3^{-}$ ion was higher (-26.7%) as compared to other ions i.e. Mg^{++} (+4.7%), $SO4^{--}$(+4.7%) and Sr^{--}(-14.8%) during the same period.

The sudden change in production and salinity data in Jan.'09 indicates the breakthrough of injection water. As such the breakthrough period in the present case is about 13 months. Similar behaviour has been observed in remaining wells of this category.

Category II: Only one string A2-13H belongs to this category. This well is about 8m structurally lower with respect to water injector A2-7zH. The performance of this well is shown in Figure 5. The well was producing liquid @379 blpd, oil @ 265 bopd oil with 30% water cut, when the well A2-7zH was converted as water injector in Sep.'09. to provide support to the producers located in western part of the platform A2. Immediately after the conversion the liquid rate and the water cut increased to 1277 blpd and 86% in Feb.'10. The salinity also increased from its base value of 28000 ppm (Sep.'09) to 32760 ppm (Apr.'10), confirming the premature breakthrough of injection water. The proximity with the injector is attributed to this breakthrough. As far as the variation in ionic concentration is concerned, all the ions have shown stable trend with respect to their base value in Sep.'09. In fact there was already salinity change from 25784 ppm (Sep.'08) to 28080 ppm (Sep.'09), prior to conversion to A2-7zH. The higher $SO4^{--}$ ions concentration in the range 500-550 ppm and declining trend from 1037 ppm to 705 ppm (Sep.'09) for $HCO3^{-}$ ions indicate the presence of injection water in produced water prior to conversion of A2-7zH. The injector A2-7zH has been closed to improve the hydrocarbon saturation around the well A2-13H. The



injection will be resumed from A2-7zH once the production scenario improves in the producer A2-13H.

Figure 5: Production performance of A2-13H

Category III: The wells namely, A3-7zH; A6-3H, 4H, 10H two more wells have not shown any response to on-going water injection project. No significant variation in salinity and ionic concentration data. The liquid rate is also declining in these wells. Such behaviour indicates the absence of any impact of water injectors in these wells. The production behaviour of well A6-4H is shown in Figure 6. The liquid rate has declined constantly. The little variation in salinity in the range 26000-25000 ppm till date does not indicate any mixing of injection water with the formation water. Similar behaviour has been seen in case of other 5 wells. It can be seen from Figure 3 that the wells A6-3H, 4H and 10H are falling are located on the other side of the fault with respect to injectors A6-6H and A6-9zH. This fault is probably acting as a barrier in the present scenario, which otherwise expected to be non-sealing in nature. Based on such findings, the well A6-11H was converted as water injector to cater the need for these three producers. A3-7zH is expected to response to the water injector A3-8zH in near future. Additional well A3-10H has been converted as water injector recently to provide support to producers in NE direction of the A3 platform.

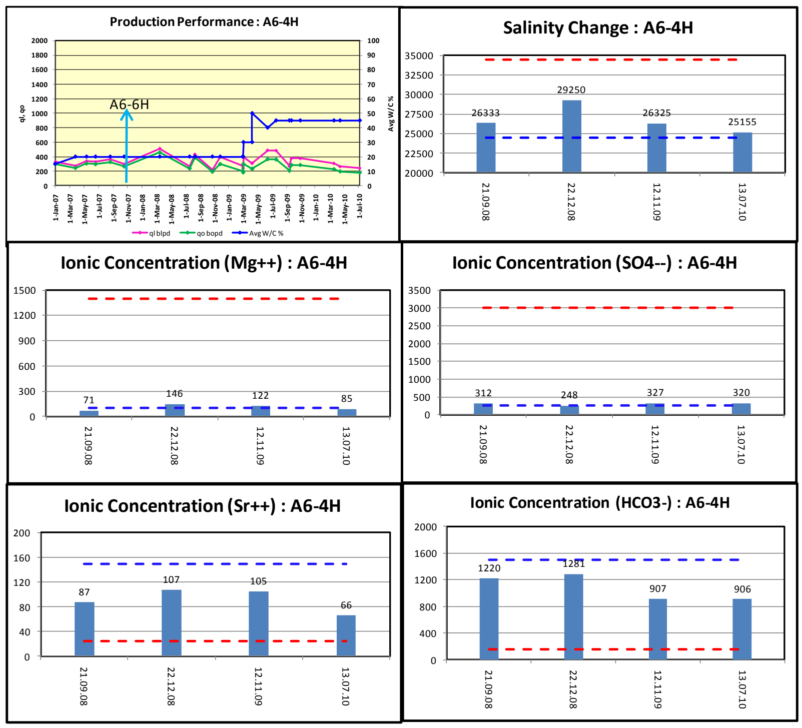


Figure 6: Production performance of A6-4H

In order to gauge the extent of success in on-going water injection project in peripheral area till date, the variation in voidage replacement ratio (vrr) is shown in Figure 7.

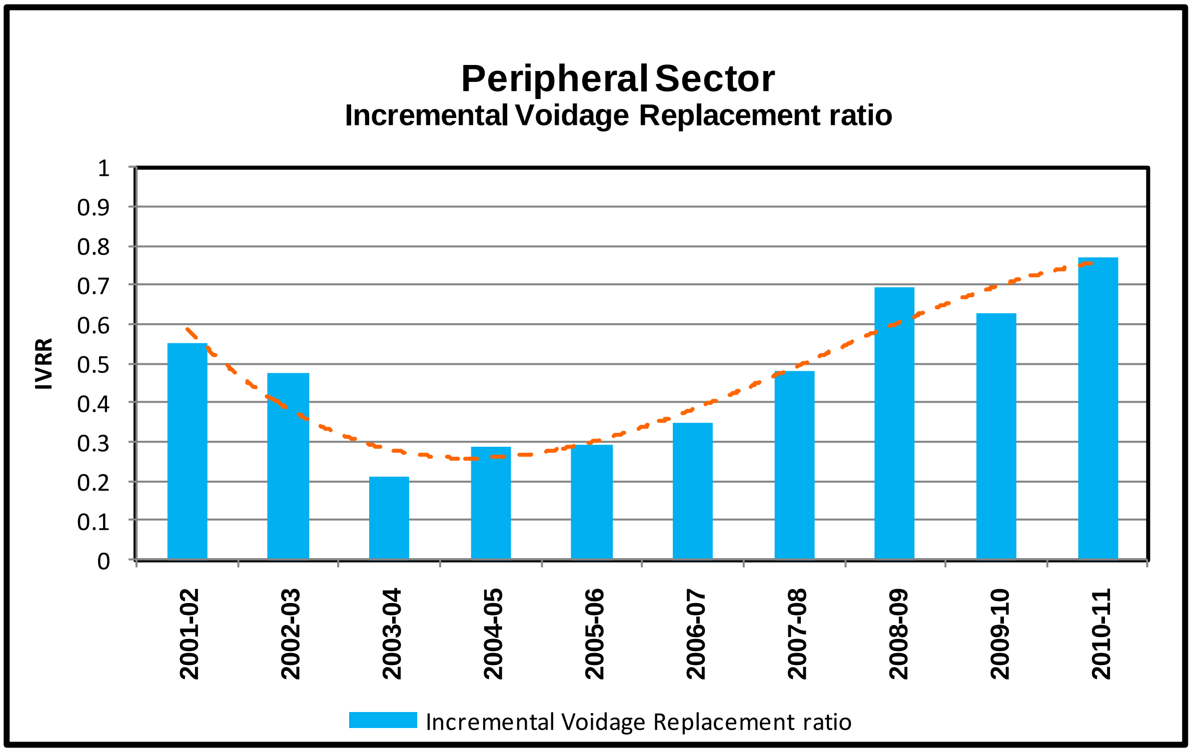


Figure 7: vrr change in peripheral sector

It can be seen from the plot that volume replacement ratio, a measure of compensation of total fluid withdrawal by injected water at reservoir condition, had declined considerably in the range 0.3-0.4 prior to start of pilot project in Nov.'07. The start of pilot project with two conversions, A6-6H and A6-9zH in November'07 and six more subsequently as discussed earlier, has resulted in significant improvement in voidage compensation scenario. An increasing trend has already been established and currently the vrr is 0.77.

From the foregoing discussions, it is inferred that,

- 19 producers have shown positive response in the ongoing water injection project in peripheral area, following the Buckley & Leverett's leaky piston type movement of the water front. Only one producer A2-13H has shown negative impact in terms of premature water breakthrough. Remaining six producers are yet to response. The well A3-7zH, A6-3H, 4H and 10H could not show any response to water injection from A6-6H and A6-9zH, probably due to permeability barrier, falling between injectors and these producers. These EW faults were supposed to be non sealing in nature, otherwise.
- The regular measurements of salinity and ionic concentration data has helped in tracking the movement of water front effectively. The findings have helped in taking the corrective measurements like Conversion of additional A6-11H, A2-10H and closure of A2-7zH
- The volume replacement ratio (vrr), the measure of compensation of reservoir energy, has improved from 0.4 to 0.77, till date.

Conclusions

From the foregoing discussions it can be concluded that,

- The response of majority of producers to the respective injector is reasonably good in terms of increased liquid and oil rate.
- The constant monitoring of production performance of monitoring wells through periodical salinity & ionic concentration measurements and its integration with production parameters has certainly helped in taking the corrective measures in time. As such, the utility of this inexpensive technique in water injection surveillance is well established.

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