Enhancement of oil production in an In-situ combustion process through unconventional and innovative approaches: Case study from Lanwa field, Cambay basin, India.

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Keywords

In-situ combustion, EOR, Flue Gas Trapping, Polymer WSO, Gravel Pack, Multi-fold production enhancement, Horizontal Wells

Abstract:

The objective of the paper is to demonstrate the 30% rise in oil production through unconventional and innovative methods in a heavy oil field "Lanwa" (oil viscosity: 1000-1500 cP) supported by active edge water drive. The non-conventional techniques involves, Water shut off (WSO) with Gravel pack in place, Aquifer management by flue gas trapping, Optimization of air injector-producer combinations in ISC affected areas and restoring the productivity of 6 horizontal wells through foam jobs by Coiled tubing. These efforts were made by revisiting the existing practices and improved technical understandings of the field. Results of field implementation of these activities helped in increasing the oil production of the field by ~ 62 m^3/day.

Water Shut Off (WSO) is being done to reduce the effect of water fingering due to adverse mobility in Lanwa field. Conventionally, WSO jobs were done by fishing out the Gravel pack (GP) assembly followed by polymer squeeze, Zone optimization and reinstalling the GP. To avoid the complicated workover operations, Rigless polymer squeeze through Gravel pack was experimented and desired reduction in water cut is observed. The rigless polymer squeeze resulted in reduction in water cut to 60% from 90-95% and remained low for 1.5-2 months and in some cases for a longer duration. The new process of WSO is very easy to execute and requires very less expenses which facilitates the increased number of WSO jobs. The number of annual WSO jobs in the field increased by 8 times. A total of 35 jobs were carried out in a year and resulted in incremental gain of 20 m^3/day of oil.

Insitu combustion process in part of the field is operational since 2010. Idea of trapping the flue gas to form a secondary gas cap to counter the aquifer encroachment was tested by closing/reducing bean size in high GOR wells. Flue gas production was reduced by 50%, which

helped in expansion of secondary flue gas cap which in turn resulted in reduced aquifer activity in extremely adverse mobility conditions. Around 22 m^3/day of oil gain has been observed in 4 oil producers along with the stability of water cut in down dip wells.

To capture the mobilized oil from the ongoing ISC process, air injector to producer distance was optimized through shifting of injectors. Drain hole of the horizontal producers were cleaned by rigless foam jobs through Coiled tubing which resulted in regaining the productivity of horizontal wells. Optimizing the injector to producer distance and productivity improvement in horizontal wells resulted in oil gain of 20 m^3/day.

Performance of Insitu combustion process can be improved by trapping the flue gas and by proper placement of air injectors. Issue of circulating fluid loss while clearing the drain hole can be eliminated by the use of foam as circulating fluid during Coil Tubing operation (CTU-Foam). As the performance of water shut off with GP inplace was found encouraging, the same can be done through rig-less approach.

Field Description and historical exploitation

Lanwa field was discovered in 1971 and put on regular production in October 1986. It is located in the northern most part of the heavy oil belt of Cambay basin. The field mainly produces from "K" pay sand and is supported by active edge water drive. The viscosity of "K" pay oil is highest among the heavy oil belt and varies from 1000 to 1500 cp from south to north. The thickness of "K" sand pay is in the range of 15-20 m and is having clean sand facies. Due to unconsolidated sand and viscous nature of the crude oil, all the producers are completed with Gravel Pack assembly and wells have been put on Artificial lift (SRP/PCP) since inception. The reservoir is highly porous with 28% average porosity and having permeability of about 5-15 Darcy.Lanwa field is homocline structure with average dip of 7^o towards east.

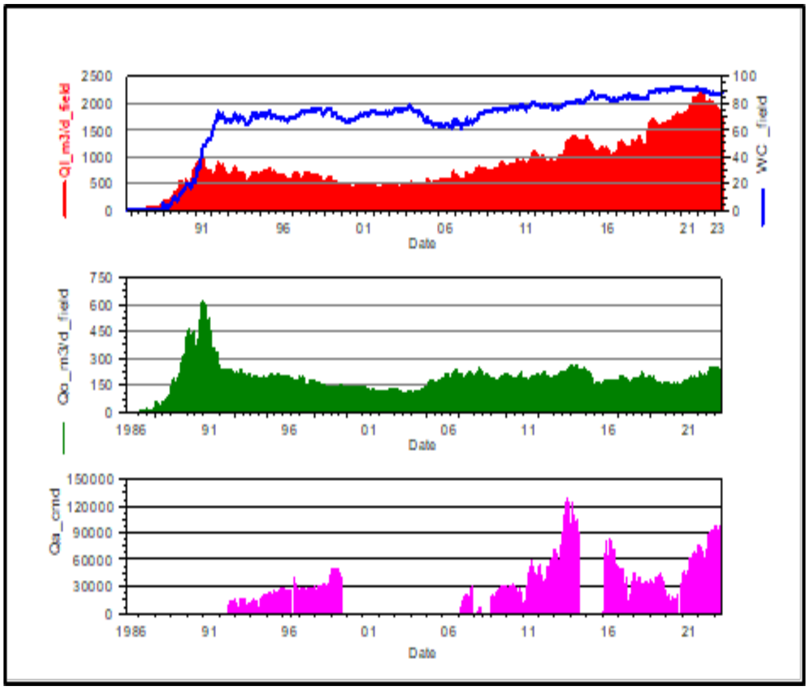


Fig. 1:

The highest oil production of around 600 m^3/d was achieved in Dec'1990.After that a rapid decline in field oil production was observed owing to increase in field water cut from 22% to 75% due to viscous fingering from edge aquifer because of the adverse mobility in K pay sand.

The poor areal sweep has affected the primary recovery which necessitated the application of suitable EOR in the field.

The primary recovery from the field prior to implication of EOR Process was 4.2% only (2010). To improve oil recovery from the field, In-situ Combustion (ISC) process was applied on pilot scale in southern part of Lanwa field during 1992-1999. Based on the results, commercial application of ISC was initiated in Nov'2010 in southern part of Lanwa field.

At present ISC process is in operation through six active air injectors, injecting around 125000m3/d of air. Presently, Lanwa field is producing 250 m3/d of oil from 125 flowing wells. As on date the recovery of field has reached to 6.5%.

Major Sub-surface challenges of the field

a) Active edge water drive in a heavy oil reservoir is always an unfavorable condition from production point of view. Owing to adverse mobility contrast, water cut in the producers rises sharply to more than 90% in 2-3 years of production making the well uneconomical to flow. This requires frequent Water shut off jobs to be carried out in high water cut wells.

b) Due to unconsolidated nature of K pay sand, all the wells are completed with Gravel Pack (GP) assembly for controlling the sand incursion into the well bore. During well intervention for zone optimization, complicated fishing of GP assembly is required. Moreover, completing the well with Gravel Pack generates additional skin around the zone causing influx issue in some wells. Premium Screen for sand control was also tried in the field as a substitute of GP but frequent choking of screen with fine sand was observed in multiple wells resulting into seizure of wells.

c) The ongoing ISC process in the southern part of field generates around 1 Lakh m^3/day of flue gas containing CO_2 & H_2S in the combined flow stream. This gas is then flared into the atmosphere after proper burning. Managing such quantity of flue gas on daily basis is a tedious task and is also detrimental for the environment. Repeated caustic dozing is required to minimize and control H_2S concentration.

d) Cleaning of drain hole section (Length: 200-300 m) in horizontal wells with Coiled Tubing is challenging due to loss of Circulation fluid into the reservoir when injected at high pressure. Drain hole choked with sand fines reduces the reservoir contact and ultimately the well productivity.

Various efforts are being made to improve the productivity by addressing the above said challenges. The following actions have resulted in improving the production from the field;

- **Rig less Water shut off With Gravel Pack in Place:**

K pay sand of Lanwa field is supported by active edge water drive and due to adverse mobility contrast, water cut in the producer wells rises abruptly. To delay the encroachment of water, wells in the field are being produced with low liquid withdrawal rate (Average liquid rate/well: ~15 m^3/d). Still the issue of high water cut is observed in the producers. To reduce the water cut because of the water fingers, Water shut off with Polymer and cross linkers is being done through rig deployment. It has been observed that after 2-3 months, as

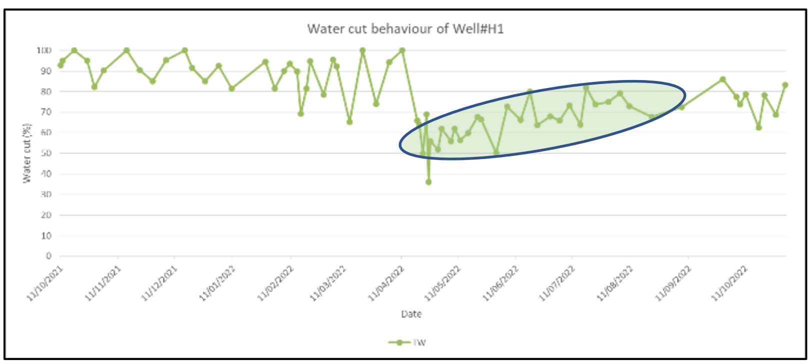


Fig. 2: Impact of WSO on water cut reduction

polymer gel degradation occurs water cut in the well starts rising. This requires the deployment of work over rigs at regular intervals to repeat the water shut off activities.

In the conventional WSO methodology, high capacity rotary rig is deployed on the candidate well for fishing out the GP assembly and carry out the Polymer gel squeeze and then zone is squeezed with cement. Once wait-on-cement is over, selective perforation is carried out and well is recompleted with Gravel pack. All these operations requires around 20-25 rig days and work over costs more than 5 Million INR. This methodology is generally preferred in reservoir with bottom water contact where selective perforation is required.

Well performance indicates that the major source of water in Lanwa is from viscous fingering hence, water shut off in one high water cut flowing well with GP in place was experimented in Apr'2021. In this methodology, Polymer solution is first injected into the zone through the Gravel Pack assembly followed by sufficient post flush brine. Well is then closed for 5 days for polymer gelation. Upon putting the well back on production, encouraging result was observed and water cut in the well dropped to 60% from earlier level of 95% and remained low for 2 months. This well's performance indicated that the rig less polymer gel squeeze can help in improving the well.

Productivity by reducing the water cut of the well. The advantage of this process is that it avoids any rig deployment as well as complicated GP fishing. This innovative methodology for WSO approach requires very minimal financial implication and complexity.

The key reason for increase in water cut of the wells is the viscous fingering of water towards the producers. As Polymer solution with cross linkers is bulldozed inside the reservoir, it has affinity to move towards high water saturated zone i.e. fingers or channels from which water is coming. As a result polymer gel blocks the least resistance path of water towards the producers and subsequently the water cut in the wells get reduced. Decline in the free water component of the produced liquid was observed which confirms the blockage of fingered water channel path.

This positive WSO results, in cost effective manner has encouraged to execute WSO with revised methodology in different wells covering the entire field. With new methodology the number of annual WSO jobs in the field increased by 8 times. This resulted in incremental oil gain of around 20 m^3/day which ultimately helped in arresting the oil decline due to frequent rise in water cut. Performance of Water shut off jobs is represented in Figure-3 below.

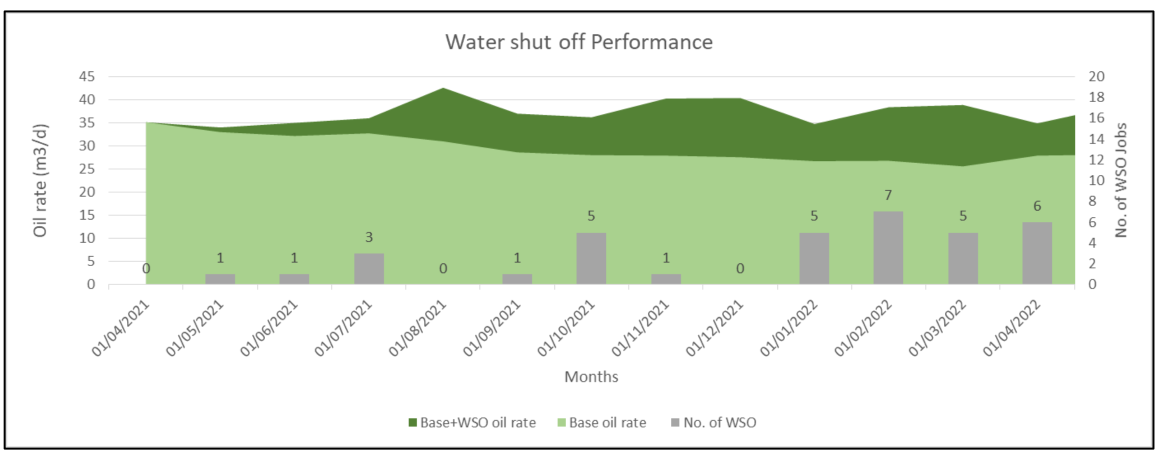


Figure 3: Cumulative WSO performance for 2021-22

Job procedures adopted for carrying out the water shut off job

1. Selection criteria for rig-less WSO job in SRP/PCP wells completed with Gravel Pack primarily depends on well's injectivity measured through annulus. Injectivity in the range

of 200-300 LPM at 40-50 Ksc pumping pressure is considered suitable candidate for rig-less WSO job.

2. **Placement of polymer tank**- Polymer Tank is required to be placed approx. 25 feet away from well in tilted position to minimize dead tank volume. Tank having two agitators is essential for continuous stirring during polymer preparation to avoid any fish eye formation.
3. Circulate brine in the well bore to replace the well fluid.
4. **Preparation of polymer gel**:-Polymer gel is prepared by mixing fresh water and common salt through continuous stirring by agitator for 15 to 20 minutes. Then, Polymer PHPA is mixed into the brine solution through Hopper which is installed on tank.
5. Cross linker is then mixed into the PHPA solution just before pumping of polymer solution into the well.
6. Squeeze the polymer solution in the wellbore at uniform rate and continuously measure the pumping pressure.
7. Close the well for 5days to allow the injected polymer solution turn into hard gel. After that put the well on production.

Practical Experience and lessons learned:

During injection of Polymer solution:

a) If the desired injectivity (200-300 LPM at 40-50 Ksc) is not found, measures for injectivity improvement such as CT cleaning of GP section, chemical stimulation of zone is required prior to polymer bulldozing.
b) Volume of Polymer solution to be injected is mostly dependent on Pay thickness, water cut of the wells and radius of polymer bank to be achieved from the water shut off job.

During Production Phase:

a) Well is to be produced at low liquid withdrawal rate (10-15 m^3/day) to sustain the effect of WSO.

b) Sometimes influx issue has been observed in the well which might be due to hard gel formation in GP section or near well bore area. Using appropriate post flush brine quantity helps in solving this issue.

c) Rig-less Well intervention like mild acid job, hot water squeezing and chemical dozing in annulus helps in improving the influx from the well post polymer squeeze.

- **Aquifer Management through Flue gas trapping:**

In in-situ combustion process (ISC), air is injected into the pay zone through the injectors located in up dip part of the reservoir which results in the generation of combustion front inside the reservoir through spontaneous or artificial ignition. Resultant combustion front movement helps in reduction of viscosity of the heavy oil which in turn gets mobilized towards the producers. The quality of combustion is examined through Gas chromatography (GC) analysis of produced flue gas (byproduct of combustion of air and crude). Presence of unutilized air in the form of free oxygen and carbon monoxide suggests incomplete combustion inside the reservoir Flue gas primarily consists of N_2, CO_2, C_1-C_5 hydrocarbons and H_2S.

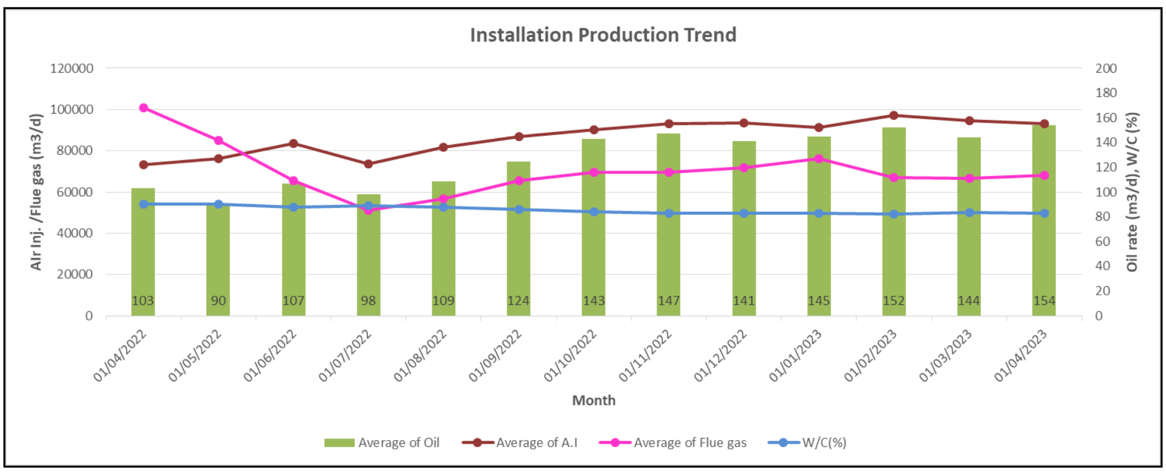


Fig.4- Installation oil & WC trend due to flue gas entrapment

The southern part of the field is under ISC since 2010. During the month of April-2022, air injection rate in the field was 75000 m3/day through six active air injectors. Flue gas production from the field through HGOR Producer wells was 100000 m^3/day (Figure-4).Excess flue gas production against the air injection is due to migration of flue gas from contiguous Balol field, located in the southern part of Lanwa field.

Due to dipping nature of K sand, flue gas gets accumulated in the shallower part of the sand, which has also been observed in the open hole logs / CNL-GR logs recorded in the updip wells.

This affects the production behavior of updip wells resulting in gassing out of wells.

Trapping of the flue gas in reservoir will help in conserving its energy by forming secondary gas cap in the up dip part of reservoir. This will assist in minimizing the aquifer encroachment through counter pressure. Further, In-situ migration of trapped flue gas containing N_2 and CO_2 assists in displacement process of oil. The affected wells are depicted as green dots in Figure-5. (Well# A, B, C, D, E, F)

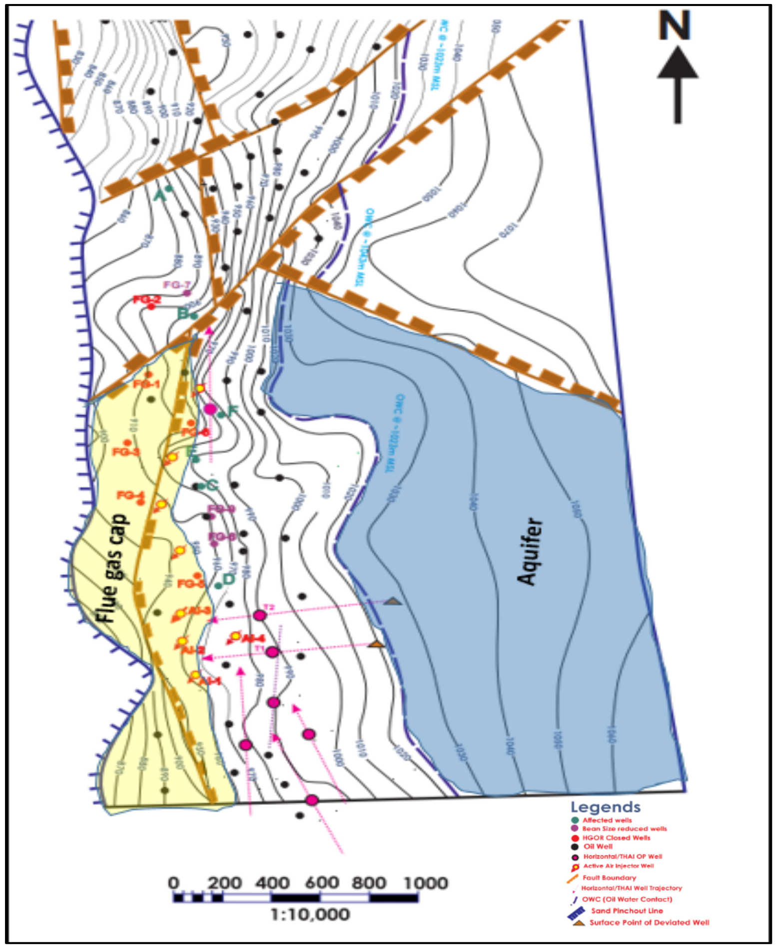


Figure 5. Part Map Structure Contour Map of K-Sand

In May'2022, the action for entrapment of flue gas was initiated and following approach was adopted.

a) 6 HGOR wells located in the up dip part of the field were closed. These wells are represented as red dots in figure-5. (Well# FG-1, FG-2, FG-3, FG-4, FG-5 &FG- 6).

b) Bean size reduction was done in 3 wells and continuous THP, CHP measurement of these wells were made for understanding the in-situ movement of flue gas. These wells are depicted as violet dots in figure-5. (Well# FG-7, FG-8 &FG- 9). To avoid gas locking issue in artificial lift pumps (SRP), annular bean size was optimized

Observations/Results:

a) **Reduction in Water cut:** Water cut of the wells in the air injection block, started to decline after 4-5 months of flue gas entrapment. As it can be seen from the water cut behavior plot, well is flowing only emulsion with no free water (Figure-6).

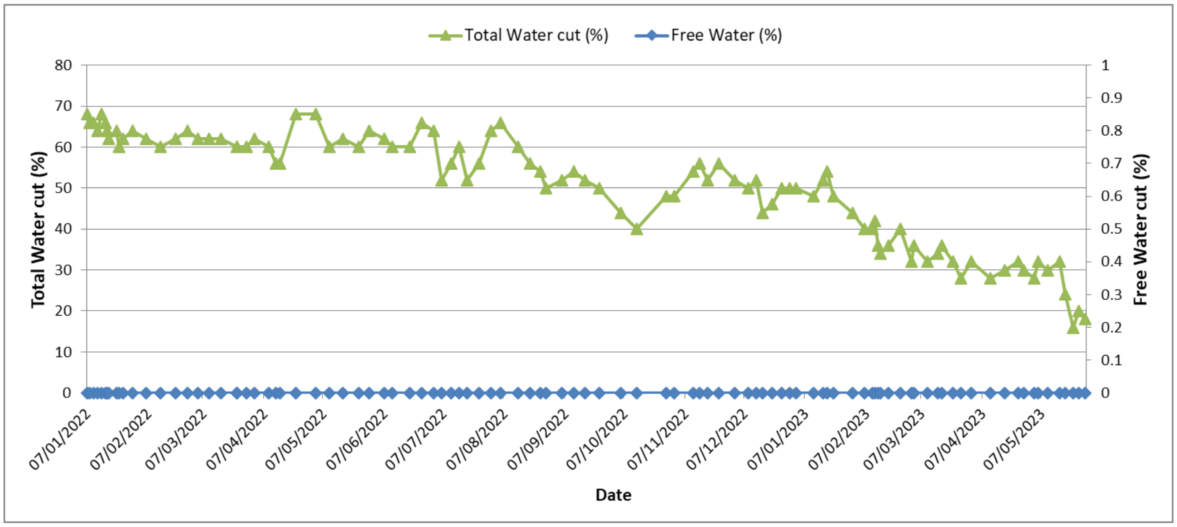


Fig.6-Water cut behaviour due to flue gas trapping

Because of entrapment of the flue gas, Well# C started flowing on self in Feb'2023 and resulted in enhancement of liquid as well as oil production (Figure-7 & 8).

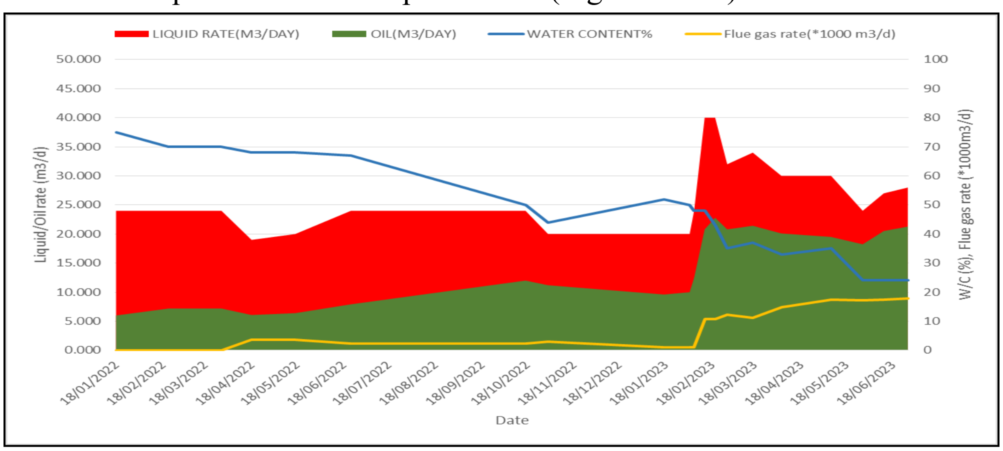


Fig.7- Production Performance of well# C

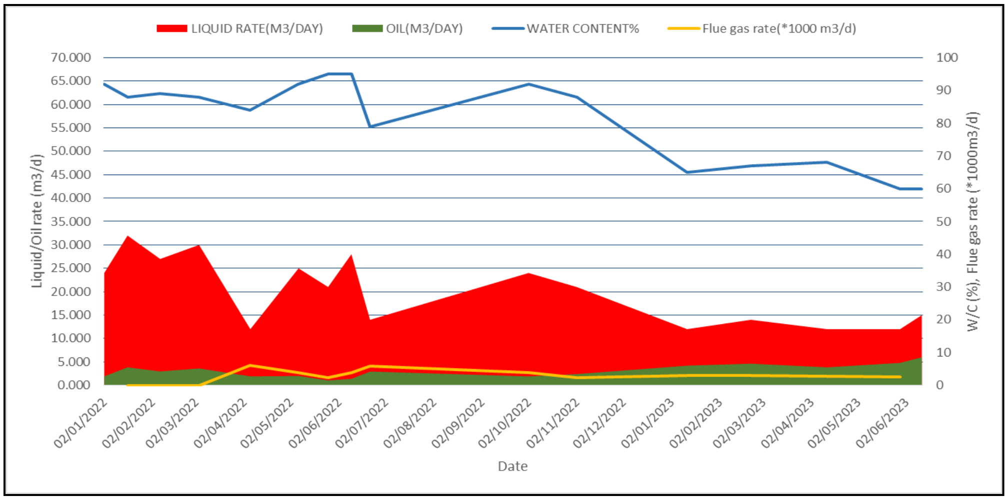


Fig.8- Production Performance of well# E

b) **Effect of flue gas r** ter cut was observed in the wells located in contiguous adjoining block after 9-10 months of entrapment. Free water from the well reduced to zero and oil production from well#A increased to 5m^3/day from previous rate of 1m^3/day.

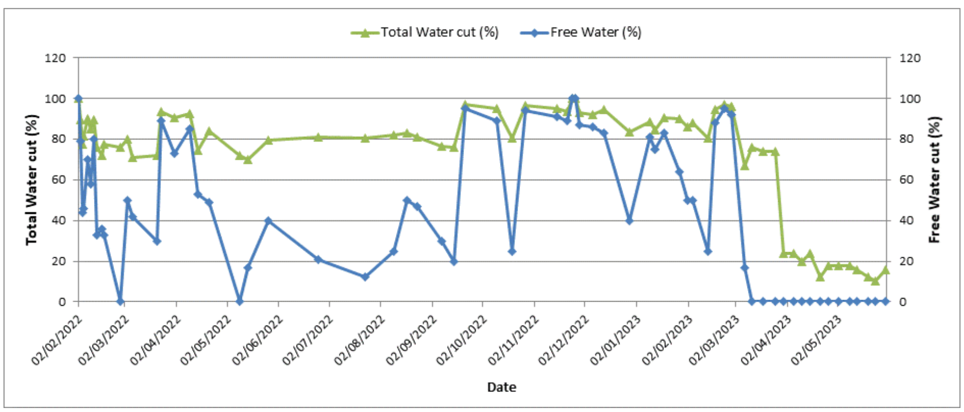


Fig.9- Water cut behaviour of well# A

Marginal flue gas production was observed in wells of this block as shown in performance plot below. (Well# B (Figure-10) & #A (Figure-11)).

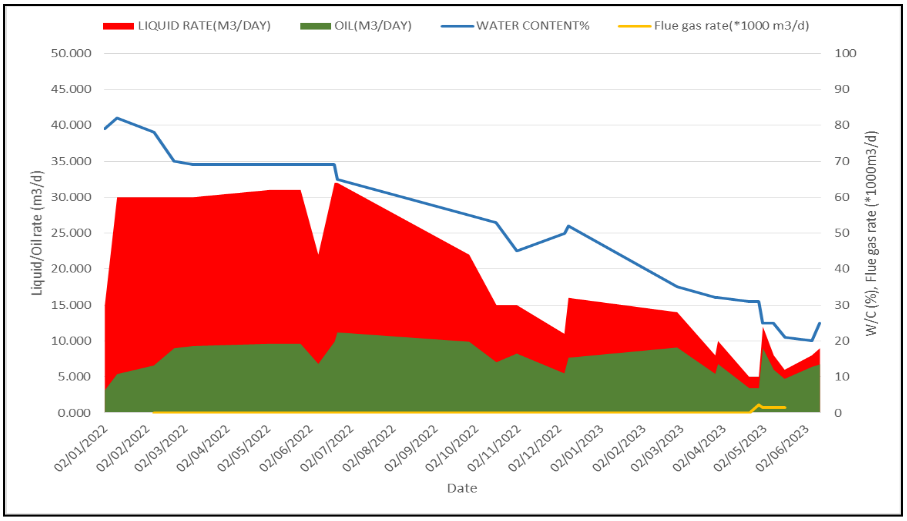


Fig.10- Production Performance of well# B

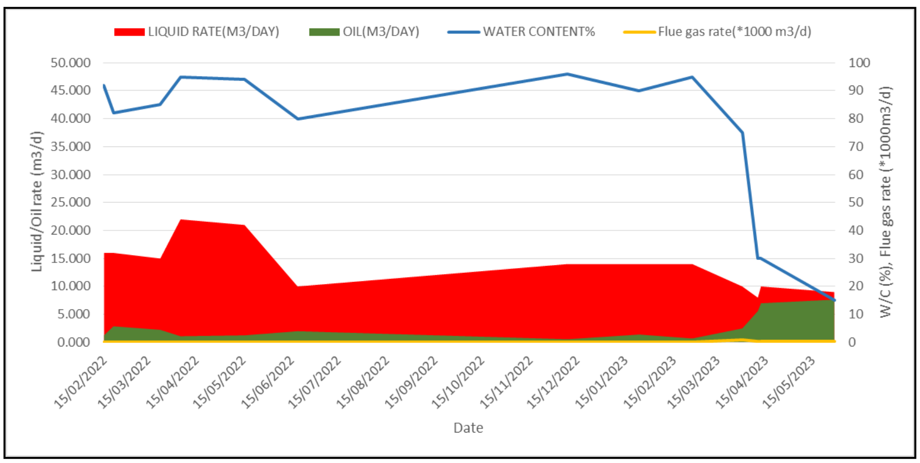
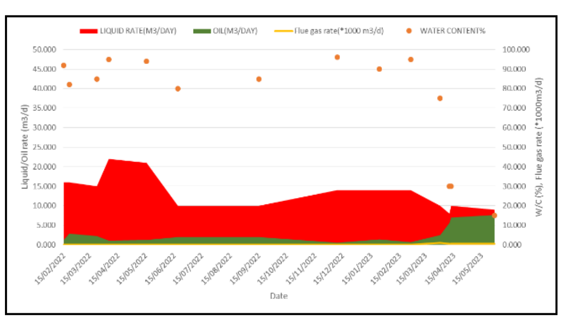


Fig. 11- Production Performance of well# A



Effect on oil production is tabulated below:

Table 1. Oil gain result due to flue gas trapping

Well	Rate before flue gas trapping				Rate after flue gas trapping			
	Ql (m^3/d)	**WC (%)**	**QO (m^3/d)**	**Qg (m^3/d)**	**Ql (m^3/d)**	**WC (%)**	**QO (m^3/d)**	**Qg (m^3/d)**
WELL#C	24	67	8	2400	28	28	20	11000
WELL#E	21	95	1	2400	15	60	6	2400
WELL#B	22	55	10	0	12	25	9	1500
WELL#A	14	95	0.7	0	10	30	7	500

- **Optimizing Air injector- Oil Producer distance in ISC process:**

Reservoir fluid is highly viscous at reservoir temperature, Viscosity of oil zone near the combustion front reduces significantly, but the mobilized oil has to travel through the cold zone before reaching the production well which cools down and increases the crude viscosity. So the distance between air injectors and corresponding oil producers play an important role in optimising the performance of the process.

In-situ Combustion Process was commenced in southern part of Lanwa in 2010. Updip line drive air injection pattern is being used in the field. Majority of oil producer wells are inclined and about 7 horizontal wells have been drilled to capture the combustion affected oil. Out of these 7 horizontal wells, 2 wells are used as THAI well producer. The extent of flue gas cap due to prolonged air injection has been established by the Gas-oil contact observed in open hole logs.

Toe to Heel Air Injection (THAI) is a special configuration of conventional ISC process involving horizontal oil producers with vertical air injectors placed at the toe section of horizontal producers. In THAI, the combination of heat from combustion reactions, mass and momentum transfer, and gravity-assisted drainage is used to mobilize the heavy oil to the surface.

Two THAI wells i.e. T1 & T2 were operating in the Lanwa field with corresponding air injectors # AI-1, AI-2 & AI-3 (Fig.-5).

It was observed that the Production Performance of both the THAI wells were not encouraging even after continuous air injection in their corresponding air injectors# AI-1, AI-2 & AI-3.

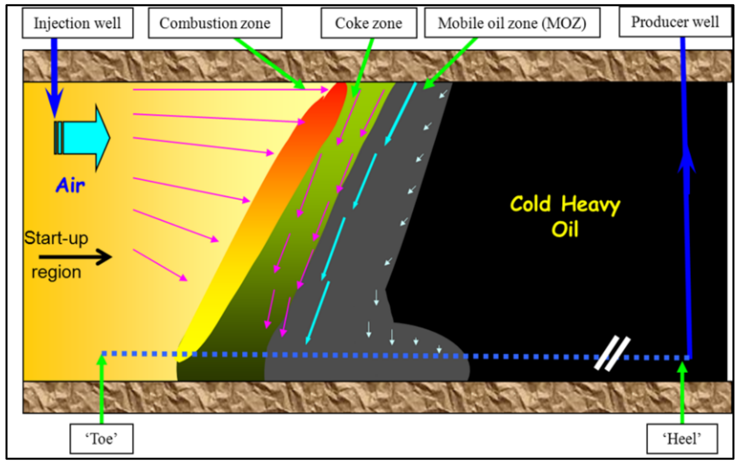


Fig.-12 THAI well Schematic

The process in the nearby areas were reanalyzed and found that the higher distance between air injector and drain hole (~150m) may be the reason for the under performance of the horizontal wells because the mobilized oil might not be reaching to the producer because of the large cold oil zone.

To improve the production performance of THAI wells, one nearby oil producer AI-4 was converted into air injector in Jan'22 which is about 90-100m away from the drain hole. Effect of the revised injection strategy was observed in oil production rate which can be seen from the production performance graph of these THAI producers, the cumulative oil production rate from both the THAI wells was increased to 25 m^3/day from the earlier production rate of 5 m^3/day. (Figure-13 and Figure-14)

Water cut behaviour and increased liquid rate of THAI wells clearly indicated the encouraging response of air injection in AI-4.

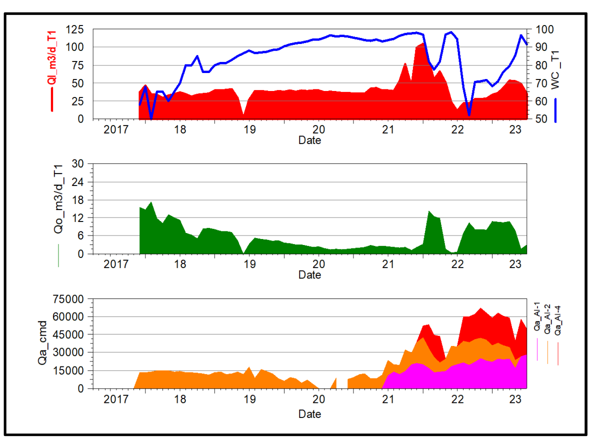


Fig.13- Production performance of THAI well T1

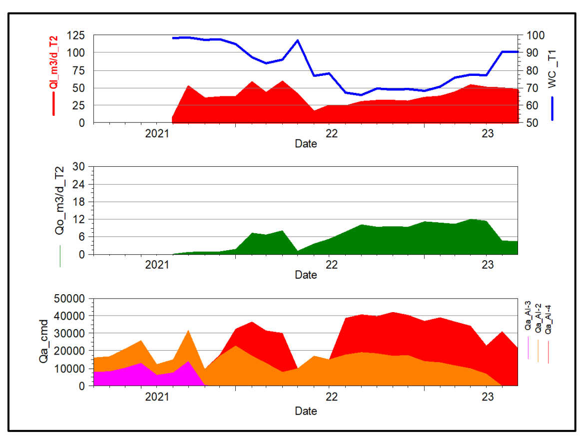


Fig.14.-Production performance of THAI well T2

- **Productivity improvement in Horizontal wells**

Horizontal wells are generally drilled to enhance the well productivity by increasing the exposed area of reservoir to the well bore thus increasing the drainage radius. Horizontal wells in Lanwa field has drain hole length in the range of 200-300m and the drain hole is completed with Gravel Pack.

Horizontal wells in Lanwa field initially produces at oil rate as high as 15 m^3/day. But due to adverse mobility contrast, water cut in the well rises sharply and the well productivity also gets down. It was also observed during the well intervention job that around 120 m of drain hole (Drain hole length: 215 m) got choked up with sand fines in 5 years of Production.

Drain hole cleaning through Coiled tubing (CT) was attempted in the well to clear the choked portion by applying the jetting pressure upto 300 Ksc, but severe loss of circulating fluid was observed in the reservoir and drain hole couldn't be cleared.

To avoid the losses and improve the sand lifting capacity of the fluid the circulating fluid was changed to Foam and it was observed that with CT-Foam job resulted in efficient cleaning of the drain hole. This resulted in improvement in well productivity.

To address the high water cut in the horizontal well, 80 m^3 Polymer solutions was injected into the well to shut the water contributory channel. Post WSO job, water cut of the well went down from 95% to 70% this resulted in increase of oil production in horizontal well.

Conclusions:

1. Flue gas trapping to reduce the aquifer encroachment has been successful as it resulted in reduction in water cut through the effect of secondary gas cap formation. The oil gain was observed through water cut reduction and self-flow activity in nearby down dip wells and wells of adjoining communicating blocks.

2. Rig less Water shut off jobs by avoiding the complicated workover operations using Polymer and inorganic cross linkers through gravel pack in an edge water driven heavy oil reservoir showed encouraging results. The ease of doing the economical jobs has helped in multifold increase in number of jobs and overall increase in oil productivity.

3. In ISC process, Placement of air injector at optimum distance from the producer is very crucial to avoid the loss of mobilized heated oil and the producer shall be close enough to capture the mobilized oil. For the current field case optimum distance is around 100m. The distance can be optimized depending upon the crude oil viscosity and reservoir properties.

4. Lengthy drain hole section of horizontal wells can be cleared using CT-Foam to avoid any loss of circulating fluid and keep the drain hole open in unconsolidated sand producing reservoirs. Rigless WSO jobs can be attempted post improved well injectivity to take the benefit of rigless WSO jobs.

Nomenclature

WSO: Water shut off
HGOR: High Gas oil Ratio
ISC: In-situ combustion
CT: Coil Tubing
EOR: Enhanced Oil Recovery
GP: Gravel Pack
INR: Indian National Rupees
PHPA: partially hydrolysed polyacrylamide
THP/CHP: Tubing head pressure/ Casing head pressure
KSc: Kg/cm^2
THAI: Toe to Heel air injection
SRP: Sucker Rod Pump
WC: Water cut
CT-BC: Coil Tubing-Bottom cleaning

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