Advanced Production and Industrial Engineering
R.M. Singari and P.K. Kankar (Eds.)

doi:10.3233/ATDE220728

Completion Strategy for Water Control in Horizontal Wells of an Indian Western Offshore Oilfield: A Case Study

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Abstract. One of the major problems faced by the oil industry is the problem of unwanted water production. High rates of unwanted water production in a well can make the well uneconomical and reduces the good lifespan. The paper studies the problems faced by a field experiencing a large amount of unwanted water production in the majority of its wells. The data gathered from one of the Indian Western Offshore Oil Fields have been analyzed to identify the problems faced in several wells. Also, the initiatives taken by the company to control high water cut has been discussed. Understanding the water shut-off methods used for mitigating the problem of high water cut and their efficiency, the availability of various Inflow Control Systems for well completion to prevent unwanted water production is studied. Studying the performance of these systems from numerous case studies and literature surveys for mitigating unwanted water production, the paper provides a complete strategy for water control in horizontal wells for different reservoir properties and for future redevelopment plan of the Indian Western Offshore Field followed by the conclusion.

Keywords. horizontal wells, inflow control system, water control, heterogeneous formation

1. Introduction

Horizontal wells are more commonly drilled these days in order to increase the amount of time the wellbore is in direct contact with the reservoir. In order to reach wells that cannot be drilled vertically, or to reduce the number of vertical wells, they are employed [1]. Typically, these are drilled to extend the area of contact with the pay zones or to access targets beneath adjacent strata. Because these horizontal wells are drilled at an angle, they are vulnerable to a variety of issues that can harm the well's production performance. Fractures, solution channels, near water zones, high permeability zones, fractures connecting water aquifers, heterogeneous oil-water contact, and heterogeneous permeability all contribute to well heterogeneity, which increases the likelihood of early water breakthrough [2]. This causes a non-uniform flow sweep in the wellbore, resulting in low oil output, steeply dropping rates of oil production, and so lowering the well's economic production life.

The problem of high-water cut is the one that will be experienced by every oil operator in the world. It not only occurs in older wells but also in newly developed wells [3]. It affects many production companies economically. Excessive water production increases the operating cost to lift the fluids, it increases the cost of separation and enhances the presence of scales, corrosion, and degradation. Overall, it affects the performance of the producing wells and reduces their lifespan. Therefore, it is very important to mitigate water cut problems. Hence, the problem of unnecessary water production can be mitigated with a good understanding of the formation and the field during the wellbore designing phase [4]. Each problem necessitates a unique method for solving it. To be successful in treating a particular water problem, the nature of the problem must be understood. The problem of high-water cuts can be addressed in a variety of ways [5]. Mechanical and chemical methods are examples of these. Expandable and non-expandable packers are utilized to segregate the sections of the wellbore responsible for the majority of water output in mechanical water shut-off techniques.

In-situ gels, polymer and swelling agents, water swelling polymers, Micro Matrix Cement, and HWSO plugging agents are only a few of the chemical approaches used. These are utilized based on the nature of the well's water cut problem. Despite the fact that there are numerous strategies available to address the issue of unwanted water production, putting these techniques into practice and achieving success in reducing water use is a difficult undertaking [6].

In the present study, we have analyzed the water cut problem of a producing oil field which is located in the Indian Western Offshore Basin (WOB). The field was discovered in 1985. The field has three different gas caps and partial bottom aquifer support. The field has an estimated OIIP of 112.48 MMT with an ultimate reserve of 42.54 MMT. The field was put into production in March’90 and water injections were initiated in July’94. Presently the field is producing oil at the rate of 14400 bbl/day with an average water cut of 90% and water injection rate of 85000 BWPD. As of March 2019, the field has produced 35.54 MMT (31.6% OIIP). In the last few years, a sharp rise in water cut (W/C) is observed in the existing as well as recently drilled/side-tracked wells.

2. Well Treatments Applied

The P-1 platform's four wells began producing in March 1990. From 1993-1994, the field produced 95,000 BOPD. In July 1994, water injection began on the W-1 and W-2 platforms in the field's south. In April 1994, water production began, and by 1999, the water cut reached 66%. The field's aerial and vertical heterogeneity made the rise in water cut uneven. The oil-producing Bassein pay has cracks, vugs, solution channels, and karstified zones. Since initiation, mud loss and water injection breakthroughs have occurred. The field's water cut increased from 0% to 40% in 1994-1998 and to 60%-70% in 2002. Due to fractures, wormholes, injector and aquifer channeling, completion near water zone, high permeability variation, water coning, etc., the field is experiencing significant water production. From zero water cut in 1994 to 70% in 2002, the field now faces a 90% water cut of overall production. In this western offshore field, 21 oil-flowing wells are vertical or inclined, and 71 are horizontal wells with slotted tubing in the production zone. Most oil-flowing wells, particularly horizontal wells, have over 90% water cut. Identifying water sources in horizontal wells with slotted or perforated tubing is difficult [7].The water cut problem is highest in the northern part of the field where the thickness is low (15-20m) as compared to the southern part of the field where thickness is highest (70m). The variation in thickness and heterogeneity resulted in variation of recovery in different sectors. The average productivity of the northern sector is 0.036 MMt/string whereas jointly in the northern and the southern part is 0.185 MMt/string. The production and injection performance of the field since inception can be referred to from the plots (Figure-1). Chemical water shut-offs were used to regulate high water production in horizontal wells. These efforts were taken in collaboration with institutes and service providers to manage horizontal well water production. Geological and reservoir parameters of the Western Offshore Field determined the chemical water shut-off jobs. Literature searches and laboratory trials were used to choose suitable water shut-off tasks based on the well's geology, reservoir, fluid properties, and water cut concerns. Later, these jobs were performed in horizontal wells with high water cut to reduce high-water production [8].

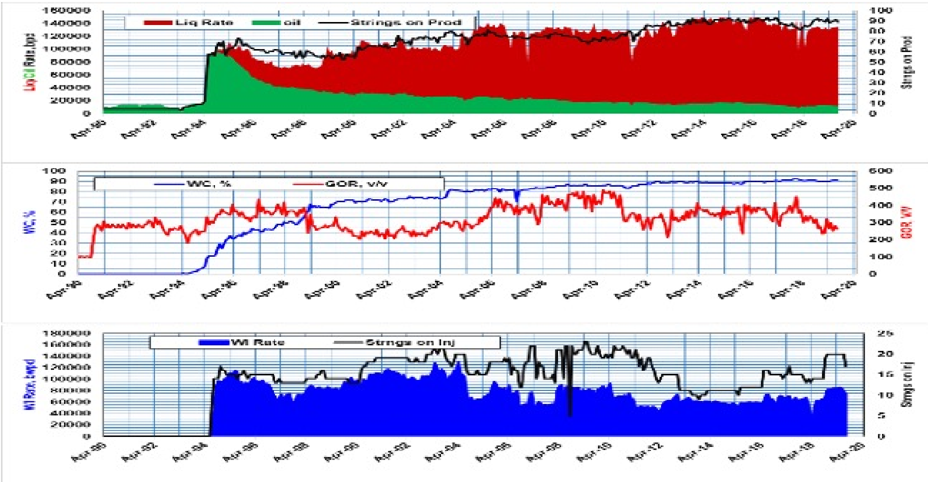

Figure 1. Production-Injection Performance of the Western Offshore Field.

The chemical water shut-off jobs used in the western offshore field were polymer gel technology: ‘PHPA Polymer with Metallic Cross Linker’ and ‘PHPA Polymer with Organic Cross Linker’. This polymer gel technology was used in performing water shut-off jobs in numerous horizontal wells which showed satisfactory results in the initial period but with an increase in field water cut and movement of water due to water coming and water breakthrough, the wells continued producing high water cut after few months of WSO jobs. Some of the Chemical water shut-off jobs performed in high water cut wells can be referred to in the bar diagrams below.

It illustrates the well, and production performance before and after performing the water shut-off job. Early findings for horizontal well polymer gel water shut-off were inconsistent. 8 of 18 Water Shut-off Job-treated wells decreased water cut and raised oil rates, 3 showed reasonable results, 2 showed no changes, and 5 showed good production. Wells that didn't improve with polymer gel was more heterogeneous [9]. Good early results after polymer gelling were sustained (3 to 6 months). With an increase in field water cut and water movement due to water coming and water breakthrough, these figures did not last, and wells experienced an increase in water cut with diminishing oil rates. After WSO jobs in these wells temporarily lessened the field's water cut, the wells began to rise. Overall, a well's water cut cannot be regulated over its whole life.

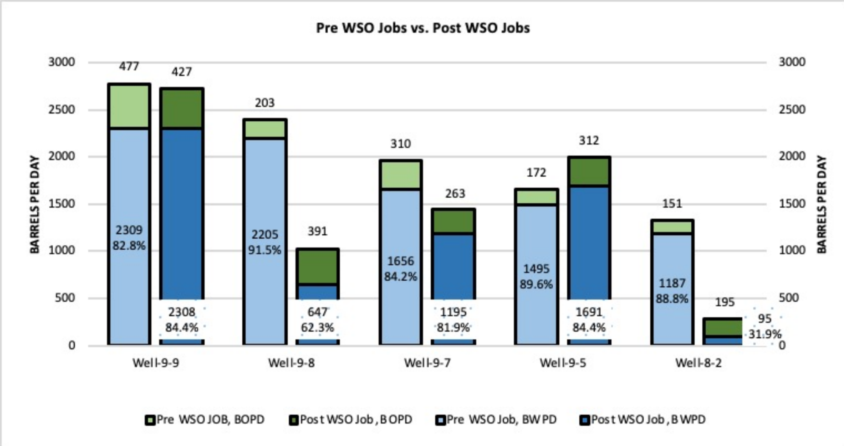

Figure 2. Performance of the wells Pre-and Post-WSO Jobs.

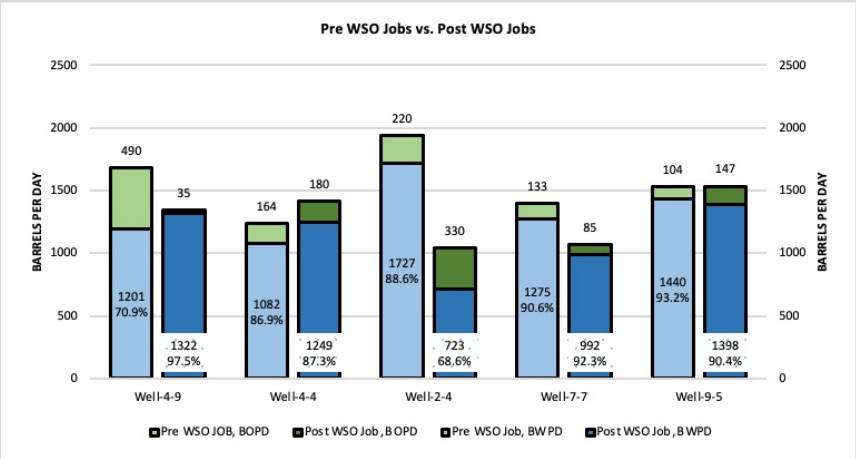

Figure 3. Performance of the wells Pre-and Post-WSO Jobs.

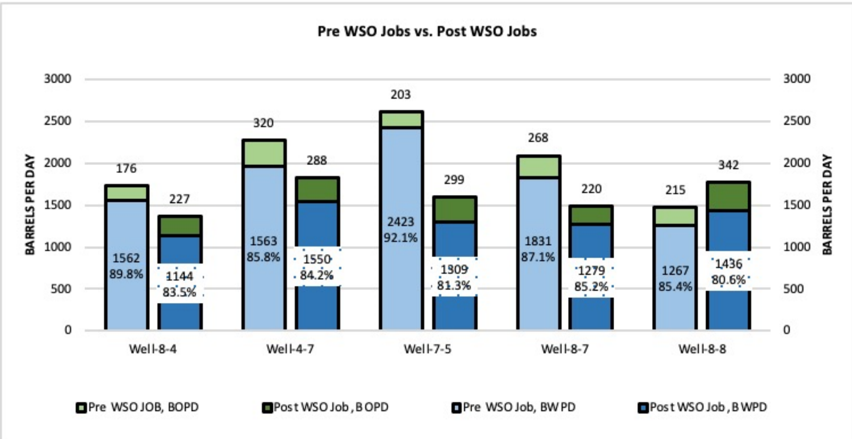

Figure 4. Performance of the wells Pre-and Post-WSO Jobs

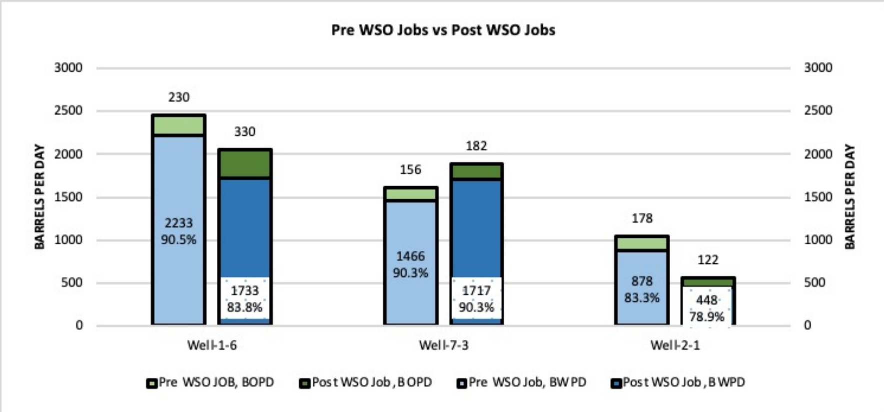

Figure 5. Performance of the wells Pre-and Post-WSO Jobs

3. Results and Discussion

After studying the Western Offshore Field, its completion, and several water shut-off jobs applied to control water production, it was determined that once the problem of water cut arises in a well, it increases gradually as water can bypass oil and obtain the entire wellbore section due to its low viscosity. Once a water cut occurs, it's impossible to manage water output since it can pass via any wellbore channel, resulting in a 90 percent water cut. Mechanical and chemical water shut-offs are common. The water shut-off procedures used to manage water cut concerns are ineffective and unreliable [10]. The water shut-off strategies can reduce water cut for a limited time, but after a certain time the well will resume producing more water since blocking water in a highly permeable heterogeneous field is difficult. Once the water starts flowing, it's impossible to manage, making products pricey and wells uneconomical.

Instead of attempting water control after the fact, a strategy might be established to prevent future water production. This technique uses preventive actions throughout a well's life to regulate water production. Using the newest inflow control systems, such as Inflow Control Device [11,12], Autonomous Inflow Control Device [13], Inflow Control Valves [15,17], and Intelligent wells [16], together with zonal isolation according to reservoir parameters, can assist prevent water penetration into a wellbore. This completion approach can increase a well's life, limit well intervention, produce hydrocarbons effectively, and reduce water output, making it inexpensive. The research shows alternative reservoir features and completion procedures to manage water production. Fractures, vugs, and solution channels dominate field heterogeneity. Some fractures are connected to the bottom water aquifer support, which helps water reach the wellbore. Near water zones and oil-water interaction cause early water breakthroughs due to water coning. The northern field thickness (15-20m) makes the well prone to water coning.

The northern and southern oil-water contacts are at 1477m. Due to its variety, the field's permeability varies greatly. The average reservoir temperature is 100-120° C and the pressure is 2000-2500 psi. The carbonate deposit has 15-25% average porosity and 1-500 milli Darcy permeability. The formation's hydrocarbon (oil) has a low viscosity difference with formation water (35-42° API gravity). At reservoir conditions, crude viscosity is 0.9 cP, formation water 0.4 cP, and gas 0.02 cP. Initial oil in place is 112.48 MMT, with 42.54 MMT in reserves. Produced 35.54 MMT (31.6 OIIP). To recover the field's remaining reserves, 9 more wells will be added to the current 92.

Using AICD will be the best completion approach for the Western Offshore Field to mitigate water cut [3-9]. Isolating the well with swell packers is crucial for AICD well completion. By segmenting the well with zonal isolation and installing AICD in each portion, the horizontal wellbore will have a consistent influx. Modeling a well with NETool or Static Simulator Software utilizing input values from other wells or drilling and logging data can predict the location and number of swell packers and AICD to be installed. AICD prevents and controls water breakthrough in a diverse Western Offshore Field while producing maximum oil. AICD controls the flow of high permeability zones to balance fluid inflow along the wellbore length [18]. This will help produce a regular flow of fluids along the wellbore and minimize early water breakthroughs caused by high permeability zones and frictional effects producing water coming. Controlling the intake helps even oil displacement in all zones, preventing early water breakthroughs produced by early water displacement from adjacent water zones and oil-water interaction.

As a very heterogeneous formation with fractures, vugs, and solution channels, regulating inflow is critical because fluids from these conduits can dominate wellbore flow and impede flow from other zones. AICD will control conduit flow and balance well inflow [19]. If these conduits are connected to a water source, water will skip oil through them. AICD will manage water and oil output upon breakthrough. Water passing through AICD will be restricted and flow tangentially around the output, but oil will flow radially readily. AICD will control gas and oil output. AICD produced hydrocarbons in a thin oil rim formation with a strong water aquifer and a gas cap. In a heterogeneous Western Offshore Field formation, AICD controls wellbore inflow to minimize early water breakthrough. On breakthrough, AICD controls water output and maximizes oil recovery. Range 1 Fluidic Diode type AICD will be the best inflow control system for the Western Offshore Field (similar to Completion Strategy Case 2). AICD restricts water production by identifying fluid characteristics. The field contains 35-42° API oil with 0.9 cP viscosity. Also, field oil (0.9cP) is thicker than water (0.4cP). AICD Range 1 Fluidic Diode (0.3-1.5 cP) produces light oil and identifies fluid differences. comparing light oil and water viscosity AICD Range 1 Fluidic Diodes inhibit water flow and increase oil production [20]. AICD is most effective for permeability variations between 0.1 mD and 500 mD. Completion with Range 1 Fluidic Diode type AICD and Zonal Isolation will be best for the western offshore field. For the field's rebuilding program, it is recommended to install Range 1 Fluidic Diode type AICD with Zonal Isolation completions.

4. Conclusion

Unwanted water reduces production from flowing wells and raises operational expenses for water handling, corrosion of sub-surface & surface equipment, pipelines, etc. Unwanted water production reduces a well's productivity. Mechanical and chemical techniques can be used to stop unnecessary water generation during workovers. These remedies can't effectively stop water production, and their odds of success are low.

- To examine problems and mitigate the water cut problem to increase field production, well-wise production and injection behavior through classical plots, examination of existing in-house water shut-off methods (both mechanical and chemical), and exploration of worldwide technologies were used.

- Studying the Indian Western Offshore Field, its water cut problems, and several water shut-off methods applied in its wells, it was concluded that controlling water production once it occurs can be very difficult, less effective, and almost impossible to increase a well's productivity for a longer period effectively. Water shut-off procedures cannot mitigate water cuts.
- A completion approach to restrict and manage water output at completion can avoid well intervention for water shut-off activities. The correct completion method will act as an effective water control measure even before the problem starts, rather than applying water shut-off tasks after the problem occurs, which has low success rates and is less effective. Preventive actions can restrict water production by delaying well breakthroughs. This incorporates Zonal Isolation and an appropriate Inflow Control System (Inflow Control Device, Autonomous Inflow Control Device, Inflow Control Valves, or Autonomous Inflow Control Valves) for the reservoir.
- On breakthrough, it analyses water's qualities and restricts its flow to control its output, while fewer limitations are applied to oil. If a completion strategy is made using a suitable Inflow Control System and Zonal Isolation according to the reservoir and fluid properties, the strategy will prevent early water breakthrough by balancing the influx across the wellbore and on breakthrough, identifying the water flow, it will restrict water production and produce oil simultaneously.
- Similarly, studying the reservoir and fluid properties of the western offshore field facing high water cut, a suitable Completion strategy using Range 1 Fluidic Diode type AICD with Zonal Isolation using Swell Packers is suggested to install in horizontal wells in the future redevelopment plan of the field. Using simulator software to calculate the placement and number of AICDs and Packers in a field's wells can successfully control water cut problems and boost future well output. This completion approach will help extract maximum oil from the western offshore field, controlling water production and increasing cumulative oil output.
- A completion strategy is considered for the future rebuilding of the field, where more wells will be drilled/sidetracked. Future wells will be completed with AICD Range 1 Fluidic Diodes. Presently, 3 P-13 development wells are being drilled and will be completed with Well Services' Passive Inflow Control Device (ICD). From May'20, 9 side-track wells on P-3, P-8, and P-4 platforms will require Range 1 Fluidic Diode AICDs.

Acknowledgments

The authors would like to express their gratitude to their colleagues for their excellent direction and assistance in completing this research project, as well as to the management for providing us with all of the necessary resources.

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