Water Flooding and Smart Well Completion: A Review

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Abstract: Water injection has been one of the best techniques to improve oil recovery and it is used to maintain the reservoir pressure and displace oil toward producers. Due to excess production of unwanted water, which can arise from events such as a coning, breakthrough in the water flooding process that ultimately causes the abandonment of the oil field. For controlling the water breakthrough and water rates, the smart well technology can be employed. This paper deals with the review of smart well completion and its various systems. Smart well technology has been one of the most revolutionary production techniques in the latest years. It is defined as the use of inflow control devices installed on the vertical or horizontal well to enhance sweep efficiency and maximize oil recovery. Spiral type ICD is used which is good in resistance to erosion and they controlled simultaneous production from various layers, saving time and higher productivity zones in horizontal and vertical wells.

Keywords: *Water flooding, Smart Wells, Inflow Control Devices, Inflow Control Valves, Spiral Type ICD*

1. Introduction

Water Flooding is a secondary recovery technique to increase oil recovery after primary recovery depletion. It is described as a water injection into the reservoir to maintain pressure. The water then flows through the pores and moves the oil towards the producing wells [1]. Water injection is the dominant technique of fluid injection utilized around the worldwide. Water's popularity is largely due to its accessibility, the relative ease of injecting water, the ability of water to spread easily through an oil-bearing formation and the efficiency of water in displacing oil [2].

Nearly every field in the globe utilizes the method of waterflooding to boost or enhance the recovery of their respective fields. In many of these reservoirs, the high permeability zones and water fingering affects the oil recovery causing early water breakthrough and increasing the residual oil saturation which leads to abandonment of the oil field. Different techniques for solving this issue have been evaluated. Smart Well technology will be used to solve the problem. Smart well technology has been one of the most revolutionary production techniques in the latest years [3].

It is defined as the use of inflow control devices installed on the vertical or horizontal well downhole to enhance sweep efficiency and maximize oil recovery. The Inflow Control Devices (ICDs) are the surface-controlled device that is used to restrict and regulate production. Inflow control will be installed on injection wells, it develops the potential results to control and control liquid stream methods through the oil reservoir will be increased. The capacity to manipulate (to some extent) oil/waterfront development offers the opportunity to search for a control approach to increase extreme oil recovery [4].

2. Water Flooding

Water injection is the secondary recovery technique in which reservoir pressure is maintained. As it is a famous technique because of the easy availability of water and it gives a lot of benefits and recovers oil but with its benefits, it also has some disadvantages using this technology [5]. Therefore, using this technology we must assess some factors which should be considered which are given below:

a) The geometry of a reservoir
b) The properties of fluids
c) Depth of reservoir
d) The properties of lithology and rock
e) Fluid saturations
f) Reservoir uniformity
g) Reservoir primary recovery mechanism(s) [5]

In a water flooding venture, two general sorts of well areas are normal the central or peripheral flooding and the pattern flooding. In the central flooding, the injectors are assembled together in a group while in the latter certain patterns of wells are repeated all throughout the field. The location of these wells is highly dependent on the reservoir volume, type, geology and the economics [6].

In peripheral flooding, the injectors are situated around the outskirts of the reservoir with the goal that the flood advances toward the center as appeared in Figure 1. After some time, the first row of producers floods out and are normally changed over to injectors. This kind of flood can prompt high oil recovery with least injectants, yet peripheral flooding generally takes a longer time than a pattern flood. Central flooding is the inverse of peripheral flooding in which injectors are set at the focal point of the field, and the flood advances outward [6].

In pattern flooding, the injectors are situated among the producers in some specific and repeating patterns. Cases of some regular pattern floods appear in Figure 2 below. Pattern flooding is extremely normal, and the determination of the type of pattern relies upon the conditions of the field [6].

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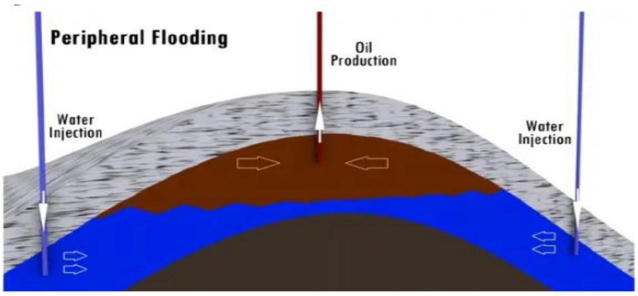

Figure.1. Peripheral waterflooding [6]

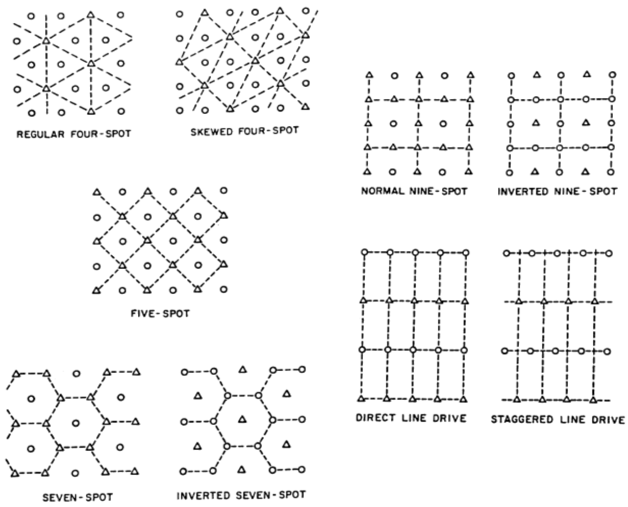

Figure.2. Various types of regular waterflood patterns [5]

3. Smart Well Technology

A smart well, also known as intelligent well, is a special category of well in which different downhole equipments (more specifically inflow control devices and downhole sensors) are used which monitors the wellbore, collect and transmit reservoir and well production data, then acts to regulate the flow downhole inorder to enhance the production from the reservoir. These devices are operated manually and automatically. Both the downhole monitoring and control system must work in parallel inorder to make a well fully “intelligent” [7].

Such wells may be drilled vertically and/or horizontally depending upon the reservoir characteristics and future production required from the well. These wells may be also be drilled as an inclined well or in multilateral configuration [7].

Multilateral and horizontal wells are a potential focus for the smart well technologies. The purpose of using smart well completion technology to multilateral and horizontal wells allows optimizing the production of oil, extending the life of the well and reducing water coning problems.

3.1 Historical Perspective

The development of the completion system started in the late 1980s, with the establishment of pressure/temperature gauges to give a continuous reading of the bottom-hole pressure. Numerous organizations around the globe attempted to automize the distinctive completion components and to make a system for checking the well automatically [8].

Until the start of the 1990s and before the advancement of unconventional completions a rig intervention is required to control and alter the zone stream. The main conceivable method for acquiring data from the reservoir was by downhole logging which represents a costly and unsafe intervention. As a result, refreshed data were absent since estimations were done periodically [8].

SCRAMS is the first smart well technology that was well dynamics (A Joint Halliburton-shell partnership) introduced to the industry in 1996. This technology helps control and monitor the wellbore by providing real-time data such as pressure and temperature [8].

Saga Petroleum, located in the southern portion of the Norwegian sea in tension with Snorre in August 1997, built the first intelligent well completion system. After the successful implementation of this technology, hundreds of smart wells are being used all over the world [8].

4. Smart Completion System Components

Smart well is divided into two single parts (more than one zones inside a single well) or multilateral wells (more than one well). SWC consists of a mix of zonal isolation devices (sealing elements and inflatable packers), inflow control devices, lasting checking systems (downhole sensors) and surface information securing and control systems. WellDynamics is the first one who has given smart well technology in 1997 [8]. A representational form of this system appears in figure 3.

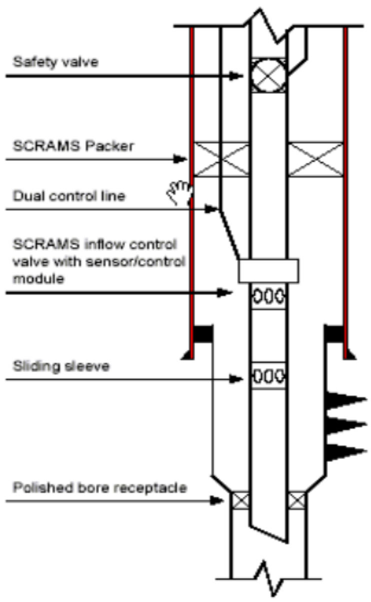

Figure.3. Snorre TLP Smart Completion 1997 [8]

The above completion process uses a remotely controlled device with packers and sensors to load zonal isolation. SCRAMS (Analysis and Management of Surface Controlled Reservoir) is employed to deal with the infinitely fluctuating interval control valves (IV-ICV) to guarantee a productive control of the stream in various sections of the well. Hydraulic forces are generated by the hydraulic control line and transmitted to the SCRAMS module, which transmits the power to the distinguishing sides of the ICV cylinder using solenoid valves. The electrical restraint line enables the transmission of pressure and signs from the good controller to all the wellbore apparatuses using a fast-speed telemetry structure [8].

The smart completion design relies upon the particular attributes of the well. Reservoir circumstances (pressure, temperature) water-oil contact, reservoir zones, and alternative static and dynamic properties. The smart well plan depends additionally on the destinations: to enhance the recovery/sweep efficiency, to upgrade well execution, or to boost NPV (net present value) [8].

An ideal smart well consists of distributive valves for control of constant and inflow sensors to measure the different physical quantities such as pressure, temperature, flow rate, the speed of seismic and acoustic waves and tension [8].

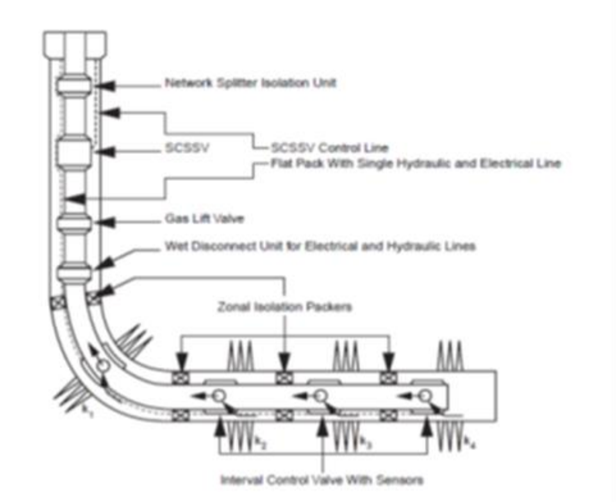

Figure.4. Intelligent Completion Design for A Horizontal Well [8]

4.1 Downhole Monitoring System

The monitoring system helps to collect information about the parameters of the reservoir such as pressure, temperature, fluid flow and some other parameters (seismic waves etc.) continuously and occasionally in a well [7]. In the oil industry, a range of downhole sensors are used. Following are the sensors which are used in downhole monitoring system [9]:

1. Electrical sensors
   a. Crystal piezoelectric gauges
   b. Silicon-on-Insulator (SOI) electronic gauges
2. Optical sensors

4.2 Downhole Control System

The downhole control system consists of various equipments used to control downhole flow in order to achieve maximum recovery of hydrocarbon through the reservoir. The two most prominent equipment of downhole control system includes inflow control valves (ICV) and inflow control devices (ICD).

4.2.1 Inflow Control Valves (ICV)

ICV are downhole equipment, which is remotely operated from the surface, is used to control the flows downhole. These valves are categorized into binary, multi-position or infinitely variable depending upon the required flow type. Binary valves have only two options- either they are fully open (ON) or closed (OFF). The multi-position valves allow different flows through adjustments. Infinitely variable contains sensors which provides choking as per the predefined requirements [10].

It is important to design carefully an ICVs because it is the main part of the smart wells. However, there is no generalized designed that can be utilized for these different types of ICVs. Therefore, reservoir management plan must be considered prior to the consideration of specific ICV in a completion string [10]. Basic understanding of the reservoir information and driving processes such as permeability, saturation, gas-oil contact, oil-water contact enables ICVs to be optimally placed in completion [11].

4.2.2 Inflow Control Devices (ICD)

Inflow control devices (ICD) are flow control devices attached in completion string. It largely delays water production and optimize oil production [12]. They can be used in water injection wells in various sand formations zones for balancing water injection profile, consequently increasing sweep efficiencies [13]. Besides, ICDs has other variety of applications as indicated by Al-Khelaiwi et al, which ranges from its application in annular isolation and artificial lifting of oil to sand control [14].

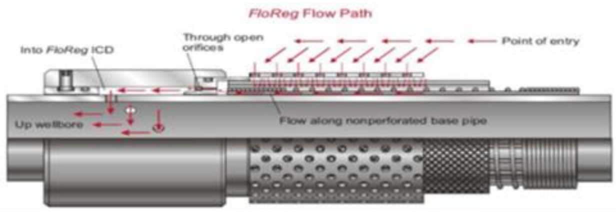

Figure.5. A typical ICD [12]

An important type of inflow control device is spiral ICD. This type of device is used to regulate a horizontal well or branch's inflow profile by implementing a further reduction of the pressure between the tubing and the sand face. This instrument is positioned in the vicinity of the tube and diverts the fluid from the neighboring portion of the structure through a sand screen into a spiral before entering the tube [15]. The extra pressure drop between a reservoir cell and a well segment with an inflow control device is expressed as [15]:

$$\Delta P_{ICD} = \left[\frac{\rho_{cal}}{\rho_{mix}}\frac{\mu_{mix}}{\mu_{cal}}\right]^{\frac{1}{4}} \frac{\rho_{mix}}{\rho_{cal}} K\, q^2 \tag{1}$$

$$K = \frac{a_{ICD}}{\rho_{cal}} \tag{2}$$

Where;

- q is flowrate through ICD.
- K is base strength of ICD.
- a_{ICD} is the ICD strength.
- ρ_{mix} is the density of fluid mixture in the segment under local conditions.
- ρ_{cal} is the fluid density used for ICD calibration.

- μ_{mix} is the viscosity of fluid mixture in the segment under local conditions.
- μ_{cal} is the viscosity of the fluid used to calibrate an ICD.

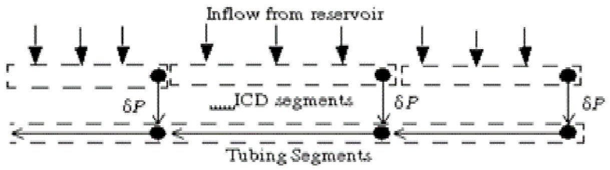

Figure.6. Typical configuration of ICD segments [15]

5. Conclusion

From the discussion, it can be concluded that Inflow control devices and inflow control valves has variety of applications in the petroleum industry specifically in smart wells and they can be used widely in optimizing the production of oil and improving the sweep efficiencies. It is also effective in downhole controlling the water production and can be used for downhole monitoring as well. Hence, water flooding technique can highly get benefit by using this Smart well completion.

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