Water Production Problems and Solutions-Part I

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Introduction

Water production is one of the major technical, environmental, and economical problems associated with oil and gas production. Water production can limit the productive life of the oil and gas wells and can cause severe problems including corrosion of tubular, fines migration, and hydrostatic loading. Produced water represents the largest waste stream associated with oil and gas production. In the United States, it is estimated[1] that on average 8 barrels of water are produced for each barrel of oil. The environmental impact of handling, treating and disposing of the produced water can seriously affect the profitability of oil and gas production. The annual cost of disposing of the produced water in the United States is estimated[2] to be 5-10 billion dollars.

This article is the first of series of articles that will discuss various aspect of technology relative to control of water production in oil and gas wells. This first article focuses on understanding the water production mechanism, causes of water production problems, and the methodology for identification of the source of the water production problem. The future topics will include discussion of various technologies for water production control, selection of an effective treatment technology to control water production, and technologies for handling the produced water.

Water Production Mechanism

Numerous technologies have been developed to control unwanted water production, but the nature of the water production must be known in order to design an effective treatment. Once the water production mechanism is understood, an effective strategy can be formulated to control water production[2]. The flow of water to the wellbore can occur through two types of paths. In the first type, the water usually flows to the wellbore through a separate path from that of the hydrocarbons. This type of water production directly competes with oil or gas production. Reducing water production in this case often leads to increased oil and gas production rates and higher recovery efficiencies. This type of water production should be the primary candidate for water control treatments. The second type of water production is water that is co-produced with oil usually later in the life of a waterflood. Reducing production of this type of water will result in corresponding reduction in oil production. For water flow to take place in the reservoir, 3 factors must be present:

1. Source of Water

   The sources of produced water include formation water, aquifer, and injected water. The formation water can be originated from a water saturated zone within the reservoir or zones above or below the pay zone. Many reservoirs are adjacent to an active aquifer and are subject to bottom or edge water drive. Water is often injected into oil reservoirs for pressure maintenance or secondary recovery purposes. The injected water is one of sources of water production problem.

2. Pressure Gradient

   Production of oil and gas from reservoir can only be achieved by applying a pressure draw-down at the wellbore which create a pressure gradient within the formation. Production from a fully penetrating and perforated well results in a horizontal pressure gradient in the formation. However, flow from a partially penetrated well will result in a vertical pressure gradient near the wellbore as well as the horizontal gradient in the formation.

3. Favorable Relative Permeability to Water

   For water to flow through a zone, the water saturation in that zone must exceed irreducible water saturation. As water saturation increases beyond the irreducible saturation, the relative permeability to water increases and relative permeability to hydrocarbon decreases. Oil, gas, and water flow mainly along the path of least resistance, which are usually the higher permeability parts of the reservoir. If the reservoir permeability was uniform throughout the reservoir (horizontally and vertically), and if the reservoir had a uniform geometry, flow will be along a simple line into the wellbore. Because of permeability variations, flow of fluids can be quite complex and not necessarily along the shortest distance to the wellbore. In water-drive reservoirs and reservoir that are subject to waterflooding, water sweeps the formation and displaces the hydrocarbon toward producing wells. In such situations, reservoir heterogeneity can result in water channeling through high permeability streaks. Examples of reservoir heterogeneity that could result in channeling include fractures, faults, discontinuous layers, and layering. Natural fractures, depending on their size, opening and frequency can have significant impact on fluid flow. Natural fractures are usually caused by tectonics, and as such may have preferred patterns. Most reservoirs consist of layers of different permeability either immediately adjacent to each other or separated by impermeable layers (usually shales). In the absence of barriers, cross flow can take place between layers. Layering and associated permeability variations are major causes of channeling in the reservoir. As the water sweeps the high permeability intervals, permeability to subsequent flow of the water becomes even higher in those intervals and lower permeability intervals remain upswept. This leads to premature water breakthrough. Channeling can be further exacerbated by lower water viscosity as compared to oil particularly during waterflooding.

Causes of Water Production Problems

Water production causes can be divided into several categories including mechanical, completion related, and reservoir related problems.

1. Mechanical Problems

Poor mechanical integrity of the casing such as holes from corrosion, wear and splits due to flaws, excessive pressure, or formation deformation contribute to casing leaks. Often casing leaks occur where there is no cement behind the casing.[3] Casing leak results in unwanted entry of water and unexpected rise in water production. In addition, the water entry in the wellbore can cause damage to the producing formation due to fluid invasion.

2. Completion Related Problems

The common completion related problems are channel behind casing, completion into or close to water zone, and fracturing out of zone.

2.1. Channels behind Casing

Channels behind casing can result from poor cement-casing or cement-formation bonds.[3] Channels behind casing can develop throughout the life of a well, but are most likely to occur immediately after the well is completed or stimulated.

2.2 Completion into or Close to Water Zone

Completion into the zones where water saturation is higher than the irreducible water saturation allows the water to be produced immediately. Often, impermeable barriers (e.g., shale or anhydrite) separate hydrocarbon-bearing strata from water saturated zone that could be the source of the excess water production. However, the barriers can breakdown near the wellbore and allow fluid to migrate through the wellbore. Even if perforations are above the original water-oil or water-gas contact, proximity allows production of the water to occur more easily and quickly through coning or cresting.

2.3. Fracturing out of Zone

When wells are hydraulic fractured, the fracture often unintentionally breaks into water zones.[4] In such cases, coning through hydraulic fracture can result in substantial increase in water production. In addition, stimulation treatments can cause barriers breakdown near the wellbore as mentioned above.

3. Reservoir Related Problems

The main reservoir related problems are channeling, coning, and depletion.

3.1. Channeling

As was discussed earlier water channeling is caused by reservoir heterogeneities that lead to presence of high permeability streaks. Fractures or fracture-like features are the most common cause of the channeling. Water production could emanate via natural fractures from underlying aquifers. Induced or natural fracture fractures can cause channeling between wells. In unfractured reservoirs often stratification and associated permeability variations among various layers can result in channeling between an injector and a producer or from an edge water aquifer to the producers. Deviated and horizontal wells are prone to intersect faults or fractures. If these faults or fractures connect to an aquifer, water production can jeopardize the well.[2]

3.2. Coning

Water coning is caused by vertical pressure gradient near the well. The well is produced so rapidly that viscous forces overcome gravity forces and draw the water from a lower connected zone toward the wellbore. Eventually, the water can break through into the perforated or open-hole section, replacing all or part of the hydrocarbon production. Once breakthrough occurs, the problem tends to get worse, as higher cuts of the water are produced. Although reduced production rates can curtail the problem, they cannot cure it. Cusping, in an inclined zone up to a vertical well, and water cresting in horizontal wells are similar phenomena to water coning.

3.3. Reservoir Depletion

Water production is an inevitable consequence of oil or gas production. There is very little that can be done to reduce water production in a depleted reservoir. Generally at the later stages of production the focus of water control will shift from preventing water production to reducing cost of produced water.[4]

Problem Identification

Numerous technologies are available for controlling unwanted water production. Each of these technologies has been developed for certain types of water production problems. The appropriate selection of the water control technology depends on the correct identification of the water production problem. Water production problems often are not properly diagnosed. In fact, incorrect, inadequate, or lack of diagnostics have been cited as one of the major reasons that water control treatments have been ineffective.[2] The reasons for inadequate diagnostics include incorrect assumption that all water production problems can be treated by one type of treatment, uncertainty about the methodology for diagnosing water production problems, and lack of time or money to perform the diagnosis on marginal wells. However, diagnosis of water production problems in most cases can be performed with information already available from routine surveillance of the reservoir and the well conditions. Methodology for identification of source of water problems and candidate selection for specific types of treatment have been discussed in a number of technical articles.[2-8] Based on the extensive reservoir and completion engineering studies and analyses of many field applications, Seright et al categorized the various types of water problems and proposed a guideline for performing effective water problem diagnosis[2]. This proposed methodology is summarized Figure 1 and will be discussed here.

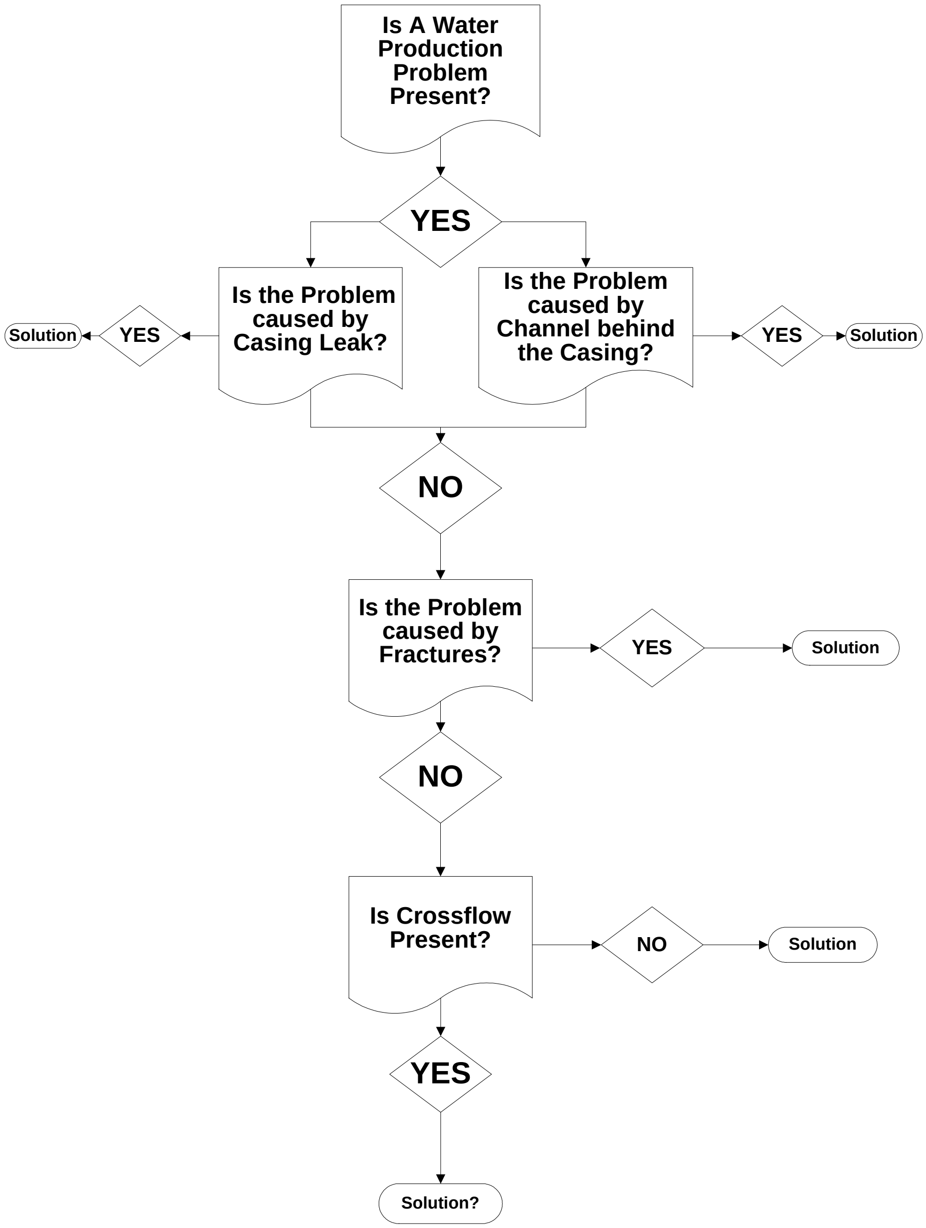

Figure 1. Guidelines for Performing Effective Water Production Problem Diagnosis

The first step is to determine if a water production problem is present. Generally, a sudden and unexpected increase in water cut is an indicator of water production problem. Plots of water/oil or water/gas ratio versus time can provide a valuable indication of when water production problem has developed. Chan proposed using log-log plots of water-oil ratio (WOR) and time derivative of WOR versus time to differentiate types of water problem.[5] However, WOR diagnostic plots can easily be misinterpreted and should therefore not be used alone to diagnose the specific cause of a water production problem.[2] If water breakthrough is experienced early in the life of the well, completion problem should be examined first for possible reason. If water entry is experienced later in the life of the well, mechanical or reservoir problems should be considered. As was mentioned before, all oil and gas reservoir inevitably experience increase in water production when they are nearly depleted. Therefore, it is important to evaluate if sufficient amount of hydrocarbons is remaining in the vicinity of the well to economically justify any treatment. Generally, the wells that are at the final stages of production or later stages of a waterflood are not appropriate candidates for water control treatments.

The second step is to determine whether the water production problem is caused by casing leaks or by channels behind casing since they are relatively easy and routine to solve.[2] The most common method used to diagnose casing leak problems is mechanical integrity test. This test is conducted by pressuring up the tubing-casing annulus and observing whether the pressure holds or not. To isolate casing leaks, pressure testing is typically conducted using a retrievable bridge plug and packer. Cement bond logs that are produced by various types of acoustic logging tools are the most common method for evaluating the condition of the cement and diagnosing the problems associated with channels behind casing. Casing and cement condition can be also evaluated and monitored by a number of different types of logging tools. These logging methods include multi-fingered caliper logs, electrical potential logs, electromagnetic inspection devices, noise logs, temperature surveys, borehole televiewers, spinner surveys, radioactive tracer surveys, and production logging.

The next step is to determine whether fluid flow around the wellbore is radial or linear. Linear flow is associated with channeling through fracture-like features, while radial flow is associated with flow in unfractured reservoirs. A number of methods are available to determine whether flow around a wellbore is linear or radial. Seright et al proposed an inexpensive and simple diagnostic method based on Injectivity/productivity calculations as follows:

$$\text{IF} \quad \frac{q}{\Delta p} \gg \frac{\sum kh}{141.2\mu \ln(\frac{r_e}{r_w})} \quad \Rightarrow \text{FLOW IS LINEAR}$$

$$\text{IF} \quad \frac{q}{\Delta p} \leq \frac{\sum kh}{141.2\mu \ln(\frac{r_e}{r_w})} \quad \Rightarrow \text{FLOW IS RADIAL}$$

The calculations can frequently provide an indication of the flow geometry near the wellbore even though they may not always distinguish between radial and linear flow. In addition core and log analyses, pulse tests, pressure transient analyses, and interwell tracer studies have been used to determine whether flow around a wellbore is linear. Relatively inexpensive interwell tracer studies provide much better resolution of reservoir heterogeneities than pressure transient analyses. Interwell tracer can indicate presence of fractures and if those fractures are the cause of a channeling problem.

Next, the possibility of crossflow between reservoir strata must be addressed once fracture-like features are ruled out as the cause of water production problems. If fluids can crossflow between adjacent water and hydrocarbon strata, effective technologies for water production control exist. In contrast, the treatments will be generally ineffective when fluids can crossflow between adjacent strata.[2] Several methods are used to assess whether crossflow exists between strata, including pressure tests between zones, various logs for determining fluid saturations, permeability, porosity, and lithology, injection/production profiles, simulation, and seismic methods. The most common method is to test the pressure differences between zones. Commonly, a packer is placed between two zones and one of the zones is allowed to pressure up. If a significant pressure can be maintained across the packer, effective barriers to crossflow exist between the zones. If a pressure difference cannot be maintained, crossflow between the zones may occur.

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