chemengineering

Article

Overview of Water Shutoff Operations in Oil and Gas Wells; Chemical and Mechanical Solutions

Abdullah Taha and Mahmood Amani *

Department of Petroleum Engineering, Texas A&M University at Qatar, P.O. Box 23874, Doha, Qatar; abdullah.taha@qatar.tamu.edu

* Correspondence: amani@tamu.edu

Received: 23 January 2019; Accepted: 10 May 2019; Published: 14 May 2019

Abstract: This paper provides an integrated overview of the water shutoff operations, starting from the causes to the solutions. The paper begins with explaining the benefits of eliminating excessive water production. Then, the different types of water production and their properties are explained. The paper also focuses in reviewing the disadvantages of producing unwanted water as well as the sources of it, followed by an explanation of the methodology for identifying the problem. Then, the chemical solutions for water shutoff are reviewed which are generally applied to solve the excessive unwanted water production in the reservoir or near the wellbore area. Finally, the paper illustrates the common mechanical solutions for water shutoff within the wellbore. The aim behind this paper is to provide a general description of identifying the unwanted water production sources and the common practices for water shutoff operations.

Keywords: unwanted water; fractures; aquifer; logging; polymer flooding; plugs

1. Introduction

Excessive water production is one of the main well-known problems that would face any oil operator in the world. Although this problem is typical in older wells, it can also occur in new developed wells as well [1]. It causes numerous economic problems for oil production companies. First, excessive water effects the performance of the production wells and shortens their lifespan. The presence of the water in the wellbore increase the weight of the fluid column which leads to an increase in the lifting requirements [2]. That increases the operating cost and leads to a lower the drawdown. For example, if the well is a gas lifted well, the amount of gas injected to lift the fluid from the wellbore to the surface is higher with the production of excessive water than without producing it. Water production also enhances the presence of scales, corrosion, and degradation in the field facilities starting from the wellbore to the surface facilities [2]. Another major problem is that the cost of separating, treating, and disposing the produced water is a great burden to oil company budgets. It costs around $1 billion/year in Alberta to dispose of the produced water [3]. Getting rid of that kind of production helps in reducing expenses for the operators and increases the profitably of their operations [4]. Therefore, water shutoff operations are essential. Finally, with good knowledge of the formation characterizations and the unique challenges of the field, unnecessary water production can be avoided from the wellbore designing phase [5].

2. Types of Water Production

Is water production always a bad thing? The right answer is definitely: no! Water is one of the most important drives for oil production since it helps in managing the reservoir, mobilizing the oil, and displacing it in the homogenous rocks. This water is known as necessary or good water production. It is the water that is typically associated with oil production in the late stages of water-flooding operations or from active aquifers. It is also the water produced at a low water/oil ratio (WOR) which maintains the profitably of a production well [1]. Attempts to reduce this kind of water production leads directly to reduction in the oil production [6]. On the contrary, unwanted water production is the type which needs to be eliminated and reduced in order to increase the productivity and the profitability of the production wells [7]. Water shutoff operations focus on eliminating unwanted water production, which is also called 'bad water'. This kind of production creates problems other than those mentioned previously, such as reduced oil production and poor sweep efficiency within the matrix rocks. Put simply, that means losing money! The worst problem among unwanted water production issues is the unswept areas and oil pockets that are left behind as a result of bad conformance jobs. This case is commonly known in water-flooding operations where water is simply injected through the injection well to displace oil toward the production well and to maintain the pressure of the reservoir however, the water goes to an open fracture or high permeability layer. It is all about the resistance of the paths in the reservoirs. The least resistance path is the winner in attracting the injected water toward it and the oil in the matrix rock stays behind without achieving the required sweep to attain efficient oil sweeping or good conformance [3]. If the production well happens to be connected to the open fracture or the high permeability layer, unwanted water production would occur. It is essential to be able to differentiate between those two types of water production in order to maintain the productivity of the well. One of the ways to identify the type of the excessive water production in a certain well is by studying the offset wells' water cut behavior. It is bad water production if the offset wells are producing with a much lower water cut [4].

3. Sources of Unwanted Water Production

After discussing the problems associated with unwanted water production, it is important to identify the reasons which lead to this kind of production in order to be able to accomplish a successful water shutoff operation. In water-flooding operations, the aim is to mobilize the oil in the matrix rock toward the production wells and to maintain the pressure of the reservoir. Open fractures and high permeability layers usually reduce the efficiency of flooding operations and leads to poor conformance. As mentioned previously, the fluid tends to take the paths least resistance and the injected water, as a result, goes to the open fractures and high permeability formations instead of matrix rock to displace the oil. In some cases, the water injection well happens to be connected with the production well through an open fracture or features which are known also as 'thief zones' [8] (Figure 1). Open features also can result in an excessive amount of water if they are connected to the aquifer (Figure 2). Additionally, fractures and open features can contribute to unwanted water production when they are connected to water formations/zones [9]. Gas hydrate reservoirs can be also a main source of excessive water production when dissociated [10].

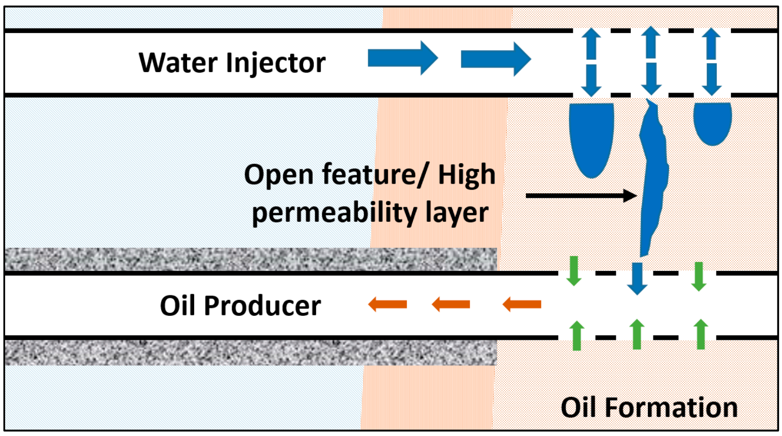

Figure 1. Example of a water injection well connected to an oil producer well through an open feature/high permebility layer.

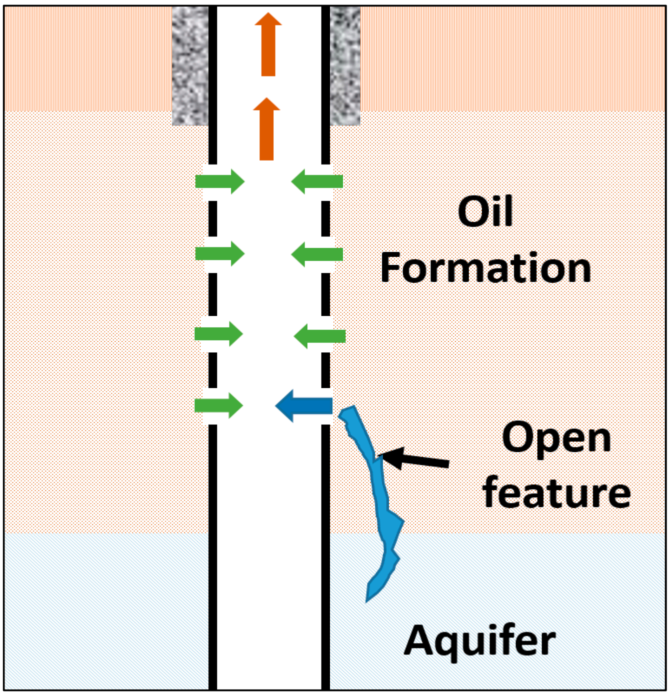

Figure 2. An oil producer connected to an aquifer through an open feature.

Another common source of unwanted water production is water coning. This situation usually occurs when the production zone is near the aquifer or water formations with a decent permeable connections between the oil production zone and the water formation. Coning arises with the drawdown of the pressure which encourages the water to migrate to the wellbore from the bottom (Figure 3). Although it can be controlled by decreasing the rates of production, it is not a favorable approach since oil production is going to be reduced as well [8]. It can be also solved by plugging the bottom of the well, however, it is considered as a short term solution [6].

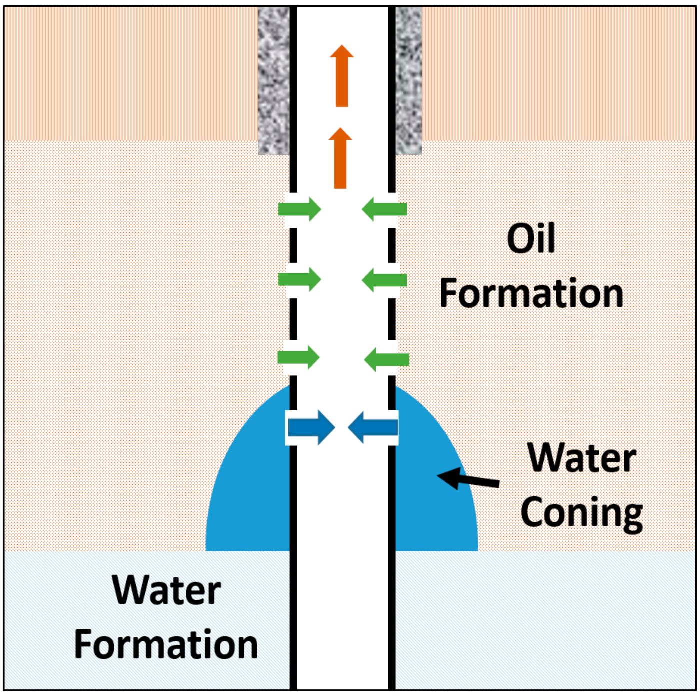

Figure 3. Water coning.

One of the most common sources of unwanted water production is poor conditions of the nearby wellbore. This kind of production typically can occur as a result of casing leaks or bad cement jobs behind the casings which usually creates channels connecting the unwanted water production formations/sources with the wellbore. The casing and the cement job behind the casing are supposed to create a seal from such unwanted layers (Figures 4 and 5).

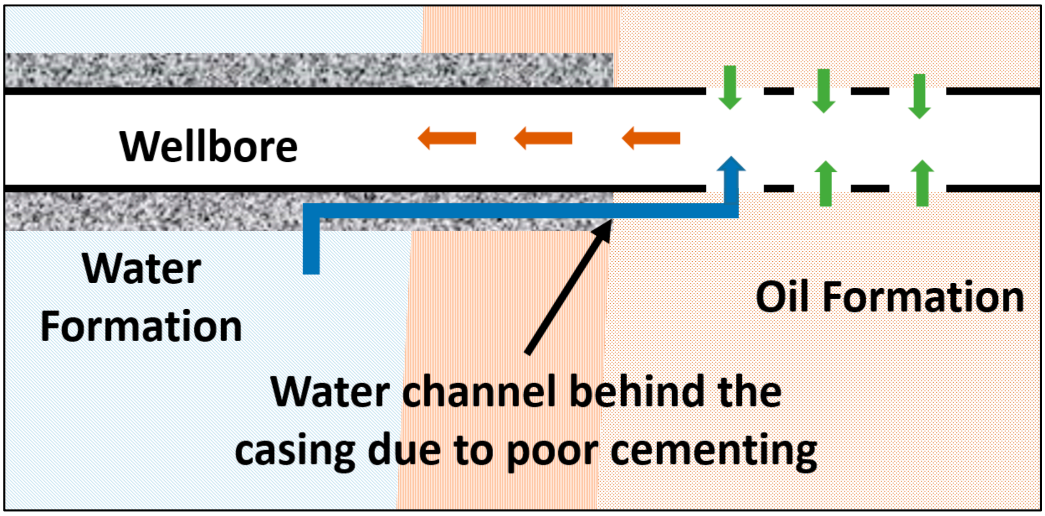

Figure 4. Poor cement behind the casing with a channel connecting water source to the wellbore.

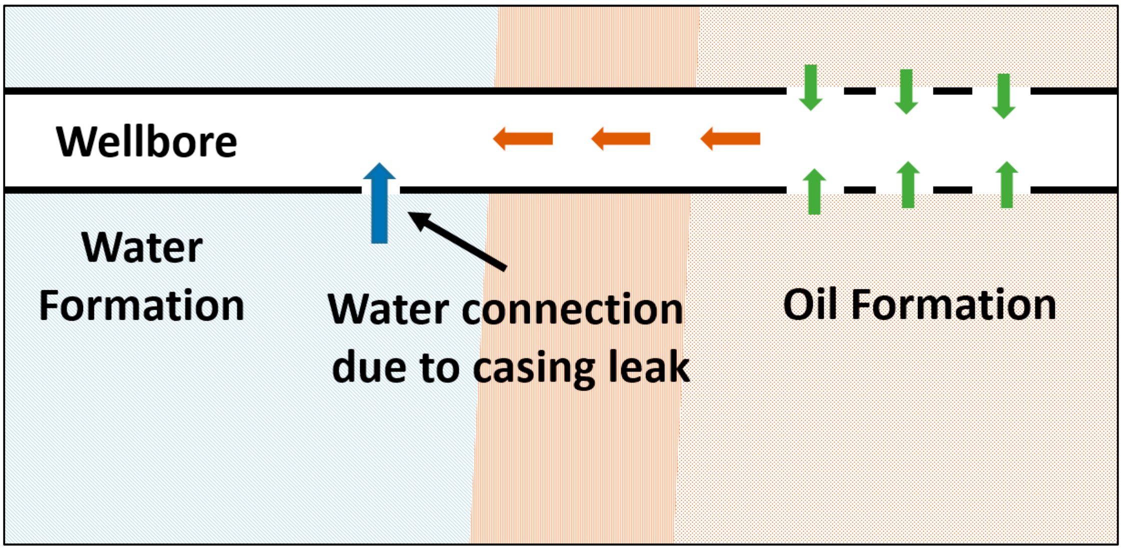

Figure 5. Casing leak connecting the wellbore with water formation.

4. Identifying the Problem

Reducing excessive water production usually starts with gathering all available reservoir and production data. Then logging tools are used to locate the water entry points. Finally, based on the results, a proper shutoff method is used [11]. The most important part in any water shutoff operation is the accurate diagnosis of the problem. It is essential to know the water entry point, the heterogeneity of the reservoir rocks, dominant production mechanisms, and the schematics of the wellbore [12]. In fact, all available information about the well is considered valuable, like drilling operations reports, logs, and production history. The reason behind that is that every well would have its own workflow based on it is properties, history, and reservoir heterogeneity. Accurate investigation leads to success in the water shutoff operation, increasing oil production, and saving water handling costs. Fayzullin et al. [13] present an example of a case study for understanding unwanted water production in an Eastern

Europe gas field. Production logging tools in production wells usually are used to identify the water production zones, which is an important step in planning for an optimized water shutoff operation. For water injection wells, water flow logs are used to identify the thief zones. However, horizontal wells are challenging in identifying the problem as well as in the intervention part. That is due to the complicity of the wellbore, flow regimes, and their effects on obtaining the required information. Luckily, advanced production logging tools can be used to identify the entry points as well as the rates [2]. Fiber optics technologies are used nowadays along with logging tools to ensure high quality real time data that help in accurately identifying the water entry zones [14]. Al-Zain et. al. [15] present a case of successful usage of fiber optics to shut off unwanted water production in an oil field. In addition to that, water/oil ratio (WOR) plots can be used to identify the excessive water production problems. In fact, it can be a more effective tool than logging in many cases as explained in [16].

For channeling behind the casings, running cement bond logs or ultrasonic pulse-echo logs plays a vital role in ensuring the integrity of the cement job behind the casing. Those kinds of logs evaluate the bonding properties of the cement job behind the casing and point out bad cement areas. For casing leaks, production, temperature, and noise logs are all means of identifying the sources of leaking [8].

5. Chemical Solutions

Far from the wellbore, in the reservoir or near the wellbore, water shutoff operations can be performed by several chemical treatments. Those chemical solutions lead to better conformance in the reservoir as well as blocking the unwanted water production zones. The idea is to be able to close the paths of least resistance in front of the water by reducing their permeability in order to prevent the water from coming to the wellbore through them. Also, they aid in forcing the water to mobilize and displace the oil in the reservoir. In other words, the aim is to block the open features and high permeability channels to force water to go toward the harder path to sweep oil from the matrix rock that results in higher overall economical returns than producing oil from fractures. In fact, induced formation damage can be used as an effective solution to control the unwanted water production [17]. The results of chemical solutions can be achieved in a couple of months to years, depending on the nature of the reservoir and the properties of the injected chemicals. The main advantage that chemical water shutoff operations have over mechanical operations is that they solve the problem of the unwanted water production instead of hiding it under or behind a plug, packer, or tubing patch. Injected chemicals can reach water features in the reservoir and reduce the permeability, resulting in closing them entirely. They also have the freedom of moving between the layers and features which helps in reaching to far extents and completely closing them. Another use of chemical injection is to increase the viscosity of the injected fluid which leads to a better sweeping efficiency and eventually reduces the production of unwanted water. The success of chemical injection operations depends on the knowledge level of the reservoir and its characterizations, chemical properties, and accurate placement of the injected chemicals [3,18]. For example, the effectiveness of water shutoff agents depends highly on the properties of the reservoir and has to be compatible with the reservoir temperature and water salinity in order to achieve an effective water shutoff [19]. In this section, common chemical solutions are discussed in detail, along with examples of the execution of the operations.

5.1. Gel

Gel injection is one of the most famous chemical solutions for water shutoff operations. It is used to reduce the water oil ratio and increase the conformance of the pattern. That happens through the ability of the gel to reduce the permeability and block the open features, fractures, and high permeability water zones. It can be applied in the wellbore, near the wellbore, and far from the production well through injection wells. It is very effective in reducing the permeability of unwanted zones and has proven its ability to improve the sweep efficiency and shutting-off the unwater water zones. The injected gel is mainly made of water, small volumes of polymers and crosslinking chemical agents [6]. Gel treatments can completely seal off layers; therefore, they are considered aggressive and risky conformance control operation [3]. On the other hand, polymer gel injection is considered relatively cheaper than other improved oil recovery operations.

Gel injection operations are divided into three main stages: modeling, designing, and executing. The first step is to model the gel injection operation by using simulation software, which is an important step for designing the program of gel injection operation [18]. In this stage, all the available information about the reservoir and the well are considered valuable, such as: reservoir parameters, water entry points, drilling operations reports, logs, and production history. The second step is to design the properties of the polymer gel fluid. Injecting gel in the reservoir depends on four properties. First one is the viscosity of the gel at the time of injection which helps in directing the gel to the lager and least resistance paths. Second is the nature of the gel phase which is usually chosen to be the aqueous phase since the water is the desired phase to be shut off. Third is the density of the gel. It very important to be designed carefully and based on the density of the formation water to avoid losing the effectiveness of the gel treatment. Fourth is the setup time or injection time. Longer injection time leads to more success in allowing the gel to seal off larger features and least resistance paths [3]. Al-Dhafeeri et. al. [20] present a case study of using gel treatments as a chemical solution to seal the excessive water zones.

5.2. Polymer Flooding

Another common technique for water shutoff operations is the usage of the polymer flooding method to increase the viscosity of the water. This technique is applied to increase the viscosity of the drive fluid (water) which helps in mobilizing and displacing the oil in the reservoir matrix rock. This technique is usually applied in the reservoir far from the production wells through water injection wells to achieve better sweeping efficiency in the reservoir. That eventually leads to preventing excessive water production. The usage of polymer flooding is very common among the oil operators and it can be prepared by dissolving the polymers in the injected water and inject it through injection wells. Polymers used in this technique are usually two types: biopolymers and synthetic polymers. Biopolymers' advantages over the synthetics are that they are not affected by the salinity of the water and they are insensitive to the mechanical degradations. However, they are more expensive than synthetic polymers. Xanthan and scleroglucan are two famous kinds of biopolymers. Synthetic polymers are more common since they are cheaper, more available, and perform well with low-salinity water. Polyacrylamide (PAM) and hydrolyzed polyacrylamide (HPAM) are two types of synthetic polymers. Polymers can also play a role in reducing the permeability if the molecular weight is increased [6]. Finally, based on the characteristics of the reservoir and the economics of the operations, the right polymer is chosen in case of chemical injection [21]. El-Karsani's paper [22] includes an overall review of the polymer systems used for water shutoff operations along with their chemical compounds and properties.

There are other chemical techniques for water shutoff operation such as resins, solid particles, and foams which are also effective in obtaining better conformance and enhance the sweep efficiency. More details about those methods can be found in [6]. Finally, Bybee [23] presented a case of a long horizontal well with excessive water production from southern Italy. Sealant was pumped as a solution to successfully solve the problem.

6. Mechanical Solutions

Within the wellbore, there are available technologies which can successfully shut off the unwanted water production. The impact can be seen in hours in contrast to the chemical solutions which was discussed in the previous section. Controlling the water production mechanically is known for it is fast outcomes as well as its cheap costs. It is usually a rigless job, which means a lower cost [2]. Mechanical water shutoff operations are preferred by operators since they are relatively cheaper than chemical solutions [4]. Once more, an accurate diagnosis is essential before attempting to apply those solutions, since it can result in losing the oil production from the well. That can be achieved, as mentioned previously, through running logs to identify the water production zones. In the case of mechanical shutoff operations, there are some factors affecting the success of them. One of them is the setting depth of the plug or the packer can be wrong due to inaccurate readings from the coiled-tubing meter. The reservoir conditions also play a great role in affecting the operations, since a cross flow between the layers can happen and leads intervention to failure. The wellbore condition is another vital factor which needs to be considered. Scale presences in the tubing can result in failure of the operations, since it can create an obstacle while running the plug or the packer downhole. Wells with high deviation angles can be challenging to run in hole with coiled-tubing since they can get stuck a lot [24]. In this section, common mechanical solutions are discussed in details along with examples of the execution of the operation.

6.1. Plugs and Packers

One of the most well-known mechanical solutions for water shutoff and isolation operations inside the wellbore is the installation of packers and plugs. They are successful in eliminating the production from unwanted water zones. They are commonly used by oil operators to aid the wells performance and shut off the excessive water production [25]. This hardware is known for being economical and reliable in achieving isolation since it can be installed without pulling the production tubing and without the drilling rig. They can be installed by using coiled tubing which can run them through the wellbore. Also, the results can be achieved relatively fast, in a couple of hours to days, in contrast with chemical injection solutions. Simply, the concept of packers and plugs is a small diameter element, mainly rubber, which can expand downhole the wellbore into larger diameters, creating a seal and isolating the well from unwanted features or zones [26].

There are different types of packers and plugs with different properties and setting techniques. Some elements expand by interacting with certain types of fluids (oil, water, or hybrid) which are known as 'swellable packers'. They also depend on pre-designed properties like temperature, pressure, and salinity of the formation fluid. That can be a disadvantage in some cases and leads to failure in setting the element. If those properties are not accounted for accurately, that might lead to a faster inflation of the elements or even slower inflation than expected. In the worst case scenario, the element might not inflate at all. Other packers and plugs inflate by applying pressure on the element in order to expand and seal. These types of plugs usually inflate by pumping darts, steel balls, or fluid to apply pressure on the rubber element and allow it to expand and increase its diameter. Packers and plugs can be used to isolate unwanted water production inside the wellbore in certain cases.

An easy example would be an open-hole well completion and the water zone is identified to be from the bottom of the well. A bridge plug can be installed to isolate the bottom section and shut down the additional water production to aid the production performance from upper oil zones (Figure 6). The difficulty increases if the water source happens to be in the middle or at the top part of the production section of the tubing in the reservoir section. In that case, a blank pipe with upper and lower packers, with a pre-designed length, can be installed to isolate the water production area without compromising the lower and upper oil production zones (Figure 7). In the case of a multi-lateral wells, if one of the laterals is watered-out or producing extreme amounts of unnecessary water, it can be abandoned by setting a plug to isolate it from other laterals. The usage of packers is also used in early stages of the well life, specifically in the completion stages after drilling. That is a common practice for operators who have a reasonably decent knowledge of the expected features and layers of their reservoir. Also logging while drilling tools can be an asset by identifying the open features which might be the future reason for bad water production. After drilling the well and collecting the data, a pre-perforated liners can be installed with packers to produce only the good layers and isolate the risky formations. Once more, an accurate and cautious pre-design of the job is essential for designing the elements to avoid failures.

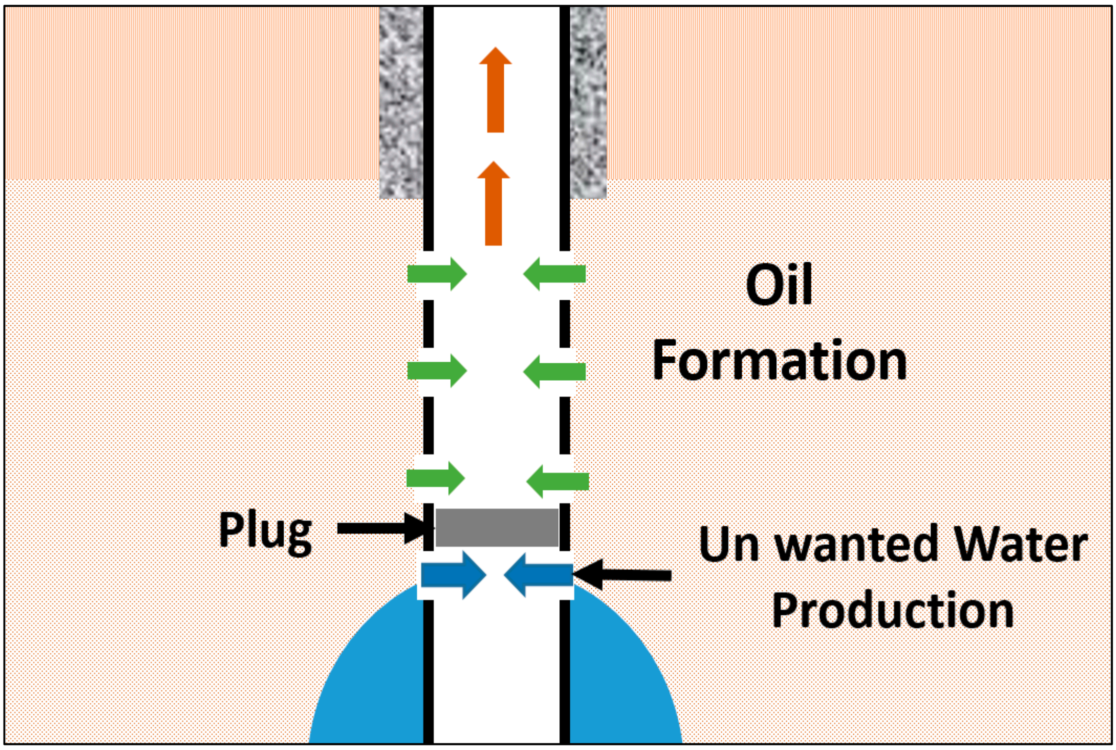

Figure 6. Using a plug to shut off the production of water from the bottom.

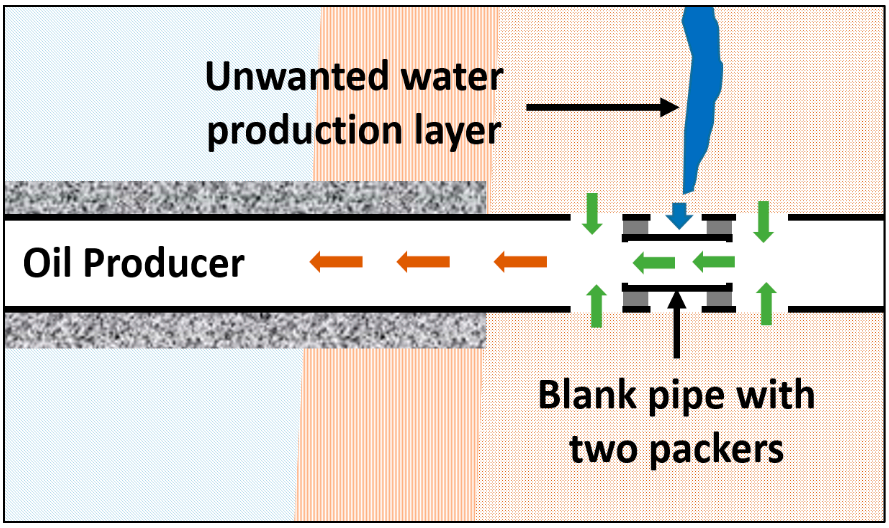

Figure 7. Two packers above and below a blank pipe to shut off the production of water from the middle and upper intervals without compromising other oil production zones.

Likewise, for water injection wells, those plugs can be used to insure better conformance outcomes and to eliminate the production of bad water from the production wells through thief zones, high permeability layers, or connected open features. For example, if any of the previous features have been identified in the injection profile of water injection well, plugs can be used to isolate injected water from going into them. If there is an open feature at the bottom of a water injection well, a plug can be installed to isolate the bottom section, to avoid wasting the injected water and direct it into oil matrix rocks instead. Similarly, if the feature happens to be at the middle or the top of the injection profile, a blank pipe with upper and lower packers can be installed to isolate the thief zones from stealing the injected water without compromising the conformance and the sweeping efficiency of the field (Figure 8).

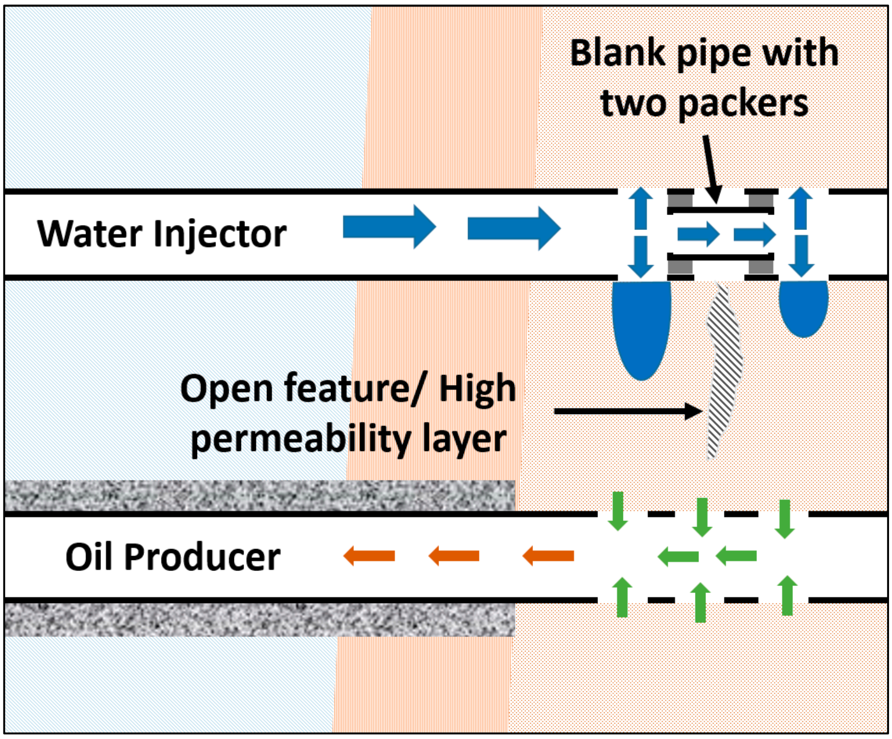

Figure 8. Two packers above and below a blank pipe to avoid injecting the water in open features or high permeability layers.

Other than that, inflatable packers are also used in chemical injection for water shutoff operations. As mentioned previously, chemicals can be used in the near wellbore area to control and shut off the unwanted water production. However, this operation considered risky because of the high cost and the risk of injecting the chemicals into the oil production zones [27]. Therefore, packers are used to direct the flow of the injected chemicals into the desired layers and prevent fluid from going into the production formation. Packers create a seal by inflating and isolating the upper and bottom intervals to make sure that chemicals do not bypass to oil zones.

6.2. Tubing Patches

This method is mainly used for fixing well integrity issues particularly casing leaks. The casing leaks problems are common in old wells and the wells which are completed in formations with corrosive gases like H_2S [28,29]. If the source of the unwanted water was found to be from a leak in the casing, squeezing cement or resins patches is considered to be a suitable solution. This method can be applied only after identifying the exact location of the leak through the methods discussed earlier. Squeezing jobs can be performed by rigs or sometimes with current technologies can be a rig-less job. Usually, inflatables are used to direct the patches toward the leaking point [30]. For small leaks, fine cement particles are squeezed to fix the well integrity issue as well as creating a seal [28].

7. Conclusion

Excessive water production causes numerous economic problems for oil production companies such as effecting the performance of the production wells, shortening their life period, increasing the operating cost, enhancing the presence of scales, corrosion, and degradation in the field facilities. It is very important to distinguish necessary water from unwanted water production since any attempt to reduce good water leads directly to reduction in the oil production. Unwanted water production can be identified by comparing the problematic well with offset producer water cut values. Unwanted water production can occur through connected open fractures or high permeability zone, water coning, casing leaks, and poor cement behind the casing. It is essential to identify the water entry point through production logging tools and study all the available information about the well in order to execute a successful water shutoff operation. Based on the case, chemical or mechanical solutions can be applied to shut off the unwanted water production. Chemical solutions are considered as permeant solutions and are more risky. Mechanical solutions are easier in execution and faster in achieving results. This paper provided a summary for the water shutoff operations starting from explaining the problem, the way to identify it, and finally the available common chemical and mechanical solutions to overcome the unwanted water production problem.

Author Contributions: A.T. conducted most of the Literature Review and case studies, and M.A. provided, guidance, supervision, assisted with the writing and editing of the paper.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Joseph, A.; Ajienka, J.A. A Review of Water Shutoff Treatment Strategies in Oil Fields. Presented at the Annual SPE International Conference and Exhibition, Tinapa-Calaber, Nigeria, 31 July–7 August 2010.
2. Ahmad, N.; Al-Shabibi, H.; Malik, S. Comprehensive Diagnostic and Water Shut-off in Open and Cased Hole Carbonate Horizontal Wells. Presented at the Abu Dhabi International Petroleum Exhibition and conference, Abu Dhabi, UAE, 11–12 November 2012.
3. Thomas, F.B.; Bennion, D.B.; Anderson, G.E.; Meldrum, B.T.; Heaven, W.J. Water Shut-off Treatments-Reduce Water and Accelerate Oil Production. *J. Can. Pet. Technol.* **2000**, *39*, 25–29. [CrossRef]
4. Permana, D.; Ferdian, G.; Aji, M.; Siswati, E. Extracting Lessons Learned of 35 Water Shut-off Jobs in Mature Fields to Improve Success Ration of Water Shut-off Job. Presented at the SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition, Bali, Indonesia, 20–22 October 2015.
5. McIntyre, F.J.; Grenon, J.P.; See, D.L. Horizontal Well Gas/Water Shutoff-Field Results. *J. Can. Pet. Technol.* **1999**, *38*, 23–27. [CrossRef]
6. Sydansk, D.; Romero-Zeron, L. *Reservoir Conformance Improvement*, 1st ed.; Society of Petroleum Engineers: Richardson, TX, USA, 2011.
7. Seright, R.S.; Lane, R.H.; Sydansk, R.D. A Strategy for Attacking Excess Water Production. SPE-84966-PA. *SPE Prod. Facil.* **2003**, *18*, 158–169. [CrossRef]
8. Economides, M.J.; Hill, A.D.; Ehlig-Economides, C. *Petroleum Production Systems*, 18th ed.; Prentice Hall PTR: Upper Saddle River, NJ, USA, 2008.
9. Guo, B.; Lyons, W.C.; Ghalambor, A. *Petroleum Production Engineering a Computer-Assisted Approach*; Gulf Professional Publishing: Houston, TX, USA, 2007.
10. Fakher, S.; Elgahawy, Y.; Abdelaal, H.; Tonbary, A.; Imqam, A. Reducing Excessive Water Production Associated with Gas Hydrate Reservoirs Using a Thermal In-Situ Heating-Inhibitor Method. Presented at the SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition, Dammam, Saudi Arabia, 23–26 April 2018.
11. Burov, A.; Kharrat, W.; Hussein, N.A. Innovative Coiled Tubing Water Shutoff Techniques in Horizontal Wells. Presented at the SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, LA, USA, 15–17 February 2012.
12. Yortsos, Y.C.; Choi, Y.; Yang, Z.; Shah, P.C. Analysis and Interpretation of Water/Oil Ratio in Waterfloods. *SPE J.* **1999**, *4*, 413–424. [CrossRef]
13. Fayzullin, M.; Tippel, P.; Gonzalez, J.; Egger, S. Understanding Excessive Water Production in Highly Faulted Mature Gas Condensate Field: From Well Operations to Revival of Integrated History Matching. Presented at the IADC/SPE Asia Pacific Drilling Technology Conference, Bangkok, Thailand, 25–27 August 2014.
14. Olarte, J.D.; Haldar, S.; Said, R.; Ahmed, M.; Burov, A.; Stuker, J.; Kharrat, W.; Wortman, H. New Approach of Water Shut off Techniques in Open Holes and World First Applications of Using Fiber Optic Services With Tension-Compression Sub. Presented at SPE/DGS Saudi Arabia Section Technical Symposium and Exhibition, Al-Khobar, Saudi Arabia, 15–18 May 2011.

15. Al-Zain, A.; Duarte, J.; Haldar, S. Successful Utilization of Fiber Optic Telemetry Enabled Coiled Tubing for Water Shut-off on a Horizontal Oil Well in Ghawar Field. Presented at the SPE Saudi Arabia Section Technical Symposium, Al-Khobar, Saudi Arabia, 9–11 May 2009.
16. Al Hasani, M.A.; Al Khayari, S.R.; Al Maamari, R. Diagnosis of Excessive Water Production in Horizontal Wells Using WOR Plots. IPTC-11958-MS. Presented at the International Petroleum Technology Conference, Kuala Lumpur, Malaysia, 3–5 December 2008.
17. Zeinijahromi, A.; Bedrikovetski, P. Controlling Excessive Water Production Using Induced Formation Damage. Presented at the SPE European Formation Damage Conference and Exhibition, Budapest, Hungary, 3–5 June 2015.
18. Surguchev, L.M. Water Shut-Off: Simulation and Laboratory Evaluation. Presented at the European Petroleum Conference, The Hague, The Netherlands, 20–22 October 1998.
19. Sun, Y.; Fang, Y.; Chen, A. Gelation Behavior Study of a Resorcinol-Hexamethyleneteramine Crosslinked Polymer Gel for Water Shut-Off Treatment in Low Temperature and High Salinity Reservoirs. *Energies* **2017**, *10*, 913. [CrossRef]
20. Al-Dhafeeri, A.M.; Nasr-El-Din, H.A.; Al-Harith, A.M. Evaluation of Rigless Water Shutoff Treatments to Be Used in Arab-C Carbonate Reservoir in Saudi Arabia. Presented at the CIPC/SPE Gas Technology Symposium 2008 Joint Conference, Calgary, AB, Canada, 16–19 June 2008.
21. Gharbi, R.; Alajmi, A.; Algharaib, M. The Potential of a Surfactant/Polymer Flood in a Middle Eastern Reservoir. *Energies* **2012**, *5*, 58–70. [CrossRef]
22. El-karsani, K.S.M.; Al-Muntasheri, G.A.; Hussein, I.A. Polymer Systems for Water Shutoff and Profile Modification: A Review Over the Last Decade. *SPE J.* **2014**, *19*, 135–149. [CrossRef]
23. Bybee, K. Solving Excessive Water Production in a Long Horizontal Open Hole. *J. Pet. Technol.* **2009**, *61*, 63–65. [CrossRef]
24. Denney, D. Factors Affecting Mechanical Water Shutoff. *J. Pet. Technol.* **2001**, *53*, 58–59. [CrossRef]
25. Offenbacher, M.; Gadiyar, B.; Messler, D. Swellable Packer Fluids Designed for Zonal Isolation in Openhole Completions. Presented at the SPE European Formation Damage Conference and Exhibition, Budapest, Hungary, 3–5 June 2015.
26. Wilson, P.; Hoffman, C.E. Zonal Isolation in Stimulation Treatments and Gas/Water Shutoff Using Thermally Compensated Inflatable Packers and Plugs. Presented at IADC/SPE Asia Pacific Drilling Technology, Kuala Lumpur, Malaysia, 11–13 September 2000.
27. Plante, M.E.; Mackenzie, G.R.J. Selective Chemical Water Shutoffs Utilizing Through-Tubing Inflatable Packer Technology. Presented at SPE/ICoTA Coiled Tubing Roundtable, Houston, TX, USA, 5–6 April 2000.
28. Lizak, K.F.; Zeltmann, T.A.; Crook, R.J. Permian Basin Operators Seal Casing Leaks with Small-Particle Cement. Presented at SPE Permian Basin Oil and Gas Recovery Conference, Midland, TX, USA, 18–20 March 1992.
29. Meek, J.W.; Harris, K. Repairing Casing Leaks Using Small-Particle-Size Cement. *SPE Prod. Facil.* **1993**, *8*, 45–50. [CrossRef]
30. Bybee, K. Unique Rigless Casing Leak Repair. *J. Pet. Technol.* **2001**, *53*, 28–29. [CrossRef]