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RESEARCH PAPER

Comprehensive review of water shutoff methods for horizontal wells

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Abstract: This paper provides a comprehensive review of the water control techniques that have been applied in horizontal wells and presents the water control methods for wells of different completion types. Water shutoff techniques are classified as mechanical methods and chemical methods. These methods can be used individually or in combination. Mechanical methods are usually used to deal with wellbore water shutoff or near wellbore water control. Chemical methods are used in plugging matrix or fractures. Completion type should be considered when designing a water shutoff project. Both mechanical methods and chemical methods can be used in open hole and cased hole horizontal wells. In the wells that completed with perforated liners and wells completed with sand screen pipe, only chemical methods can be used to control excess water production, while the mechanical methods can only provide temporary zonal isolation. Mechanical methods are slightly higher in cost than chemical methods, and the depth correction is a challenge. Mechanical and chemical methods can be individually used if the water entry point is at the toe. A combination of packers should be designed for the wells with water entry point near the heel or along the lateral.

Key words: horizontal well; water control technique; mechanical water shutoff; chemical water shutoff

Introduction

Excess water production is one of the most serious problems for oil or gas fields, especially for mature reservoirs. Water production impacts the economic life of reservoirs and ultimate recovery. It brings up operating expenses, such as pumping costs, water/oil separation costs, and equipment costs. The excess water production also causes wellbore corrosion, scale, and sand-production problems. Due to the chemical complexity of produced water, it requires seriously environmentally friendly concern when disposing the produced water. This likewise increases the disposal costs. Therefore, coming up with a proper and economical way to shut off or lower the excess water has become one of the most significant tasks for petroleum engineers. Most recently, more wells are drilled horizontally to increase contact area with reservoirs thus to increase oil production. With a shift in drilling strategies from vertical wells into horizontal wells, water production problem should also be considered seriously in horizontal wells.

1. Water shutoff methods

Generally, there are two main types of water shutoff methods in horizontal wells: mechanical and chemical method. The two methods can be used individually or in combination[1, 2].

1.1. Mechanical methods

Mechanical methods can be achieved by using packers to seal the water excess zone. Packers can be classified as expandable packers and non-expandable packers as shown in Table 1. Expandable packers have inflatable elements which are designed to expand in wellbore and provide isolation. After inflating, the volume of the inflatable elements will increase until fully occupy the gap to provide isolation. Most of the expandable packers are retrievable; however, sometimes they are combined with cement plugs to provide permanent sealing in open holes.

Expandable packers. Expandable packers include: inflatable packer, bridge plug, swell packer, straddle packer, inflatable cement retainer, and expandable tubular. The inflatable processes are triggered by different mechanisms. The inflation of inflatable packers is achieved by the expansion of rubber blades. The expansion of bridge plugs and expandable tubular is achieved by mechanic expansion. The pressure between the base of the cone and the shoe of the clad will expand the tubular[3]. The swelling of swell packer is caused by in contact with fluids in wells. Some expandable packers such as straddle packers with two inflatable elements and a nipple can be used as both zonal isolation tools and injection tools. The two

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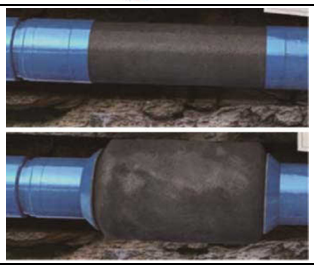
Table 1. Common-used packers characteristics and sealing mechanisms.

Name	Appearance	Expansibility	Retrievability	Sealing mechanisms
Cement plug		No	No	Cement fully plugs the annulus by forming a rigid block
Inflatable packer		Yes	Yes	The inflation of inflatable packers is achieved by expansion of rubber bladder. Inflatable elements fully occupy the annulus to provide isolation
Bridge plug		Yes	Yes	The expansion of bridge plugs is achieved by mechanic expansion. Inflatable elements fully occupy the annulus to provide isolation
Straddle packer		Yes	Yes	The inflation of straddle packer is similar to the inflatable packer. Inflatable elements fully occupy the annulus to provide isolation
Swell packer		Yes	Yes	The swelling of swell packers is caused by contact with fluids in well. Inflatable elements fully occupy the annulus to provide isolation
Cement retainer		Yes	Yes	The inflation achieved by expansion of rubber bladder. The cement is injected after the expansion.
Expandable tubular		Yes	No	The pressure between the base of the cone and the shoe of the clad will expand the tubular to provide sealing
External casing packer (ECP)		Yes	No	The inflation is achieved by expansion of rubber bladder. Inflatable elements fully occupy the annulus to provide isolation

inflatable elements provide zonal isolation, while the treatment fluid can be injected from the nipples in between. Inflatable cement retainers have similar function. It provides zonal isolation by inflatable elements for later chemical treatment and chemical injection into the target zone.

One special expandable packer is external casing packer (ECP). It is frequently used with liners or sand screens and set at intervals along the openhole. It has an inflatable section which is the rubber bladder over a section of casing. Once this section inflates, the annular will be sealed by the packers.

Non-expandable packer. Cement packer is a commonly used non-expandable packer in vertical wells. Applied in horizontal wells may face with uncompleted sealing in annulus due to the gravity effect. It is suitable for isolation of the upper zones to shut-off unwanted fluids. A novel foamed cement packer has been used in the fields. Foamed cement is created when a gas, usually nitrogen, is injected at high pressure into a base slurry that incorporates a foaming agent and foam stabilizer[4]. It has higher mud displacement in a small annulus than conventional cement. Due to the structure of