AGH DRILLING, OIL, GAS • Vol. 32 • No. 3 • 2015

http://dx.doi.org/10.7494/drill.2015.32.3.581

Jerzy Stopa*, Robert Czarnota*, Paweł Wojnarowski*, Damian Janiga*

OIL PRODUCTION TECHNOLOGY FOR UNCONVENTIONAL RESERVOIRS

1. INTRODUCTION

Interest in the subject related to the oil production from unconventional hydrocarbons, which can be classified as Rich Liquid Basins type formations, clearly increased in recent years, due to relatively low natural gas prices and conversely high oil prices [8]. Operation of such reservoirs requires the use of modern technological solutions that enable the production of reservoir fluids in quantities economically advantageous. Therefore, it is important to plan in advance and analyze a series of steps that allow for the adaptation and selection of optimal solutions. The leader in this field are USA.

The basic issues that should be considered when planning the provision and operation of the Rich Liquid Basins formations are:

– drilling and completion,
– stimulation,
– artificial lift equipment selection,
– monitoring of production wells in real time [1].

2. DRILLING AND COMPLETION OF UNCONVENTIONAL RESERVOIR WELLS

The selection the right way to drill unconventional hydrocarbons resources is closely dependent on the individual properties of the reservoir rock. Due to the nature of this type of reservoir, the drilling process should provide access to a maximum volume of reservoir due to low permeability and heterogeneity of the rock. For unconventional reservoirs are applicable to vertical, directional, horizontal and multilateral wells.

* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland

Vertical wells were drilled in Lance tight gas reservoir and Mesa Verde in Wyoming (Pinedale Anticline) and oil-bearing sands in Canada. Directional drilling was introduced in the formation of Kuparuk, Alaska [10], and the horizontal wells are drilled currently, even those oil fields where vertical wells exist. Geological formations, which introduced such a solution are: Spraberry Sandstone, which is characterized by a low porosity and permeability, as well as the Wolfcamp, Eagle Ford and Niobrara [10].

Currently in the USA there is a noticeable trend of converting existing vertical wells in the horizontal or multilateral [7]. Professional service companies providing services in the field of drilling, have tools in diameter of 3 5/8" [12]. This type of treatment has a number of benefits, from reducing the costs of drilling a new hole, through the ability to monitor two different levels of production from one well, ending with the economic benefits [9]. One way to increase the flow of fluid from the reservoir to the vertical part of wells is to perform additional horizontal segment at an inclination exceeding the value of 90°, called “drilling up” or “toe up”. The inclination angle range is between 92–95° [10].

In case the project brings financial benefits, then it is worth drilling another horizontal segmentin directions opposite to the already existing ones. Another important aspect when planning field development is the completion stage.

During the selection of the optimal technology it is important to determine some of the specific challenges, which can be summarized as follows:

- adequately gridding horizontal wells with multiple fractures;
- including natural fractures and discrete natural fracture systems in an already complex model;
- availability of adequate PVT data for liquid-rich environments;
- the selection of optimum stimulation treatment design:
  - effective fracture length,
  - fracture conductivity,
  - effective drainage volume,
  - optimum fracture spacing,
- very low effective reservoir permeability;
- complex, multi component reservoir systems;
- severe vertical heterogeneity;
- significant lateral heterogeneity [6].

In order to minimize the time to drill new wells in dense grid, walking drilling rigs can be employed. In this way, the time required for transferring it to another location is considerably reduced [2].

3. UNCONVENTIONAL RESERVOIR STIMULATION

Unconventional oil reservoirs are characterized by unfavorable properties of rock formations, in which are accumulated, as well as unfavorable parameters of reservoir fluids. Oil reservoirs of this type occur in many places on Earth, and are the vast majority, if it comes to the global resources of hydrocarbons. In most cases, subject to the economically justified oil production is necessary to perform the stimulation treatments, like hydraulic fracturing or acidizing.

Treatments to the stimulate production of crude oil such as hydraulic fracturing or acidizing are designed to increase the productivity of wells by improving permeability properties of reservoir rock. In the case of hydraulic fracturing the decisive factor for cracks propagation is the stress distribution in the subsurface. The stresses occurring inside the rock formation are the most compressive stresses and comes mainly from the weight of the overlying rocks; in this form are relatively easy to predict. Phenomena such as tectonics and plastic deformation of the surrounding formation, strongly influence the changes in the stresses equilibrium in the bed rock, which are much more difficult to predict.

The stresses caused by the pressure of the rock mass (often referred to as vertical) are the sum of all the pressures caused by overlying layers, so if there is no additional external influences and the rock acts like an elastic, then stresses are a function of the pressure gradient and depth of the rock mass. Vertical stresses are generally significantly greater than its horizontal stresses in the rock, which means that in most cases created during the hydraulic fracturing treatment are vertical fractures. The creation of horizontal fractures is possible in the oil bearing zones at shallow depths or due to a reorientation of the main directions of stresses due to tectonic phenomena. The size and direction of stress are important from the point of view of the direction of cracks propagation in the rocks [3].

Table 1

Numbers of hydraulic fracturing treatments performed in Geologic provinces in the USA [4]

Geologic province	Number of hydraulic fracture treatment records
Appalachian Basin	25,5186
Gulf Coast Basin	79,069
Permian Basin	67,879
Uinta-Piceance Basin	56,182
Southwestern Wyoming	47,284
Bend Arch-Fort Worth Basin	44,683
Anadarko Basin	34,913
Arkoma Basin	28,567
San Joaquin Basin	21,322
Denver Basin	20,440
Cherokee Platform	16,156
San Juan Basin	14,802
Michigan Basin	9,797
Raton Basin-Sierra Grande Uplift	8,955
Black Warrior Basin	8,404
Williston Basin	7,905

The Wolfcamp Shale formation in Texas (USA), where oil is produced, hundreds of hydraulic fracturing operations have been performed. Some of them have not generated positive results. The best results produced hydraulic fracturing by means of water ("slick water") and sand, in the amount of 9,000 lbs of proppant and 250,000 bbl of fluid. Some of the reasons for the failure of part of the treatments included the use of too much concentration of friction reducer, indicated that the optimum concentration is 0.35 per 1,000 gal fracturing fluid [15]. The application of liquid-type "slick water" is not possible in all formations of this type because of the very frequent high clay content. While the application of high viscosity liquids can cause damage low permeable rock matrix and as a result a lack of fluid flow into the fractures.

An alternative way to increase the flow of reservoir fluids is acidizing treatment. The most popular acids include hydrogen chloride and hydrogen fluoride solution.

Hydrofluoric acid is currently being examined for use as a treatment liquid, especially in geological sedimentary formation Monterey, California (USA). The main reason is the lack of positive results in improving the permeability parameter after performing hydraulic fracturing treatments. For this unconventional oil reservoir is assumed to drill vertical wells, the inject acid to the oil-bearing horizons to form a network of opened and interconnected pores and micropores.

The main problem when using hydrofluoric acid is its high toxicity and aggressiveness to the surrounding matter. Acid concentration of 30% may result in e.g. casing damage, as a result of the treatment fluid will migrate to surrounding layers [14].

4. ARTIFICIAL LIFT SYSTEMS ON THE UNCONVENTIONAL OIL RESERVOIRS

Due to its unfavorable properties unconventional oil reservoirs demand a state-of-the-art and sophisticated (expensive) technology. Therefore, in the past there have not been operated for economic reasons (the low price of oil), or the lack of appropriate technology of extraction [5]. These formations next to the low permeability and heterogeneity, are characterized by a low level of energy reservoir, what brings the need for an artificial lift, production in large pressure decline and the use of directional drilling wells technology. In addition, the unfavorable rock properties in conjunction with deep depth of occurrence of hydrocarbons make often impossible to implement conventional solutions.

One of the most popular pumping equipment is a rod pump, but the applicability of this solution is restricted by TVD (true vertical depth) of wells, as well as the inclination of the wellbore. In some cases, the load reduction of rod pump unit in deep oil wells can be achieved by the use of a fiberglass rod. Unfortunately, it is a costly solution. In the case of low production volumes of oil which often take place in unconventional reservoir, may be unprofitable. An alternative solution can be used for driving the downhole pump unit by installing a long stroke pumping unit. These devices carry heavier loads compared to a typical pumpjack, provide significant lengthening the stroke of the pump rod.

If there is no possibility of application a typical rod pump alternative option would be the use of a hydraulic piston pump. The device is driven hydraulically from the surface using a downhole hydraulic motor and downhole pump in the wellbore. Energy is provided to pump by fluid, which is pumped from the surface to the hydraulic motor. Equipment of this type is applied to a depth of approximately 5,000 m [13]. These pumps can also be used in directional or horizontal wells. A drawback of such pumps is the low resistance to solid particles.

Hydraulic jet-lift system is also hydraulically driven from the surface and is resistant to solid particles. These types of pumps can be installed in wells with a depth of 5000 m [13]. Unfortunately, the device has low energy efficiency and for producing wells with small volumetric flow rates may be uneconomic. Both the presented hydraulic pumps require high pressure piping on the surface, which working fluid is supplied to the wells.

Another device that is used for oil production from unconventional oil reservoirsis the Progressive Cavity Pump (PCP). By default, the device is used for heavy oil reservoirs, however, does not exclude its use for pumping light crude oil. In a standard configuration, these devices are powered by an electric motor located on the surface, and the energy is transmitted to the pump by means of the rod. This solution implies restrictions on the applicability of the device, commonly installed in vertical wells to a depth of 2,400 m [13]. In the case of deep depth and directional wells, it should be used a pump with a downhole electric motor. The advantages of the pump are: high resistance to solid particles, high efficiency and relatively low investment and operating costs [13].

During oil production from unconventional oil reservoirs the Electric Submersible Pumps (ESP) are also used. Pumps of this type can be used in a wide range of conditions under which the operation is carried out. Installation depth reaches up to 6,000 m [11], including directional and horizontal wells. However, in the case of potential wells with sand problems, which a source of sand particles come from the reservoir rock carried by the fluid into the well, as well as sand derived from hydraulic fracturing. It can be harmful for the pump. In such a situation, it is necessary to use materials resistant to the abrasive action of the sand and the system, which allows for more accurately separate gas, which brings with it increasing the cost of the equipment. In addition, small volumetric flow rates obtained from wells in unconventional oil reservoirs, can make the application expensive and vulnerable to damage ESP unprofitable [11].

5. CONCLUSIONS

Common practice in the case of oil production from unconventional reservoirs was drilling a dense grid of vertical wells and then to perform hydraulic fracturing. At present, this type of reservoirs new directional and horizontal wells are drilled or the existing vertical wells are converted to horizontal, directional or multilateral wells, which are also stimulated by hydraulic fracturing or acidizing. As a result increased oil recovery is recorded.

While a hydraulic fracturing operation is performed swelling clay material may occur (limited use of water as a liquid fracturing). During oil production pumps can suffer from sand, which source can be proppant, as well as the sand from the reservoir. The use of high viscosity fluids can lead to damage to the permeability of the reservoir rock.

Rod pumps are the most commonly employed for shallow and vertical wells. In other cases, the application of the unconventional pumping units can be introduced, such as: a hydraulic piston pump or an electric submersible pump, a progressive cavity pump or a hydraulic jet lift. Therefore, the selection of pumping units for unconventional oil reservoirs will primarily be determined by the trajectory of the well, the depth of the pumping, the ability to ensure the constant operation of a pump and the cost of the solution. Effective fluid removal and artificial lifting of horizontal wells will remain areas of focus in the development of liquid-rich formations.

For the Polish potential oil reservoirs located in Subcarpathia the most appropriate solution seems to be adopting solutions used in the US market for the Polish oil and gas industry. Especially drilling directional wells that intersect the greatest amount of geological strata considered to be prospective, followed by a hydraulic fracturing.

In the event that hydraulic fracturing would not improve the permeability parameter, it seems reasonable to apply technology for the geologic formation Monterey e.g. acidizing formation by means of dilute hydrofluoric acid.

REFERENCES

[1] Beckwith R.: *Revitalizing Mature LRS: Tactics, Techniques and Technology*. Journal of Petroleum Technology, vol. 66, issue 12, 2014.

[2] Berg M.: *Liquid-Rich Shale Potential of Utah's Uinta and Paradox Basins: Reservoir Characterization and Development Optimization*. Utah Geological Survey 2014.

[3] Economides M.J., Nolte K.G.: *Reservoir Stimulation*. 2nd edition. Prentice Hall, New Jersey 1989.

[4] Gallegos T.J., Varela B.A.: *Trends in Hydraulic Fracturing Distributions and Treatment Fluids, Additives, Proppants, and Water Volumes Applied to Wells Drilled in the United States from 1947 through 2010 – Data Analysis and Comparison to the Literature*. Scientific Investigations Report 2014–5131, U.S. Geological Survey, Reston, Virginia 2015.

[5] Honarpour M.M., Nagarajan N.R., Orangi A., Arasteh F., Yao Z.: *Characterization of critical fluid, rock, and rock-fluid properties – impact on reservoir performance of liquid rich shale* [in:] *SPE Annual Technical Conference and Exhibition, 8–10 October, San Antonio, Texas, USA*. SPE-158042-MS, Society of Petroleum Engineers, 2012.

[6] Kumar A., Dusterhoft R., Siddiqui S.: *Completion and production strategies for liquids-rich wells in ultra-low permeability reservoirs* [in:] *SPE Annual Technical Conference and Exhibition, 30 September–2 October, New Orleans, Louisiana, USA*. SPE-166177-MS, Society of Petroleum Engineers, 2013.

[7] Mamadou D., Gazawi A., Barree R.D., Cossio M., Tinnin B., McDonald B., Barzola G.: *Refracturing on Horizontal Wells in the Eagle Ford Shale in South Texas – One Operator's Perspective* [in:] *SPE Hydraulic Fracturing Technology Conference, 3–5 February, the Woodlands, Texas, USA*. SPE-173333-MS, Society of Petroleum Engineers, 2015.

[8] Miranda C., Yang H.: *A study of dynamic and static factors that are critical to multi well reservoir simulation of liquid rich shale plays* [in:] *SPE Unconventional Resources Conference, 1–3 April, The Woodlands, Texas, USA*. SPE-169025-MS, Society of Petroleum Engineers, 2014.

[9] Stopa J., Rychlicki S., Wojnarowski P.: *Zastosowanie odwiertów multilateralnych na złożach ropy naftowej w późniejszej fazie eksploatacji*. Wiertnictwo, Nafta, Gaz, vol. 24, no. 1, 2007, pp. 495–501.
[10] Vincent M.: *Optimizing Transverse Fractures in Liquid-Rich Formations* [in:] *SPE Annual Technical Conference and Exhibition, 30 October–2 November, Denver, Colorado, USA*. SPE-146376-MS, 2011.
[11] www.halliburton.com [04.2015].
[12] www.schlumberger.com [07.2015].
[13] www.weatherford.com [04.2015].
[14] www.thenextgeneration.org/blog/post/monterey-shale-series-distracted-by-fracking.
[15] www.ogj.com/articles/uogr/print/volume-1/issue-3/urtec-wolfcamp/wolfcamp-shale-graduates-to-world-class-play.html [04.2015].