Improving the efficiency of horizontal wells at multilayer facilities

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Abstract. The paper presents the results of testing of new production equipment of wells, as well as the operating modes of horizontal wells in the conditions of development of multilayer facilities. The paper also presents the results of drilling small-diameter wells, the methods of oil production intensification, and the principles of operation of pumping equipment with an electric valve with account for optimal draw-downs on reservoirs. The suggested approach to the operation of horizontal, sub-horizontal and directional wells of small diameter allows increasing the technical and economic indicators of the development of complex multilayer facilities. It is proposed to use the developed technology in the operation of two or more reservoirs in conjunction with the implementation of dual injection into the exploited reservoirs through injection wells in the center of the element of development.

1. Introduction
The intense development of small oil fields with hard-to-recover reserves, characterized by low profitability brings up the issue of searching for new technologies of drilling, well operation and facilities development with the aim of reducing the cost of production [1-11].

2. Materials and methods
Small oil company Karbon-Oil LLC has been developing six small fields in the Republic of Tatarstan since 2006. Deposits of high-viscosity oil are confined to the inner side zone of the Aksubaev-Melekess draw-down. In terms of the geological structure, the deposit is classified as a complex with a high degree of heterogeneity. The main object of operation is represented with carbonate reservoirs of the Bashkir tier of medium carbon, which are characterized by low filtration and capacity properties, weak hydrodynamic connection with the aquatic part of the reservoir, as well as inter-well zones.
Today, there are no low-cost technologies that ensure high efficiency of development of such fields, so the rate of oil reserves extraction is low there.

In 2007-2008, the first horizontal wells for the Bashkir tier with open shafts were drilled at the Nekrasov field. Since 2014, the company has adopted a strategy of drilling fields with a system of horizontal wells and multi-hole horizontal wells. Construction, development and operation of wells are carried out only with the use of Russian equipment, including extractable deflector wedges. All shafts of a multi-hole horizontal well are located separately from each other. Since 2014, two-hole horizontal wells have been equipped with dual operation of two-lift structures with separate shafts and separate operation of each shaft. To reduce the cost of horizontal well construction, drilling was carried out with 155.6 mm bits, and 114 mm-diameter production columns were used. The construction of horizontal wells has allowed accumulating experience in using optimal well designs: in the filter section 200-300 m long, magnesium acid-soluble plugs (REA filters) are used, as the least expensive option in comparison with cumulative (on a hard cable) and hydro-mechanical perforation.

Various designs of horizontal well stems were used: open non-cased shafts; cased cemented shafts; cased non-cemented shafts, separated into intervals by column-type swollen packers. Complicating and increasing the cost of the well design does not always lead to an increase in well flow rates. Cased cemented shafts separated into a few intervals by REA filters (sections of horizontal well) are considered to be the most optimal option for well completion. Development of horizontal wells was also carried out in different variants: from simple openings of REI with acid bath installations followed by swab development to REI opening in dynamic modes with subsequent point-to-point bottom hole treatment with resetting the packer layouts opposite the sections of horizontal wells. The volume of acidic compounds used for development from drilling increased from 10 to 50-60 m³. All this made it possible to increase start-up flow rates and reduce the rate of decline in flow rates after wells were put into operation. As of 1 December 2019, 37% of the production well stock is made up of horizontal wells, including 3% of multi-hole horizontal wells, with the total revenue from horizontal wells being 55% of the company's total. The transition to horizontal drilling allowed eliminating the drop in the average flow rate of wells, which was observed from 2006 to 2014, and even increasing by 10-15% over the last 2 years.

Further potential for increasing the average flow rate of the well stock and improving the performance of development projects consists in the introduction of returnable objects and the organization of separate operation of each object by one well in the new operating mode. The stock of wells drilled since 2014 is mainly represented with small-diameter wells. There are restrictions on the implementation of deep-pumping equipment layouts for separate operation.

3. Results and Discussion

In this regard, a new approach is proposed in the dual operation of beam pumping units or vertical sludge pumps with a packer and an electric valve MIXER for ORD produced by Tekhproekt company. Cons: the cost of a set of electric valves. Pros: the ability to run into the operating column with a diameter of 114 mm or more. Flexible adjustment of selections according to controlled parameters on-site (bottom-hole pressures, selection/accumulation time, pump drive operating frequencies). Additionally, the built-in manometer-thermometer allows taking the pressure build-up curve of each object and setting the optimal draw-down and selection time. The control station allows calculating the total flow rate of the well from the measuring device at the mouth of the time spent for each object of operation. This type of configuration of MIXER for ORD equipment allows operating a well, or rather two objects in the well, taking into account different properties in the mode of dual production.

In 2019, a successful output test was carried out on the variant of the downhole pumping equipment layout for the operation of a horizontal well with two objects in the dual production mode. The horizontal well drilled in 2016, exploiting the Bashkir tier with a product viscosity of 250 MPa·s was selected for the test. During the well overhaul, the upper return object, the verey horizon, was perforated and selectively developed. In accordance with the Program for pilot testing of production equipment MIXER for ORD produced by Tekhproekt LLC in Karbon-Oil LLC, pilot tests of dual
production equipment MIXER for ORD had been conducted over the period from 29 May 2019 to 25 October 2019 in a well with the small diameter of 114*7.4 mm.

The tests allowed for:
– evaluating the possibility of using the equipment to implement the technology of dual operation of two objects in the conditions of oil fields of Karbon-Oil LLC in small-diameter wells with a large horizontal routing;
– checking the performance of the equipment in downhole conditions of oil fields of Karbon-Oil LLC;
– assessing the performance quality of the equipment;
– updating the criteria for equipment use;
– making decisions on the feasibility of putting into operation the equipment at the facilities of Karbon-Oil LLC and giving recommendations on its further use and acquisition.

Brief description of operation of the equipment: the electric valve MIXER for ORD provides operation of two objects separated by a packer, in the mode of dual (separate-alternate) production. The equipment is mounted between the packer and the pumping unit (Figure 1).

The operating mechanism of the equipment moves the spool of the electric valve by a signal coming from the wellhead control station via a geocable, providing a message to the pump reception of either the upper object, or the lower object, or 2 objects simultaneously. Switching between objects is carried out either by the parameter of the liquid extraction time (timer mode) or by the value of the minimum bottom-hole pressure for each of the objects (pressure mode). The pressure and temperature of the liquid at the pump intake are registered by a depth gauge-thermometer. After the objects are examined, the control station automatically supports the specified operating modes of the electric valve and pump, including control of the frequency of the pump drive depending on the object currently in operation.

To reduce losses, the optimal mode of operation of each object is adjusted according to the recorded pressure recovery curves from each object of operation. The mode of short-term selection and accumulation allowed increasing the pump filling coefficient. For carbonates with their double matrix and crack porosity, there is need for accumulation time to ensure flow from the matrix to the crack during operation. When switching selections to the accumulation mode, the reservoir inertia remains in operation with liquid accumulation in the production column and the bottom-hole part of the reservoir for subsequent intensive selection. Moreover, this mode in the well allowed not only preserving the flow rate of the lower, previously operated object, but also increasing its flow rate by 28%.

Test results include evaluation of performance criteria in accordance with the output test program, namely:

1. Implementation of dual extraction of two objects with differentiated draw-downs for each, created by a single pump.

   Liquid was collected from two objects at the well. The liquid was lifted by a single 175-TNM pump. The mode of dual operation of the upper and lower objects in automatic modes "by timer" and "by pressure" is implemented. The frequency of operation of the pump drive changes in accordance with the set points on-site.

2. Possibility of separation of the objects.

   The separation of objects is confirmed by changing the depth gauge values when switching between objects (Figure 2).

3. Possibility of researching one of the objects when the second object is stopped.

   The equipment allows sampling of the fluid produced from each object under the following condition: one of the reservoirs disabled, the well bred to steady state selection, the final selection of not less than 3 volumes of the inner space of the tubing to the liquid outlet of the studied reservoir.

4. Possibility of controlling bottom-hole pressure on objects in the dual production mode.

   Pressure monitoring of each of the objects is performed by a single depth gauge in the process of liquid extraction from this object. It is possible to build pressure recovery curves for each of the
objects when the well operation is stopped. To study the pressure recovery curve of one of the objects without stopping the second, it is necessary to introduce an additional sensor into the downhole pumping equipment, but this condition can only be implemented in wells with an operating column of 146 mm in diameter.

Figure 1. Diagram of setting of the electric valve Mixer as part of the downhole pumping equipment

Figure 2. Graph of pressure changes during the operation of objects
5. Possibility of automatical switching between objects in the dual production mode by pressure parameter or by timer.

The mode of dual operation of the upper and lower objects in automatic modes "by timer" and "by pressure" is implemented. Switching is automatically controlled by timer according to the modes set at the control station. The mode is not quite suitable for objects with low properties in terms of pressure, since a few days of operation past and frequent automatic switching between objects begins. During the period of operation of one object, the second one didn't have enough time to accumulate the pressure required to start the cycle of operation, whereby periods of the selection cycle for each of the objects have been rapidly declining, and attempts to reduce the working frequency of the pump drive each of the objects have led to the decrease of the total flow rate of the objects.

6. Lack of refusals during the test period.

No equipment failures were detected during the test period. It should be noted that operation of the well where the equipment was tested, was complicated by the high viscosity of the extracted fluid.

7. Possibility of measuring the flow rate of the objects

By-object account of fluid withdrawal was carried out in real-time according to the counter BSCI (the RING). Accounting was carried out in the mode of dual operation without stopping the operation of the pumping unit.

8. Possibility of remote monitoring and change in the parameters of the solenoid valve and pump installation.

Remote monitoring and change in the parameters of the solenoid valve and pump installation were carried out via the control panel (Figure 3).

Using a special application that repeats all the functions of the control station on the well, operation of the equipment was adjusted (Figure 4).

![Figure 3. Interface of the well monitoring system and data archive](image)
Figure 4. Remote control application for electric valve operation

The mode of dual production as a method of operation of a submerged downhole electric valve is a conceptually new mode of operation of downhole equipment, which was not previously described in the scientific literature, since it has not been used in practice until now due to the lack of technologies and appropriate equipment. The first attempts at such equipment operation were made in 2016 at two oil wells in the Perm region with a production column of 146 mm in diameter by the producer of the equipment MIXER for ORD, Tekhproekt LLC. At that time, the main operational characteristics of layouts and criteria for selecting wells for the introduction of innovative equipment were not formulated due to the imperfection of software, the failure to achieve the required operating time of equipment components, as well as minimal experience in selecting operating modes.

At the beginning of 2018, pilot tests of the MIXER for ORD equipment were successfully completed, key operating modes of the equipment were tested, including automatically supported modes, the criteria for selecting wells and downhole pumping equipment layouts were clarified.

As early as by the end of 2018, with the joint participation of Tekhproekt LLC and Karbon-Oil LLC, a set of MIXER for ORD equipment for small-diameter wells (114*7.4 mm) was developed and put into the well. It should be noted that the pumping well under study was the first platform for successful testing of the method of well operation with one operational facility having a large horizontal distance, and the high viscosity of the produced fluid, where the lack of necessary technology determined the lack of opportunity for providing the necessary drainage remote from the pump portion of the horizontal section, the so-called well toe. The well was divided into two horizontal sections by a packer, which were dually connected to the pump by the MIXER for ORD valve, and the draw-downs were created differentially for each zone. Thus, an additional draw-down in the remote area of the horizontal well provided an additional influx. In practice, the result exceeded expectations and the increase in oil production made 48%.

The dual production mode was also appropriate at the next small-diameter well, where the
previously undrained upper object was attached to the main production facility. When switching to the mode, it was noted that the new object with high reservoir pressure, and, consequently, when using a common lift, the lower object is silenced by the liquid of the upper object and does not operate. Flow and filling of reservoir pressure of the lower object take place. After switching to the dual mode, the pressure of the upper attached object remained stable above the lower one for some time, after which it decreased, and the pump operation mode was changed, and the lower object continued to work in the originally selected mode. Changes in the operation of the bundle: objects of operation – well and pump – are analyzed remotely from the archives, and the adjustment of the operation mode is made from a PC and takes no more than 3-5 minutes.

4. Conclusion

Thus, this approach to the operation of horizontal, sub-horizontal and directional wells of small diameter allows increasing the flow rate, reducing the payback period of wells and upgrading the technical and economic indicators of the development of complex multilayer facilities.

Application of the mode of dual operation of two reservoirs together with the implementation of the mode of dual injection into the exploited reservoirs through an injection well is the further perspective direction of development of this technology. Equipment in the design for SMD, necessary for the intelligent implementation of the mode of dual injection, is currently being developed by Tekhproekt LLC. Karbon-Oil LLC selected an experimental two-object site as a development element with an injection well in the center and surrounding production facilities. Implementation of this technology with a comprehensive approach to production and injection at this pilot site is planned between 2020 and 2021.

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