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New Technologies to Improve the Performance of High Water Cut Wells Equipped With ESP

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Abstract. The article deals with theoretical and practical issues of improving the efficiency of operation of high-water cut oil wells by developing and applying double-acting pumping systems based on electric submersible pumps. This combination is providing down-hole gravitational separation of oil and produced water, lifting low-water-cut oil to the surface with simultaneous injection of most of the separated water into the absorbing formation without lifting to the surface. Moreover, it is providing low-cost regulation of the ratio of the volumes of the lifted product and the injected water, as well as monitoring the quality of the injected water with the required frequency.

Keywords.EPS, Gravitational separation, Water-cut, DSWO, DAPS, Oil separation, Down-hole technology.

1. Introduction

At the late stages of oil fields development with the use of water-flooding, the water cut of the well production increases, in many cases reaching 90% or more [1], [2],[3].

At the same time, operating costs for oil production increase significantly, since a significant part of the electricity is spent on lifting and subsequent utilization of water. For example, in many of oil companies, the average water cut of production is about 83.5% [4], [5], [6].Therefore, the costs of electricity, lifting, transportation, preparation and utilization of associated water are very significant. At the same time, as a result of tough competition, unstable dynamics of oil prices, an increase in the tax burden and prices for electricity, gas, metal, and the conditions for the activities of oil companies are steadily tightening. Moreover, these problems do not cancel the need to implement the courses proclaimed by the countries leaderships to modernize and increase energy efficiency of these countries economy. The foregoing substantially aggravates the problem of saving operating costs.

One of the directions that provide prerequisites for increasing the efficiency of operation of water-cut oil wells by reducing the volume of pumping of associated water, the cost of its utilization, separation, preparation, pumping through pipelines and pumping back into the reservoir [7], [8], [9]. All these technologies represent the technologies used in the down-hole separation of water and oil (DSWO) with the use of double-acting pumping systems (DAPS) [10], [11], [12], [13]. The concept of this technological direction is not to raise most of the water entering the well from the reservoir to the surface in cases where a zone or horizon suitable for water injection is available from the same well.

The possibilities of implementing the elements of DSWO in the USSR were investigated in the 60s of the twentieth century [14], [15]. The studies were to find cost-effective ways to extract water from reservoir fluids entering the well and re-injecting it into the productive zone or into another reservoir, penetrated by the same well. As a result, methods were proposed to reduce the amount of water raised to the surface, and various DSWO systems were brought to practical use [16], [17], [18], [19]. However, these developments have not spread out.

In later works, an integrated approach to solving the issue was supposed to use installations of electric centrifugal (ESP) and rod pumps (SRP), down-hole separators, packers, special tools and control measuring devices, injection of chemical reagents [20], [21], [22], [23].

The DSWO technology with simultaneous water discharge should solve the following tasks, which are decisive in the development of schemes for possible down-hole water injection:

- Separate oil from water;
- Ensure the disposal of water and ensure that all oil reaches the surface;
- Provide isolation of the water discharge zone;
- Provide quality control of the injected water with the required frequency.

The main limiting condition for solving the listed tasks is the economic feasibility of implementing the technology.

In General, there are two ways to separate water and oil in a well: mechanical and gravitational [24], [25], [26]. Mechanical separation usually takes place in a special down-hole separator. However, the cost of such separators is high; each standard size works in a relatively narrow range in terms of dimensions and performance of liquid separation. Therefore, due to the conditions of some of the oil companies, the use of mechanical separators seems inappropriate.

The possibility of effective and low-cost implementation of the DSWO, based on the gravitational separation of oil and water under the conditions of the oil companies in the wells operated by the ESP, has been proven by the successful development and testing of the ESP with a double-action pump DAP 38/44 [27], [28], [29]. This combination ensures the injection of most of the associated water into the underlying absorbing formation without lifting to the surface [30], [31], [32].

However, this solution is not acceptable for high-production wells. Moreover, it does not provide quality control of the injected water during the operation and has a structurally predetermined ratio of the lifting performance of the oil-water mixture to the surface and pumping water into the absorbing formation.

To expand the application range of DSWO technologies based on the gravitational separation of oil and water into high-production wells, it is necessary first of all to determine the marginal performance of these wells. At this production, under specific conditions, the effective separation of oil from water will stop, i.e., at which the velocity of oil rising in the water will be lower than the velocity of water moving down.

The velocity of oil surfacing in the water is usually within 10 - 20 cm /s [33], [34], [35]. The greater the ratio of the velocity of oil surfacing in water to the velocity of water movement, the higher the probability that the oil will not be carried away by water.

The velocity of water moving down, to be the right one, is determined by the cross-sectional area of the channel. In this case, the larger is the area of the channel, the lower the speed of the water.

The channel is usually circular and is formed by the inner surface of the production string and the outer surface of the tubing. With a constant diameter of the production string, the smaller is the tubing diameter, the larger the area of the ring channel. The results of the assessment of the marginal performance at various coefficients of excess of the velocity of oil surfacing in water over the velocity of water movement (reserve factors) and channel cross-sections are presented in Table 1.

Table 1. Marginal Performance Under Different Coefficients Of Excess Of The Oil Ascent Velocity In Water Over The Velocity Of Water Movement And Channel Cross-Sections

Exceeding the ascent velocity of oil in water over the velocity of water, times	Pipe Assortment	Marginal production m^3/day	
		Production string	
		146 mm	168 mm
2,00	Tub	49,5	68,5
	Tub	45,1	64,1
	Tub	39,3	58,3
1,75	Tub	56,6	78,3
	Tub	51,5	73,2
	Tub	49,8	66,5
1,50	Tub	66,4	91,8
	Tub	60,5	85,9
	Tub	52,6	78,1

From this table, it can be seen that when water moves down the annular channel at a speed 2 times less than the worst indicator of the oil ascent velocity in water (10 cm /s), up to 45 m3/day of water can be separated in a well with a production string of 146 mm and up to 64 m3/day of water in a well with a production string of 168 mm (in the case of using tubing 60).

The above stated allows us to qualitatively assess the application range of DSWO based on the gravitational separation of oil and water according to the wells flow rate and their water cut. The corresponding "idealized" dependencies for wells with production strings with a diameter of 146 and 168 mm with a coefficient of excess of the oil ascent velocity in water over the water velocity equal to 2 and an outer tubing diameter of 60 mm are shown in Fig. 1.

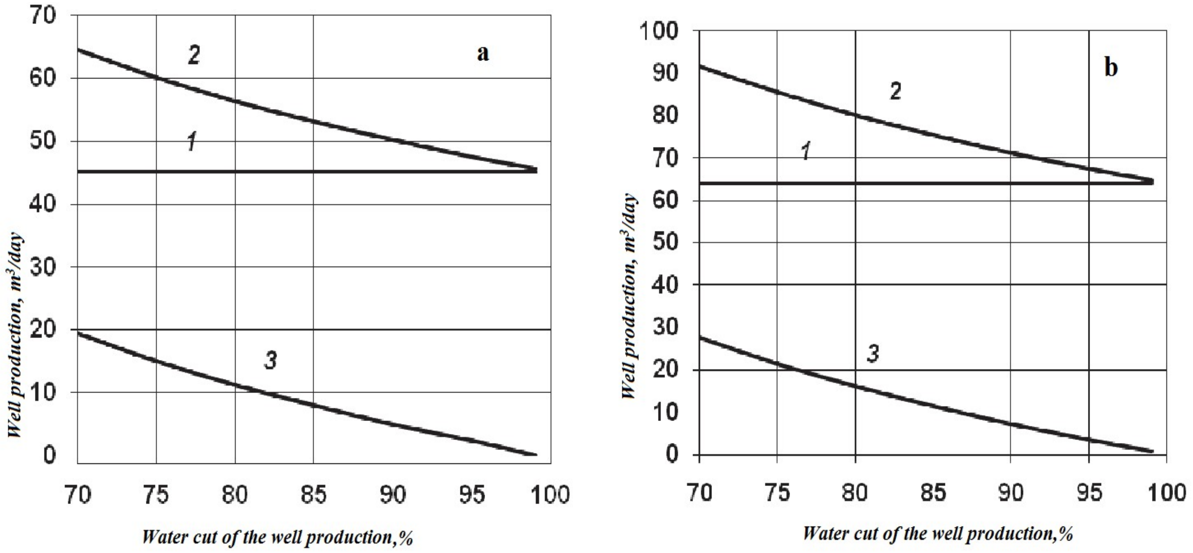

Figure 1. Fields of application of DSWO technologies based on gravitational separation of oil and water according to production rate of wells and their water cut, where: a and b - production strings with a diameter of 146 and 168 mm, respectively; 1 - water discharge performance; 2 - fluid

production rate from the productive formation of the well; 3 - lifting performance to the surface

In practice, the water injection performance will be lower than the marginal one, since part of the water must be raised to the surface. Hence, based on the change in the water cut of the product being raised, it is possible to make a decision on adjusting the lifting performance in order to prevent oil injection into the absorbing formation.

On the other hand, in a number of cases the marginal performance can be higher due to a decrease in the "reserve" when choosing the value of the excess of the ascent velocity of oil in water over the velocity of downward movement of water. Generally speaking, the justification of this choice is a separate and very difficult task. Often its most accurate solution, for specific conditions, can only be obtained by setting up relevant field experiments on "pilot" wells that precede the mass introduction of the technologies.

To assess the feasibility of implementing DSWO technologies, it is necessary to solve the inverse task: at a given well flow rate, depending on the initial water cut of the fluid coming from the reservoir and at the maximum permissible water injection rate, determine the water cut of the fluid lifted by DAPS to the wellhead. As an example, Figs. 2 and 3 show the results of assessing the water cut of the product being raised and the degree of its reduction as a result of the introduction of DAPS at different "reserve factors" in terms of the rate of oil rise in water. This is depending on the water cut of the fluid flowing from the reservoir at the well flow rate of 100 m3/day and the diameters of the production string and tubing, respectively, 146 and 60 mm (assuming that the oil flow rate of the well has not changed).

2. Methodology

Based on the above results, it has been developed a variant of the efficient and low-cost implementation of the DSWO technology with the gravitational separation of water and oil and the injection of most of the separated water into the overlying absorbing reservoir. This new variant solves all the tasks set, as well as the use of DSWO-based on ESP.

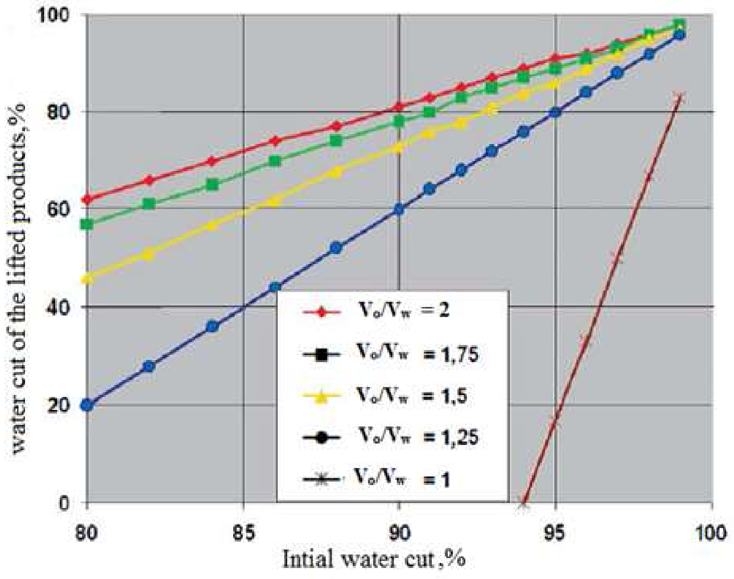

Figure 2. Dependence of the water cut of the lifted product by DSWO to the wellhead at different "reserve factors", in terms of the velocity of oil ascent in water, on the water cut of the fluid flowing from the reservoir at well flow rate of 100 m3 / day and the diameters of the production string and tubing, respectively 146 and 60 mm.

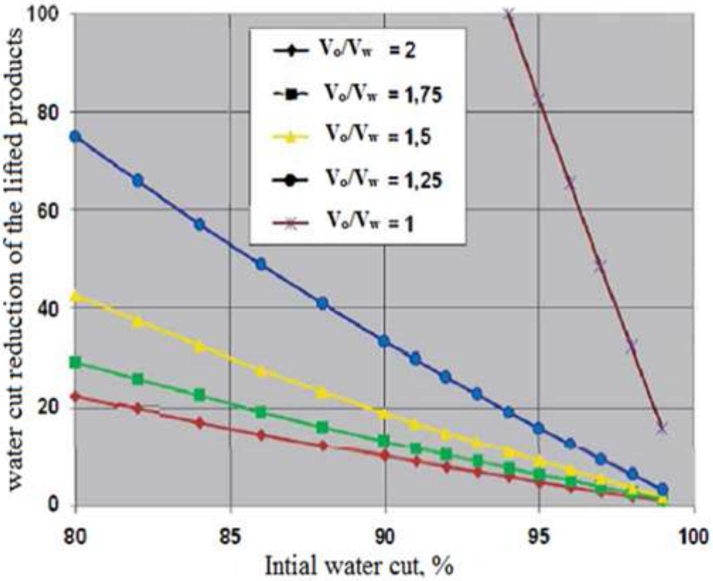

Figure 3. Dependence of the degree of water cut reduction of the lifted product by DSWO to the wellhead at different "reserve factors", in terms of the velocity of oil ascent in water, on the water cut of the fluid flowing from the reservoir at well flow rate of 100 m3 / day and the diameters of the production string and tubing, respectively 146 and 60 mm.

The technology and prototype equipment tests were carried out for an oil well in two stages. At the first stage, the effectiveness of the gravitational separation of oil and associated water was checked when using the DAPS in the field. For this purpose, the gravitational separation of oil and water in the well was organized with their rise to the surface through separate channels (Fig. 4), assessment of water quality, performance of DAPS and return of oil and water to the oil gathering system.

A packer (1) was installed above the productive reservoir, above which the same ESP (4) was placed on the tubing string (7) at the same depth as the well was operated before the tests. The ESP was placed in a housing (2) , hermetically connected to the packer by a liner (3). At this stage, the absorbing formation was not exposed. As part of the tubing string there is a special sub (8) with holes that communicate the tubing string cavity with the annular space of the well. Parallel to the tubing, a flexible tubing (9), sealed at the wellhead and connected to the main flow line of the well, was run into the well to the interval of the absorbing formation.

When the ESP (4) was started, the liquid from the highly water cut reservoir entered from under the packer (1) into the tubing string (7), rose through it to the subs with holes (8) and entered the annular space of the well, where the gravitational separation of the reservoir fluid into water and oil took place. Oil along the tubing string cavity and along the annular space of the well, located above the subs with holes, rose to the wellhead, and the water occupied the annular space below the subs. During further operation of the ESP, oil was delivered to the discharge line through a regulating unit, which used as removable chokes (24).

By reducing the flow of fluid through the " oil " line in the well, the force of the ESP created an excess pressure, under the influence of which water rose through the lower open end of the flexible pipe (9) to the surface, where its flow was measured and samples were taken, and then returned to the collection system.

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The regulation of the volumes of withdrawal and injection of fluid was carried out by installing chokes of different diameters on the manifold of the "oil" line.

During the work, the production rate of the" oil” line was reduced from 67 to 29.5 m3/day, and the water cut of the extracted products from 95 to 87 %. The production rate along the" water” line increased from 20 to 49 m3/day with a water cut of 100 %.At the same time, for the period of one month, the water in the samples had the following quality indicators: the average content of petroleum products, 0,146 mg/dm3, the average content of mechanical impurities, 0.411 mg/dm3. The permissible, according to the regulations, for petroleum products is 60 mg/dm3, for mechanical impurities 50 mg/dm3 [36], [37]. At the same time, during the observation period, the content of oil products and mechanical impurities in the separated associated water never exceeded the permissible values.

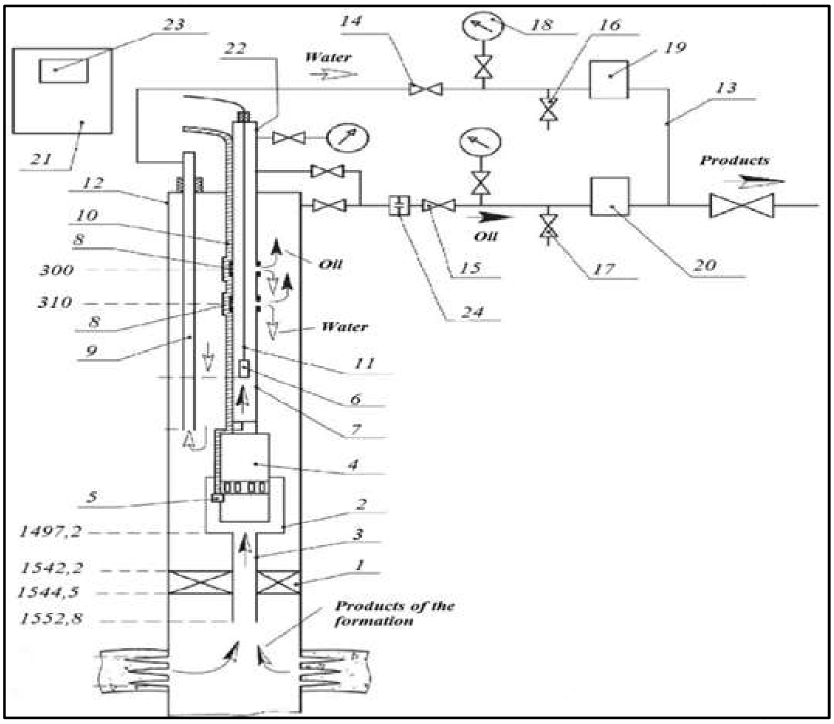

Figure 4. Layout of equipment for experimental verification of the effectiveness of gravitational separation of oil and water when using DAPS with ESP in the tested well. Where: 1 - packer; 2 - casing; 3 - shank; 4 - ESP; 5 - pressure and temperature sensor at the pump intake; 6 - borehole flow-meter with a pressure sensor at the pump outlet; 7 - tubing string; 8 - sub; 9 - flexible pipe; 10 - motor cable; 11 – down-hole flow meter cable; 12 - wellhead equipment with flexible pipe inlet; 13 - strapping a flexible pipe at the mouth; 14 - water flow control valve; 15 - oil flow control valve; 16 - water sampler; 17 - oil sampler; 18 - manometer; 19 - wellhead flow-meter for water; 20 wellhead oil flow meter; 21 - control station; 22 - lubricator; 23 - electricity meter; 24 - connection.

The results obtained confirmed the effectiveness of gravity separation of oil and water in the wellbore when using DAPS with ESP at field conditions. This allowed us to proceed to the implementation of the second stage of testing. At this stage, inside the well, the absorbing formation was perforated and water was injected into it. The studies were carried out in the period of three months.

The absorbing formation was penetrated at the interval of 1896.3 -1898.3 m. A packer was installed between the exposed layers. The equipment layout that worked in the well at the previous stage of testing was reinstalled (Fig. 4). At the same time, water was pumped into the upper absorbing formation, oil rose to the surface through the tubing string and the annular space. The presence of flexible tubing in the downhole equipment assembly provided a separate channel for lifting well fluid from the depth of the absorbing formation to the surface, which made it possible to directly measure both the quantity and quality of water injected into the absorbing formation with the required frequency.

Table 2. Geological and technical characteristics of the tested well and performance indicators of a conventional ESP and DAPS well

Indicator name	When testing a conventional ESP	When testing DAPS
Perforation interval of production formation, m	1922,2 - 1923,9	
Perforation interval of the absorbing formation, m	----	1896,3-1898,3
Current bottomhole, m	1938,2	
Nominal diameter of production casing wall thicknesses, mm (commissioning year)	146 x 7,0 (2001)	
Conditional tubing diameter, mm	73	60
Packer type	---	Ml-X
Packer depth, m	----	1909,4
Pump type	ESP M5-50-1300	ESPM5-60-1500
Average performance of ESP (extraction of liquid from productive formation), m^3/d	71	90,4
Pump suspension depth, m	1500	1484
Oil flow rate, t / day	1,82	4,2
Production water cut, %	97	88

3.Results and Discussion

With an average water density of 1,180 kg/m3, oil of 899 kg / m3 and the ESP capacity of 87, 9 - 92.4 m3/day, the DAPS prototype provided injection into the absorbing formation of 46.6 - 50.6 m3/day of water separated in the borehole, which was almost 55.2% of the fluid withdrawn from the productive reservoir. Production rate of 37.3 - 45, 8 m3/day was supplied to the surface water cut 85-88 %. The average content of petroleum products in the water discharged into the absorbing reservoir under this mode of operation of the DAPS, according to the results of the analysis of water samples, was 0.50 mg/dm3, and the average content of mechanical impurities was 0.36 mg/dm3. These numbers represent 120 and 139 times, respectively, lower than the indicators allowed by the regulations.

Geological and technical characteristics of the investigated well and performance indicators of a conventional ESP and DAPS are shown in Table 2.

It seems appropriate to expect the greatest effects from the use of the technology in the following cases.

1. The use for the development of individual areas, fields where there is no reservoir pressure

maintenance system, or its modernization for the development of these areas is impossible or impractical.

2. The use in areas with excess water, when not all associated water is used for injection for reservoir pressure maintenance, and therefore part of the raised water must be disposed of.
3. The use in areas where, for one reason or another, fresh water is used for reservoir pressure maintenance and reservoir water has to be disposed of (protective zones, etc.).

If it is necessary to confirm the effectiveness of gravitational separation of oil and water in real conditions for a single well field and/or section at the initial stage of technology implementation, the absorbing formation is not connected and its role is performed by a flexible pipe lowered into the annular space of the well. Thus, in field conditions, the effectiveness of the gravitational separation of oil and water with a specific density difference is experimentally tested when using DAPS with an ESP in a well with typical geological and technical characteristics. When positive results are obtained, the absorbing layer is penetrated; a packer and a set of equipment that have already been operated in the well are installed between the penetrated layers.

4. Conclusion

The field of application and criteria for evaluating the effectiveness of the implementation of the down-hole technologies were established. According to these technologies, gravitational separation of water and oil in wells, operated with ESP, was performed, including at the flow rates and initial water content of well products.

A double-acting pumping system based on an ESP has been developed, which, with low-cost means, provides down-hole gravity separation of water and oil. This system lifts low-water-cut oil from the well with simultaneous injection of most of the associated water into the overlying reservoir and monitoring the quality of injected water with the required frequency.

Moreover, a technology has also been developed for operating high-water cut wells.

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