New Technology of Optimization of Production of Liquid Hydrocarbons

New technology has been developed and successfully tested for optimizing production for oil fields with high gas to oil ratio, (GOR), theory and in practice, we have demonstrated that oil reservoirs with high GOR have a pressure flow rate relationship with a clear maximum. A specially designed bottom-hole assembly (BHA) automatic maintenance of the bottom-hole pressure on optimal level. The theory and calculations of this technology rest upon the building of an accurate mathematical model of the entire well-bottom-hole assembly-formation which takes into account all of its components. This mathematical model makes it possible to carry out an analysis of the processes taking place in the well, in its bottom-hole zone and in the reservoir, which, in turn, makes it possible to maximize the flow rate and increase production.

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from Reservoirs Containing Oil or Condensate with High GOR and Oil Rims of the Gas Formation

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BACKGROUND

A lot of articles were dedicated to researching processes in formations saturated with oil with high gas content, including such classical works as [1,2] by M. Musket, in which he described and analyzed the corresponding unsteady two-phase filtration equations. W.J. West and etc. [3] solved those equations on a computer by applying a number of simplifying assumptions. Later W.T. Weller [4] suggested an approximated method, which yielded approximate solutions with good precision. These theories allowed calculating dynamic behavior of oil rate, GOR, formation pressure, saturation at any moment of oil well's life. They also allowed obtaining and analyzing distributions of pressure and oil saturation inside formation vs. distance from the well for any moment of time in dependence from PVT parameters of fluid, relative permeability and properties of formation [2, 5]. J. V. Vogel [6] and later M. B. Standing [7] developed simple theories for building Inflow Performance Relationship (IPR) curves for solution-gas drive reservoirs. They demonstrated that IPR curves can be described by simple algebra equations (parabolic curve) and its general form is not greatly affected by PVT and other parameters of fluid and formation [5, 6, 7, 8]. According to these theories the oil rate maximum is always achieved when bottom hole pressure is equal to zero. Later some researchers found that these theories did not always yield sufficient precision [9, 10]. M. Hussain [10] noted that skin effect sometimes arises in formation in a zone near the wall of well in solution-gas-drive reservoirs. As a result actual IPR curves can noticeably differ from Vogel curves. Influence of skin effect on IPR curves is analyzed in [5], except it is assumed that skin effect does not depend on the value of bottom hole pressure and maintains a constant value at any pressure. In reality this is not the case because the relative permeability and width of skin zone depend on the bottom hole pressure and saturation. Nevertheless in [5] it is shown that skin effect has very strong influence on productivity index of well and on IPR curve but has no influence on Vogel form of IPR.

The present paper analyzes influence of bottom hole pressure on the effects reducing oil relative permeability and increasing oil viscosity in the zone of formation near the bottom hole. Reducing productivity index, which happens in this case, may lead to the following phenomenon: when bottom hole pressure is gradually reduced below a specific value, oil rate stops increasing and begins to drop, contrary to Vogel theory which predicts that it should continue to increase. Which means the IPR curve has a maximum oil rate at non-zero bottom hole pressure.

SUMMARY

Over the last 15 years, a new technology has been developed and successfully tested for optimizing production for oil fields with high gas to oil ratio, (GOR), which we will now refer to as TOP (Technology for the Optimization of Production). Both in theory and in practice, we have demonstrated that oil reservoirs with high GOR have a pressure flow rate relationship with a clear maximum level. For example, the bottom hole pressure is clearly defined and provides the maximum open flow production on the reservoir. The consequential decline in bottom hole pressure results in decreased oil production, while the gas cut of the produced oil grows. This may be caused by either the gas skin-effect in the bottom-hole area of the reservoir, or the formation of gas coning. Both of these factors result in a decline in production as the bottom hole pressure drops. Basically, as the GOR and water content of the reservoir increases, so the reservoir production declines. Moreover, it was demonstrated that when the pressure drop is below a certain optimal value, conditions emerge under which the well becomes unstable and gas conditions occur [13]. This can explain the difficulties that take place with the production of oil and gas condensate from layers of gas fields that contain oil with a high gas factor. Our interpretation of this phenomenon is as follows.

When you create a difference in pressure and arrive at a certain bottom hole pressure value, let's call it the optimum pressure, gas coning moves up to the casing perforations. As this process takes place, the gas concentration within the fluid starts increasing while the bottom hole pressure decreases more and more, contributing to increased gas coning and a further drop in bottom hole pressure. In other words, positive feedback is taking place here. This ultimately leads to the oil being driven back from the casing perforations and a shifting of the well into gas conditions.

Our technology makes it possible, with the use of a special bottom-hole device, to diminish the positive feedback, and, while maintaining bottom-hole pressure at

certain optimal levels, to prevent the phenomenon described above. On the other hand, the TOP technology makes it possible to increase the condensate flow rate and productive capacity
of gas condensate fields.

It is well known that as gas condensate fields are developed, its bottom hole pressure drops. Because of this fact, due to its **retrograde behavior,** it starts liquidating. This process takes place, most intensively, at the bottom of the formation, which is normally lower than the pressure of the formation itself. As a result of this, skin effect takes place in the bottom of formation. In other words, there is an accumulation of liquid condensate which prevents gas from leaving the formation and, accordingly, well production decreases and there is a danger that this can lead to complete well shut off. It should be noted that the pressure flow rate relationship of such a formation has the same form as the above mentioned case, although it is worth noting that the physics of this phenomenon is quite different. Therefore, a certain critical value of bottom hole pressure exists when any further draw down leads to a condensate dropout into the liquid phase of the bottom-hole formation zone and to a decline of the condensate flow rate. When determining, with the use of specially made simulators, the critical value of the bottom-hole pressure at which such phenomenon occurs, we build up bottom-hole pressure and maintain it in such a manner that leads to the reversed inversion of the condensate from its liquid state into the gaseous one. In this regard, the bottom-hole formation zone gets unblocked and the gas condensate flow rate goes up. We should note that the GOR of the produced oil gets noticeably lower, while the condensate production rate gets higher.

A specially designed bottom-hole assembly (BHA) enables more flexible regulation and automatic maintenance of the bottom-hole pressure to the desired level in order to prevent the dropout of condensate from the bottom-hole zone into its liquid state, and therefore preventing a severe decrease in well performance. The BHA also serves to stabilize well performance.

The latest test of the TOP took place at two gas condensate wells in Uzbekistan in 2014, both of which proved the efficiency of the technology. The rate of condensate flow increased by over 200% following the installation of specially designed BHAs.

3. Positive results following the application of TOP

TOP is applicable for formations with high gas content (GOR>100 m3/m3) and for the production of oil and condensate from the layers of gas fields containing oil with high gas factor (GOR). It can also be applied in cases where there is gas and water coning. It is applicable for any production technique –flowing, gas lift and pumping. However, it is most efficient for natural lift.

3.1 Principal positive effects of TOP application:

» it increases the current production rate of oil and condensate;
» it increases the oil and condensate recovery factor of
well and of the entire field;
» it reduces the content of water and gas in produced oil.

3.2 Additional pluses of TOP:

» it extends the service life of the well;
» it minimizes (or completely eliminates) gas and
water coning;
» it slows down formation pressure drawdown;
» it stabilizes upwelling;

» it makes it possible to prevent early loss of
reservoir energy;
» it eliminates zones of elevated toughness in the
bottom-hole formation zone;
» it increases oil permeability of the formation;
» it increases the efficiency of gas lift and pumps;
» it reduces the cost of power supply for pumps and
compressors for gas lift;
» it reduces sand washout from reservoir, its mechanical
damage and loss of in-place permeability;
» it makes it possible to produce oil from oil rims of a
gas formation.

This is called the optimum value Popt (Fig.1). If the bottom-hole pressure value drops below the bubble-point pressure, then the relative permeability of the reservoir oil starts dropping in the bottom-hole formation zone, whereas its gas saturation grows due to the gas separating from the oil. Oil viscosity then increase as well, due to degassing. This leads to a reduction index of productivity. As a result of this, a reduction in the bottom-hole pressure to below both the bubble-point and the value of optimal pressure may lead to a reduction of flow rate, not an increase. This is contrary to the conclusions that were presented by the widely used Vogel model. With the gradual reduction in bottom-hole pressure due to increased drawdown in the reservoirs the flow rate, at first, increases. However, if we start from the optimal pressure point, the flow rate starts to decrease in spite of an increase in drawdown, which, as mentioned above, is contrary to the Vogel Model. The cause of this is that after optimal bottom hole pressure is achieved, the effect of the reduced productivity index on the production becomes dominant.

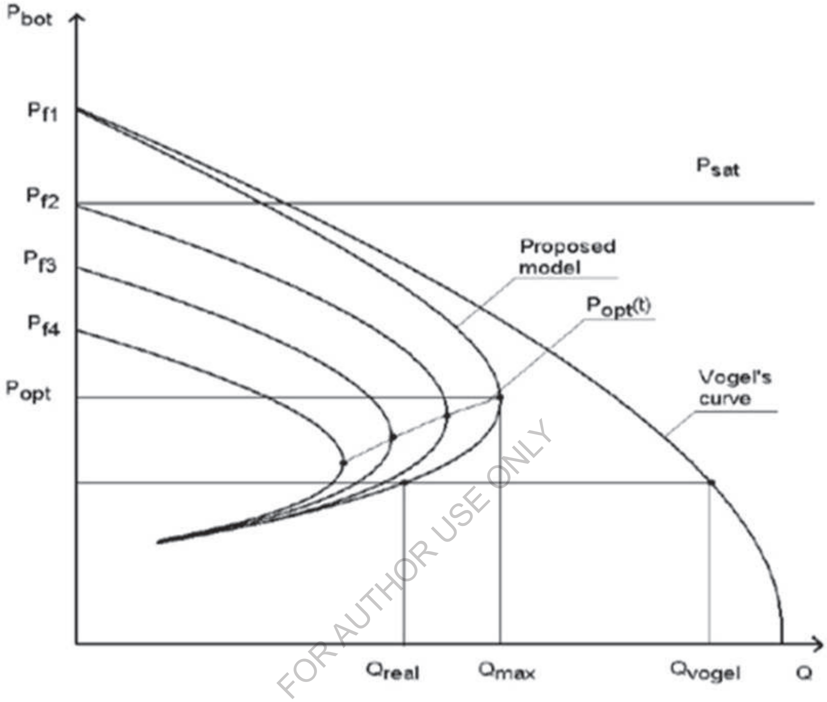

Fig.1. Inflow Performance Relationship curves

We can see from the above that the optimum pressure value was proved both theoretically and in practice. It depends on the reservoir characteristics (permeability, porosity, saturation and pressure) PVT –fluid characteristics (Rs(P,T) – solubility of gas in oil; Bg(P,T) – gas compressibility factor; μo (P,T) – oil viscosity; μg (P,T) - gas viscosity) and various other characteristics of the "well-formation" system.

The maximum flow rate can be achieved by maintaining the drive, which minimizes the negative effects in the bottom-hole zone (Fig.2). These negative effects arise due to a buildup of the skin-effect (because the gas is in free phase and after the pressure drawdown get below the value of the bubble-point pressure, separates from the oil and obstructs its flow), factors of gas and water coning, as well as due to formation of zones of viscous degassed oil near the wellbore. The gas content of the produced oil then increases because the relative permeability of the bottom hole formation increases, as the producible oil index decreases.

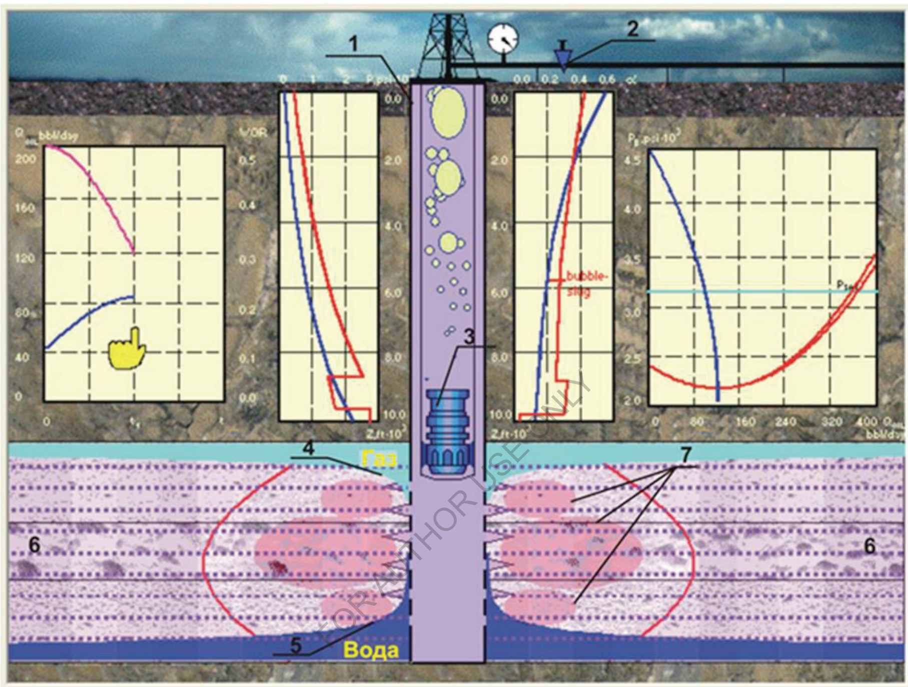

Fig. 2: Negative effects in the bottom-hole formation zone. In figure: 1 – well, 2 – wellhead choke, 3 – downhole device, 4 – gas coning, 5 –water coning, 6 – formation, 7 – regions of reservoir with low workability viscous oil.

We should note that when this technology is implemented, it slows down the rate at which the reservoir loses pressure because it minimizes early gas and water disengagement from the reservoir. Because of this the GOR value goes down. This, in turn, extends the life of a well and improves the oil recover factor.

A similar effect is achieved in gas condensate wells: by determining, with the computer models, the cut- off value of the bottom-hole pressure, at which the retrograde dropout of the condensate as a liquid occurs, we increase and maintain the bottom-hole pressure at the level at which the condensate reverts from a liquid to gaseous state. As a result, the formation blockage is removed.

3.3. List of Alternative Applications for TOP

1. Maintenance of bottom-hole pressure in order to maximize current production rates achieved by -

a. reduction of skin-effect within the near field of a well;

b. reduction of water/gas coning which emerged in the near field of formation;

c. maintenance of good oil mobility which is necessary for efficient oil production

2. An increase in productivity in a nearby field due to a reduction in skin effect and minimizing water/gas coning by placing a downhole device for a short period of time. Following this, we will witness an increase in the current flow rate – there are cases of this positive effect at an offshore well in the Gulf of Mexico. This increase in productivity is similar to the effect that takes place following hydraulic fracturing.

3. Wells that have previously been shut down due to extremely high GOR, above 100 m3/m3 can be revived using this technique. One such example was in Turkmenistan, when a previously shut down well (#469) started producing 12 to 15 tons of oil per day, after the TOP device was installed (3 months later the well was shut-down due to its inefficiency and high GOR value).

4. Well stabilization, which can increase production [13].

5. Due to the above-mentioned effects, TOP can be efficiently utilized for oil production from rim oil within gas fields, that contain oil with high gas factor. There are billions of tons of oil at stake here, which cannot be
recovered so far as no suitable efficient technology is currently available.

6. The TOP makes it possible to increase production wells that use sucker rod pumps and ESPs, which can be inefficient in high GOR environments. The application of well logging devices based on the TOP technology contributes to the solution of this problem.

7. Increasing flow rates at gas condensate fields. This technology is effective at reducing skin effect that can take place in adjacent fields due to the drop out of liquid condensates. If the optimum bottom hole pressure is maintained, the condensate recovery rate can be increased.

4. Simulators and math models use to calculate the dynamics of the system well – the formation and all the elements of the TOP devices

The theory and calculations of this technology rests upon the building of an accurate mathematical model of the entire well-bottom-hole assembly-formation which takes into account all of its components. This mathematical model makes it possible to carry out an analysis of the processes taking place in the well, in its bottom-hole zone and in the reservoir, which, in turn, makes it possible to maximize the flow rate and increase production. Current mathematical models make it possible to accurately identify the existing reservoir characteristics, with a view to maximizing production. In addition to calculating the value of Popt, these models and computer programs enable us to determine other characteristics such as the optimum pressure for gas lift, pump output, etc, and to calculate other essential characteristics of design of the surface equipment and submersible devices, as well as forecasting the expected increase in oil production. These highly accurate simulations make it possible to run diagnostics to test the current state of the well and forecast its future performance, including changes in oil production, distribution of pressure and gas saturation

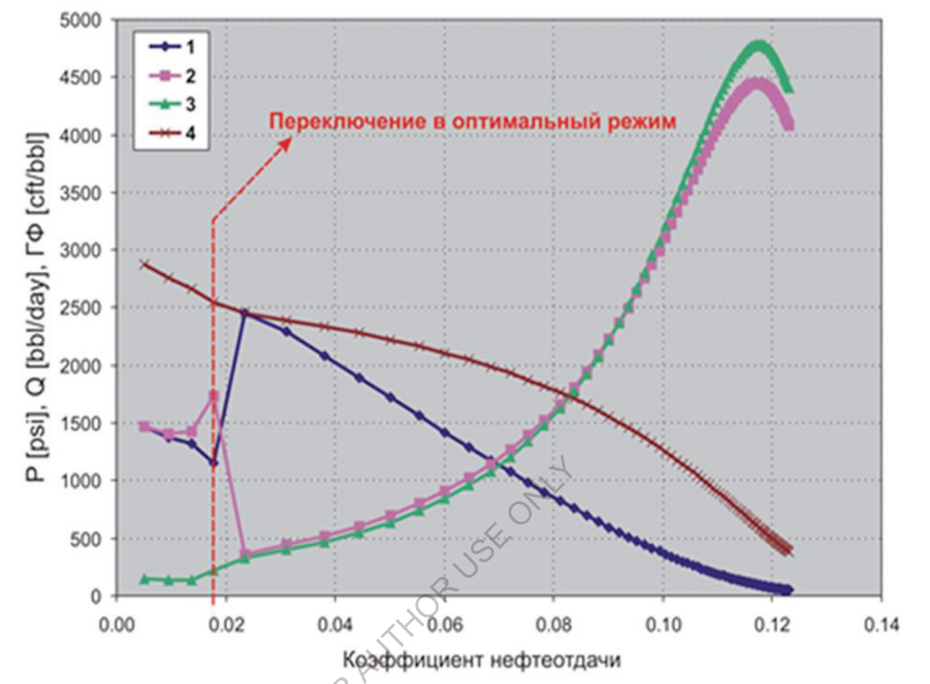

Fig. 3: Computer simulation results:

1 – oil flow rate*10 (Q), 2 – GOR/10, 3 – GOR/10, 4 – formation pressure (P) according to oil recovery factor (1 atm = 14.7 psi, 1 m3 = 6.3 bbl, 1 m3/m3 = 5.6 cft/bar)

Current mathematical models make it possible to accurately identify the existing reservoir characteristics, with a view to maximizing production. In addition to calculating the value of Popt, these models and computer programs enable us to determine other characteristics such as the optimum pressure for gas lift, pump output, etc., and to calculate other essential characteristics of the design of the surface equipment and submersible devices, as well as forecasting the expected increase in oil production. These highly accurate simulations make it possible to run diagnostics to test the current state of the well and forecast its future performance, including changes in oil production, distribution of pressure and gas saturation within formation, GOR value and the oil recovery factor of formation.

4.1. A summary of the mathematical model of Reservoir.

The theory and calculations of this technology rest upon the building of an accurate mathematical model of the entire well-bottom-hole assembly-formation which takes into account all of its components. This mathematical model makes it possible to carry out an analysis of the processes taking place in the well, in its bottom-hole zone and in the reservoir, which, in turn, makes it possible to maximize the flow rate and increase production.

Musket equations [3] were picked as mathematical model which describes main processes of unsteady two-phase filtration in formation; with some simplifying assumptions:

1) formation is one dimensional and there exists only radial flow;
2) porous media is isotropic and uniform;
3) gravity and capillary effects can be neglected ;
4) compressibility of rock and water can be neglected;
5) constant pressure exists in both oil and gas phase

These assumptions make it possible to describe the two-phase flow of oil and gas by the partial differential equations [3]:

$$(1)\quad \begin{cases} \dfrac{1}{r}\dfrac{\partial}{\partial r}\left(r\dfrac{K_{ro}}{\mu_o B_o}\dfrac{\partial P}{\partial r}\right) = -158.064\dfrac{\varphi}{K}\dfrac{\partial}{\partial t}\left(\dfrac{S_o}{B_o}\right) \\ \dfrac{1}{r}\dfrac{\partial}{\partial r}\left(r\left(\dfrac{K_{rg}}{\mu_g B_g} + \dfrac{R_s}{5.615}\dfrac{K_{ro}}{\mu_o B_o}\right)\dfrac{\partial P}{\partial r}\right) = -158.064\dfrac{\varphi}{K}\dfrac{\partial}{\partial t}\left(\dfrac{1-S_o-S_w}{B_g} + \dfrac{S_o}{B_o}\dfrac{R_s}{5.615}\right) \end{cases}$$

Zero flow condition on the outsize border of the zone is:

$$\left.\frac{\partial P}{\partial r}\right|_{r=r_e} = 0$$

On the wall of well we set a border condition due to known value of pressure or oil rate:

$$\left.P\right|_{r=r_w} = P_w(t) \text{ or } \left.\frac{\partial P}{\partial r}\right|_{r=r_w} = F_w(t)$$

Initial conditions are also set:

$$(2)\quad P(r,t) = P_0(r,0); \quad S(r,t) = S_0(r,0); \quad .$$

To the system (1) is completed with some PVT data, dependence of relative permeability of different phases from saturation and with other properties of reservoir:

$\mu_o(P)$, $\mu_g(P)$, $B_o(P)$, $B_g(P)$, $R_s(P)$, $K_o(S_o)$, $K_g(S_g)$, K, □, Pf, Pbp, rw, ri, Sw, Sg crit.

The system (1), (2) was solved using finite differences method [11], differs somewhat from the one used in [3]. Firstly the value saturation was excluded from the system and then after some transformations the nonlinear equation relative a pressure was acquired:

$$(3)\quad \frac{1}{r}\frac{\partial}{\partial r}\left(r\left(\frac{K_g}{\mu_g B_g}+\frac{R_s}{5.615}\frac{K_o}{\mu_o B_o}\right)\frac{\partial P}{\partial r}\right)+F(P)\left(\frac{1}{r}\frac{\partial}{\partial r}r\left(\frac{K_o}{\mu_o B_o}\frac{\partial P}{\partial r}\right)\right)=C(P,S_o(r,t))\frac{\partial P}{\partial t}$$

Where F (P), C (P, So) are functions depending from PVT data and formation properties.

The equation (3) was made linear by using method of shift along time axis by a small step □ during calculation of functions F (P), C (P, So), i.e. for its calculation there were used values P(r, t-□), So(r, t-□). Further the equation (3) was solved using finite differences method on a grid with variable step.

4.2. Simulator of processes occurring in the lift part of the well

Along with the creation of a simulator that simulates the processes occurring in the reservoir, we have created an original simulator that simulates the processes occurring in the well during the flow of three-phase fluid in it. This simulator allows you to calculate the parameters of the lift part of the well in order to maintain the bottomhole pressure at the optimum level using the results of calculations obtained as a result of modeling the processes taking place in the reservoir. This is the second part of the invention under consideration.

At the same time, the simulator, along with fluid flow in tubing-compressor pipes , includes a model of a surface choke and a model of a bottomhole device , which is a system of Venturi tubes, a diffuser (Fig. 4)

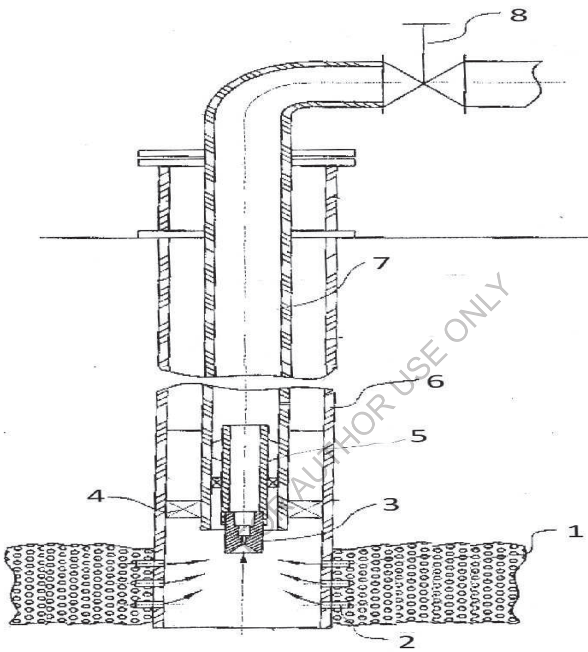

Fig.4. System of well-formation with bottomhole device

Where: 1 - formation; 2 - perforation; 3 - bottomhole device; 4 - packer; 5 - mandrel; 6 - casing; 7 - tubing; 8 - surface choke

The bottomhole device is our own and allows you to automatically maintain the operating point on the indicator curve near the maximum (see Fig. 1). This can be explained as follows.

As already noted, when the bottomhole pressure drops below the optimum, due to the physical successes occurring in the reservoir, the oil production begins to decrease, and t GOR starts to increase sharply. (see Fig. 5)

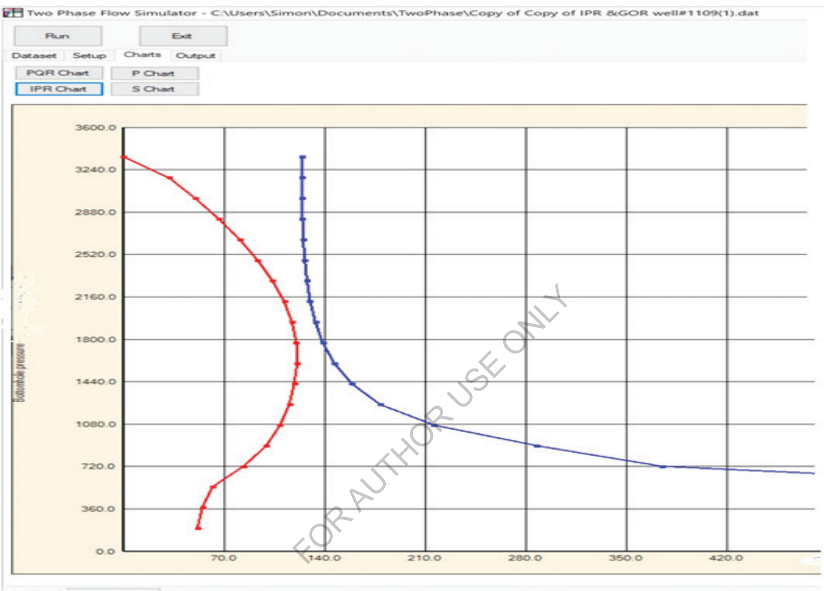

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Fig. 5 , Y-axis downhole pressure (psi), abscissa axis -oil flow rate (bbr / day), GOR (cft / bbr) * 102**

IPR (----) and GOR (----) as a function of bottomhole pressure - simulation results

In this case, the bottomhole device is designed in such a way that as the bottomhole pressure drops below the maximum point, the hydro resistance of the charger begins to increase dramatically due to an increase in the fluid velocity and friction in the bottomhole device, which leads to an increase in pressure drop on the charger (DP). calculations carried out using the Lift part of Simulator, despite the decrease in pressure drop in the tubing and pressure drop over the memory (Pbot1), this leads to a slight increase in the total pressure at the bottom of the well (Pbot2.) (see Tab. 1)

Qoil bbl	GOR cft/bbl	Pbot1psi	Pbot2 psi	DP psi
100	15300	1527	1757	230
115	15500	1556	1830	274
120	16500	1268	1758	490
119	17100	1265	1781	516
115	18500	1269	1886	617
110	19000	1262	1994	732

Tab. 1

Where: Qoil -oil rate, GOR -Gas Oil Ration, Pbot1- pressure bottom tubing under device , Pbot2-pressure below device , DP – pressure on device,

Those. when lowering the operating point (lowering the bottomhole pressure below the maximum point Qoil) to the lower part of the IPR, the pressure drop on the charger (DP) begins to increase sharply, thereby increasing the total bottomhole pressure (Pbot2) and shifting the operating point back towards the maximum. In this case, as soon as the operating point is shifted to the upper part of the IPR, due to the decrease in the GOR, the pressure drop (DP) on the bottomhole device decreases, which leads to a decrease in the bottomhole pressure. This in turn shifts the operating point back to the maximum point.

Thus, the bottom hole device automatically maintains the operation of the well near the IPR maximum point, i.e. in the optimal mode. It should finally be noted that the calculation of fluid flow in the tubing and surface choke is performed using known models of the flow of three-phase fluid in them [9].

4.3 This way the simulator algorithm works as follows:

1. Using the tank simulator, set it to the state corresponding to the moment of the expected start of the installation of the Zu. Thus it is necessary to use all available information about Rezevuar: geometry, PVT characteristics of fluids, pre-history of operation, dynamics of change of reservoir and downhole pressures. Type of relative permeability, values of accumulated fluids, etc. Determinate also the current saturation values (Soil and Sgas) taking them for the initial conditions when solving the equation (3).

2. Calculate the current type of IPR characteristics corresponding to the moment of TOP installation with the help of the tuned Reservoir simulator.

To do this, the simulator switches to the appropriate mode. The IPR curve is removed in the same way as the experimental definition of it by means of a step-reading change of the downhole pressure and determination of the appropriate values of oil and gas debits (Qoil, Qgas).

In this case, the maintenance of the Downhole pressure constant (for measuring IPR at one point) is longitudinal for several hours (not less than 12 hours) necessary for the establishment of stationary mode of operation of the reservoir. If the reservoir is currently compliant, when the TOP (IPR has maximum) can be effectively used, using the obtained IPR1 curve, we determine the values of the optimal downhole pressure of the Popt1, the debit Qoil1, the gas factor GOR1, the reservoir Pressure Pf1, saturation on oil Soil1.

3. Next using the lift simulator, determine the parameters the lift part, including the parameters of the bottom hole device, surface choke, pressure distribution, oil flow rate, gas content, etc. anywhere in the well.

4. Using the values of parameters obtained as a result of reservoir simulation, using them as initial conditions , using the simulator of Reservoir, calculate the behavior of the reservoir (the dynamics of pressure, saturations, oil debit, GOR) during some time DT1 (e.g. for several months). Then we carry out new calculations defining IPR2, P2opt, Qoil2, GOR2, etc. As described in paragraphs 2, 3.

5. Continue such calculations through every DTi until we get a sequence of optimal downhole pressures (Popt1, Popt2, Popt3,....) and expected values of oil and gas rates for the period of time (T) of the entire life of the well (Fig. 5), The time of use of the TOP simulator.

6. Based on the received calculations of bottom-hole pressures we get the curve Popt (t) (Fig. 9) (Popt1, Popt2, Popt3…. Qoil1, Qoil2,...., GOR1, GOR2,....) and simultaneously determine the parameters of the lift part of the simulator required to maintain the hole pressure at the optimum level in throughout the life of the well.

Note that when calculating the lift part of the simulator and the optimal downhole pressure Popt (t), we use the appropriate simulator, allowing to calculate the pressure division in the tubing (using the correlation [12]). The article contains a huge number of different formulas and expressions and therefore we will not cite them in this brief description of the TOP simulator. Note that together with the simulator bottom hole device this model allows to calculate the distribution of pressure and costs between the wellhead and the borehole, the parameters of the reservoir, the size of the surface choke , i.e. all parameters of the li part of the simulator.

That is, using the calculated-dynamics of the liquid and gas of the reservoir, we determine the values of the parameters of the bottom hole device, surface choke, etc.

7. Note that in order to adjust and maintain the downhole pressure at the optimum level, if necessary, it is possible to apply a superficial choke, using the results of the current measured parameters and simulation (downhole pressure , reservoir pressure, flow rates, etc.)

8. Further, the Simulator works by repeating the steps described starting from paragraph 3, for DT1 including calculations of the elevator part of the system, definitions of Popt2, etc.

8. Simulation steps are repeated for the next period of time until the entire life of the well is calculated, which is determined by the achievement of the minimum acceptable oil flow rate or the minimum allowable formation pressure (Fig. 9).

Thus, the Simulator algorithm allows to obtain the dynamics of all the parameters of the well-reservoir system during the well operation time in the optimal mode. In particular, the dynamics of changes in the value of optimal bottomhole pressure Popt (t), Qoil (t), gas factor GOR (t), well life time (until it reaches the minimum allowable value of reservoir pressure or the minimum allowable flow rate), the value of the total value of produced oil and gas, etc.

4.4. Working with the simulator files: Data file Simulator, file of simulation results, list of possible modes of the simulator

In Fig. 4 shows the main screen of the reservoir simulator. In the upper part, on the left of the screen there are buttons: Start simulator, exit from simulation, variant library, settings of the calculated variant, presentation of simulation results graphs (formation pressure, GOR and oil rate vs. Cumulative recovery index and time (Fig. 5)), Reservoir pressure distribution graphs (Fig. 6) and Saturation Soil (Fig. 7) Depending on the seam radius for different moments of time and presentation of numerical simulation results.

At the bottom of the screen (Fig.4) are the windows that specify the parameters of the simulator and the buttons to set the mode of Operation Simulator.

5. EXAMPLES

Example 1

The Evaluation of Efficiently Application of TOP Technology on the Example of Oil Well № 1 Oil Field

Below shown List of required baseline data on oil well to assess the effectiveness of TOP technology Well № 1

Data on the productive horizon:

Reservoir pressure:

Initial __25, 9 _MPa, Current __22, 0__MPa,

GOR, actual:

Initial __262__m3/m3; Current __331, 6__m3/m3;

Oil density 0.820 g/cm3

relative density of gas by air 0.820 kg/m3

Water density 1, 02 kg/m3

Viscosity:

Decarbonated oil_2_ sps ; Gas __ 0.015 ___sps ; Water ____ 1.05 sps

Well and productive horizon data:

Starting date of the operation of _ 24.06.2016

Altitude __109__m

The depth of the productive horizon:

To the roof 3033 m ; To the bottom of 3051 m

diameter and length of tubing _73mm, 3023.60 m

Surface Choke Size _12 mm

Perforation interval (current) ___3033-3055; 3058 -3060 m

Permeability of the seam 8, 2 MD

Porosity 16%

temperature in the seam ____85C

Surface temperature -13, 5C

Current operating conditions of the well:

The data will be sent as soon as the well-candidate is determined

Date 07/02/2018

Oil 19 m3/day (nozzle diameter 12 mm)

Gas 36331m3/day (12 mm choke diameter)

Water 1 m3/day (choke diameter 12 mm)

Downhole pressure 7 MPa

* Pressure in the assembled oil pipeline 2.3 MPa

Pressure at the mouth (before the choke) 3.3 MPa

Using approximations expressions   (Fig.4) get next dates:

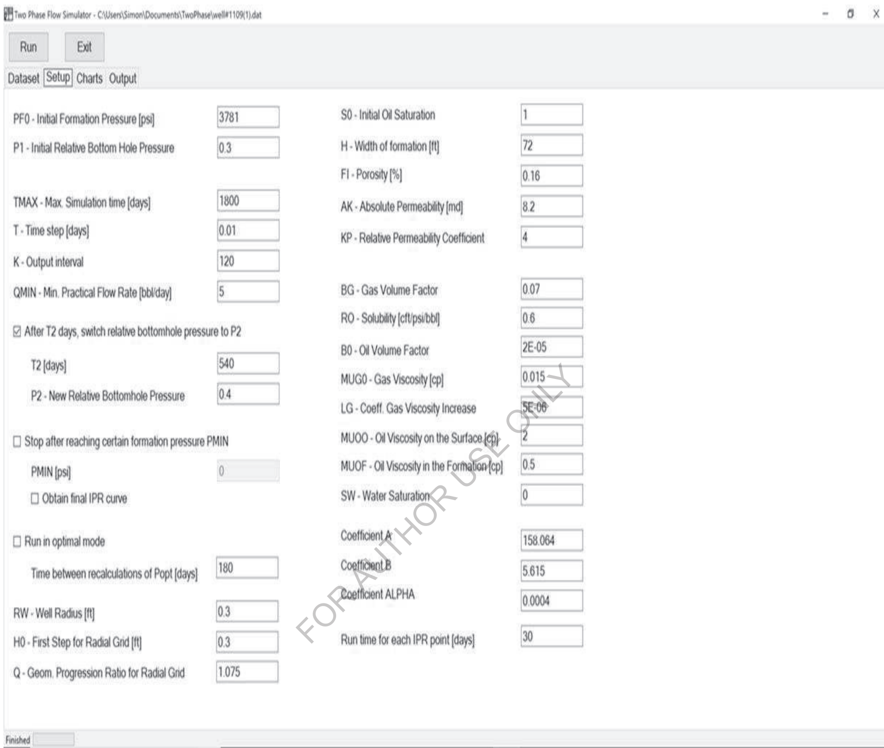


Fig. 6 , screen with the data given necessary for simulation processes in well #1

In result of Simulation got:

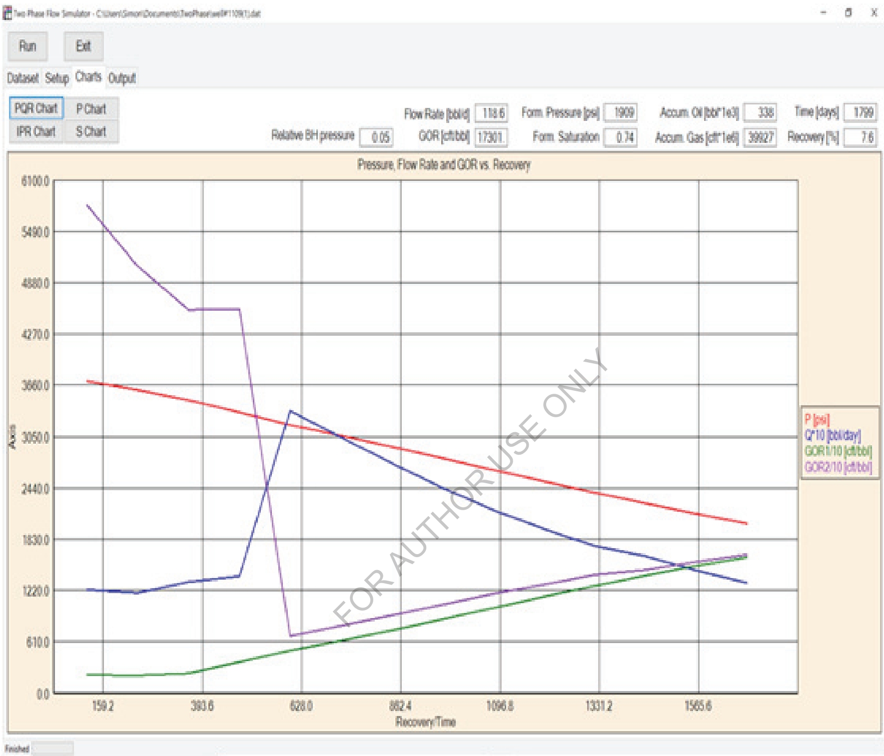


Fig.7

Shown Change of formation pressure Pfor (t), oil rate Qoil (t), GOR1 (t) (inside), GOR2 (t) (at the exit from the well) with time. In 1.5 years (547 days) well was switched to optimal mode.

We got also others results shown on Fig.8 and Fig. 9:

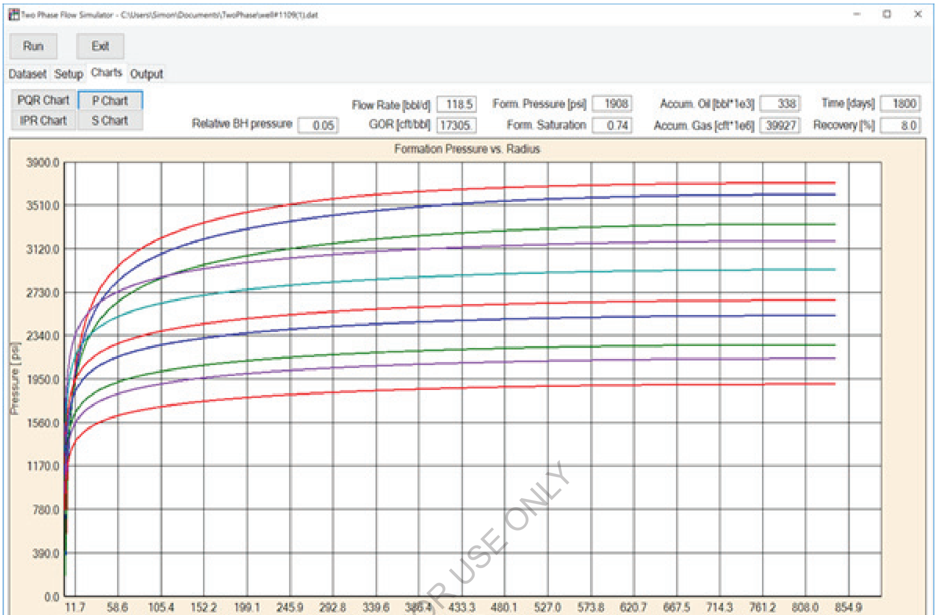


Fig. 8

Shown Change of formation pressure Pfor (r, t) by radius (feet) for different moments of time.

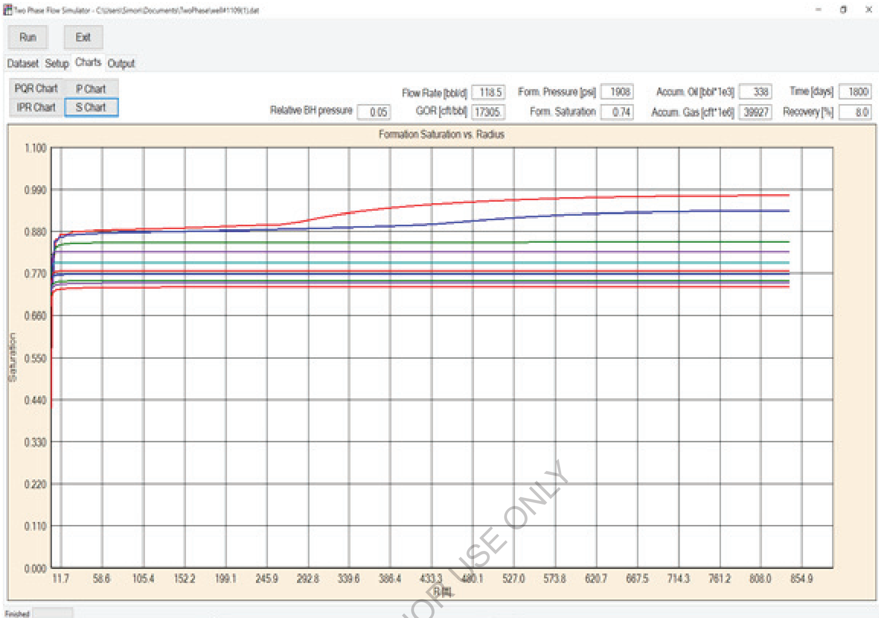


Fig. 9

Shown change of oil saturation of Soil (r, t) by radius (feet) for different moments of time.

The main conclusions obtained according to the results of evaluation calculations:

1. The use of TOP technology effectively affects the productivity of the well № 1
2. The oil debit increased from 120 to 334 bbl/day (2.8 times).
3. The GOR thus decreased from 45000 to 7000 cft/bbl (in 6.4 times).
4. The value of optimal downhole pressure should be changed from 7 to 8.77 MPa.
5. The diameter of the choke reduced from 12 to 10 mm
6. In this case increase significantly by 5.9%, due to the reduction of premature gas output from the reservoir., Ultimate Recovery Index and the Well's life should

Example 2

Comparison of two working modes of the well № 1

A). At first, we conduct simulation of the well in an nonoptimal mode, supporting all the life of the well of the downhole pressure equal to Pbot (t) = 0.3 Pform (t). and the condition of the end of the account is the achievement of oil rate equal to Qoil = 30.5 barrels per day.

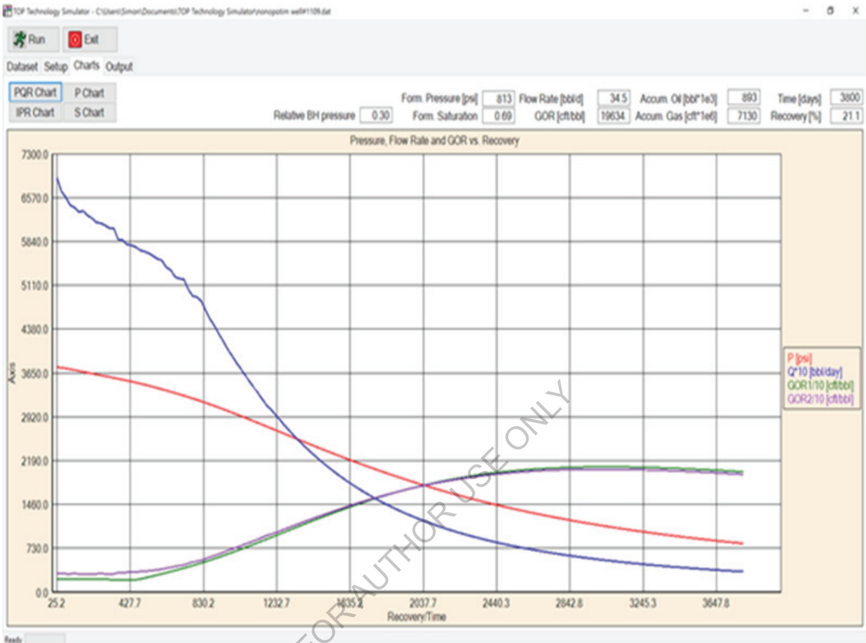


Fig. 10

shown a change in the formation pressure of Pform (t), Oil Rate Q (t), and GOR (t) depending on the time of **Fig. 10**

Well worked 3800 days (10.41 years) until the debit fell to 30.5 barrels. A day. At the same time Ultimate Oil Recovery reached = 21.1%, total the amount oil accumulated oil reached 893000 bbl. And in total the value of the received gas reached 7130 million cft.

B). And then the well was calculated on condition that it was working in Optimum mode and the condition of a stop of a well was accepted same -achievement of a rate of oil equal to Qoil (t) = 30.5 barrels in a day. And the downhole pressure was determined by the construction of a new IPR every six months and the determination of the Popt of the downhole pressure. (Fig. 11).

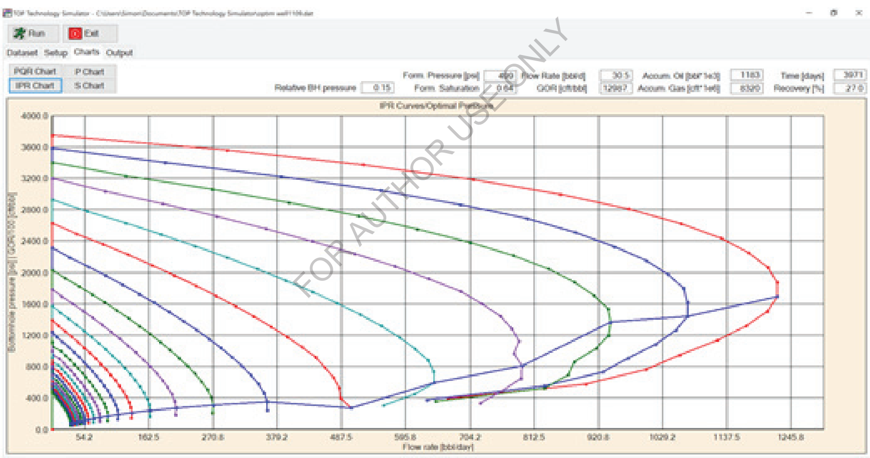


Fig. 11, As a result of the simulation of the second optimal mode, the following results were obtained.

Well worked 3971 days (10.88 years) until the debit fell to 30.5 barrels per day. At the same time Recovery Index reached = 27%, total the amount of accumulated oil reached 118300 bbl

And in total value of the received gas reached 8320 million cft.

Compare the results and evaluate the benefits of be by optimizing the well № 1:

1. Ultimate Recovery Index increased by 5.9%,
2. the amount of oil extracted increased by 298561bbl
3. and gas decreased by 1198 million cft.
4. So, the well having worked almost one and that time has given additional (proceeding from cost oil of barrel = $60 ,) profit equal = $17.880.000

6. Here are some results of the application of the TOP technology in practice

Some Results of implementation TOP technology. The TOP technology is relatively simply implemented by using a specially designed device placed downhole with the use of a cable which would enable adaptive management of the bottom-hole pressure during the course of oil production. This device automatically maintains the bottom hole pressure as equal or close to the optimal value of Popt.

At first, the well was not put into operation in optimal drive mode (Pbh ≠ Popt); however afterwards it was switched to a state nearing optimal drive, when Pbh was maintained closely equal to Popt.

1) Well A1, South-East Asia, 2008 (Fig.4). As a result of the applied TOP technology:

» Production increased from 23.5 to 50.5m3 per day
» GOR decreased from 6864m3/m3 to 2221m3/m3
» Water content decreased from 27% to 5%
» Oil recovery factors considerably increased, since the well was stabilized and GOR and water content had decreased.
» Incremental ultimate recovery of oil amounted for 2 months to: 1816 m3 (Over $1,000,000)
» After the TOP device was extracted from the well we noticed that the flow rate suddenly increased as the TOP helped to prevent the downhole gas and water coning, reduced the viscosity of oil and improved the permeability of oil in this zone, as well as decreasing the permeability of the gas.

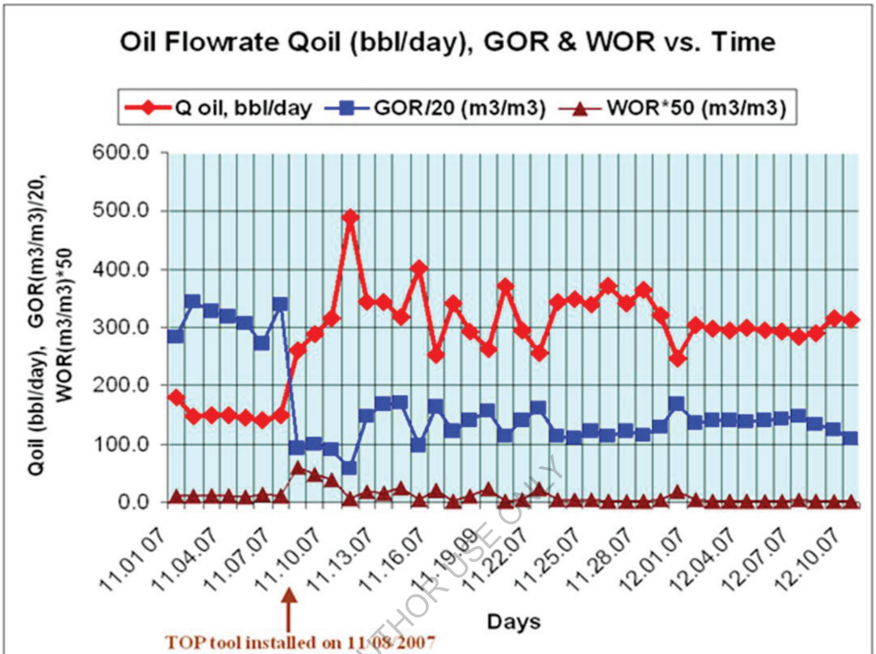


Fig. 12: The TOP technology test results (well A-1, South—East Asia)

2) Deep offshore well (over 4 km) with gas lift in the Gulf of Mexico. The following test results have been achieved :

- GOR was reduced from 586 to 227 m3/m3
- Oil flow rate increased from 19.2 to 26 m3 per day
- Water content decreased from 9.5% to 0.43%
- After the TOP device was extracted from the well we noticed that the flow rate suddenly increased as the TOP helped to prevent the downhole gas and water coning, reduced the viscosity of oil and improved the permeability of oil in this zone, as well as decreasing the permeability of the gas.

3) Well 289 in Uzbekistan (Kokdumalak field) в 2001 -2008) :

• The application of the TOP technology increased daily production by 18%, from 123.8 to 146 m3 per day, decreased GOR by 15% from 1071 to 803.6 m3/m3, and the water content dropped down to zero.

• The TOP device was installed at the bottom-hole in the tubing string to provide optimal bottom-hole pressure and stabilizing the upwelling.

• Skin-effect decreased in the bottom-hole zone, and gas and water coning was eliminated in the perforated sector.

• The utilization of the TOP device made it possible to incrementally produce 5952 m3 of oil for a 9-month period.

• Over the course of 7 years, as TOP technology was applied, the well increased produced oil to the value of 10 million USD.

4)Testing of the TOP at wells in Uzbekistan proved the efficiency of the technology of oil recovery from the layers containing high gas factor.

A specially designed downhole device was installed in 2011 at a well with a production rate of 6 tons, a GOR equal to 30000 m3/m3 and the water content of 20%. The oil flow rate increased by 50%, the water content **went down by 7% and the GOR was reduced twofold.**

5) TOP technology was successfully implemented in 2014 at two wells in a gas condensate field in Uzbekistan.

The findings are presented in fig. 13a, 13b.

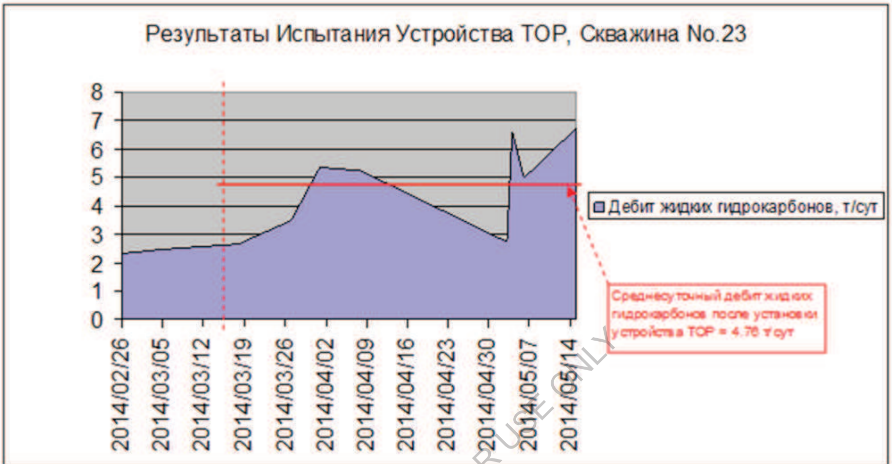
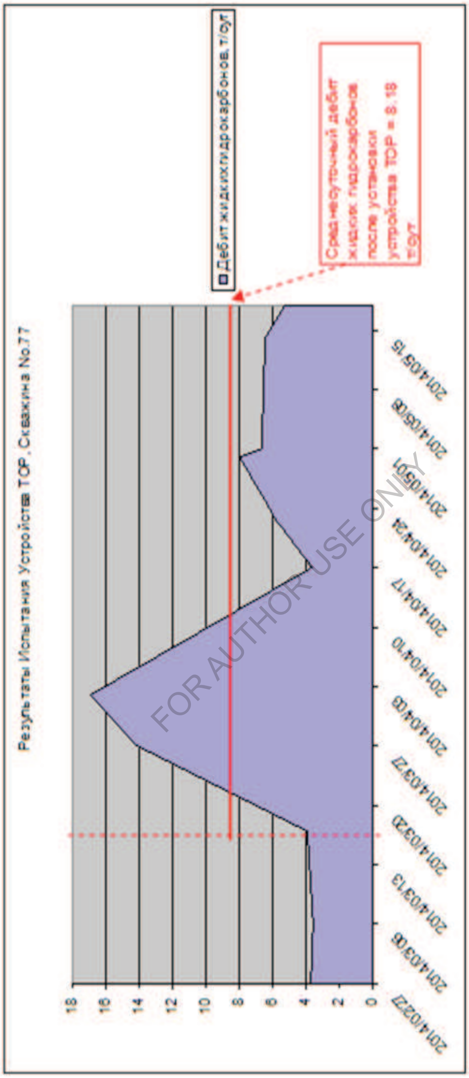

Результаты Испытания Устройства TOP, Скважина No.23
8
7
6
5
4
3
2
1
0
2014/02/26
2014/03/05
2014/03/12
2014/03/19
2014/03/26
2014/04/02
2014/04/09
2014/04/16
2014/04/23
2014/04/30
2014/05/07
2014/05/14
Дебит жидких гидрокарбонов, т/сут
Среднесуточный дебит жидких гидрокарбонов после установки устройства TOP = 4.76 т/сут

Fig. 13a

Fig. 13b


Результаты Испытания Устройства TOP, Скважина No.77
Дебит жидких гидрокарбонов, т/сут
Среднесуточный дебит жидких гидрокарбонов после установки устройства TOP = 8.18 т/сут
18
16
14
12
10
8
6
4
2
0
2014/02/27
2014/03/06
2014/03/13
2014/03/20
2014/03/27
2014/04/03
2014/04/10
2014/04/17
2014/04/24
2014/05/01
2014/05/08
2014/05/15

Well 23– the flow rate of condensate increased from 2,7 ton to 4,76 ton/day on average.
Well 77 – the flow rate of condensate increased from 3.9 ton/day to 8.18 ton/day.

The latest testing proved the efficiency of the TOP application for production of oil and condensate from the layers of gas and gas-condensate fields, containing high gas factor.

Throughout the world (and in Russia, in particular) there are a number gas fields that have oil layers with high gas factors. Currently, there is no efficient technology that enables operators to recover oil from these layers. Releasing gas condensate from bottom hole zones is also an important feature of TOP technology. Indeed, the implementation of this technology may yet solve these problems and the production of millions more tons of high-quality oil and condensate.

7. The following may be advantages of using the Simulator

1. Using Musket equations in the mathematical model allowed acquiring new results for solution of optimization problem of oil production from reservoirs with high GOR.

2. The simulator allowed to analyze the influence of bottomhole pressure level on dynamics of oil rate, formation pressure, oil saturation, GOR and oil recovery index.

3. Special kind of IPR curves may be determined using the simulator of the invention, which achieve maximum oil rate when bottomhole pressure is Popt(t) not zero.

4. The simulator is capable of analyzing the dynamics of appearance of skin effect zone, when the bottomhole pressure is below a bubble point pressure.

5. The simulator has demonstrated that sometimes GOR isn't constant along a radial direction.

6. The simulator allows calculating of IPR curves including Vogel and Standing curves as special cases, for any moment in a lifetime of the well.

7. The simulator of the invention allows analyzing and predicting future behavior of a well, depending on previous history and properties of the system; including calculation of ultimate oil recovery index and lifetime of the well.

8. The simulator of the present invention allows determining optimum operating parameters for the well by keeping the bottomhole pressure at an optimum level, so that it gives maximum oil rate and enhanced oil recovery.

9. Along with the simulator of processes that occur in the reservoir we created another original simulator, for processes happening in the lift part of the well for the three-phase fluid. This simulator allows you to calculate the parameters of the lift part of the well, including the parameters of the bottom hole device , the size of the surface choke, the flow of three-phase fluid in the tubing, allowing to hold the bottom hole pressure at the optimum level on the basis of calculations, based from simulation of the processes passing in the reservoir.

Abbreviations

P - pressure, psi

So - oil saturation

Sg - gas saturation

Sw - water saturation

K - permeability, md

Koo - relative oil permeability

Kgo - relative gas permeability

φ - porosity

μo - oil viscosity

μg - gas viscosity

Bo - oil volume factor

Bg - gas volume factor

Rs - solution gas ratio, cft/bbl

Pf - formation pressure, psi

Pbp - bubble point pressure, psi

t - time, sec

r - radius, ft

rw - well radius, ft

rl - outlet radius, ft

H - formation width, ft

Sg crit - critical gas saturation

Qo - oil rate, bbl/day

Qg - gas rate, cft/day

Popt - optimal pressure, psi

Conclusions

1.The number of wells in which utilization of TOP technology may lead to an increase of production of crude oil and condensate, is very big.

2.It should be noted that most of the current healthy production wells can become our candidates for optimization soon.

3.The value of bottomhole pressure has a great effect on the amount of the ultimate oil recovery.

4.TOP technology can be used both for the development of new oil fields and to improve production of already operating wells.

5.The economic effect from the use of this technology can be expressed in production of more oil and condensate or savings of hundreds of millions of dollars without the need to drill additional wells, or to build expensive offshore platforms.

6. Oil production from the oil rims of oil-and-gas and gas fields is a complex but promising technological task.

7. With the help of the models which incorporate the bottomhole pressure, gas cone and water cut for each well, it is possible to considerably increase the specific productivity index while reducing the well's water cut.

8. The wells demonstrating a substantial production level decline may be returned to their previous optimal level using a special bottomhole assembly (TOP).

9. The experience gained from wide-scale well testing shows that the effect is achieved in any high GOR wells.

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