Aspects of Development of Oilfields with Hard-to-recover Reserves on Closing Field Development Stage

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Most oilfields have complex geological structure and low production. Even though they are multilayered and characterised by depleted reservoir energy, they have a considerable amount of remaining oil in place. That is why developing of efficient methods of bed stimulation for achieving the highest recovery of reserves is up-to-date scientific and manufacturing task.

To provide increasing of oil production volumes from multilayered formations, it was proposed to single out separate development targets by means of employing dual completion technology, which gives an opportunity to develop several objects with different reservoir characteristics, fluid composition and occurrence depth by a single well pattern more efficiently. Operational benefit from employing dual completion technology is estimated by additional oil production volume from the inclusion of new operation facility to a well according to current well operating conditions. Appraisal of technological acceptability of dual completion on oilfields is proposed, calculations of the technological effectiveness of the introduction of dual completion technology are carried out. Dual completion implementation expediency was proved from technology viewpoint due to increasing of formation coverage and well density grid without drilling additional wells, recovery of undrained retained oil in reservoirs of complex structure and increasing of ultimate oil recovery factor

Examined dual completion technology and dual completion assembly allow decreasing of capital expenditures on drilling of new wells and accelerating oilfield development rate. In addition, they allow increasing of oil recovery factor as well as oil production. Failures of dual completion equipment are observed, and recommendations for decreasing causes of failures are given.

The problem of asphaltene-paraffin-resin deposition (APRD) is becoming more and more important due to the transition of many oilfields to the closing stage of oilfield development. The process of APRD forming is determined by many factors, which include exploitation conditions of technological equipment during production and oil properties. Known methods which are preventing dual completion oil equipment from APRD do not allow solving of the problem. That is why a need for deposit removal stays topical. By influencing on nature of interaction of asphaltene, paraffin and resin, we can control structure formation in oil system

Key words: *dual completion, oilfield, declining production, pumps, failures, oil recovery factor, assembly, dual completion, troubles in well performance, asphaltene-paraffin-resin deposition (APRD), resins, asphaltenes, protection coatings, scrapers, coaxial pipes*

Introduction

The main aspect of oilfield development is conversion into declining production stage. Characteristic features of this stage of development are high production-decline rate and considerable water cut growth of well fluid. To provide increasing of oil production output, it is possible to produce hard-to-recover reserves by singling out separate development targets (Akbarzadeh, 2005).

Joint formation development using one well spacing pattern results in partial recovery of low-pressure beds with worsened filtration characteristics. Considerable pressure difference and little space between layers create conditions for fluid output ceases for a layer with lower reservoir pressure (Pechersky et al., 2011). For these purposes, wells are converted on exploitation by means of equipment which allows separate fluid withdrawing from two formations with measurements of yields, water cut and bottom hole pressure (Oberhaensli et al., 2011)

Crude oils are complex mixtures of organic compounds covering a wide range of polarity, molecular weight, size, shape, solubility, and elemental composition and containing a large number of closely related. Variations in crude oil composition are to a certain extent inherited from different source rocks. The compounds are controlled initially by the nature of the organic matter in the source rock. Crude oils, as well as bitumen extracts from source rocks, are divided into fractions corresponding to the main structural types (Razza et al., 2017; Al Ameri et al., 2016).

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Hydrocarbons contain only organic carbon and hydrogen. Apart from the organic matters, the alkanes are non-cyclic compounds that contain carbons and hydrogen while the cycloalkanes are cyclic compounds that contain carbons and hydrogen (Mohammadzaheri. et al., 2016). High-sulfur crude oils frequently related to carbonate- type source rock. Aside from the influence of source rock faces, the state of maturity of the source material is also of importance (Šoltés, 2010). The processes of crude oil alteration (thermal alteration, deasphalting, biodegradation and water washing) tend to obscure the original character of the oil, and therefore affects crude oil correlation, furthermore influence the quality and economic value of petroleum (Sviatskii et al., 2016; Sentyakov et al., 2016).

To increase oil production output, it is possible to employ dual completion technology, which enables to develop oilfields with several development targets using one well spacing pattern more intensively (Mikhailov et al., 2016). Dual completion technology can be used even though reservoir characteristics, fluid composition and a cover thickness of the targets are different (Baranov et al., 2016; Beshagina 2014). One of the conditions for the formation of exploitation objects is providing the greatest reservoir coverage with economically feasible recoverable oil reserves for the whole working life of a well (Bakhtizin et al., 2012).

Dual completion technology for two layers is appropriate for a single formation too, in case that its cross-section includes sublayers with different permeability (Baranov et al., 2016). Different permeabilities require exploitation of the sublayers with different draw-down pressure as well as regulation of the uniform flow of deposit water to increase oil recovery. Layers to be chosen must be separated by a unit of impermeable rocks thick enough to prevent from cross-flow between the lower layer and upper layer with lower pressure (Bakhtizin et al., 2012).

As the result of research it was found out that (Baranov et al., 2016; Garipov et al., 2007; Nizaev et al., 2010) dual completion technology will allow:

- increasing of oil recovery and well yield by means of additional involving low-permeable sublayers in development,
- enhancing of reservoir coverage index and intensity of multilayer oilfield development by means of separate involving of thin sublayers with different permeability in development,
- reducing of capital expenditure for well-drilling,
- intensifying the process of regulation of recovery and injection in time and cross-section of a well,
- increasing of economically feasible development life of oilfield,
- decreasing of operating costs,
- providing a record of extracted production from every single layer and working agent injection in each of them,
- quick controlling of reservoir pressure and regulating of direction and rate of reservoir fluid filtration,
- preventing bottom hole formation zone from the negative influence of kill mud, sealing up beds (isolating well unit from the formation) without negative technological impact,
- reducing the probability of troubles with hydrates formation, asphalt, resin and paraffin deposits, great values of temperature, gas-oil ratio, water cut and viscosity of extracted production, high content of solids, salts, sulphur and corrosion-active compounds,
- exploitation of a well with leaky production string,
- using of gas from gas cap or gas formations to arrange for natural pressure gas lift or intrawell gas lift, joint developing of oil rim and gas cap without gas cone forming,
- producing water-drive reservoirs preventing from water cone forming.

Material and methods

Dual completion equipment can consist of the following assembly, separated by packers: screw pump-sucker rod pump, electric submersible pump - sucker rod pump. This equipment allows separate exploitation of two development targets. What is more, necessary bottom-hole and reservoir pressure, as well as the drawing of fluid samples, is provided for each of them. In addition, parameters needed for exploitation of development target can be controlled, fluid and oil yields can be determined in each development target. Introduction of the dual completion assembly will allow both conducting of separate monitoring of reservoir properties and fulfilment of individual development control by changing well injectivity profile and oil withdrawal. The assembly also allows bringing additional horizons into development.

Operational benefit from employing dual completion technology is estimated by additional oil production volume from the inclusion of new operation facility to a well according to current well operating conditions. The input of fluid, gas and water or their mixtures occurs as a result of bottom-hole pressure stabilising lower than reservoir pressure. In homogeneous reservoir fluid flow near the well becomes similar to radial.

By employing dual completion technology, wells get imperfect due to nature of opening, because layers of the upper horizon are lined with casing, which is perforated, that is why fluid yield is determined: the following way:

$$q_{ж} = \frac{2\pi kh \cdot (P_k - P_c)}{\mu(\ln \frac{R_k}{r_c} + C)} \quad (1)$$

where k – reservoir permeability; μ – dynamic viscosity; h – formation thickness; C - filtration resistance factor; $P_к$ – boundary pressure; P_c – bottom-hole pressure; $R_к$ – supply contour radius; r_c – well radius.

Oil yield $q_н$ was estimated using equation 2:

$$q_H = q_{ж} \cdot (1 - w / 100) \cdot \rho \quad (2)$$

where ρ – oil density; w – water cut

Results and discussion

Results of the oil production calculations are shown in Fig. 1.

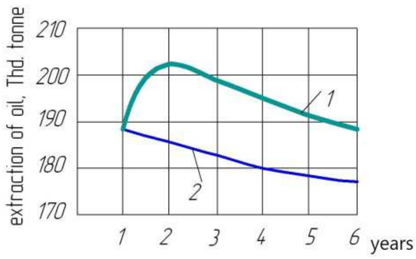

Fig. 1. Dynamics of oil production after introduction of dual completion 1 - case after implementation of dual completion, 2- base case.

It is necessary to mention that introduction of dual completion is the most efficient method of oil well stimulation from technology viewpoint due to increasing of coverage factor by means of well pattern thickening without drilling additional wells, recovery of undrained retained oil in reservoirs of complex structure and increasing of ultimate oil recovery factor.

All in all, implementation of dual completion technology is up-to-date and prospective for problem-solving in development and exploitation of multilayered oilfields. Efficient and reliable equipment, different patterns and assemblies for specific development conditions will allow decreasing of capital expenditures on drilling of new wells and accelerating oilfield development rate.

As the result of research (Ivanova et al., 2016; Pustovalov et al., 2010; Sharifov et al., 2005) the main causes of failures of dual completion pumps were identified: insufficient flow, obstruction by solids, water cut growth, corrosion, unstable work of downhole pumping equipment due to high viscosity of extracted production.

To reduce the influence of high solids backflow on pump failures the following is recommended. Firstly, it is necessary to improve the quality of bringing the well on the line during well intervention; secondly, it is recommended to employ pumps of corrosion-resistant design which allows exploitation with a high content of solids, thirdly, it is required to use sludge traps. To reduce influence of corrosion on pump failures, it is necessary to employ equipment of corrosion-resistant design as well as devices protecting from corrosion or use capillary tubing for chemical supply in under-packer zone (Nasyrov et al., 2013; Leonov et al., 2003; Garifov et al., 2009; Ibragimov et al., 2008; Božek et al., 2013).

Thus, the implementation of dual completion technology is an up-to-date and prospective way to solve the tasks of development and exploitation of multilayered oilfields. Efficient and reliable equipment, different assemblies for specific conditions of oilfield development will allow decreasing of capital expenditures for well-drilling, speeding up oilfield development rate, increasing oil recovery factor as well as oil production.

Asphaltene-paraffin-resin deposits (APRD) are hydrocarbon physical-chemical mixtures which consist of the following substances: paraffin, asphalt pitch, silica-gel resin, oils and mechanical impurities. Their content depends on conditions of oil pool formation. According to the weight content of paraffin oil is classified into three groups: low-paraffin oil (less than 1.5 %wt), paraffin oil (from 1.5 to 6 %wt), high-paraffin oil (more than 6% wt). No matter how high paraffin content is, elimination of paraffin-connected troubles is required. Paraffin is dissolved in oil under reservoir conditions. The deeper occurrence of oil is, the higher percentage of paraffin is present. The temperature of melting of solid paraffin hydrocarbons increases together with their molecular weight. It was found out that the less paraffin content in oil is, the higher content of resins, called asphaltenes are present. Resin content increases together with water cut.

While studying the influence of the physical-chemical composition of oil on the process of paraffin formation, it was discovered that in case if asphaltenes are added, paraffin crystals do not join together and thus they do not form a continuous lattice. Paraffin crystal adsorbs asphaltenes, forming a layer, preventing from ribbon structure formation. On the contrary, adding resins contributes to paraffin formation. By increasing asphaltene-resin to paraffin ratio, paraffin crystallisation temperature is reduced, and the depth where APRD begin to form is decreased. Possible ways of preventing from APRD:

- increasing of asphaltenes content in the flow of extracted paraffin oil or increasing of surface activity of asphaltenes associates which are found in oil by means of dispergating.
- reducing of paraffin saturation temperature to the level which is less than reservoir temperature.

The main factors which govern the possibility of passing of APRD processes in oilfield and down-hole equipment of dual pumping wells of oilfields are: intensive cooling of well production fluid during oil degassing process, oil cooling during the process of fluid lifting through tubing string and its moving in oil-gathering system; high paraffin content in extracted oil of oilfields.

Under conditions of bottom-hole zone amount of factors contributing to precipitation of APRD from oil dramatically increases. It is governed by employing different ways of bottom-hole treatment for regenerating of well productivity. Due to bottom-hole zone pressure falling below bubble-point pressure, oil degassing results in both decreasing of fluid temperature and reducing the ability of an oil to keep APRD fractions dissolved.

The most likely troubles in employing of dual completion technology are: formation of APRD in the tubing string, corrosion of tubing and oilfield equipment, the formation of a highly viscous emulsion. During employing coaxial pipes for a variant of oil production from upper layers and water pumping in lower layers intensity of APRD formation in the tubing is higher than for usual production practice due to the little flow area of the tubing. As a result of the analysis of well performance of one of the oilfields in Udmurtia in 2015, causes of failures of dual completion equipment were discovered. It was found out that backflow of mechanical impurities, APRD, emulsion influence, corrosion and salification are the main causes of failures of the assembly which includes ESP-SRP and hydromechanics packer with cable inlet.

Pumping equipment of dual pumping wells, equipped with ESP-SPR, is exposed to APRD, depth of intensive formation of APRD increasing as water cut of production fluid rises. It is explained by more intensive cooling of watery oil during lifting due to its increased thermal conductivity. APRD accumulates on the internal surface of the tubing, decreasing open flow area, increasing resistance and stress applied to horse head and sucker-rods. It results in increasing of leakages in the pump and sucker-rod breakages. Defined by calliper tool APRD accumulation thickness inside the tubing and on sucker-rods is shown in Fig. 2 a-c.

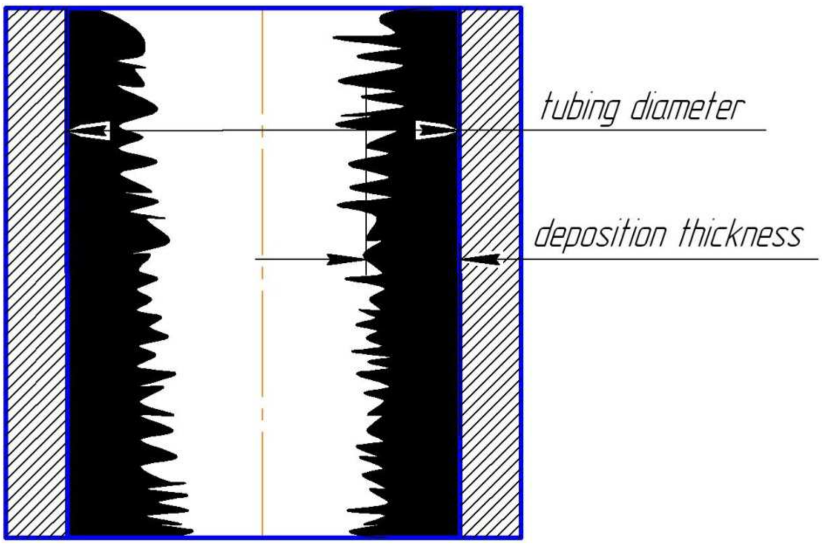

Fig. 2. a) APRD accumulation thickness inside tubing defined by calliper tool.

Fig. 2. b) APRD accumulated on sucker-rods.

Fig. 2. c) Technical state of tubing after retrieval.

Field experience shows that intensity of APRD precipitation often rises due to increasing of well productivity (when diameters of pipes and viscosities are equal, Reynolds number is proportional to well productivity), but this precipitation increase is not limitless. When flow rates increase, so do the tangential stresses of liquid applied to pipe walls. The stresses remove APRD formations.

The depth of intensive formation of APRD in wells, producing Vereiskian strata changes from 1047 to 1200 m, paraffin crystallisation temperature is around 20 – 22 °C, corresponding values of bubble-point pressure in cross-section of tubing reach 6 - 10 MPa. In wells of the Bashkirian strata, the depth of intensive formation of APRD changes from 1210 to 1300 m, average paraffin crystallisation temperature reaches 18 – 22 °C under bubble-point pressure ranged from 5 to 11 MPa.

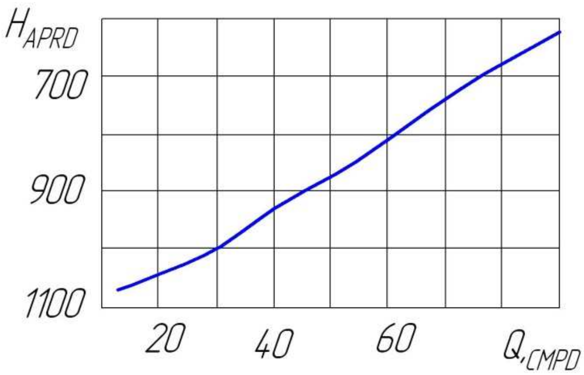

Fig. 3. Dependence of the depth of intensive formation of APRD on well yields.

Research into main methods of APRD prevention and elimination was carried out. As shows analysis of results of the research, preventing from APRD is the most efficient, because the most stable and accident-free work of oilfield equipment is reached as well as costs of oil producing and pumping are decreased.

The problem of tubing and sucker rod cleaning is solved by periodic hot water treatment of wells. Hot flushing is a preventive measure. It stabilises recovery within 20 days. APRD removal is also made by means of surfactant and liquid flushing. The liquid flow rate is less than 26 cmpd; surfactant flow rate reaches 4.0 cmpd under injection pressure being lower than 210 atm and liquid temperature reaching 30-40 °C. The maximum intensity of APRD melting is observed during first four hours, then it decreases. A new technology was developed for multilayered reservoirs under APRD conditions in intervals of the low permeability of beds and presence of watery, high permeable layers. It involves sequential pumping of surfactant solutions with gradually increasing concentration, soluble in hydrochloric acid or forming a fine dispersed stable emulsion with it. Surfactants provide APRD washing away and homogeneous dispersion forming that prevents pipe walls from repeated APRD precipitation. Bringing the well to stable production is carried out after previous temporary blocking of a high permeable zone of rock series by means of inverted oil emulsion (Ibragimov et al., 2008; Blanco et al., 2001; Beshagina, 2014).

However, employing thermochemical methods with using of washing agents often result in pump jamming. In this case, struggle against APRD is carried by means of the following methods: dosage of APRD inhibitor inside well annulus; well flushing by means of solvents; thermochemical well treatment; steam and water supply in injection line, reducing water pumping to a minimum with simultaneous hot oil pumping in production string.

The following extraordinary solution to overcome this problem is proposed. It involves variability of pump setting depth. Usually, there is a tendency to increase this depth to decrease the negative impact of non-associated gas on the work of pump. However, under increased water cut of production fluid, the negative impact of non-associated gas reduces. Moreover, it provides a possibility to decrease the pump setting depth to the optimum value. The decrease of fluid flow temperature on this depth value results in increasing of fluid viscosity. It hinders free movement of paraffin crystals thus the intensity of APRD accumulation on elements of pumping equipment can be reduced.

To prevent dual pumping wells from APRD, it is recommended to take the next measures:

- Employing APRD inhibitors inside well annulus by means of dosage pumps.
- Employing tubing string with glass enamel coating.

Employing this kind of coating for tubing allows decreasing of APRD amount on the internal surface of the tubing and protecting it from corrosion and abrasive wear.

To eliminate APRD, it is proposed to use the neat methods:

1. In case of little wellbore deviation (zenith deflection is not more than 5 - 10°) and zero formation of stable emulsions, it is recommended to employ laminated scrapers on sucker-rods with rod rotor, scratchalizers or petal scrapers (rabbler).
2. Tubing string flushing by means of the following types of solvents: OBSENOL RM45, ML-72, ML-80 as well as hydrophobic emulsion solutions, hexane fraction, diesel-gasoline mixture.

All of these reagents are used in oilfields of Udmurtia. Flushing by means of recirculation method "tubing string-annulus" allows APRD removal from well equipment surface in the interval from the top of the well to its bottom. Employing steamers to remove APRD from well equipment surfaces, internal surfaces of short flowlines and pipelines, constructed from steel pipes without fettling, measuring group units as well as other units and machinery, which do not have details made from temperature-sensitive materials is efficient during well servicing.

Table 1 shows the results of the technical-and-economic assessment of the efficiency of employing of technical equipment and technologies preventing from APRD formation.

Tab. 1. Efficiency of employing of technologies preventing from APRD.

	Technology	Share of wells with decreasing of, [%]		Share of wells with simultaneous decreasing of flushing and well servicing rates, [%]
		flushing rate	well servicing rate	
1.	**Underground heating cable lines**	75	86	64
2.	**Well containers filled with inhibitor of combined effect**	50	90	40
3.	**Well containers filled with reagent**	55	94	45
4.	**Well containers with chemical feeder**	69	98	68
5.	**Wellhead chemical feeders**	69	76	50
6.	**Wellhead chemical feeders with tube lined to pump suction**	79	75	64
7.	**Steamers**	80	96	79
8.	**Tubing with glass enamel coating**	70	50	64

Average value of technological success ratio (simultaneous decreasing of flushing and well servicing rates occurred on wells for the period 2014 - 2016) of all methods is 59.2%. Average well cleaning interval before employing these technologies reached 116 days, after introducing them it reached 193 days. Amount of well flushing during a year has decreased from 3 to 1, if calculated with regard to one well.

Additional oil production extracted from wells with equipment preventing from APRD formation is by average equal to 1.5 tonnes per day on a single well.

One of the ways allowing us to influence on the process of APRD formation is the injection of the following additives in oil flow: depressors, structure modificators, dispersants, paraffin inhibitors. The main flaws of these additives are their directed action on solving of one single problem (reducing of crystallisation temperature, decreasing of viscosity) and often high cost.

Conclusion

It was established that it is necessary to provide a stable laminar flow of fluid to prevent from APRD accumulation on pipe walls and decrease hydraulic resistance in pipelines.

As the technical-and-economic assessment of methods and technologies showed, preventing from APRD and used for their removal, the best technological parameters are reached by means of top dosing systems with pipe laid to pump suction, steamers, tubing strings with glass enamel coatings. Employing these types of equipment decreased flushing rate by three times, and the well servicing rate fell by half.

The choice of technological equipment and technologies preventing from APRD must provide decreasing or complete elimination of amount of flushings and well servicing, connected with APRD removal from well equipment.

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