SOI: 1.1/TAS DOI: 10.15863/TAS

International Scientific Journal

Theoretical & Applied Science

p-ISSN: 2308-4944 (print) **e-ISSN:** 2409-0085 (online)

Year: 2022 **Issue:** 09 **Volume:** 113

Published: 03.09.2022 **http://T-Science.org**

Issue Article

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DEVELOPMENT OF GAS CONDENSATE FIELDS BY THE METHOD OF DUAL COMPLETION

Abstract: *The article analyzes in detail the issues of operation of gas wells, analyzes the existing systems of dual completion (hereinafter referred to as DC) for gas wells.*

The positive effect of the use of DC technology is expressed in the reduction of capital investments for the construction of wells for each of the operational facilities, in the reduction of operating costs and the term of development of a multi-layer field, in the increase in hydrocarbon production and the term of final oil recovery with cost-effective operation of wells.

A feasibility study of three development options for a reasonable choice and recommendations for approval was carried out. The volume and technological factors affecting the level and dynamics of economic indicators are: the volume of production drilling, the number of wells put into operation from drilling, the volume of oil, gas and condensate production, the fund of producing wells.

The calculation of economic indicators was carried out in accordance with the projected levels and dynamics of technological indicators according to options using economic standards set depending on changes in technological factors.

The use of the latest technologies helps to increase the production potential both by extracting hard-to-reach oil from long-exploited fields, and by putting into development previously inaccessible deep-lying oil horizons. Currently, the oil industry of Turkmenistan is facing the issue of involvement in the active development of hard-to-recover oil reserves, the bulk of which is located in low-permeability reservoirs. The importance of solving this problem is determined by the depletion of reserves in long-exploited areas with a sharp decrease in well productivity

The technology with multi-packer-sectional layouts makes it possible to refine the basic highly watered, depleted oil formations with good profitability until the planned oil recovery is achieved, together with the connection of new anhydrous oil fields to dual completion under certain conditions. At the same time, through one well elevator, due to regulation by downhole shut-off valves simultaneously-separately or alternately (periodically), selection and injection into several oil formations is carried out, as well as constant accounting and monitoring of fluid production and injection of the working agent is carried out.

Key words: *field, flow rate, jamming, concentric suspension, packer, operational column, depression, dual completion.*

Language: *English*

Citation: Geldimyradov, A. G. (2022). Development of gas condensate fields by the method of dual completion. *ISJ Theoretical & Applied Science, 09 (113),* 21-29.

Soi: http://s-o-i.org/1.1/TAS-09-113-3 ***Doi***: crossref https://dx.doi.org/10.15863/TAS.2022.09.113.3

Scopus ASCC: *2209.*

Introduction

The Korpedje field is a multi-layer one, where gas condensate and oil and gas condensate fields occur at different depths and are characterized by different parameters.

An alternative to field development by drilling wells for each of the numerous fields is a method of development based on the DC of formations by one well drilled to the lower reservoir, which gives a significant economic effect from reducing the cost of drilling a large number of wells [1, 2].

The aim and objectives of the study.

In this regard, various schemes of DC are presented and analyzed in relation to optimal well designs used in drilling practice at the Korpedje field in accordance with the actual geological and technical conditions.

Materials and methods.

The development of proposals for the choice of DC technology and a rational set of equipment is consistent with the general requirements for this method of operation of multilayer fields.

In accordance with the general requirements, technical and technological solutions for DC should provide:

- obtaining optimal flow rates for each of the exploited formations (in accordance with the development project);
- the possibility of operational regulation of the total flow rate of the well with a rational ratio of the flow rates of individual formations;
- conducting research work to determine the characteristics of each of the layers;
- effective implementation of operations for the development and silencing of formations and wells as a whole;
- the possibility of effective repair work;
- the presence of elements in the complex of equipment that ensure the prevention of open gushing of the well;
- the possibility of carrying out chemical effects both on the fluid flow in the tubing and on the exploited formations (inhibitors of hydrate formation, etc.).

The technical and technological solutions adopted may vary significantly for specific different conditions of gas condensate fields [3, 4].

At the same time, the fulfillment of all of the above requirements with maximum completeness may not be possible in some specific conditions. The factors of well depth and casing diameter are particularly significant. The large depth of wells (as in the case of the Korpedje field) and the small diameter of the production columns significantly limit the possibilities of using downhole equipment that structurally meets all the requirements for the DC of gas reservoirs.

The task of analyzing existing equipment complexes for DC was to determine the real option for the development of the Korpedje gas condensate field using the method of DC of two layers with one well.

Well complexes of equipment, including equipment of foreign companies, were analyzed in comparison with data on the design of gas wells of the Korpedje field.

The main indicators of the technological characteristics of the equipment complexes are:

- operating pressure;
- maximum gas extraction;
- nominal diameter of lifting pipes;
- minimum diameter of the through hole;
- diameter of passage of replaceable throttle nozzles;
- nominal diameter of the production column (suitable for this complex);
- outer diameter of the packer;
- maximum depth of the packer descent;
- working environment;
- maximum temperature of the working environment;
- dimensions and weight of the packer (without lifting pipes).

Complexes were analyzed:

- Installation of the FCI (fountain concentric instalation) FCI with a concentric suspension of pumping and compressor pipes for DC extraction of gas from two reservoirs by the fountain method.
- Installations of PGI and IG types with parallel suspension of pumping and compressor pipes for dual completion gas production.
- A complex of the KSG type for the operation of a single packed gas reservoir with downhole flow control.

From the consideration of the above materials, it follows that the FCI, IPG and IG complexes cannot be used in the presented modifications for the equipment of gas wells of the Korpedje field, since they require a larger diameter of the production column (146-168mm) and are designed for significantly lower operating pressure [5, 6, 7].

Similar equipment complexes with parallel tubing suspension and with concentric tubing suspension of foreign companies available for our consideration of modifications are designed for lower operating pressure and cannot be directly applied to the wells of the Korpedje field.

A detailed examination of the complex of equipment of the KSG type leads to the conclusion that it can be used at the Korpedje field when some changes are made to the overall layout of the elements, which is permissible, since each of the elements of the complex (above the packer) performs its functions independently of the other nodes.

Our proposal is based on the fact that in a simplified version of the DC (KSG complex could perform all its regulatory functions for the extraction of gas from the reservoir located in the sub-packer zone with the regulation of its flow rate using a "deep" throttle. At the same time, it is possible to introduce products of the upper layer into the tubing column above the packer (with the appropriate design of the input node). At the same time, the tubing column must be equipped with one circulation valve in the upper formation zone (for simultaneous development and silencing of both layers), and the separate gas extraction from two layers carried out as a result of such an arrangement can be controlled by the discharge by changing the pressure in the tubing in the upper formation connection zone.

The informativeness of the research work can be brought to an acceptable level when calculating the pressure in the annular space at the level of the upper perforation zone of the production column (i.e., at the level of the upper layer) by a known annular pressure.

With a known cross-sectional area of the throttle holes (nozzles) at the upper horizon gas inlet into the tubing, it is possible to determine the flow rate of the upper reservoir and then - the calculated determination of the flow rate of the lower reservoir by the total well flow rate measured on the GMU (group measuring unit).

An important necessary element of such an arrangement of equipment is a check valve built into the upper horizon gas inlet chamber into the tubing string.

The need to install a check valve is determined by a significant difference in the reservoir pressures of objects whose products are combined in a common tubing string.

For such an DC scheme, an important technological factor is the ratio of the values of the projected depressions to the exploited layers [8].

When jointly lifting the production of NK-7d and NK-7g formations on one tubing string, a sufficiently large difference in depressions on the upper and lower layers and a relatively small amount of depression on the upper layer, providing a given gas extraction, should be taken into account.

It is obvious that if, for some reason, the pressure at the level of the upper layer increases, for example by 25 kgs/cm^2, in a well equipped according to the proposed option and operating with depression on the upper layer of ΔP = 23,9 kgs/cm^2 and on the lower layer of ΔP = 92,5 kgs/cm^2, for some reason, the pressure at the level of the upper layer increases, for example by 25 kgs/cm^2, then this will mean the occurrence of repression to the upper layer with the lower layer working (with a reduced flow rate), i.e. the flow of gas from the lower layer to the upper one.

The reason for the increase in pressure in the filter zone of wells may be, for example, the sealing of tubing in the wellhead zone or in the well plume with a corresponding increase in wellhead pressure. The danger of interplastic flows is somewhat reduced with the joint operation of horizons in the remote period of field development, which, however, does not change the general requirements for the equipment complex used.

Three options for the development of gas fields of the Korpedje field are considered.

The first option is basic. Development is provided by the existing well fund.

In the second option, drilling of 20 new producing gas wells is recommended.

In the third option, it is recommended to refrain from drilling five new wells on the horizons of NK-7b, NK-7g and NK-7d by opening these horizons with the use of DC in wells projected on the underlying horizons. Thus, according to the third option, 15 new production gas wells are recommended for drilling.

The placement of wells recommended for drilling in the third variant along the horizons is given below.

Horizon NK-9. Block III - 6 wells (№№ 001, 002, 003, 004, 005 and 006);

Horizon NK-8: Block 1-2 wells (№ 008, 009);

Block II - 1 well - № 007;

Block III - 1 well - № 0015 (drilled with the opening of the NK-9 horizon);

Horizon NK-7d. Block NTa - 3 wells (№ 0010, 0011, 0012);

Horizon NK-7g. Block IV - 2 wells (Nos. 0013, 0014).

At the same time, instead of drilling producing wells, it is recommended to attach the overlying horizons indicated below to the design horizon for operation with an DC for five wells: in well № 0010 - NK-7g horizon, in well № 0011 - NK-7g horizon, in well № 0012 - NK-7g horizon, in well № 0013 - NK horizon-76, in well № 0014 - horizon NK-76.

The project provides for a reserve fund - 2 project wells.

In all variants for wells of the existing fund, it is planned, after working off the exploited horizon, the production of well returns to the overlying horizons.

It is also recommended to continue the operation of wells using new technologies at the same time-the separate operation of two horizons in one well and the operation of wells using an in-well gas lift.

In addition to gas reserves of industrial categories, natural gas reserves of category C_2 are taken into account on the balance sheet at the Korpedje field. Exploration of them with their transfer to industrial categories and commissioning into development will increase the production capacity of the field for gas [9].

The main economic indicators characterizing the effectiveness of the proposed development options are capital investments, operating costs, total costs, as well as the cost of oil production.

We take discounted annual cash flow (income-expenses) as the criterion for choosing development options.

The calculation of economic indicators was carried out in accordance with the projected levels and dynamics of technological indicators according to options using economic standards set depending on changes in technological factors.

The volume and technological factors affecting the level and dynamics of economic indicators are: the volume of production drilling, the number of wells put into operation from drilling, the volume of oil, gas and condensate production, the fund of producing wells.

Using technological indicators and accepted economic standards, capital investments in drilling wells and in the areas of oilfield construction, depreciation charges for new wells, operating costs by cost items are calculated.

To date, a significant part of the oil and gas reserves has been taken from the field, and reservoir pressures on fields have significantly decreased. As a result, the existing system of natural gas collection and transportation does not correspond to the current conditions of well operation. In the coming years, it is planned to reconstruct the oil and gas collection system and build a new compressor station for receiving low-pressure gas, which was taken into account when predicting the technological indicators of the development for the future [10].

The need for capital investments for the long-term period is due to the commissioning of new gas wells and their arrangement, therefore, for the first option (basic), in which drilling of wells is not provided, annual capital investments were not calculated. The largest volume of capital investments is noted for option II.

The calculation of operating costs for the production of oil, gas and condensate for the long-term period according to the options was made in accordance with the current calculation methodology, depreciation rates and approved rates of deductions for geological exploration [11].

The upcoming costs represent the sum of capital and operating costs in the corresponding accounting year of the inventory development period under consideration.

In case of DC of two horizons, the layers are separated from each other by a packer. One or two rows of pumping and compressor pipes descend into the well, which are lowered in parallel or concentrically. With DC of two or more horizons, reservoir development can be carried out according to the following schemes: fountain-fountain; fountain-pump; fountain-gas lift; fountain-injection; gas lift-pump; gas lift-gas lift, gas lift-injection; pump-pump; pump-injection; pump-injection [12]. The field experience of operating two layers with one well by the DC method indicates its high efficiency. On average, capital investments and operating costs are reduced by 30% in comparison with the costs of drilling and operating fields with independent grids for each formation. The DC method makes it possible to seal the grid of wells (producing and injection) without additional drilling footage (Fig.1).

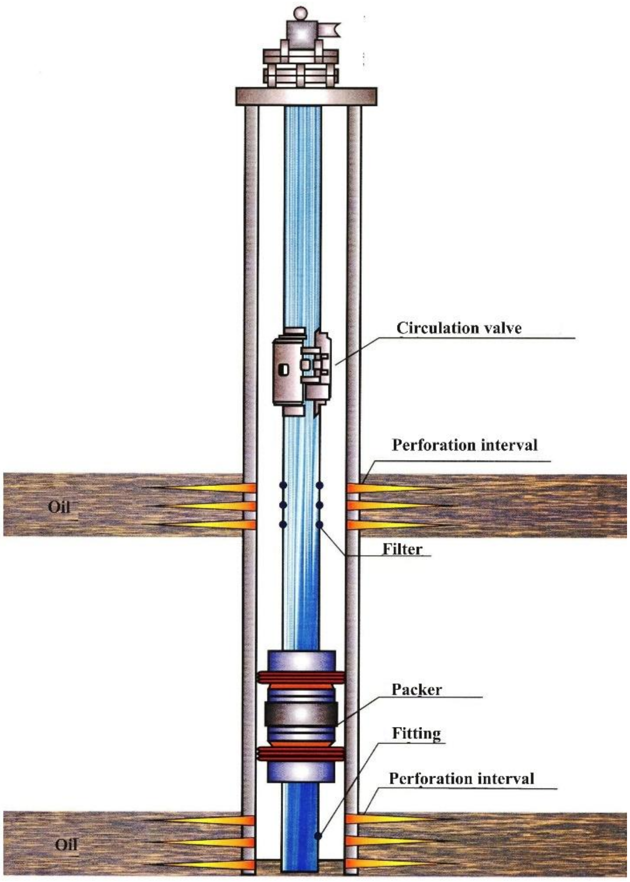

Figure 1. The scheme of the DC of a gas condensate well.

The choice of the optimal development option is made by a comparative analysis of costs and results by options for the entire period of inventory development. This period for each of the considered options is assumed to be equal to the time from the beginning of field development to the year of reaching the enlarged standard of the economic limit of development.

According to the results of technical and economic calculations, option 3 - for gas fields and option I - for oil fields was economically feasible.

Currently, the oil industry of Turkmenistan is facing the issue of involvement in the active development of hard-to-recover oil reserves, the bulk of which is located in low-permeability reservoirs. The importance of solving this problem is determined by the depletion of reserves.

The rise of the production of two layers in the well by one tubing column leads to a significant pressure drop between the filter zone and the wellhead, which required special calculations of the temperature regime of the wells to identify the conditions of hydrate formation in the wellhead zone of the tubing.

Using the methodology described in [13], calculations were performed according to the formula:

$$T_x = T_{downh.} - G_x \frac{1-e^{-a_m x}}{a_m}\left[G_m - \frac{D_i(P_{downh} - H_x}{x}\right]\beta \quad (1)$$

where T_x - is the temperature of the gas at a depth of x, °C;

G - average geothermal gradient, °C/m;

D_i - is the Joule-Thomson differential coefficient in the borehole.

°C/kgs/cm^2;

P_x - pressure at depth h, kgs/cm^2;

A- thermal equivalent of mechanical work, 1/427, kcal/kg*m;

C_r - is the average heat capacity of the gas at

$$P_{aver} = \frac{(P_{downh.} + P_x)}{2} \text{ kcal/kgs;}$$

α - is the coefficient , $\alpha = \frac{2\pi\lambda}{GC_r(\tau)}$;

here λ - is the thermal conductivity of rocks, kcal/m *hour*°C;

$f(\tau)$ - is a dimensionless function of time

$$f(\tau) = Ln(1) + \sqrt{\frac{\pi\lambda_g\tau}{C_n R_c^2}};$$

The calculation was made for the projected (conditional) well intended for dual completion (DC).

The temperature at the wellhead is calculated with the following received data:

Total gas flow rate ΣQ_g = 54 thousand m^3/day;

Downhole pressure (NK_7d) $P_{downhole}$ =398 kgs/cm^2;

Wellhead pressure (up to the fitting) $P_{wellhead}$ = 215 kgs/cm^2;

Total condensate (liquid) flow rate G_c -1108,33 kg/hour;

The total weight flow rate of the mixture G_m = 18052,45 kg/hour;

Downhole temperature $T_{downhole}$ =73 °C;

Estimated length of tubing x = H, H = 3360m;

Geothermal gradient G = 0,023 °C/m;

Average thermal conductivity coefficient of rocks λ_r = 3 kcal/m * h * °C; Volumetric heat capacity of rocks S_r = 4,697 kcal/kg °C;

The thermal equivalent of mechanical work A = 2,34* 10-3kcal/kg * m.

In accordance with the calculation methodology, given the final temperature corresponding to the equilibrium conditions of hydrate formation (T=23 °C at $R_{wellhead}$ = 215 kgs/cm^2) after determining the given values of pressure and temperature:

$$P_{giv} = \frac{P_{aver.}}{P_{cr.}} = 6.51$$

where P_{cr} - is the critical pressure,

$$T_{giv.} = \frac{T_{aver.}}{T_{cr.}}$$

where T_{cr} - is the critical temperature according to the corresponding functional dependencies, the following are determined:

- the heat capacity of the mixture

$$C_r = C^0{}_r + \Delta C_r = 17{,}26\frac{kcal}{kmol^0C},$$

where $\Delta C_r = f(T_{giv}, P_{giv.})$ is the function of $f(D_i)$ = 0.4 (according to the values of P_{giv} and T_{giv}), the value of the Joule-Thomson coefficient is further determined

$$D_i = \frac{T_{cr} f(D_i)}{P_{cr} C_r} = 0{,}158\frac{{}^0C}{kgs/sm^2}$$

After substitution in formula (1), T = 23,7 °C was obtained, which corresponds to the equilibrium condition of hydrate formation for a gas with a relative density $\bar{\rho}$ = 0,6.

The calculation result in terms of determining the Joule-Thomson coefficient was also verified by the analytical formula of I.A. Charny, derived on the basis of thermodynamic calculations in accordance with the Vander-Waals real gas model [14,15].

The average throttle effect according to I.A. Charny is calculated by the formula:

$$T_o - T = \frac{(k-1)T_{cr.}(P_o - P)(7.12\,T_{cr.} - T_o)}{8kT_o P_{cr}} \quad (2)$$

where T_0 is the initial temperature of the throttled flow, °K;

k = 1,3- adiabatic index;

T_{cr}=190.55°C according to the calculation conditions;

P_{cr} = $46.95\frac{kgs}{cm^2}$ according to the calculation conditions;

P_0 = $397\frac{kgs}{cm^2}$ - initial pressure before throttling;

P = $P_{wellhead}$ = $215\frac{kgs}{cm^2}$ - final pressure (wellhead).

Results and discussion.

As a result of calculations, we obtain a temperature drop (T_0 - T) equal to 62,05 °C and the final temperature T_f = 10.95 °C, which corresponds to the Joule-Thomson coefficient $D_i = 0.024 \frac{^0C}{kgs/cm^2}$, taking into account the correction (lowering) coefficient of I.A. Charny, taking into account the imperfections of the real gas model formula adopted in the derivation [14].

Taking into account the value of the Joule-Thomson coefficient obtained in the second calculation, we come to a positive conclusion about the possibility of hydrate formation in the near-mouth zone of the well, the operation of which is calculated according to the specified conditions and the need to provide for the possibility of supplying a hydrate inhibitor to the tubing column (in the connection zone of the upper reservoir) in the complex of equipment.

Pressure losses in downhole equipment are taken into account in cases when the formations are high-flow and the flow rate strongly depends on a slight change in depression on the formation.

The most characteristic elements of underground complexes in determining "additional" pressure losses (in relation to the total pressure drop in the tubing string) are packers and valves. Practical methods for determining pressure losses in downhole equipment have been developed, for example, described in [13]. The design features of packers and shut-off valves used in the CIS countries and by foreign firms make it possible to determine the losses arising in them as pressure losses when gas passes through a pipe segment or diaphragm.

The calculations made by us according to the methodology set out in [13] for the packer included in the KSG complex (calculation of pressure losses in a pipe segment with flow parameters reduced to the average length of the packer section) showed that the pressure losses do not exceed $\Delta P = 3 \frac{kgs}{cm^2}$ for the NK-7d and NK-7g horizons.

Calculations of losses in valves of various designs, including foreign firms, based on the dependences of the flow coefficients of valves on their diameters determine the pressure losses in them in the area of $\Delta P = 3 - 4 \frac{kgs}{cm^2}$

When comparing the pressure losses in the downhole equipment compared with the values of depression on the formations established by the conditions of their development, it was concluded that taking into account these losses does not affect the technical and technological decisions taken and allows the use of fountain fittings used according to the basic version of the DC at the Korpedje field.

When choosing objects for the application of technology dual completion (DC) of two horizons in one well, the following geological and technical conditions of field development are taken into account:

- coincidence on the plan of the main parts of the productive areas of the horizons intended for DC;
- comparability of the amount of gas reserves drained by one well;
- absolute value of current reserves;
- the distance along the section between the horizons intended for the DC;
- the degree of depletion of horizon reserves;
- the value of reservoir pressure and temperature;
- modes of drainage of fields;
- productive characteristics of formations;
- the possibility of reducing the number of wells for drilling.

The development of proposals for the choice of technology for DC and a rational set of equipment is consistent with the general requirements for the method of operation of multi-layer fields.

In accordance with the general requirements, technical and technological solutions for DC should provide:

- obtaining optimal flow rates for each of the exploited formations (in accordance with the development project);
- the possibility of operational regulation of the total flow rate of the well with a rational ratio of the flow rates of individual formations;
- conducting research work to determine the characteristics of each of the layers; - effective implementation of operations for the development and silencing of formations and wells as a whole;
- the possibility of effective repair work;
- the presence of elements in the complex of equipment that ensure the prevention of open gushing of the well;
- the possibility of carrying out chemical effects, both on the fluid flow in the tubing and on the exploited layers (inhibitors of hydrate formation, etc.).

The technical and technological solutions adopted may vary significantly for specific different conditions of gas condensate fields. At the same time, the fulfillment of all of the above requirements with maximum completeness may not be possible in some specific conditions. The factors of well depth and casing diameter are particularly significant. The large depth of wells (as in the case of the Korpedje field) and the small diameter of the production columns significantly limit the possibilities of using downhole equipment that structurally meets all the requirements for the DC of gas reservoirs

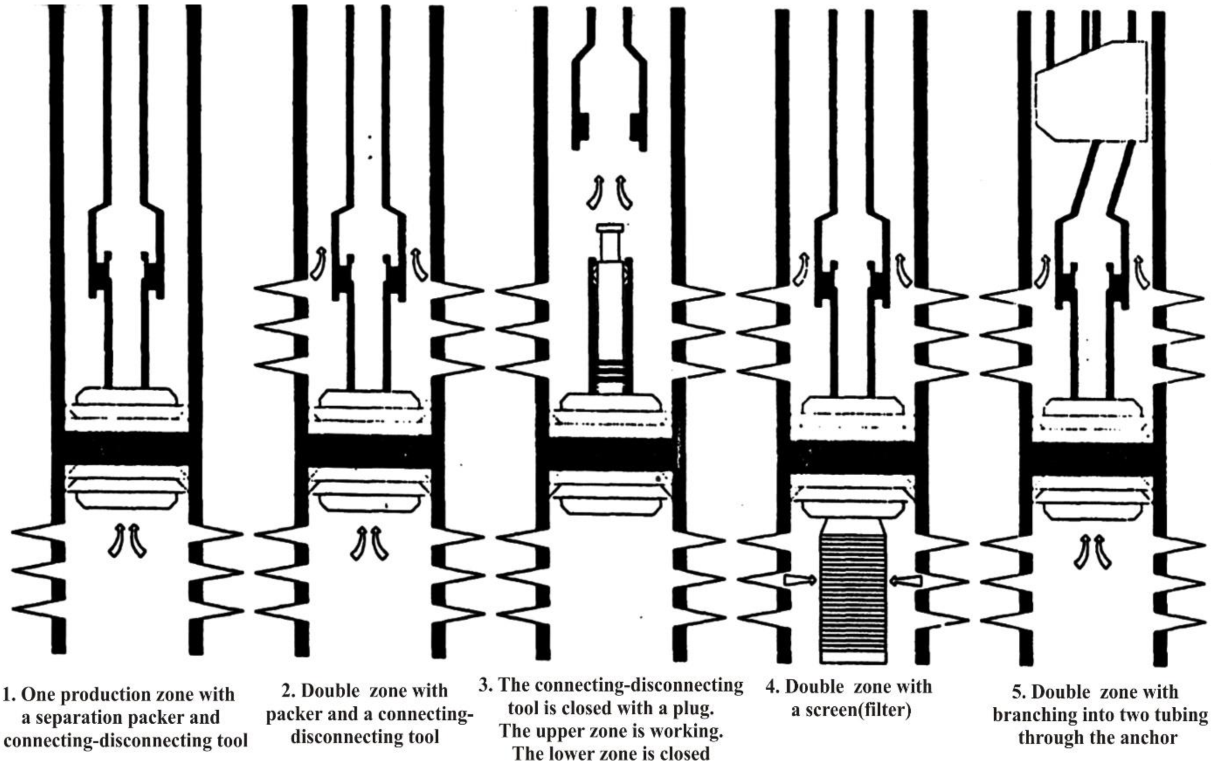

Figure 2. Functional diagram of the KSG equipment complex for DC operation of two layers

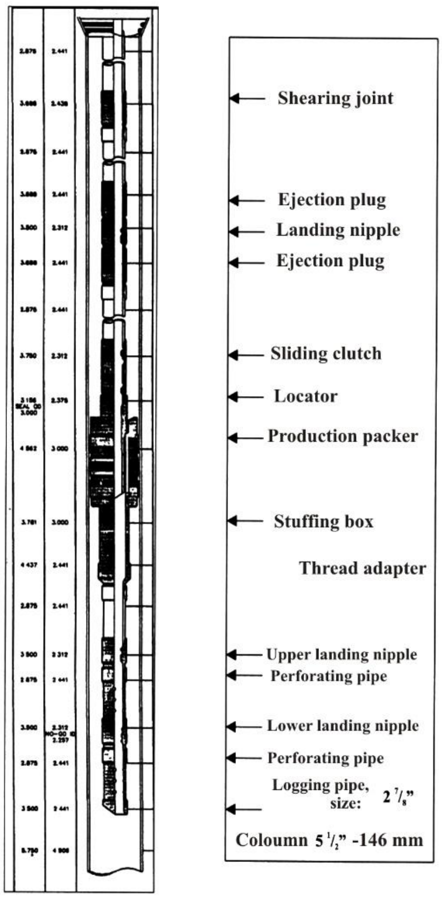

Figure 3. Downhole equipment for DC operation of two layers of the Korpedje field

When analyzing the technical documentation available to us (of an advertising nature), it was found that for simultaneous joint extraction of gas from two reservoirs with the lifting of their products to the surface with one lift of the tubing column at the Korpedje field, the principal possibility is the use of a set of equipment from Cummings Oil Tools Inc., designed for the operation of two reservoirs. This corresponds to the basic dual completion (DC) technology we have adopted and is a technical alternative to the well equipment option based on the KSG complex.

The basic functional diagram of the company's equipment complex is shown in Fig.2 with the design refinements shown in Fig.3.

The essence of this technological scheme can be defined as a variant of planned and operational regulation of the operation of reservoirs, which is carried out by installing at appropriate depths regulating throttle devices that provide any ratio of gas flow rates of two reservoirs [16,17,18].

This arrangement is characterized by the fact that it does not exclude, under certain conditions, the occurrence of gas flow from one formation to another, but, at the same time, provides opportunities for regulatory action on any of the two formations in operation in order to bring the well to the design operating mode. The regulating effect (change of throttle devices) is carried out from the surface with the help of rope equipment at the sealed mouth of a working well.

The component composition of the gas (almost complete absence of aggressive impurities) and the projected parameters of the development of productive formations do not exclude the possibility of the DC of two layers with the rise of the production of the upper layer in the annular space.

The technology and technique of such an DC method has been well studied and tested at various fields, and could be applied when using a complex of equipment such as KSG. However, the implementation of such a technological scheme cannot be recommended for the Korpedje field, which is due to the problem of reliability of operational columns. Thus, when using an operational column as a hydraulic channel, significant pressure fluctuations in the near-mouth zone are possible with corresponding changes in the stressed state of the column and, as a consequence, with the risk of intercolonial manifestations [19].

When analyzing the actual data on the operation of the fund of gas wells, cases of defects in production columns are identified.

This, when implementing the DC scheme, determines some changes in the recommended layout of underground equipment, namely the need to install a second packer above the upper productive horizon.

Installing the packer above the upper production horizon makes it possible to reduce the pressure in the annular space of the well between the production column and the tubing column (to the limits determined by the permissible pressure drop on the packer). Pressure reduction in the near-mouth zone of the well is especially effective in the case of filling the annular space with any liquid (which simultaneously reduces the pressure drop on the packer).

When installing the second packer over the upper productive reservoir, however, it is necessary to take into account the one-time introduction of a number of technological restrictions, namely the difficulty in developing and silencing the well, the supply of inhibitors, etc., in addition, the ability to control the pressure in the filter part of the upper reservoir is limited [20].

Results.

With this variant of the layout of the underground equipment of the well, control over the development of formations can be carried out either by deep, for example, geophysical instruments (flowmetry, manometry) in the intervals above and below the upper formation, or with selective wellhead regulation of the flow rate of one formation when silencing another by setting the appropriate plug (disconnecting tool) using cable equipment, as provided by the recommended complexes of equipment.

Another significant change in the design version of the DC according to the recommended schematic diagram is the use of 3" tubing in a 140 mm operational column, which will significantly reduce pressure losses in the tubing column.

However, with such a variant of the equipment layout, pipes with a diameter of 3” should be replaced with 2.5" in the packer installation area, since the design dimensions of the packer should be consistent with both the diameter of the production column and the diameter of the tubing column. In the recommended set of KSG equipment, the design of the packer corresponds exactly to this ratio of the diameters of the operational and tubing columns.

Discussion of results.

The technological capabilities of the KSG complex recommended for use, as well as the equipment of foreign firms, expand when they are placed in operational columns with a diameter of 168mm. At the same time, a packer with two through holes can be used as part of the KSG complex, i.e., an DC scheme is implemented with the lifting of products of various layers along two columns of elevator pipes.

Similar opportunities are provided when using Cummings Oil Tools Inc. equipment.

Conclusion Acknowledgments.

The review of materials advertising gas and oilfield equipment revealed significantly greater functionality of underground equipment corresponding to operational columns of at least 168 mm, which gives reason to recommend the use of these columns in the design of well construction in the near future, with the aim of improving the efficiency and reliability of the DC at the Korpedje field.

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