Development of a cutoff valve for thermal-mining oil production

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Abstract. The paper describes a cutoff valve developed by the authors for thermal-mining method of oil production. The location of the cutoff valve components in the initial position and at the maximum opening of the hydrodynamic link between a borehole cavity and a gathering main are schematically shown. The procedure of installing the cutoff valve in the well bore is given. The cutoff valve is used to equip the wells of high-viscosity oil fields developed via thermal treatment. The design of a cutoff valve for a horizontal well at Yaregskoe field was carried out. The given design proved that the device allows for online fine adjustment and tuning of operating practices (opening and closing pressure) without dismantling. The proposed design will make it possible to increase the quality and efficiency of operating wells at Yaregskoe field.

1. Introduction
For the first time the thermal-mining method of high-viscosity oil production was implemented at Yaregskoe field [1]. In 1972 a series of scientific studies were carried out resulting in the development of a productive formation via thermal recovery [2]. This technology includes formation drilling by a dense grid of production and injection wells from underground workings developed either in a formation or in overlying rocks [3].

The distinctive geological feature of Yaregskoe field is the concentration of large reserves of high-viscosity oil and titanic ore in one productive horizon. There are no naphtha fractions in Yaregskoe oil field [4]. The remaining oil reserves in-place make 224.2 mln t. The remaining oil reserves in the area of associated occurrence with oil grade of titanic ore equal to 72.1 mln t. The oil reserves in the area of associated occurrence with oil grade of ore and oil make 37.9 mln t [5].

The analysis of the current status of Yaregskoe field development and the applied development systems showed that there is a need to improve the thermal-mining method of oil production within the considered object.

2. Results and discussion
In this regard, the authors carried out a patent search [7-9]. A considerably new design of a cutoff valve is developed [10].

Device operation
Cutoff valves are installed in high-viscosity oil wells developed through a thermal-mining method. The cutoff valve is installed vertically on a horizontal well bore getting into the gathering main placed in a tunnel. The assembled cutoff valve is adjusted to a connection port (2) of a horizontal well bore through the connecting thread.
When the excess pressure is supplied from a well inside the device, it affects the sectional area of a pusher (5) and a collar of a face valve (11). At excessive initial force of a spring (8) of a pusher (5) starts moving towards the face valve (11) thus entering into a face contact (Figure 1).

With further pressure increase and the creation of a rated axial force (opening pressure), the pusher (5) disengages a face valve (11) from a saddle (3) thus forming a gap between them where the formation fluid from an axial channel (10) of a split casing (1) is getting with the downward impact on the internal face surface of a face valve (11) along the internal groove (15). The excess pressure is also perceived by the sectional area of a hollow rod body (12) thus triggering its down movement with additional compression of a spring (13) and opening of a bigger gap between a saddle (3) and a face valve (11) for free passage of a formation fluid to the axial channel of a hollow rod (12).

![Figure 1. Position of cutoff valve parts at the time of opening](image)

At the same time, the pusher (5) returns to initial position by a spring (8) force (Figure 2). The formation fluid flow from the axial channel of a hollow rod (12) is supplied to a baffle plate (24) from which through punched holes (30) in a regulating blind (29) it gets into the axial channel (23) of a nozzle (14). Then, through longitudinal grooves (31) of a baffle plate (24) it is passed to axial holes (27) from where through radial holes (28) in an adjusting nut body (26) it gets to the axial channel of a split casing (1) and further to the gathering main. At maximum dynamic pressure of a formation fluid flow getting from the axial channel of a hollow rod (12), a baffle plate (24) moves in the axial channel...
(23) of a nozzle (14) with subsequent compression of a spring (13) and change of a gap between a baffle plate (24) and an end face of a hollow rod (12).

![Diagram of the cutoff valve position](image)

**Figure 2.** Position of the cutoff valve at maximum opening of hydrodynamic link of a well cavity with a gathering main

The baffle plate (24) cushions the axial force on a spring (13) at sharp face valve (11) bounce from a saddle (3) when the formation fluid at the maximum differential pressure influences the face valve (11) with a hollow rod (12). In case of dynamic pressure from a formation fluid flow a baffle plate (24) squeezes a spring (25) and makes oscillating motions along the axis of a nozzle (14) which are imposed on a formation fluid flow passing through the axial channel (10) of a split casing (1) into a gathering main.

The formation fluid outflows via the device with the pressure decrease in a well bore. In case of the estimated pressure drop (closing pressure) via the force of a compressed spring (13) the face valve (11) together with a hollow rod (12) return to initial position fitting on a saddle (3) and interrupt the supply of formation fluid from a well bore via the device into a gathering main.

The formation fluid is accumulated in a well bore with pressure increase to the estimated opening value thus actuating the device to repeat the process.

The operation mode of the device is adjusted as follows: by changing the force of preliminary compression of a spring (8) influencing a pusher (5) - rotation of an adjusting nut (7); by changing the clamping force of a face valve (11) to a saddle (3) through the change of preliminary compression of a
spring (13) by conjoint rotation of a holder (19) with a nut (21), thus influencing the tabs (16) of a nozzle (14) and their relocation in longitudinal grooves (17) of a split casing (1), relocating a nozzle (14) in axial channel (10) of a split casing (1); by rotating the adjusting nut (26) thus ensuring its axial relocation together with a baffle plate (24) in the direction of a hollow rod (12) or back thus influencing a fluid flow.

Such adjustment is made taking into account the known production parameters - maximum flow, pressure drop, flow rate, well depth before mounting the device on a well bore.

In the course of operation the operation mode of the device is changed by conjoint rotation of a holder (19) with a nut (21) through interaction with tabs (16) on a nozzle body (14) thus moving its in the axial channel (10) of a split casing (1) by applying a spring (13) of a face valve (11) to a saddle (3) - without dismantling the device from installation and work standby.

Let us consider the design of the cutoff valve for a horizontal well of Yaregskoe field developed by thermal-mining method (Figure 3).

![Figure 3. Process flow diagram of installing a cutoff valve on a well bore](image)

1 – cutoff valve; 2 – well; 3 – fluid level; 4 – gate valve; 5 – adit; 6 – gathering main

**Figure 3.** Process flow diagram of installing a cutoff valve on a well bore

**Calculation conditions.**
- length of a well horizontal area \( L = 250 \text{ m} \);
- tilt angle towards galleries \( \alpha = 5^\circ \);

Let us determine the height \( H = L \cdot \tan(\alpha) \) and hydrostatic pressure \( P_{hs} \) of a formation fluid column (oil):

\[
P_{hs} = \rho \cdot g \cdot H = \rho \cdot g \cdot L \cdot \tan(\alpha),
\]

where: \( \rho \) - density of formation fluid (oil), \( \text{kg/m}^3 \);
\( g \) - gravity acceleration, \( g = 9.81 \text{ m/s}^2 \);
\( N \) - height of a fluid column in a well, \( \text{m} \);
\( L \) - length of a well bore in horizontal direction, \( \text{m} \);
\( \alpha \) - tilt angle of a well bore to the horizon towards galleries;
\( \tan(\alpha) \) - tangent of a well bore tilt angle.
Having accepted the average density of oil equal to $\rho=850 \text{ kg/m}^3$, let us define the hydrostatic pressure:

$$P_{hs}=\rho \cdot g \cdot L \cdot \tan(\alpha)=850 \cdot 9.81 \cdot 250 \cdot \tan(5^\circ) \cdot 10^{-6}=0.18 \text{ MPa},$$

The vapor pressure on the end of a well bore over the fluid level is accepted equal to $P_v=0.15 \text{ MPa}$ (1.5 kgf/cm$^2$). Thus, in case a well bore is filled with oil and the accepted vapor pressure over it, the total pressure on a cutoff valve will make:

$$P_{op}=P_{hs}+P_v=0.18+0.15=0.33 \text{ MPa},$$

where $P_{op}$ - valve opening pressure, MPa.

Let us accept this pressure as the estimated pressure opening a cutoff valve thus discharging a formation fluid from a well bore into a gathering main.

The vapor temperature from a vapor generator makes 150-160 °C, the temperature in a well bore makes about 75-80 °C. When the cutoff valve is opened, it ensures adiabatic expansion of vapor and further pressure drop in a system. The valve closing pressure is accepted equal to $P_c=0.1 \text{ MPa}$ (1 kgf/cm$^2$).

To illustrate the calculation let us accept the following geometrical parameters of the cutoff valve (numbers are given according to Figures 1-3):
- diameter of a pusher body (5): $D_{push}=35 \text{ mm (0.035 m)}$;
- outer diameter of a hollow rod (12): $D_{hr}=60 \text{ mm (0.06 m)}$;
- diameter of the axial channel of a hollow rod (12): $d_{hr}=50 \text{ mm (0.05 m)}$;
- outer diameter of a face valve (11): $D_{fv}=65 \text{ mm (0.065 m)}$.

Let us define the areas:
- pusher (5) sectional area:
  $$S_{push.}=\frac{\pi \cdot D_{push.}^2}{4}=\frac{\pi \cdot 0.035^2}{4}=9.6 \cdot 10^{-4} \text{ m}^2,$$
- sectional area of a hollow rod body (12):
  $$S_{hr.}=\frac{\pi \cdot (D_{hr.}^2-d_{hr.}^2)}{4}=\frac{\pi \cdot (0.06^2-0.05^2)}{4}=8.6 \cdot 10^{-4} \text{ m}^2,$$
- sectional area of a face valve collar (11):
  $$S_{fv.}=\frac{\pi \cdot (D_{fv.}^2-D_{hr.}^2)}{4}=\frac{\pi \cdot (0.065^2-0.06^2)}{4}=4.9 \cdot 10^{-4} \text{ m}^2.$$

Let us calculate the forces of preliminary compression of springs to ensure operation of a valve within the given process parameters:

Force ($F$) acting on design elements as a result of pressure of liquid (or gaseous) media filling the device is equal to the product of pressure ($R$) (or pressure drop) on square ($S$) through which the pressure is acting:

$$F = P \cdot S.$$  \hspace{1cm} (2)

The condition expressed by the following equation shall be met to open a valve:
\[ F_{p.p.} > \left(F_{pr.p.} + F_{pr.hr.} + F_{p.fv.}\right), \]  

where \( F_{p.p.} \) - axial force of liquid pressure action on the pusher (5) with the given opening pressure of the cutoff valve, N, equal to the product of the opening pressure on the sectional area of a pusher body:

\[ F_{p.p.} = P_{op.} \cdot S_{push.}; \]

\( F_{p.fv.} \) - axial force of liquid pressure action on the face valve (11) with the given opening pressure of the cutoff valve, N, exerting downward action on the face valve towards its pressure to a saddle (3) and equal to the product of the opening pressure on the sectional area of the face valve collar:

\[ F_{p.fv.} = P_{op.} \cdot S_{fv.}; \]

\( F_{pr.p.} \) - force of preliminary compression of a spring (8) of the pusher (5), N;

\( F_{pr.hr.} \) - effort of preliminary compression of a spring (13) of the hollow rod (12), N.

The force of preliminary compression of a spring (13) of the hollow rod (12) defines the pressure ensuring the closing of the cutoff valve, i.e. \( P_{cl.} \).

The condition for closing the cutoff valve is as follows:

\[ F_{pr.hr.} > F_{p.hr.}, \]  

where \( F_{p.hr.} \) - axial force of liquid pressure action on the body of a hollow rod (12) from a well at the given closing pressure of the cutoff valve, N, and equal to the product of the closing pressure on the sectional area of a hollow rod body (12):

\[ F_{p.hr.} = P_{cl.} \cdot S_{hr.}; \]

Using the equation 3 let us express and define the force of preliminary compression of a spring (8) of the pusher (5), having accepted the force of preliminary compression of a spring (13) of the hollow rod (12) equal to \( F_{pr.hr.} = P_{cl.} \cdot S_{hr.} \):

\[ F_{pr.p.} = F_{p.p.} - F_{pr.hr.} - F_{p.fv.} = P_{op.} \cdot S_{push.} - P_{op.} \cdot S_{hr.} - P_{op.} \cdot S_{fv.} = 0.33 \times 10^6 \cdot 9.6 \times 10^{-4} - 0.1 \times 10^6 - 8.6 \times 10^{-4} - 0.33 \times 10^6 \cdot 4.9 \times 10^{-4} = 69 \text{ H (7 kgf)}. \]

The force of preliminary compression of a spring (13) of the hollow rod (12) is as follows:

\[ F_{pr.hr.} = P_{cl.} \cdot S_{hr.} = 0.1 \times 10^6 - 8.6 \times 10^{-4} = 86 \text{ H (8.8 kgf)}. \]

The force of preliminary compression of a spring (8) of the pusher (5) is set through rotation of an adjusting nut (7) before mounting a device (rough adjustment), and then after being mounted or directly during operation the force of preliminary compression of a spring (13) of the hollow rod (12) is adjusted by conjoint rotation of a nut (21) and holders (19) with relocation of a nozzle (14) (fine adjustment).

3. Conclusions

The implementation of the described cutoff valve with the thermal-mining method of oil production will make it possible to achieve the following benefits:

1. A possibility to adjust the device on the optimum operating mode when the formation fluid is passing through the device in case of small pressure drop;
2. A possibility to increase the carrying capacity of the device in case of diametric restrictions by reducing the hydraulic resistance;
3. A possibility to change the axial force for additional compression of a return spring of a hollow rod by considering the additional area of pressure drop intake;
4. A possibility to decelerate the formation fluid via the device by using a sprung reflector.

Thus, the device allows making fine adjustment and setup of a process mode (opening and closing pressure) while in operation without shutting down a well and dismantling the device. The implementation of the proposed device will provide for higher quality and efficiency of well operation within Yaregskoe field.

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