Investigation of methods for setting packers used for hydraulic fracturing

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Abstract. Hydraulic fracturing is one of the effective methods of increasing the oil recovery of reservoirs. An important factor in hydraulic fracturing is the reliability of the packers, which are used to ensure the integrity of the production column. To prevent complications associated with tightness of casing pipes during hydraulic fracturing, studies were conducted to evaluate the methods of setting packers. After analyzing the practice of the application of packers, it was realized that five methods of setting them are used. The paper discusses the advantages and disadvantages of packer setting techniques. It is revealed, that the most reliable method is the combined version of setting of packers. The use of the combined setting method significantly increases the success of sealing the annular space of the well.

Keywords: Packers, hydraulic fracturing, casing pipes, annular space, well, complications

1. Introduction
The increase in the productive characteristics of oil and gas wells in fields that are at the final stage of development or operating low-permeable formations is often associated with the use of hydraulic fracturing [1]. In the bottom-hole zone of a productive formation, cracks are formed when a special agent – hydraulic fracturing fluid is injected [2]. The effectiveness of conducting the hydraulic fracturing of layer is determined by several factors, for example, the reliability of the equipment inside the well, especially packers, which are used to ensure the integrity of the well casing [3]. Packer assembly must maintain the differential pressure, created below the packer with the fulfillment of operation hydraulic fracturing.

The design of packer includes the main elements: anchor, sealer, the setting mechanism [4]. Inside the packer assembly, a special channel is provided for equalizing the pressure after removing the seal. The practice of using packers shows that for high-quality isolation of the annulus, it is necessary to create contact stresses on the wall of production casing higher than the pressure created during hydraulic fracturing.

2. Materials and methods
The paper examines the interaction of various packer assemblies with the casing string. 5 ways of setting packer assemblies are described. To conduct the study, a detailed analysis of scientific and technical journals on this topic is carried out and a patent search for packer setting techniques is conducted. In the reviewed literature, it is noted that the anchor slips have a serious impact on the production casing when the packer is set in the planned interval. Frequently, the breakdown of the anchor slips is possible during
the hydraulic fracturing operation. Appropriate studies are required to assess the strength of the packer elements. To reduce the risk of complications during the installation of the packer, it is necessary to assess not only the bearing capacity of the production casing in the productive formation, but also various cement faults behind the production casing.

3. Research results
To calculate the permissible stresses of interaction between the anchor slips and the production casing, we consider the use of a spear with six slips for setting a packer.

In [5], the authors identified that the pressure transferred from the anchor slips to the casing is equally distributed over the contacting surface. The effort is calculated from the formula:

\[ q = \frac{G(1-f\tan\alpha)}{2\pi Q h \epsilon (1 + \tan \alpha)} \]  

(1)

where \( G \) is the expulsive force, which influences packer and anchor slips; 
\( F \) is the coefficient of friction at the "pipe-slip" interface, 
\( \alpha \) is the angle of inclination of the conical surface of the slips to the anchor; 
\( Q \) is the radius of curvature of the production string, equal to half the sum of the semiaxes of the ellipse; 
\( h \) is the height of the slips; 
\( \epsilon \) is slip-casing contact factor

The contact factor is calculated using the formula:

\[ \epsilon = \frac{e}{120^6}; \]  

(2)

where \( e \) is the angle of interaction of the slips with the casing;

\[ e = 2 \sin^{-1} \left( \frac{l}{2\pi Q} \right); \]  

(3)

where \( l \) is the width of slips.

The force is calculated by the formula:

\[ N = \frac{G l k}{\pi Q \epsilon}; \]  

(4)

In the section on one of the axes of the force action \( N \) and the torque \( M_0 \), tensile and bending stresses arise:

\[ \sigma_t = \sigma_t + \sigma_b = \frac{N}{F} + \frac{M_0}{W}; \]  

(5)

where \( F \) is annular area; 
\( W \) is the axial moment of resistance of ring.

Axial moment is calculated by the formula:

\[ W = \frac{h a x^2}{3}; \]  

(6)

where \( a x \) is the minimum pipe thickness that is not affected by the well;

\[ \sigma_t = \frac{G l k (\sigma_{ax} + 3Q(1 - \cos \beta) + 6\sigma_b)}{\pi Q h \epsilon \sigma_{ax}^2}; \]  

(7)
It is noted in [6] that the differential pressure $q$ arising from the anchor and acting on the casing is distributed unevenly along the length of the slip and reaches the highest values at a certain distance from the upper end of the slips.

It is evident from (7) that the length of slips $L$ affects the stresses which appear in the pipe.

In practice, the most widely used methods of setting packers are the following:
- transfer of the weight of the drill string to the sealing element
- through cutting off packer through with a ball valve;
- hydraulic setting using a hydraulic cylinder;
- mechanical method of setting packers;
- combined setting.

Let us examine each method in detail.

1. **Transferring pipe weight to the packer.** The annular gap is closed by a sealing element under axial loading of the packer with expansion in the radial direction. Compression of the sealing element shows that there is uneven distribution of contact stresses at the seal-casing contact. The greatest contact stresses occur at the point of application of the axial load on the sealing element of the packer, which gives rise to hydraulic impact and the loss of sealing ability by the seal. Uneven stress distribution reduces the effectiveness of sealing the packer assembly.

   It is possible to distribute stresses at the seal-casing boundary by radial expansion of the packer by inserting a cone [7]. The use of a cone reduces the axial load required to set the packer element. By changing the shape of the expandable cone, the required contact stresses are achieved along the length of the seal. Sealing element is considered to be the most vulnerable element in packers. Under the influence of significant loads, the rubber seal gets into the gap between the packer body and the casing wall, which can lead to sticking of the assembly in the well. Analysis of production data shows that fracture usually occurs at the end of the seal when the gap between the support push part and the production string is closed.

   The radial clearances for overlapping the annular space in the well vary within $3 < \delta < 5$ mm, which is more than the recommended clearances between the connecting parts. Therefore, there is a problem of leakage of the seal material into the gap of the mating parts. With axial compression-deformation of the sealing element, this task is difficult to accomplish. It should be noted that axial compression displaces the push part and the seal relative to the production string. In some cases, the seal wears out and breaks down.

2. **Setting by cutting of the packer bore with a ball valve**
   The ball is released from the seat of the axial channel of the packer due to the excess of the working agent pressure over the seating force by 2.5-3 MPa. The phenomenon of water hammer occurs.

   The maximum allowable velocity of the flushing agent when installing the packer assembly is calculated taking into account the condition of the flushing agent flowing from the pipes towards the closed cavity. In this case, the velocity of the flushing fluid acquires maximum values.

   $$V_0 = \mu \sqrt{\frac{\Delta P}{\rho_l}};$$

   where $\mu$ is consumption coefficient;
   $\Delta P$ is pressure drop between the inner surface of the tubing and the below-packer space, Pa;
   $\rho_l$ is density of liquid, kg / m$^3$;

   For fulfilling the calculation let us assign the following initial data:
   $\Delta P = 20$ MPa, liquid density $\rho_l = 1000$ kg / m$^3$, flow coefficient $\mu = 0.82$.

   Let us substitute original values into (8):

   $$V_0 = 0.82 \sqrt{2 \cdot 20 \cdot 10^6 / 10^3} = 164 \text{ m} / \text{s};$$
In the below-packers zone, a pressure jump is observed with a direct water hammer during the opening of the seal barrel. The resulting pressure drop can be determined from the expression:

\[ \Delta P_h = \rho_l v V_0; \]  

where \( v \) is the velocity of the shock wave propagation, m/s.

The velocity of the shock wave propagation is calculated from the expression:

\[ C = \frac{9900}{\sqrt{48.3 + \alpha^2 \delta^2}}, \]

where \( \alpha = 0.5 \) is dimensionless coefficient for steel;
\( d \) is the inside diameter of casing;
\( \delta \) is the thickness of casing wall.
We accept \( d = 6.2 \) cm; \( \delta = 0.55 \) cm for tubing.

After substituting the data into (10), we get:

\[ C = \frac{9900}{\sqrt{48.3 + 0.5^2 \cdot 6.2^2}} = 1.356 \text{ m/s}; \]

The pressure increase in the below-packers zone in accordance with (9) will be:

\[ \Delta P_h = 164\cdot1\cdot1.356 = 222.3 \text{ MPa}; \]

Let us assume that the packer assembly is installed in a production casing with a diameter of \( D_y = 168 \) mm, with a wall thickness of \( \delta = 9 \) mm.

The force acting on the packer assembly caused by water hammer can be calculated using the formula:

\[ \Delta Q = \Delta P_h \cdot \Delta F; \]  

\[ \Delta F = F_n - F_{tub} = 134.8 \cdot 10^{-4} \text{ m}^2; \]

Then

\[ \Delta Q = 222.3 \cdot 134.8 \cdot 10^{-4} = 3016 \text{ kN}; \]

The impact force is calculated taking into account the minimum amount of space under the packer.

The pressure in the below-packers interval is higher than the pressure of the working agent when the landing seat with the ball valve is cut off. The anchor is not able to hold the packer element in the installation zone, which moves the packer to a higher location, violating the integrity of the sealing element and the tightness of the annular space of the well.

If the packer does not lose tightness after being affected by the shock wave of sealer and transferring this force to the expanding cone of the anchor slips, an additional force is exerted on the production string. To remove the packer from the setting site, it is necessary to create additional axial stress, which is higher than the lifting capacity of the unit.

In [9], it was revealed that during hydraulic setting of a heat-resistant packer element, it is problematic to ensure complete impermeability, because heat-resistant seals have a low coefficient of elasticity and, under the influence of a water hammer, lose their strength.

3. Hydraulic packer setting.
For hydraulic setting, the design of the packer includes a hydraulic cylinder and landing seats. In [8], the authors studied the packer schemes with this setting technology. To implement the hydraulic method of setting the packer, a shear valve is described, taking into account the effect of the shear mechanism on the structure. However, this technology, when the channel is released from the seat, can lead to a water hammer. In the case of sealing the annular gap and due to the influence of reservoir pressure drop, it becomes difficult to retrieve the packer from the well. Difficulties are associated with the fact that the pullout force exceeds the lifting capacity of the equipment and the strength of the tubing. It is necessary to use special technical means. If the leakages through the sealing element appear when conducting packer pressure test (after setting of the packer), then the packer is removed from the well quite easily.

4. Mechanical setting of the packer. Mechanical setting is used for many purposes - well development, stimulation of production, isolation, workover, etc. When setting the packer assembly by turning the pipe string, it becomes difficult to account for the torque that is transmitted to the packer, since there is no possibility of monitoring the interaction of the tubing with the production string wall. This negative factor is especially evident in the bend of the well. With the mechanical setting method, the required contact stresses on the wall of the packer assembly with the production casing are not fully achieved. Therefore, when performing hydraulic fracturing, there is a risk of exposure to high pressure of the working agent on the production string of the well.

5. Combined setting. The most reliable option for setting packers is the combined method. The combined setting takes into account the advantages and disadvantages of the above methods. The required contact stresses at the boundary of the sealant with the pipe wall of the production casing are achieved without serious problems. Production casing is reliably protected with the combined method, which is very important in conditions of hydraulic fracturing.

4. Conclusion

The packer assembly carries out one of the main roles in hydraulic fracturing, since the protection of the production string from significant pressure drops is paramount during hydraulic fracturing. To date, there are various structural elements of packers and methods of their use. Despite the variety of existing packers and setting methods, there are significant reserves for increasing the efficiency of their use when performing hydraulic fracturing. Certain difficulties arise when setting packers in horizontal wells. There is no possibility of transferring the required load to the packer and therefore the tightness of the assembly may not be maintained, especially in conditions of hydraulic fracturing, when it is required to create a significant pressure drop.

Having considered the main options for setting packers, it is proposed to use the combined setting method as the main one. This option allows successfully installing the packer at any interval of the casing and thereby reducing the risks of packer failure from the installation site during hydraulic fracturing.

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