Packer design research used in hydraulic fracturing

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Abstract. The purpose of the packers is determined by the specific technological tasks. The design of a packer and the principle of bringing it into action provide protection from early wear during the tripping process. In addition, the design of a packer ensures manufacturability of its use and reliable control over the work in the well during the hydraulic fracturing, regardless of the depth of the installation. The experience with the use of packers for the test beds showed that in most cases packer items become inoperative due to the destruction of the lower part of the rubber element. In practice, the isolation annulus packer with different ways of planting is important and necessary to ensure reliable fixing of a packer at the place of installation in the borehole. It happens due to the use of anchoring unit and different designs of seals of packers.

1. Introduction

Packers are used to separate formations, isolate casing strings from the effects of the well medium during the operation of oil, gas, gas condensate wells, as well as to carry out repair and maintenance work and eliminate absorption.

Packers are used for hydraulic fracturing, acid and thermal treatments of a reservoir, for the performance of insulating works, sandblasting, installing wire filters and shut-off valves, cleaning bottom holes, gas lift operation, etc. Packers are put into a well on tubing. The packer pass should allow a tool and equipment to be lowered freely to carry out the necessary operations for well development and operation, eliminating complications or performing the necessary technological operations.

A packer must withstand the maximum required pressure drop acting on it under extreme conditions (operating pressure). The problem of ensuring the reliability of the annulus overlap by a packer is relevant at the present time, especially under conditions of hydraulic fracturing (HF) using high pressure working fluid.

2. Methods and materials

In this paper, the authors study anchor nodes and packer seals.

Sealed isolation of the space of the production or intermediate casing string is ensured by the selection of the diameter of a packer in accordance with the inner diameter of pipes, creating an optimal gap between a packer and the wall of pipe string.

In order to absorb the force from the pressure drop acting on a packer in one or two directions, a packer must have an appropriate anchor device (anchor).

Sealing elements are pressed and expand against the casing under the action of axial load (tubing weight or force from the hydraulic piston).
For sealing elements, synthetic rubber of 4326, 4327, 3825 grades is used for Packers with small deformation of the sealing element (self-sealing) and 4004, 3826-C grades for elements with high deformation.

All sealing elements have a cord for hardening the rubber element, which is made of cotton fabric, polymer or metal fiber.

The block diagram of a packer includes the following elements: sealing elements, packer support, packer control system, technological devices.

3. Results and discussion

The analysis of the applied designs of anchor nodes of Packers showed that the main type of fixation is the design in the form of rams, expandable in the radial direction when the expandable plugs are introduced into interaction with them. [1-4].

The plugs on the outside facing the wall of casing pipe have a notch by which they adhere to metal. The problem of the interaction of plugs of an anchor nod with a pipe is relevant and requires additional research, taking into account the wear factor of casing pipes and the possibility of their destruction.

The analysis of the above mentioned formula [5] as defined by the force q of the interaction of plugs of a casing grab with a pipe shows that the height of plugs has a significant effect on their bearing capacity.

In the formula (1), the maximum load-bearing capacity of the tube plugs depends on pipe useful area, its radius, the height of plugs and the angle of their interaction:

\[ \sigma_{KP2} = \frac{\sigma_T F_c Q h \varepsilon}{R_2^2 CK} \]  

where:
- \( \sigma_T \) – yield limit of pipe material;
- \( F_c \) – cross-sectional area of a worn pipe;
- \( Q \) – inner pipe radius;
- \( h \) – height of plugs;
- \( \varepsilon \) – pipe perimeter coverage factor;
- \( R_2 \) – outer pipe radius;
- \( C \) – coefficient characterizing stress concentration in a dangerous section;
- \( K \) – the coefficient of coverage of the pipe surface with plugs and the angle of inclination of the conical surface of the plugs to the device body;
- \( \sigma_{KP2} \) – it is determined for the interaction of the plugs of the tube (in the amount of 6 pieces) and the implementation of the suspension of a hidden column.

A similar problem is solved in order to ensure the fixation of a packer by plugs during the perception of excess pressure from below, for example, in the case of hydraulic fracturing.

Analyzing the formula (1), it is possible to conclude that with the increase in the height of the plugs, the holding capacity of a packer increases.

If it is imagined that the height of the plugs tends to zero, then according to this formula: G is the force perceived by a packer and transmitted to the plugs, which tends to infinity. It is also necessary to take into account the Barlow formula:

\[ \sigma_{pr} = \frac{pD}{2\delta} \]  

where:
- \( p \) – pressure of liquid;
- \( D \) – casing inner diameter;
- \( \delta \) – casing wall thickness.

According to this formula, with a known force, perceived by a packer and reported to the plugs, it is possible to determine the allowable contact stresses at the interface “seal” - the wall of the casing pipe.
From the practice of the installation of a packer in the casing, it is known that contact stresses at the boundary should exceed the working pressure by 10-15%. From the formula (2), it is possible to determine the limiting value of pressure $P$:

$$P = \frac{\sigma_p 2\delta}{D};$$

With the existing parameters of the casing and the material from which it is made, the limiting value of $P$ is determined.

Initial data for determination of $P$:
- $\sigma_KP = 5.0$ MPa for steel pipe of strength group $D$;
- $\delta$ – wall thickness, $\delta = 10$ mm;
- $D$ – pipe inner diameter equal to 148 mm.

Then the limit value is determined:

$$P = \frac{5 \cdot 2 \cdot 0.01}{0.14} = 0.71 \text{ MPa (710 kg/cm}^2).$$

The analysis of the result shows that the contact stresses at the seal-wall boundary of the casing string are close to the limiting values, especially this must be taken into account to overlap the annular space in the old well stock with a worn casing string.

The use of the traditional method of deformation of the seal in the radial direction due to axial loading requires the application of a sufficiently large force. In this case, it is necessary to change the seal landing mechanism according to the principle reflected in the research work [6], where it is noted that a uniform stress distribution along the entire length of the sealing element can be obtained if an expanding cone is used for its radial deformation.

The practice of using this method of packer seating shows that the use of an expanding cone significantly reduces the necessary axial load for deformation of the sealant, which is especially important for wells of the old foundation.

Contact stresses at the boundary of the seal with the casing are determined by the diameter of the expanding cone for its deformation in the given cross section.

In the research work [1], several designs of packers are presented, equipped with an additional piston-type anchor of hydraulic action in addition to the plugs of the anchor node (with the expansion due to the use of the expanding cone). In the research work [1], a piston-type anchor, YaG1, is separately presented, which provides protection against mechanical impurities entering the gap of the matched movable parts of the die-casing.

![Diagram](image_url)

**Figure 1.** Piston type anchor - YAG1
Figure 2. Mechanical-hydraulic packer
Due to the fact that during hydraulic fracturing, the working fluid is under high pressure, perceived by the packer from below (with sticking of the expulsive force on the anchor plugs), there may be a loss of seal tightness and packer leaving the installation site. This leads to the termination of the fixation process. The preservation of the tightness of the annular space directly depends on the reliability of the anchor nod. In the research work [7], a new design of the anchor nod for installing the packer is presented. Fixing occurs due to equipping the bursting plugs with split spring rings, which are embedded in the casing body to the calculated depth. In order to assess the feasibility of using this method of installing the packer, the authors consider the design [7] shown in Figure 2.

The hydromechanical packer consists of a barrel 1, rigidly connected with its upper end to a conductor 2. A barrel 3 is mounted on the outer barrel 1 to form an annular chamber 4 between them, in which a piston 5 is placed with an expanding cone 6. The barrel 3 is rigidly connected to a metal sealing shell 7. At the lower end of the barrel 1, a split shell 8 is installed, with its upper end inside the metal sealing shell 7. A sealing ring 11 of elastic material is placed in the body and cased by threaded screw 12.

In the channel 13 of the barrel 1, a stepped spring sleeve 14 is installed with a seat 15 and a ball plug 16. A check valve 18 is installed in the axial channel 17 of the spring-loaded step 14 from the axial channel 13 of the barrel 1.

Step spring plug 4 is connected with the barrel 1 by a shear element 21. The annular chamber 4 above the piston 6 is constantly hydraulically connected with the axial channel 13 of the barrel 1 by radial channels 22.

The setting of the device, out to a predetermined depth, is carried out by installing the ball plug 18 on the seat 15 and create excess pressure in the pipe string, which is fed through the radial holes 22 into the annular chamber 4 of the cylinder body 3 and acts on the piston 5 with an expanding cone 6 with moving inside the split ring 8. The ring extends in the radial direction to ensure the deformation of the metal sealing shell 7 with the ring 11 to tight contact with the inner surface of the casing.

With further movement of the piston 5, the sealing ring 11 is compressed and the teeth of the armature 10 are introduced into interaction with the casing wall. Thereby, overlapping of the annular gap between the tubing string and the casing is achieved.

After this, the under-packer zone for insulation work is prepared.

In this design, it is important to study the anchor node. In order to assess the feasibility of implementing such an anchoring technology, the authors give a technological calculation.

Technological calculation of anchoring:
- the diameter of the inner casing string, mm 148;
- diameter of the outer packer, mm 136;
- diameter of the axial channel of the barrel, mm 55;
- outer diameter of the barrel, mm 70;
- inner diameter of the body, mm 120;
- Packer setting pressure, MPa 25.

The area of the piston is determined as follows:

\[ F_п = 0,785(d_{ин.ц.}^2 - d_{ст}^2); \]
\[ F_п = 0,785(12,0^2 - 1,0^2) = 74,5 \text{ cm}^2. \]

The force developed by the piston is calculated by the following formula:

\[ q_п = F_п \cdot P; \]
\[ q_п = 74,5 \cdot 250 = 18625 \text{ kgs}. \]

At cone angle\( \alpha = 12\):

\[ Q = q_п \cdot \tan \alpha; \]
\[ Q = 18625/0,2126 = 87606 \text{ kgs}. \]
The authors take the total transverse length of the teeth equal to ½ of the perimeter, i.e. the perimeter of space is:

\[ \Pi = 2\pi R = 2 \cdot 3.14 \cdot 6.8; \]  
\[ \Pi = 2 \cdot 3.14 \cdot 6.8 = 42 \text{ cm}; \]  

(6)

Then the length of the teeth equal to 21 cm is taken.

The force of the introduction of the teeth into the wall of the casing, subject to their full interaction is determined. The tooth penetration depth \( \delta = 0.3 \text{ mm} \) is taken. The angle of inclination of the chamfer of the tooth is taken \( \beta = 45^0 \).

When solving the triangle method, where \( \delta = 0.3 \text{ mm} \) is a leg, the contact area is determined by the following formula:

\[ L_{tot} = \Pi \cdot \frac{\delta}{\sin 45^0}; \]  
\[ L_{tot} = 420 \cdot \frac{0.25}{0.7} = 150 \text{ mm}; \]  

(7)

The area of the packer, perceiving the burst pressure from below is determined:

\[ F_n = 0.785 \cdot d_{in}^2; \]  
\[ F_n = 0.785 \cdot 13.6^2 = 145 \text{ cm}^2; \]  

(8)

Taking into account the weight of the pipes of the elevator column \( Q_{tr} = 20000 \text{ kg} \) it is obtained:

\[ Q_e = F_n \cdot P - Q_p; \]  
\[ Q_e = \frac{145 \cdot 200}{56000} - 20000 = 36 000 \text{ kg}. \]  

(9)

Verification of the condition:

\[ \sigma_t = \frac{Q_e}{F_{tot}} \leq [\sigma_g]; \]  
\[ \sigma_t = \frac{36000}{15} = 2235 \text{ kg/cm}^2 \leq [\sigma_g]; \]  

(10)

Conclusion: the packer is able to withstand a greater pressure drop, since \( [\sigma_t] = 6000 \text{ kg/cm}^2 \).

The transmission of expulsive force to the teeth leads to the fact that they work on the cut. The authors believe that the cross-sectional area of the tooth is:

\[ S = 2h \tan \alpha; \]  

(11)

where \( \alpha = 45^0; h = 0.3 \text{ mm}; S = 0.6 \text{ mm}. \)

Total tooth length – \( L_{tot} = 150 \text{ mm}; \)

Sectional area of teeth perceiving \( Q_{exp}; \)

\[ S_p = S \cdot L_{tot} - 0.06 \cdot 15 = 1 \text{ cm}^2. \]

The packer is removed from the installation site when exposed to expulsive force \( (Q_e = 36,000 \text{ kg}). \)

It is necessary to provide an additional number of teeth with an increase in the depth of their introduction. For plug-type anchors, it is necessary to have the introduction of teeth to a predetermined depth with external contact with the entire area of the plugs. Such a design was implemented in the research work [8], where the anchor plugs have two protrusions distributed in height, which increases the adhesion force of the anchor to the casing.

**Effectiveness assessment of the use of packers with various sealant designs**

The usual scheme of the deformation of sealant by the action of axial force has a number of significant drawbacks. At the moment of axial compression of the sealant, it moves when the lower end is stationary. When the packer comes into contact with the casing string, a friction force appears and builds up against the displacement of the points of the sealant surface along the casing surface, which prevents the axial load from transmitting the force acting from above to the lower end face of the sealant. It leads
to an uneven distribution of contact stresses with their decrease to the lower end of the sealant. The contact stresses in the lower part are smaller in value than the pressure of the medium being sealed, and in the upper part these stresses are overestimated, exceeding the strength characteristics of the sealant material.

With such a setting-deformation of the sealant, it is necessary to take into account the friction force. Negative factors affecting the reliability of the sealant can be avoided by providing a change in the force acting on the sealant with the replacement of the action of the force in the radial direction.

In the research work [9], the sealant deformation mechanism was considered in detail by introducing an expandable cone into its axial channel of a certain configuration and diametrical size. For packers with such a mechanism of deformation of the sealant, the requirement of the ratio “length - thickness” is not imposed. This allows making the sealant thinner, which, in turn, allows getting the increase in the inner diameter of the trunk of the packer. This condition is important to reduce hydraulic resistance to the flow of the working fluid, for example, during hydraulic fracturing.

A fairly large number of technical solutions for the design of packer sealants are known, for example they are presented in the research work [10]. The device makes an attempt to increase the coefficient of uniformity of loading of the sealing element due to the concentric installation of the packer inside the axial channel of the casing. The sealant itself has a cylindrical shape with the placement of extrusion washers on its ends. The packer is set using a special hydraulic setting tool. The sealant is deformed in the radial direction by the action of the axial load from above.

There is a sealing element of the packer [11], in which the packing element is integral, and for its protection, the partitions are used between the sealing rings, which are made curly and with radial channels.

The enclosed space between the partitions and the metal shell is filled with a sealing compound. Each of the toroidal rings is enclosed in a split, closed (on the outside) with a gap (on the inside) metal shell.

The setting of the is performed by creating an axial load that exceeds the yield strength of the sheath material in its value, with the transmission of axial force to the weight of the part of the sealing element. The metal shell is deformed with compression of the sealing ring and a uniform distribution of stresses.

As a result of this distribution of force, the metal shell is tightly pressed against the wall of the casing pipe with a repetition of its geometric shape. The sealing compound is also extruded through the radial columns into the annulus. The sealing element is designed for drilled packers. The pressure drop perceived by the sealing element is low.

By the analogy with the design, a technical solution is issued, reflected in the research work [12]. This well sealant node is designed to overlap the annulus during insulation work or hydraulic fracturing. Improving the reliability of the sealant is provided by normalizing the load on each of them. Sealants in the form of rings are installed between the washers forming the trapezoidal chambers.

The washers themselves are made and installed with the possibility of protection against overloads of the sealing rings. The compression of the package of sealant rings and washers is carried out by axial loading with a packing follower that senses the pressure drop of the working medium.

The technological gap between the washers and the inner wall of the casing is within 3 <δ <5 mm. Sealing rings during compression of the washers are deformed in the radial direction with the overlap of this gap. With the perception of the pressure drop from the side of the working medium, the entire package of sealing rings will inevitably be squeezed out (starting from the lower ring), with a violation of their integrity.

It is proposed to solve the problem of leakage of the rubber sealant into the technological gap by introducing a springing element in the form of a spiral into the packer element. The spring is vulcanized to the rubber body over the entire surface of the wire at the point of transition of the cylindrical part to the conical, on the load side. The development is protected by a patent of the Russian Federation [13].

The analysis of the design of the sealing elements presented in the materials of the patent shows that in order to ensure radial deformation of the sealant it is necessary to apply a sufficiently large axial force of 120-140 kN. In this case, the rubber body can flow into the annular gap between the packer body and the casing pipe wall.
The disadvantages of all existing sealants include the following: the latter are painted on the ends even in the presence of extrusion washers. When the packer is returned to the transport position, the destruction of the rubber material at the ends may be observed. The reliability of the sealant can be improved by preventing the rubber from leaking into the sealable gap, which will prevent its destruction along the end surface during unpacking.

The analysis of the materials of the patent shows that the deformation of the sealing element occurs according to the old traditional scheme — axial loading from the weight of the pipes.

The efficiency of the packer sealing element according to the research work [13] can be improved by using another deformation method, reflected in the article [9]. Since the rigidity of the packer sealing element at the installation location of the spiral spring is higher than in another cross section, it is advisable to place the sealant so that the expanding cone interacts with it at the location of the spiral spring.

In this case, the distribution of contact stresses along the length of the sealing element will be more uniform. In the direction of ensuring the reliability of the sealing element, the design in which the end conical surfaces are made of different sizes is proposed [14].

The upper end surface is made in the form of an internal tapered bore with a landing pass, and the lower one is in the form of an external tapered surface with a taper angle that is smaller than that of the upper tapered bore. The expansion takes place by introducing the upper movable tepered stop, into the inner bore with deformation in the radial direction until it contacts the casing wall. At the same time, with a large taper angle, the sealant is loaded with an axial component, i.e. there is a combined landing method. At the same time, the condition of non-uniform pressing of the sealant remains along its height.

To conclude with it is necessary to note that the main sources of environmental pollution in oil fields are production and injection wells, especially during their repair [15]. The correct selection and operation of packers will minimize environmental risks.

4. Conclusion
1. The analysis of the applied designs of the anchor nodes of the packers showed that the main type of fixation is the design in the form of plugs, expandable in the radial direction when the expandable cones are introduced into interaction with them.
2. The usual scheme of the deformation of the sealant by the action of axial force has a number of significant drawbacks. Negative factors affecting the reliability of the sealant can be avoided by providing a change in the force acting on the sealant with the replacment of the force action in the radial direction.

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