ANÁLISE DAS RAZÕES DA PRESSÃO ENTRE COLUNAS COM O EXEMPLO DE CAMPO DE ZHANAZHOL**INTERCASING PRESSURE CAUSES ANALYSIS ON THE EXAMPLE OF ZHANAZHOL FIELD****АНАЛИЗ ПРИЧИН МЕЖКОЛОННЫХ ДАВЛЕНИЙ НА ПРИМЕРЕ МЕСТОРОЖДЕНИЯ ЖАНАЖОЛ**

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RESUMO

As pressões entre colunas nos poços de gás e petróleo operacionais são um dos problemas mais significativos, pois perturbam o equilíbrio ecológico dos territórios do campo, levam à perda de fluido de formação e representam um perigo para o pessoal. Apesar da melhoria contínua da tecnologia de construção de poços em muitos campos de petróleo e gás, os fluxos entre colunas e manifestações de fluidos na boca ainda são um tipo comum de complicação. Infelizmente, a maioria dos métodos para a eliminação das pressões entre colunas envolve a injeção de compostos selantes no espaço entre colunas a partir da boca, que é um método extremamente ineficaz, pois fecha os sinais visíveis, mas não exclui suas causas. Portanto, o estudo das causas da pressão terá um significado acadêmico e prático, uma vez que a maneira mais eficaz não é eliminar, mas impedir as pressões entre colunas durante a construção e completação do poço. Neste artigo, a ocorrência de pressão no reservatório é considerada no exemplo dos poços do campo de Zhanazhol. Foi realizado um estudo de 40 poços na região. Para determinar o grau de influência de fatores geológicos, técnicos, tecnológicos, físico-químicos e mecânicos na ocorrência das pressões entre colunas, foram utilizados os procedimentos de análise estatística e de correlação, análise da composição do fluido intermediário e análise de material de campo. Com base nos resultados disponíveis, foram apresentados os métodos e técnicas possíveis da ocorrência das pressões entre colunas, bem como os princípios que poderiam ser usados para evitar a pressão durante a construção e operação do poço.

Palavras-chave: *espaço anular, pressão anular, equilíbrio ecológico, fluidos de reservatório, curvas de recuperação de pressão.*

ABSTRACT

In the operational reserve of gas and oil wells, formation pressure (ICP) is one of the most significant problems, since it violates the ecological balance of the field areas, leads to the loss of formation fluid and is dangerous for personnel. Despite the continuous improvement of well construction technology at many oil and gas fields, adjacent flows and fluid effects at the wellhead are still a common type of complication. Unfortunately, the majority of methods for the ICP elimination involves the injection of sealing compounds into the inter casing from the wellhead, which is an extremely inefficient technique, since it covers visible signs, but does not exclude their causes. Therefore, the study of the causes of pressure will have both academic and practical significance, since the most effective way is not to eliminate, but to prevent PMS during the construction and completion of the well. In this paper, the occurrence of pressure in the reservoir by the example of wells of the Zhanazholsky field was considered. The research of 40 wells in a given region was conducted. To determine the degree of influence of geological, technical, technological, physicochemical and mechanical factors on the occurrence of ICP,

statistical and correlation analysis procedures, an analysis of the composition of the intermediate fluid, and analysis of field material were used. Based on the available results, possible methods and ways for the ICP occurrence were shown, and also principles were formulated that could be used to prevent pressure during construction of wells and further exploitation.

Keywords: *annular pressure, annular space, ecological equilibrium, formation fluids, pressure recovery curves.*

АННОТАЦИЯ

Межколонные давления (МКД) в эксплуатационном фонде газовых и нефтяных скважин являются одной из наиболее значимых проблем, поскольку нарушают экологическое равновесие территорий месторождений, приводят к потере пластового флюида и представляют опасность для персонала. Несмотря на постоянное совершенствование технологии строительства скважин на многих нефтяных и газовых месторождениях, межколонные перетоки и флюидопроявления на устье все ещё остаются распространённым видом осложнений. К сожалению, большинство методов ликвидации МКД предполагает закачку герметизирующих составов в межколонное пространство с устья, что является крайне неэффективным приёмом, поскольку закрывает видимые признаки, но не исключает их причины. Поэтому изучение причин давления будет иметь как академическое, так и практическое значение, поскольку наиболее эффективным способом является не устранение, а предотвращение МКД во время строительства и заканчивания скважины. В данной работе рассмотрено возникновение МКД на примере скважин месторождения Жанажол. Было проведено исследование 40 скважин в данном регионе. Для определения степени влияния геологических, технических, технологических, физико-химических и механических факторов на возникновение МКД использовались процедуры статистического и корреляционного анализа, анализ состава межколонного флюида и анализ полевого материала. На основе имеющихся результатов были показаны возможные источники и пути возникновения МКД, а также сформулированы принципы, которые можно было бы использовать для ликвидации и предотвращения МКД во время строительства скважин и их дальнейшей эксплуатации.

Ключевые слова: *межколонное давление (МКД), межколонное пространство, экологическое равновесие, флюидопроявления, кривые восстановления давления.*

1. INTRODUCTION:

The complication of inter casing pressure treatment is due to the variety of their causes and the multitude of migration routes of formation fluids from the reservoir to the wellhead. Among the causes of annular pressure are the productive formation operation mode, temperature fluctuations in the well during operation, external pressures of plastic clay rocks, or salts (Gao *et al.*, 2013). In this case, the leakage of the casing head packer, the leakage of the cement ring, or casing string should be distinguished as the paths of fluids movement that create the ICP.

Unfortunately, the majority of methods for the ICP elimination involves the injection of sealing compounds into the inter casing from the wellhead, which is an extremely inefficient technique, since it covers visible signs, but does not exclude their causes. In this regard, the most effective way is not the elimination, but the ICP prevention during the construction and completion of the well.

The analysis of field data for the main gas producing regions shows that the number of wells, especially gas wells, in which inter casing pressure occurs, is vast (Govier and Fogarasi, 1975; Curtis, 2002). As the duration of field development

increases, the number of such wells, generally, increases. The most significant percentage of wells with inter casing pressure is typical for underground gas storage facilities. Moreover, the time of occurrence (detection) of ICP can be from several hours to several months.

Despite the continuous improvement of well construction technology in many oil and gas fields, inter casing flows, and fluid exposure at the wellhead still remain a common type of complication (Peffer *et al.*, 1988). Since the causes of inter casing pressure (ICP) may be common, let us consider them for further details.

The authors of (Mavlyutov *et al.*, 1984; Bulatov *et al.*, 1969; Bulatov, 2017; Mamadzhano and Halfin, 1963; Malevanskiy, 1963; Davies *et al.*, 2014; Glover, 2009; Adams and MacEachran, 1994; Dong and Chen, 2017; Mwang'Ande *et al.*, 2019; Baynham *et al.*, 2003) works subdivide the ICP into two groups. The first group includes inter casing shows caused by the direct flow of fluid (gas, oil) from the production horizons through the cement ring (Brown *et al.*, 2016), the gaps between the cement ring and wellbore, between the cement stone and casing strings. The second one is fluid shows arising due to the leakage or depressurization of casing strings in the process

of well operation. The authors of (Bulatov *et al.*, 1969; Bulatov, 2017; Mamadzhanov and Halfin, 1963; Malevanskiy, 1963; Liu *et al.*, 2014; Brownlow *et al.*, 2017; Lackey and Rajaram, 2019; Pattillo *et al.*, 2004; Narozhnyy and Ilyenko, 2017) consider the channels in the contact zone as the main paths of gas shows through the annular space, which arise when the quality of cementing of the column is low and the presence of thick mudcake, as well as channels in the cement stone, formed as a result of water separation.

According to the researchers (Bulatov, 1990; Chernenko and Kuksov, 1972; Rakhimbayev, 1976; Bulatov, 1971; Levain *et al.*, 1980), immediately after punching the cement slurry into the annular space, suspended solid cement particles begin to sediment, and the free mixing fluid displaced from the cementing system forms filtration streams in the pore space. The system forms a series of areas with increased porosity connected by channels of different diameters, lengths, and configurations. At the same time, cement stone is in the process of hydration due to contraction (Raikhel and Konrad, 1979) sweeps away water from the mudcake to form a network of canals in a dried crust.

According to (Bulatov, 2008; Vidovskiy and Bulatov, 1977; Halal and Mitchell, 1993), the appearance of pressure at the wellhead may be associated with a decrease in the "active" pressure column of the cement slurry on the wellbore walls during its hardening, as well as filtration of excess mixing water into the formation. Researchers (Agzamov *et al.*, 2011) associate one of the main reasons for the failure of lining wells with contraction. When hardening in a closed volume, such as the inter casing of wells or the space close to dense and impermeable rocks, contraction can lead to a vacuum inside the hardening stone, shrinking deformations in it, leakage of the contact zones or an increase in the permeability of the cement stone.

The reasons for the inter casing showings, according to (Krylov *et al.*, 1981; Mamedov, 1990; Fattakhov, 1991), can be various technological operations carried out in the well: pressure integrity testing and perforation of casing strings, drilling out a cement column, deepening the wellbore, etc.

Thus, the analysis of scientific and technical literature (Țicleanu *et al.*, 2014; Bamberger and Oswald, 2012; Howarth *et al.*, 2011; Lu *et al.*, 2016; Cocuzza *et al.*, 2012; Tariq *et al.*, 2019; Bellarby *et al.*, 2013) allows to identify the main factors that are considered the most

reasonable in explaining the reasons for the inter casing showings:

1) Technological factors due to the penetration of fluid into the cement slurry as a result of a decrease in operating pressure on the formation, formation of channels between the cement ring and the string while reducing the pressure in it wait-on-cement time (WOC time), a low degree of drilling fluid displacement from the inter casing.

2) Physical and chemical factors caused by changes in the micro- and macrostructure of the cement slurry during its hardening, especially in contact with the "pinched" drilling mud or mudcake under conditions of high temperatures and pressures.

3) Technical factors associated with the formation of a channel between the cement ring and casing strings due to their deformation during pressure integrity testing of the casing and other technological operations.

Therefore, the study aimed to consider in detail the causes of inter casing pressure and develop recommendations for preventive measures to eliminate them.

2. MATERIALS AND METHODS:

To identify the degree of influence of geological, technical, technological, physicochemical and mechanical factors on the occurrence of ICP, the research was conducted in which statistical analysis procedures were applied using the STATGRAPHICS application software package (Leach and Adams, 1993).

The analysis was subjected to 40 wells, in which the inter casing pressure was recorded and were divided into groups depending on the degree of pressure of the P-shaped casing. Among them: 19 wells with Pinter casing ≤ 10.0 MPa, 11 wells with Pinter casing ≤ 20.0 MPa.

At the first stage from the whole well fund the more detailed actual material was collected on wells, in which the ICP value exceeds 2.0 MPa. The primary analysis was carried out on the array, which includes all the wells of the production fund with the value of ICP higher than 2.0 MPa.

To assess the degree of influence of various factors on the value of the inter casing pressure, elasticity coefficients were calculated, which showed that for the analyzed data set, the following factors had the most significant influence on the value of the inter casing pressure:

- power of the strong brine exposure

complex;

- the depth of the descent of the intermediate string;
- the depth of descent of the production string;
- density of the washing liquid;
- the volume of cement slurry.

Particular attention in the analysis was paid to the types of casing heads (CG) installed in the wells. In this case, it was taken into account that in fields with ICP, due to the leakage of CG, the value of ICP should be equal to the intercasing pressure (Ma, 2006).

When processing an array of data, a correlation analysis procedure was applied, which made it possible to conclude the degree of statistical relationship between factors using a sample. Since to assess the statistical significance of many factors, a larger amount of initial data is necessary to evaluate the effect on the ICP values by various groups of factors (geological, technological, properties of drilling fluids, properties of cement slurry and cementing technology).

Initial data and a list of analyzed factors are given in Table 1. The analyzed data included:

- dependent factors (performance indicators), namely – the value of the ICP (numerical variable, MPa);
- independent factors affecting performance indicators, including geological, technical and technological, physical and chemical, mechanical, etc. (42 factors in total), the degree of influence of which on the occurrence of ICP could be assessed by statistical methods.

3. RESULTS AND DISCUSSION:

According to the geological information (Passey *et al.*, 2010), there are no other reservoirs in the crosssection that contain oil or gas (except for the productive formation) and that are capable of becoming a source of ICP (Guseynov *et al.*, 2005). Therefore, the number one source is the productive formation. Another source of ICP can also be a strong brine exposure horizon occurring in the interval of salts.

The source of the ICP can also be a liquid located outside the production string and pushed out during the flow of the salt mass and plastic clays that are in the Kunguri interval. Fluid outside the production string can create ICP also due to thermal expansion as a result of warm formation fluid lifting into the cooled upper part of the well. Analysis of the composition of the intercasing fluid

will help to clarify these assumptions (Oudeman and Kerem, 2004; Bloys *et al.*, 2007; Azzola *et al.*, 2004).

Wellhead equipment leakage is one of the most likely causes. This is testified by the large amount of bibliographic and field data obtained at other fields, as well as some experience of the Zhanazhol field, when, after repairing the well and replacing the sealing elements of the casing head ICP decreased or disappeared. At the same time, the experience of other fields shows that for a given reason for the occurrence of ICP, its value is usually equal to the annular pressure. Analysis of field material showed that these values are not equal, i.e. this factor can be excluded as the cause of ICP.

Leakage of the production string is not excluded, although it seems unlikely, since pipes that are used for casing are of increased tightness of threaded connections, recommended for gas wells. Leakage of the cement ring, considered as the main cause of ICP. It is also necessary to take into account the impact of variable loads on the lining of the well in the form of pressure integrity test, perforation, development, flow stimulation, installation of underground equipment. As a rule, these technological operations are accompanied by loads correlated even with the strength of the column and the matrix of cement stone, although the zone of adhesion of the cement ring with casing metal is the most vulnerable point in the intercasing isolation.

The composition of the intercasing fluid. These can be gas, oil, hydrocarbon liquid, strong brine, liquid used for mixing cement slurry, pore liquid of cement stone, circulation liquid or its filtrate, brine water from the overlying horizons, etc. The probe (in except of the gas) should be collected during the periodical ICP discharge and be transmitted for analysis. The composition of the annular fluid will help to determine the most likely source of ICP and the path of fluid inflow. The volume of fluid leaked from the intercasing space is necessary for evaluating the reservoir characteristics of the ICP source. The recovery rate of ICP will determine the source of the ICP and the path of fluid flow.

The presence or absence of ICP for the intermediate string. This information is very important for assessing the tightness of the lining of the well (the cement ring and its contact zones), since there is a high probability of destruction of the cement ring behind the intermediate string and the conductor when drilling with the rotor under the following columns.

Simultaneous control of the annular pressure when measuring the pressure in the inter casing. Date of the first detection of ICP in wells will allow you to specify the source of the ICP. To detect the causes of ICP it is proposed to use the following Table 1. Identification of the ICP source and the fluid-conducting channel with the greatest probability is more possible only with a comprehensive assessment of all the information characterizing this type of complication.

1. In case of leakage of wellhead equipment, it should be oil or gas entering the inter casing from the annular space. If the pressure in the inter casing is higher than the saturation pressure, then the more likely fluid will be oil. ICP discharge time should be short for a few minutes only. The pressure recovery time makes up several hours due to the small length of the channel, so that the ICP is comparable to the annular pressure.

2. In case of leakage of the production string, the outgoing fluid may be oil or gas if the cement slurry height raises up to the wellhead. The fluid may be mud, located above the cement stone if the height of the cement slurry does not reach the wellhead. Depending on the location of the leak, there will be different rates of pressure build-up. If the leakage occurs in the non-cemented zone, the pressure build-up rate is fast enough. If the leakage occurs in the cemented zone, the rate of pressure build-up will slow due to fluid filtration in the cemented zone. Moreover, the higher the quality of cementing and the height of the cement rise, the longer the pressure is restored. With the passage of oil through the leakage of the cement ring there may change the composition of oil and gas in the direction of reducing the content of hydrogen sulfide, which is partially neutralized by the hardening products of cement.

3. In the case of a cement ring leakage, the composition of the formation fluid depends on the assignment of the well. In the case of injection wells, water is more likely, the one that is similar in composition to the injected water, as well as a mixture of oil and water, a mixture of water and mud that remains above the cement grout. The value of the ICP should be correlated with the injection pressure. Depending on the flushing of the channel, the pressure build-up rate can reach from several hours to several days. In these wells it is necessary to pay attention to the sealing of the annular space, because the efficiency of reservoir pressure maintenance is sharply reduced, since there is a high probability that water to be pumped into other layers.

In production wells, the most likely fluid from the inter casing will be oil, gas and mud. Oil and gas may not contain hydrogen sulfide. The pressure value maintained lower than the annular may correlate with the reservoir pressure in the productive horizon.

If, due to the leakage of the cement ring, the strong brine exposure horizon shows, the composition of the fluid from the inter casing should coincide with the composition of the strong brine, and the pressure should correlate with the pressure of the strong brine exposure horizon. In case of the cement ring leakage, the pressure growth rate in all cases is slowed down due to the filtration of fluids in the cement stone. To carry out preventive maintenance of the ICP sources and fluid penetration paths, samples were taken and analyzed from the annular space of the wells.

Based on the available results, possible methods and ways for the ICP occurrence were shown, in particular:

- leakage of the casing head may occur in 3 wells;
- leakage of the cement ring may occur in 13 wells;
- casing string leakage may occur in 2 wells.

Since the main cause of the inter casing pressure is the leakage of the cement ring, then it is worth paying particular attention to it. First, it is necessary to establish the height of the cement ring behind the production string. Next, it is necessary to evaluate the injectivity of the inter casing by the injection of fluid (water or oil) and evaluate the possibility of pumping the sealing compound into the inter casing.

With a small height of the cement ring, the recommended method for the elimination of ICP consists in that the fluid located there is pumped out from the inter casing of the well. After that, the gelling sealant is pumped into inter casing. In this case, the injected suspension should be of low structural strength. With a small volume of annular space and a certain injectivity, it is possible to pump the sealing compound into the inter casing from the wellhead. The last way to eliminate the ICP may be the injection of a sealant into the inter casing above the productive formation through unique holes in the casing string.

Since the elimination of the leakage of the cement ring is a very complicated and expensive procedure, it is necessary to find out the possibility of the operation of wells with ICP under tight control of the fluid composition, pressure values, dynamics of their changes. It is necessary to

determine the maximum possible pressure value to prevent the intermediate tubing burst. Taking into account the method of drilling and work carried out inside the casing string, it is necessary to predict the growth of the number of wells with ICP for this reason.

Therefore, it is necessary to improve the technology of cementing of wells under construction. This may be the application of cementing technology with a movable packer (Agzamov *et al.*, 1989), the use of self-healing cements (Ismagilova *et al.*, 2017), the use of carbon swellable packers placed on the casing string above the dangerous horizon.

In general, the fact of the ICP presence in the well does not in pose itself a danger or a threat if there is no uncontrolled showing of hydrogen sulfide-containing fluid at the wellhead or around it.

For certain specific measures for each well with ICP, it is important to assess the causes of the occurrence of ICP and its value as a percentage to the ultimate pressure (UP) relative to the previous column. The following system can be used:

- Category 1: wells in which the measured inter casing pressure is 100% or higher of UP.
- Category 2: wells in which the measured inter casing pressure ranges from 50 to 100% of the UP.
- Category 3: wells in which the measured inter casing pressure is from 25 to 50% of the UP.
- Category 4: all other wells with ICP.

The following principles can be used to make decisions in this regard:

- Category 1: perform a control release and/or well killing, perform workover the well or well abandonment, and carry out a control release of the ICP, if it is necessary to ensure the safe conduct of work. Perform daily monitoring.
- Category 2: if the annular pressure communicates with the productive formation and it exceeds 50% of the UP, then to include the well in the well killing schedule. To release ICP if it necessary to ensure the safe conduct of work. Perform daily monitoring.
- Category 3: in case of ICP occurs due to the formation, and it raises up to 50% of the UP, it is necessary to continue to conduct weekly monitoring and to release the ICP, if it is necessary to ensure the safe conduct of work.
- Category 4: Perform weekly monitoring.

4. CONCLUSIONS:

1. The occurrence of ICP in gas and oil wells is one of the most common and significant complications in the development of fields that require correct solutions for the reason of affecting the environment, production and safety of personnel.

2. Technological, physical, chemical and technical factors influence the appearance of the ICP in the wellbore.

3. To solve the ICP problem, firstly it is necessary to carry out diagnostics, which makes it possible to identify the causes of the occurrence of the ICP, its source, paths of the fluids and to take appropriate decisions.

4. The main causes of ICP are leaks in the cement ring, leaks in the production string, leaks in the wellhead equipment, and each of these causes corresponds to a certain type of fluid.

5. Four categories of wells can be distinguished depending on the value of the ICP, and each category corresponds to recommendations for making decisions on the further operation of the wells.

6. Most technologies for the elimination of ICP involve the injection of sealants from the wellhead, which only eliminates the visible signs of the ICP occurrence, but does not eliminate its source. Therefore, the most effective is not the elimination of the ICP but the prevention of its occurrence during the construction of wells and their further operation.

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Table 1. Diagnostic table of intercasing pressure

No.	ICP source	ICP cause	ICP characteristics			
			Fluid type for ICP	$P_{\text{annular}}/P_{\text{intercasing}}$ rate	Release time	The recovery rate of the P_{IC} to the original value
1	Production well. Productive formation	Cement ring leakage	Oil Gas, circulation fluid when cement slurry does not reach the wellhead	$P_{\text{annular}} \geq P_{\text{intercasing}}$	1–20 min	Slowly up to several days or weeks
2	Injection well. Productive formation	Cement ring leakage	Pumped water Water + oil Water + mud	$P_{\text{annular}} \geq P_{\text{intercasing}}$	1–20 min	Slowly up to several days or weeks
3	Strong brine exposure interval	Cement ring leakage	Brine water, Brine water + mud	$P_{\text{annular}} \neq P_{\text{intercasing}}$ $P_{\text{intercasing}} = P_{\text{formation}} - \rho g h$	1–10 min	Slowly up to several days
4	Casing head	Casing head packer leakage	Oil, gas	$P_{\text{annular}} \approx P_{\text{intercasing}}$	5–10 min	Fast for a few hours
5	Production interval	Casing string leakage	Oil, Gas, Mud	$P_{\text{annular}} \geq P_{\text{intercasing}}$	1–10 min	Slowly up to several days if the leak is below the cement level
6	Clay solution in intercasing	Temperature fluctuations	Mud	$P_{\text{annular}} \neq P_{\text{intercasing}}$	1–10 min, decreases when the well is stopped	Increases at bringing well into production