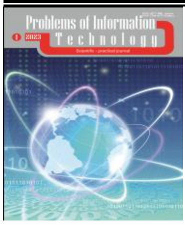

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Method for operational forecasting of high-pressure zones in oil and gas wells

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ABSTRACT

The article analyzes methods and technologies for estimating anomalous reservoir pressure and predicting anomalous zones when drilling oil and gas wells. Methods for forecasting abnormal reservoir pressure, as well as signs (factors) used for these purposes are systematized and classified. The advantages of the developed methods are substantiated based on the dependence between the technical parameters of drilling. It is shown that the systems created on the basis of these methods make it possible to carry out the forecasting process without stopping drilling and in real time. The state of application of these systems in the drilling operations of SOCAR is investigated. A method included in this forecasting group is proposed. For the design of a working system based on the proposed method, the principle of forecasting, the algorithm of work and the conceptual architectural model are given. Information is given about experiments carried out by computer simulation to test the principle of the system.

1. Introduction

The oil and gas industry in the national economy of the Republic of Azerbaijan is the leading sector and depends significantly on the state of the country's macroeconomic indicators. As in other fields, increasing the work efficiency in this field is one of the urgent issues and subject to primarily on the efficiency of well drilling, construction and operation processes. Obviously, a number of accidents and complications (AC) due to abnormally reservoir pressure - ARP (in particular, abnormally high reservoir pressure - AHRP and abnormally low reservoir pressure - AHLP) in the process of oil exploration and drilling of production wells occur: closed and open fluid fountains, griffons, fires, lost circulation collapse of well walls, shedding of wells, drill string grab, etc. Starting from the first oil well fountain in the world (Bibi-Heybat, July 14, 1848), various AC have occurred in most of the wells drilled and operated so far. To date, many theories and hypotheses about the mechanisms of the formation of ARP are available, though none of them comprehensively explains the issue. Although the design of wells is based on the results obtained in the exploration process, geological-technological and mining data of operational wells at close distances, in many cases the lithological sections, various pressures and other indicators indicated in the project significantly differ from real drilling indicators. Although all these data provide certain prognostic-informative information about high reservoir pressure, subjectivity (human factor) plays an important role as their interpretation is based on the skills and practical experience of the drilling crew. Therefore, various accidents and complications are probable to occur in any drilling site due to the abovementioned reasons (Agayev B.S., et al., 2018). Eliminating these situations can lead to a large amount of additional financial costs, loss of time and human resources, environmental pollution, and even human casualties. Specifically heavy AC does not allow wells to be drilled to the design depth, resulting in their cancellation (conservation). Therefore, taking into account the results of explorations, geological-geophysical, geological-technological studies, timely detection and forecasting of ARP zones in the process of well drilling and exploitation, geological-geophysical, geological-technological research, correct compliance with the requirements of project documents, along with timely detection and prediction of ALT zones are one of the main ways to increase work efficiency to prevent AC. In this regard, the world's leading oil companies use forecasting technologies and systems with different purposes and functional capabilities. Over time, the need to increase the design depths of wells for the extraction of hydrocarbons makes the application of these systems even more urgent.

Research conducted in SOCAR's oil and gas fields showed that in the process of drilling wells, operative mode technical tools created by using the dependence between the technical parameters of the drilling process are not used to predict the AHRP zones. However, many advanced foreign companies operating in Azerbaijan widely use these systems. Undoubtedly, the use of this technique enables the necessary preventive measures to be taken to prevent AC in many cases. This article examines the method for proposed predicting AHRP zones based on the technical parameters of the drilling process.

2. Some problems of oil and gas well drilling process

Currently, oil and gas extraction (oil work) from wells of a depth of 400-500 m around the world is almost finished: in most countries, as well as in Azerbaijan, drilling works are mainly implemented in layers deeper than 5000 meters. The efficiency of oil work in these depths depends primarily on the modern achievements of geology-geophysics science, the use of modern techniques and technologies, as well as the correct comprehension of the formation mechanisms of ARP in mountain rocks and the taking of necessary preventive measures to avoid AC. The formation of ARP zones is closely related to factors as the thicknesses of layers and horizons, lithology, mineralogical composition, reservoir characteristics, etc. in the sections of mountain rocks. Each region has its own mechanism of formation of ARP zones. Therefore, the drilling of systematic intellectual wells, which respond promptly to changes in project parameters and collect information online, is considered an urgent and important issue. AC in the drilling process mainly occurs due to improper adherence to project documents, failure of drilling equipment, unprofessionalism and negligence of the drilling crew (human factor), ignoring the data of the used management and control systems, including ARP.

Currently, there are different approaches to the systematization and classification of AC cases. This article refers AC to the followings:

- accidents associated with drill and casing strings (or their elements) ;
- drilling and casing protective belts obstruction;
- accidents related to the drilling tool (chisel) or its elements;
- poor quality cementing;
- external objects falling into the well, etc.

Complications (CO) refers to the cases complicating or making impossible the well dredging as a result of a violation of the drilling process. Common and dangerous CO cases due to ARP or abnormal pore pressure (APP) include (Vadetskij Ju.B., 2013):

- fludo developments;
- violation of the integrity of the well walls;
- lost circulation;
- collapse and shedding of well walls, etc.

As a result of serious AC, disruption of the normal drilling process, failure of well equipment, fire, human casualties, environmental pollution may occur. As an example, we can mention two CO cases occurred due to ARP in SOCAR's drilling practice.

A strong open gas fountain occurred during the drilling of gas well No. 90 of the Bulla-Deniz deposit (VIII horizon, project depth 5800 m, Girmeki Sandy Bunch), (August 13, 2013). Gas development was detected at the depth of 5553 m., an explosion and fire occurred: the wellhead equipment was destroyed and the tower collapsed. Despite all the efforts of local experts, the fire lasted for 68 days. On October 25, with the help of foreign experts, the fire was extinguished and the wellhead equipment was restored. Thus, the fountain was stopped, and as a result of a number of technological measures, the drilling was brought to the project depth. Fontan caused a huge amount of product loss: according to data, the average daily gas-condensate loss of 4.8 million m^3, 704 tons of oil loss, serious environmental pollution and other damaging circumstances. Further analyzes showed that the fountain occurred as a result of the fact that the real reservoir pressure during drilling was higher than the design parameters, in other words, the well pressure exceeded the permissible limit of the mud hydrostatic pressure.

Failure to detect signs of entering the AHRP zone (increase in mechanical drilling speed, volume and degree of mud gasification, decrease in density, etc.) is associated with the human factor. After the restoration works, the drilling was continued and reached the project depth. After 7 months of operation (up to 07.05-2014), the well was canceled because of the high-risk removal of strong obstruction. Some sources state that 7 months of production has covered all the financial expenses in excess.

Remarkably, as a result of the next serious accident, in the new vertical exploitation well drilled nearby as an alternative to the canceled well No. 90 (Bulla-Deniz deposit, Stationary Marine Base (SMB) No. 122- well No. 124) the incorrect estimation of the real reservoir pressure caused another complication, i.e., the mud loss. Consequently, at the depth of 5280 m of the well (VIII horizon), strong mud loss occurred as the real reservoir pressure gradient was lower than the design value (1.15 MPa/m) (case of ALRP). Most likely, slowing down the decrease of the design value (2.1-2.15 g/cm^3) of the drilling mud density to 1.72-1.65 g/cm^3 (human factor) also played an important role. As a result of the necessary technological measures (washing, fludo bath, etc.), the normal drilling mode was restored and the well was brought to the design depth (6000 m).

Another open fountain took place on 02.05.2014 in the drilling well No. 341 in the DSB No. 10 (deep sea bed) of the "May 28", Oil and Gas Production Department (OGPD). Within a day, the fountain was handled and handed over to the drillers. Fontan caused a lot of damage to the Complex Drilling Company (Bakirov Sh. Kh., 2010).

In many cases, the well is canceled (conversion) as it is impossible to eliminate the CO caused by ARP. In general, according to the conducted statistics, during the years 2000-2010, 54 wells were canceled as a result of accidents occurring in wells in the sea area in Azerbaijan alone, and more than 88,300 hours were spent on their elimination (Dadashov I.H. & Abyshov C.H., 2012). Obviously, AC could be prevented through reliable forecasting.

3. Modern AHRP forecasting methods and signs (factors)

Research conducted by both Azerbaijani and foreign scientists proves that during the drilling of wells in all oil and gas regions of the Earth, anomalous high-pressure zones may arise in the layers of mountain rocks. The study of the geological conditions during the drilling of wells in the Baku archipelago and the South Caspian depression shows that one of the main reasons for the occurrence of the AC is the presence of AHRP or AHPP in the intersection (Parisa E.Z., 2016, Mammadov A.A., et al., 2021).

AHRP prediction methods differ mainly according to the detection signs (factors) used. In general, in all types of wells (exploratory, assessment, measurement-control, monitoring, exploitation and other special wells), AHRP forecasting methods are divided into three groups according to the time of obtaining the necessary data (Iskandarov M.M., et al., 2021, Korotayev B.A., et al., Kerimov K.M., et al., 2000):

- before starting the drilling of wells (in the process of exploration);
- in the course of drilling wells. In turn, these methods are divided into two parts: methods that allow evaluation of wellbore dredging with and without stops;
- after the completion of drilling process. These methods are also divided into two subgroups: before and after lowering the drill column (until the well is put into operation).

According to the goals of this article, only the results of researches related to the second group of methods will be considered here.

Most of the methods used to estimate pressure anomalies, as well as predict anomalous pressure zones, are based on the use of geophysical well logging (GWL) data. In this regard, first of all, one or more geophysical parameters reflecting the change of porosity of clayey rocks with depth along the section opened by the well are determined. Based on the GWL data, clayey layers are selected for all sections opened by the well, and the values of the parameters selected for these layers are determined. According to these values, mutual variation curves of various parameters are constructed (mainly distribution characteristics by depth) and the obtained graphs are interpreted for decision-making purposes. Achieving the mentioned results requires conducting various logging operations, which are costly and time-consuming and require stopping the drilling process.

The monitoring of the methods practiced at SOCAR reveals that for the detection of AHRP zones, logging methods are used mainly through stopping drilling (with a delay). In other words, the methods predicted according to the mechanical parameters of drilling are **not used (1). However**, in the drilling practice of many developed countries, real-time forecasting methods are widely used without stopping drilling. In order to create forecasting systems for all three mentioned groups, first of all, the signs (factors) ensuring forecasting should be determined. Each of these systems is based on the identification of a basic and one or more additional signs taken from a set of signs. The followings are attributed to these signs (Madatov A.Q. & Sereda A-V.I, 2000).

Torque of drilling tool - TDT (real-time method without stopping drilling). AHRP detection is based on the principle that since the not fully compacted (porous) layers are more plastic, as a result of the narrowing of the well diameter, the rotation speed of the DT decreases, and the torque increases sharply. But since TDT is affected by many other factors, it can be used as an additional method to confirm the detection of AHRP zones.

Hook load increase (real-time method without stopping drilling). In the case of "pistoning" effect caused by filling the wellbore with the porous layer clays as a result of the AHRP and the raising of the drilling pipes, the load on the hook is much higher than the weight of the column. However, the possibility of the load increase due to other reasons (wellbore bending, etc.) should also be taken into account.

Pressure at the outlet line of the drilling mud pump (delay mode method without stopping drilling). During the opening of the layer ceiling with AHRP, a sharp change in pressure caused by the pump creates a difference between the density of the mud injected into the well and the density and pressure of the mud rising from the surrounding space to the ground surface. This occurs as a result of the disturbance of the state of balance between the hydrostatic and reservoir pressures. This condition can be used as a factor for the detection of AHRP.

Increase of gas content in AC, change of AC density, AC level in receiving reservoir (delay mode method without stopping drilling). Each of these are considered simple and important signs used to detect HRP. As a result of high reservoir pressure (in the case of -ΔP), the gas content of the reservoirs or downhole fluid mixes (leaks) into the AC and reduces its density (increases its volume). As a result, the level of AC in the intake reservoir also increases. These signs can also occur during the drilling pipe logging and raising and lowering operations (while the pump is not running). Therefore, it is important to determine the causes of these signs.

AC temperature in discharge line (delay mode method without stopping drilling). During the opening of porous layers with DT HRP, the geothermal gradient increases and the AC keeps its temperature fairly stable. Consequently, the AC cools down less until it reaches the wellhead, that is, its temperature is higher. However, when the AC passes through sandy layers with high thermal conductivity, its geothermal gradient decreases, although these layers may not have high reservoir pressure. Since the lithological composition of the layers is known with sufficient accuracy from the beginning, it is not difficult to differentiate these factors.

It is technologically and economically more appropriate to use mechanical drilling parameters to estimate HRP and predict these zones in the drilling process. Since these methods do not require stopping the drilling process while allowing to obtain forecast data in real time.

Obtaining basic data (measures) needed for forecasting from equipment located outside the well is also considered an advantage of these methods (Biletskiy M.T., et al., 2019). One of the most important methods included in this group is based on the use of mechanical drilling speed (MDS) parameters as a detection factor. This method has long been the main method used to predict AHRP and is still widely used to both predict and estimate high reservoir pressure.

Obviously, under other conditions, as the depth of the well increases, the compaction degree of the layers increases, and the porosity decreases: this dependence is recognized as a "normal line seal" (curve). The fluid layer in rocks with fluid saturated pores is compressed under the weight of the upper layers, creating high pressure. As the porosity increases, the value of MDS sharply tends to increase from the "normal line seal". In other words, MDS can be viewed as a function of the of reservoir rocks compaction degree. This dependence makes it possible to detect AHRP zones (Zaitsev V.I. & Karpikov A.V., 2022, Orekhov A.N. & Amani M.M., 2020). However, this correlation depends on a number of other randomly varying parameters, and in cases when their values remain fairly constant, MDS can be used as an unambiguous detection factor. The main factors influencing the MDS are as follows (Zilberman V.I., et al., 2016).

- lithological composition of rocks;
- formation compaction degree;
- differential pressure;
- Load on DT, rotational speed and its hydraulic characteristics, etc.

4. On a proposed improved d-exponent method

Since the middle of the last century, it has been known that the MDS depends on the mechanical parameters of the drilling process, as well as on the drilling characteristics of the rocks. This dependence is generally expressed as follows.

$$V_{mex} = nf_1(P_y / D_{qa})\cdot f_2(V_{fs})\cdot f_3(T_{qa})\cdot f_4(\Delta_p) \qquad (1)$$

where, n is a coefficient representing the drilling characteristics of rocks; f_1 (P_y/D) – a function characterizing the effect of drilling tool load and drilling tool diameter; f_2 (V_{fs}) – a function characterizing the effect of drilling tool rotation speed; f_3 (T_{qa}) – a function taking into account the drilling tool boring; f_4 (Δ_p) - a function taking into account the differential pressure.

At the early 60s of the previous century, Bingham proposed the following formula representing the relationship between the drilling speed and the drilling tool load and the drilling tool diameter (Bingham M.G., 1964).

$$V_{mex} = a\ (V_{fs} / D)^d$$

where, V_{mex} denotes ft/min; V_{fs} – cycle/min; D – inches; a – lithological coefficient; d - rock density exponent.

In 1966, Jordan and Shirley solved this expression according to the d-exponent and adapted it to the units used in the US oil industry. Correspondingly, under the condition of unchanged lithological parameters, (a=1) received the following formula (d-exponent formula, d-eks) (Jordan I.R. & Shirley O.I., 1966).

$$d \approx \frac{\lg(\frac{V_{mex}}{18V_{fs}})}{\lg(\frac{0{,}067P_y}{D_{qa}})}$$

where, V_{mex} denotes ft/min; V_{fs} - cycle/min; P_y – pound; D_{qa} – inch.

The analysis of this formula shows that the ratio $V_{mex}/18V_{fs}$ is always less than unity and characterizes the MDS according to the Drilling tool rotation speed, and its absolute value changes inversely proportional to the drilling speed. Therefore, the value of d-eks also changes inversely proportional to the drilling speed and generally depends on ΔP. In cases where the lithology remains unchanged, d-eks allows to monitor the compaction degree and differential pressure of the rock. That is, it is possible to estimate the HRP and detect these zones according to the change in the d-eks value when opening the porous layers.

Numerous subsequent drilling tests have shown that there is indeed a strong correlation between formation pressure V_{mex} and the parameters *d-eks* (Figure 1) and that this relationship can be used to detect anomalously high reservoir pressure (the graph curves are idealized).

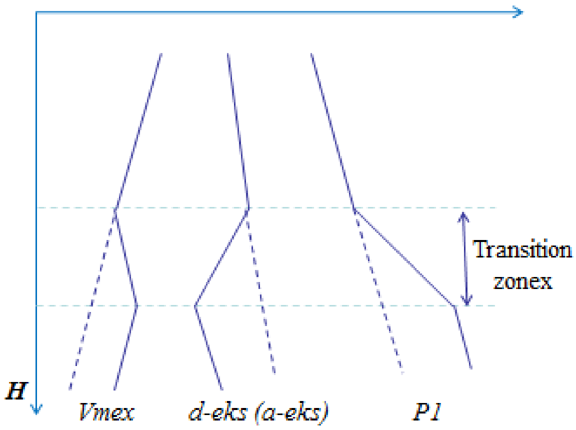

Figure 1. Correlation between parameters V_{mex}, ***d-eks (α-eks), P_1*** (Jean-Paul M., Alan Mitchell, 1989)

As the graph illustrates, up to a certain depth, the reservoir pressure varies according to the "normal compaction curve". According to the normal pressure mode, MDS decreases linearly inversely proportional to the depth. From the moment of opening DT porous mountain sediment layers (entering the transition zone), formation pressure P_{lay} increases sharply, and rocks in this zone are drilled faster: V_{mex} increases sharply. According to the change of these parameters, the value of the *d-eks* function also decreases monotonously. However, in order to increase the accuracy of the result obtained by the formula as mentioned above, the effects of other factors should be taken into account too. For example, replacing DT with a new one as it has become dull leads to an increase in MDS. Similarly, the change in the drilling speed is due to the change in the lithological composition of the rocks, differential pressure, etc. can be masked by the decrease caused by the effects of factors. Later, many modified versions of the *d-eks* formula were developed in order to take into account the effects of the mentioned factors. For example, one of these versions includes the average density parameter of the reservoir fluid calculated for the oil-gas region into the *d-eks* function and is called modified *d-eks*. (Fertl W.H., 1976).

$$d_c - eks = d - eks(P_1/P_2)$$

where, P_1 denotes the average density of reservoir fluid for the considered region; P_2 - the density of AC. However, accurate determination of the average density of the reservoir fluid is quite difficult and requires suitable logging methods with stopping drilling.

The collective of co-author of the article worked out several modified versions of the *d-eks* formula, and three of them (Makhmudov Ju.A. et al., 1984, Makhmudov Ju.A. et al., 1985, Makhmudov Ju.A. et al.) were defended with patents of invention (and two more refer to the measurement of the parameters of the proposed function–(Makhmudov Ju.A. et al., 1984, Makhmudov Ju.A. et al., 1986)). Among them, the mathematical expression called *α*-exponent (*α-eks*) and taking into account the density of AC is as follows.

$$\alpha = \frac{\lg \dfrac{V_{mex}}{60V_{fs}}}{\lg \dfrac{P_y}{\rho_{qm} D_{qa}^2}} \tag{2}$$

where, ρ_{qm} denotes the drilling fluid density, kg/cm³; P_y–kg; D_{qa}–cm. Other parameters and units are the same as in (Agayev B.S., 2018). Creating a forecasting system based on this model has several advantages. These systems allow the process of predicting AHRP zones without stopping drilling, as well as in real time. All technical tools generating data can be located in the field of ground equipment. Moreover, the device for automatic measurement of the density of AC can be installed at the output line of the injection pump or at the inlet of the drilling pipe. The density of AC can be classically measured with hydrometers and entered manually or from digital systems designed according to the input interface (protocols) of computing devices.

The system principle of detection of AHRP zones is illustrated in the graph below (Figure 2).

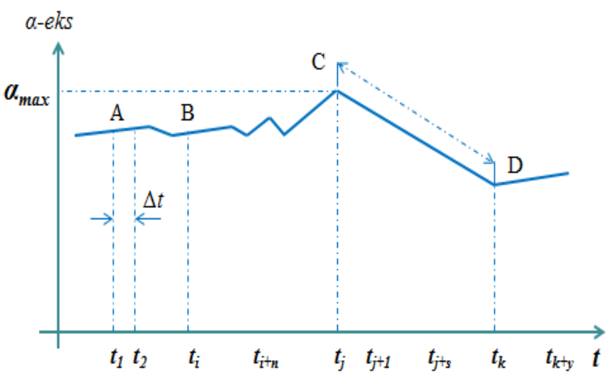

Figure 2. AHRP zone identification chart

If the wellbore dredging lasts under normal reservoir pressure conditions, the value of α-eks increases monotonously due to the mechanical parameters of the drilling process (small-amplitude deviations are not taken into account). From the moment that DT opens the porous HRP zone, MDS increases sharply and correspondingly, α-eks value decreases monotonously. It is not considered as an anomalous zone, since the α-eks decreases once in the segment AB (during t_1-t_i) and twice in the segment BC (t_i-t_j). In the segment CD (t_j-t_k), if it decreases consistently by m times due to the strength of the zone layer, MDS, etc., this case is identified as AHRP zone.

The technical parameters of drilling are collected from the well equipment in the input signal forming system block. Here, the signals are formed in accordance with the requirements of the input interface (protocol) of the calculator (for example, PC) and transmitted to the PC sequentially. PC calculates the α-eks function. If the sequence of changes of α-eks values satisfies the condition of the algorithm (the case where the α-eks value decreases monotonously m=m_t times), it is identified as the case of the DT entering the HRP zone and sends sound and light warning signals to the driller's control panel (DCP). The system then calculates the required new (weighted) value of AC according to α_{max} value and outputs it to DCP. The work of the system was approved through experiments conducted by computer modeling method. The conceptual architectural model of the prediction system working with the mentioned algorithm is presented below (Figure 3).

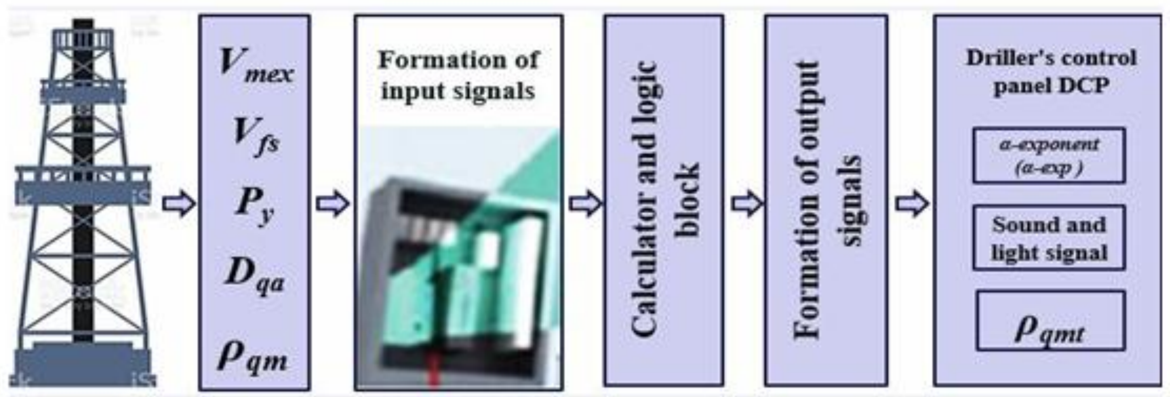

Figure 3. Conceptual architectural model of the prediction system

Conclusion

This article explored the problems of anomalous reservoir pressure assessment and prediction of anomalous zones in the drilling of oil and gas wells and some solutions to these problems. We proposed an improved variant of the widely used d-exponent method for predicting AHRP and called it α-exponent. The advantage of this method was that it was estimated to enable the prediction process to be carried out in real time without stopping the drilling. The state of use of the systems created on the basis of these methods was monitored in SOCAR's drilling work. It turned out that this type of equipment was not used in the work practice of SOCAR. We stated our considerations regarding the appropriateness of the application of these systems in SOCAR.

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References

Agayev B.S., Aliyev T.S., Aliyeva K.T., Agayev S.B. (2018). On the method for predicting zones of abnormally high reservoir pressures in oil wells. International Scientific Conference "Information Systems and Technologies: Achievements and Prospects", Sumgayit, SSU, November 15-16, 230-232.

Bakirov Sh.Kh. (2010). Experience in drilling wells in complicated conditions of the fields of the Baku archipelago on the example of wells 759 names "March 8". Azerbaijan oil industry, 4, 14-18.

Biletskiy M.T., Ratov B.T., Delikesheva D. (2019). Automatic mud density measurement device. MIAB. Mining Inf. Anal. Bull. 7, 140-148. DOI: 10.25018/0236-1493-2019-07-0-140-148.

Bingham M.G. (1964). A new approach to interpreting rock drillubility. Oil and Gas J. 62 (46), 173-179.

Dadashov I.H., Abyshov C.H. (2012). The main indicators of drilling operations in Azerbaijan and the possibility of their improvement. Azerbaijan oil industry, 10, 14-18.

Fertl W.H. (1976). Abnormal formation pressures. Implications to Exploration, Drilling and Production of Oil and Gaz Resources. Elsevier, Amsterdam-Oxford-New York, 398 p.

Iskandarov M.M., Pashayev N.V., Samadzade A.A., Baghyrzade N.Z. (2021). Modeling of geofluid pressures based on electrometry data. Azerbaijan oil industry, 8, 4-9.

Jean-Paul M., Alan Mitchell. (1989). Abnomal pressures while drilling. Boussens, 288 p.

Jordan I.R. & Shirley O.I. (1966). Application of drilling perfomance data to overpressure detection. J. Petroleum Technol., 28 (11), 1387-1394.

Kerimov K.M., Abbasov C.C., Zabolostani P.I. (2000). Possibilities for forecasting AHRP zones at great depths. Azerbaijan oil industry, 1, 11-14.

Korotayev B.A., Basekha B.M., Onufrik A.M. (2017). A method for assessing reservoir pressure during exploratory drilling. Bulletin of MSTU, 20 (1), 104–110. DOI: 10.21443/1560-9278-2017-20-1/1-104-110

Madatov A.Q., Sereda A-V.I. (2000). Direct and inverse problem of geofluid dynamics in application to forecasting AHRP zones in sedimentary basins. Practical aspect. Bulletin of MSTU, 3 (2), 351-367. https://cyberleninka.ru/article/n/pryamaya-i-obratnaya-zadachi-geoflyuidodinamiki-v-prilozhenii-k-prognozirovaniyu-zon-avpd-v-osadochnyh-basseynah-2-prakticheskiy-aspekt

Makhmudov Ju.A., Aliev Q.Kh., Aqaev B.S., et.al. (1984). A device for determining zones of abnormally high formation pressures. Certificate of authorship No. 1254782.

Makhmudov Ju.A., Aliev Q.Kh., Aqaev B.S., et.al. (1984). Device for measuring and recording the speed of the shaft of a downhole downhole motor. Certificate of authorship No. 1265294.

Makhmudov Ju.A., Aliev Q.Kh., Aqaev B.S., et.al. (1985). A device for determining zones of abnormally high formation pressures. Certificate of authorship No. 1275940.

Makhmudov Ju.A., Cafarov A.A., Aqaev B.S., et.al. (1985). A device for determining zones of abnormally high formation pressures. Certificate of authorship No. 1275940.

Makhmudov Ju.A., Kuzmin V.M., Aqaev B.S., et.al. (1986). A device for measuring the depth parameters of an oil well. Certificate of authorship No. 1368433.

Mammadov A.A., Qakhramanov Q.N., Mammadova G.A. (2021). The role of abnormally high formation pressure in the forecast of oil and gas distribution in the South Caspian depression. Azerbaijan oil industry, 2, 4-9.

Orekhov A.N., Amani M.M. (2020). Studying the abnormal formation pressure zones by analyzing seismic field attributes on the example of western siberia deposits. Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering, 331 (5), 46–56. DOI 10.18799/24131830/2020/5/2635

Parisa E.Z. (2016). Characteristics of variations in thermobaric parameters in fluid-oriented layers in deep layers. Diss, academic degree PhD. Baku State University, 158 p.

Vadetskij Ju.B. (2013). Drilling of oil and gas wells. Textbook. Academy, Moscow. 352 p. ISBN: 5-7695-1119-2.

Zaitsev V.I., Karpikov A.V. (2022). Well drilling with combined pressure control. Earth sciences and subsoil use. 45 (1), 60-72. https://doi.org/10.21285/2686-9993-2022-45-1-60-72

Zilberman V.I.,Serebryakov V.A., Gorfunkel M.V., Chilingar G.V. (2016). Prediction of abnormally high formation pressures (AHFP) in petroliferous salt-bearing sections. Journal of petroleum science and engineering. 29 (1), 17-27. DOI:10.1016/S0920-4105(00)00087-5