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EFFECT OF FRACTURE PRESSURES ON THE SELECTION OF DEPTHS FOR CASING SETTING IN SLOVAKIA

Ja. Pinka[1], O. Vytyaz[2*]

[1]*Faculty of Mining, Ecology, Process Control and Geotechnology, Technical University of Košice, Košice, Slovakia*
[2]*Institute of Petroleum Engineering, Ivano-Frankivsk National Technical University of Oil and Gas, Ivano-Frankivsk, Ukraine*
**Corresponding author: e-mail o.vytyaz@gmail.com, tel. +380342727182, fax: +380342242139*

ВПЛИВ ТИСКУ ГІДРАВЛІЧНОГО РОЗРИВУ ПЛАСТА НА ВИБІР ГЛИБИНИ СПУСКУ ОБСАДНОЇ КОЛОНИ В СЛОВАЧЧИНІ

Я. Пінка[1], О. Витязь[2*]

[1]*Факультет гірництва, екології, управління технологічними процесами та геотехніки, Технічний університет Кошице, Кошице, Словаччина*
[2]*Інститут нафтогазової інженерії, Івано-Франківський національний технічний університет нафти і газу, Івано-Франківськ, Україна*
**Відповідальний автор: e-mail o.vytyaz@gmail.com, тел. +380342727182, факс: +380342242139*

ABSTRACT

Purpose. The purpose of the article is to describe the method of casing wells for oil and gas in the Slovak Republic.

Methods. Apparently there is no general method or procedure that gives the optimal location. This article is an attempt to define this optimum casing seat location. The potential benefits will improve safety and economy of the operation. The methods of predicting fracture gradients for deeper wells already exist. In this article, a method of predicting fracture gradients for shallow well has been derived. This method is combined with kick tolerance criteria to obtain a casing depth selection method. Also, the variation in fracture pressures at any depth has been investigated.

Findings. The two major factors determine the depth of the casing shoe, that is, the fracture pressure and the pore pressure. A third factor is the lithology, because it is desirable to place the casing shoe in a competent shale section. Practical implications of this method is applicable in casing designing in deep hole drilling.

Originality. Originality of this method lies in the fact that in this process casing wells is achieved only essential as necessary length-casing with respect to all safety and strength parameters.

Practical implications. This interpretation provides the basis for vital decisions, such as selection of depths for casing setting, the maximum permissible values of mud density, method of drilling and the tightness verification of cement and cementation work. Incorrect estimates can result not only in a increase the cost of the wellbores, but also can cause potentially hazardous situations, such as lost circulation of drilling fluid, problems with managing the boreholes, borehole stability problems and also blowouts.

Keywords: *casing strings, fracture pressure, pore pressure, fracture gradients, deep hole drilling*

1. INTRODUCTION

The processes of well drilling are carried out in rocks formation with different lithological composition, physical and mechanical properties, the degree of saturation and the fluid type. These rocks lie in layers with pressures that are lower than normal pressure or in layers with anomalous pressure (Long, 1996). Sedimentary rocks – the common rock types in drilling for hydrocarbons – are usually unstable, either by pressure of overburden or by treatment with drilling fluid (Güyagüler, 1991).

The primary stage of well design is determination of the borehole structure, that is to say determination of the number of casing strings, casing depths, diameters of drill bits and conditions of the cementation (Gil, & Roegiers, 2002; Ovchynnikov, Ganushevych, & Sai, 2013). Thus, the selection of the borehole structure is related to drilling conditions, the level of the equipment and technologies used in drilling, the possibility of quick and smooth disposal of difficulties and accidents, but also the borehole structure must meet the desired objectives and be economical. For this purpose, it is necessary to determine the maximum of geological and other data, at least two, namely: *formation pressure (pore pressure) and fracture pressure depending on the depth*. In addition to the basis of program for casing, both parameters are important for cementation and subsequently for stimulation during the extraction (Xia, Wang, Wang, & Zhao, 2013).

The condition for the successful drilling is that the density of drilling fluid and also the hydrostatic pressure are slightly higher than the formation pressure. This condition can be very clearly documented via the dependence of the equivalent density or the density of drilling fluid on the wellbore depth, expressed graphically in Figure 1.

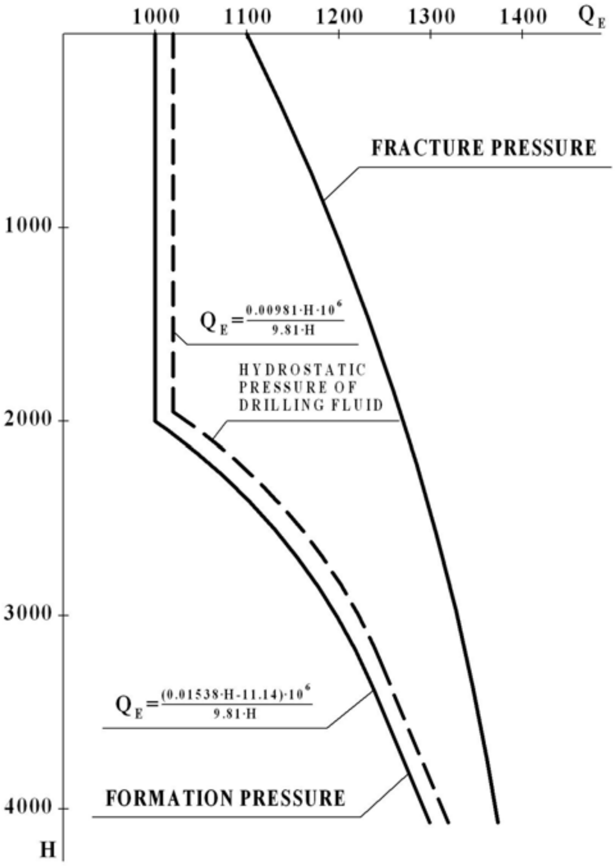

Figure 1. The relationship between the wellbore depth H (m) and the equivalent density of drilling fluid Q_E (kg/m^3)

We can move in the workspace which is to the right of the indicated curve that limits the possibility of blowout. The working surface is also bounded on the other side by the fracture pressure equivalent density curve with the wellbore depth that may cause loss of drilling fluid.

2. FRACTURE PRESSURE

The fracture pressure limits the upper bound of the pressures in the borehole. Rocks resistance to leakage of fluid in the open borehole is a function of the rock strength, its lithology, the geological age, the borehole depth and the overall state of in-situ stresses within the rock mass. Our aim in this article is to determine the natural state of stresses by artificially increasing the local stresses and subsequently to observe the changes that will occur. This method is used in determining fracture pressures below the casing shoe. The overall state of stresses in rocks is characterized by three principal stresses, which are unequal in value.

The fracture pressure must be approximately equal to the smallest value of these three stresses. The leak-off test pressures are shown in Figure 2.

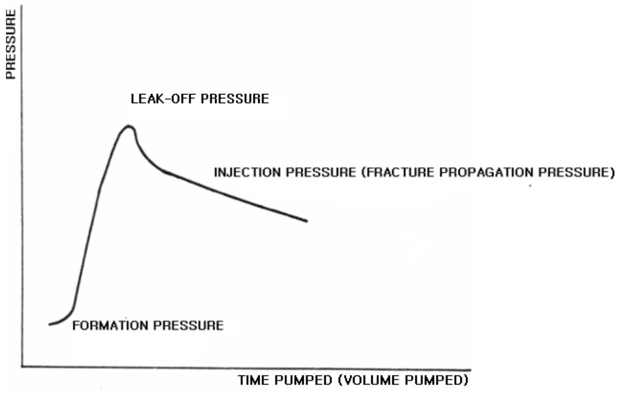

Figure 2. Schematic representation of pressure during leak-off test depending on the pumping volume (pumping time)

Detection of fracture pressures is an important technological operation and the procedure to determine fracture pressures is prescribed in the operating rules (Zeman, Pinka, Klempa, & Struna, 2014; Zeman, Pinka, Klempa, & Struna, 2014; Zisťovanie štiepnych…, 2010).

The design process does not require specific borehole data, because for approximate determination of fracture pressure values one of the recommended methods, e.g. Hubbert and Willis method, Matthews and Kelly method or Eaton’s method is used (Švrček, 2014; Samudra, 2011; Strnište & Šmolík, 1992).

3. THE PRINCIPLE OF DESIGN SETTING DEPTH OF CASING STRINGS

The method for determining the casing depth of casing strings is explained in graphic record of the formation and fracture pressure trends with wellbore depth (Fig. 3). For simplification, it is assumed that the hydrostatic pressure of drilling fluid is equal to the formation pressure. The planned borehole should be cased to the depth H_1, using the production casing string. It is possible to allow drilling at the indicated depth, provided that the drilling fluid has a minimum density $\rho_{1,2}$, to eliminate the formation pressure effect at that depth. This drilling fluid density allows drilling at depths greater that $H_{2,3}$, because at depths less than $H_{2,3}$, without casing the intermediate casing string there is a possibility of fracturing the rocks. As drilling progresses from top to bottom, the drilling fluid density at depths $H_{2,3}$ can be equal to the max value $\rho_{3,4}$. As before $\rho_{3,4}$ density is determined by the depth of further intermediate casing string $H_{4,5}$. From this procedure it also follows a principle method for determining the borehole structure – casing program, as shown in Figure 3. The correct choice of designing the casing setting, depending on the borehole depth with equivalent drilling fluid density should thus be placed on the area between the formation pressure (pore pressure) curve and the fracture pressures curve (Fig. 3).

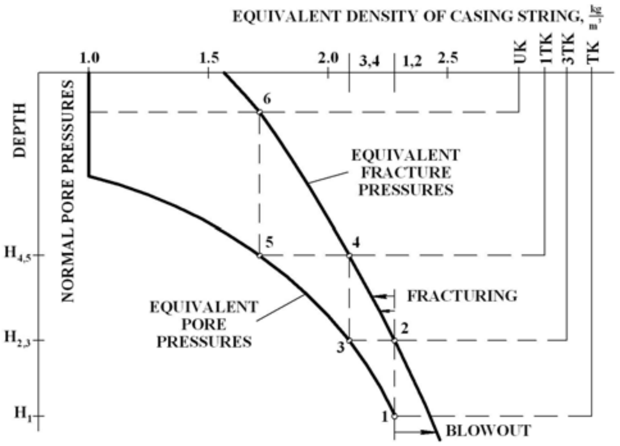

Figure 3. Method for determining the casing depth of casing strings

Therefore, it is more correct and precise to say – between the safety margins of fracture pressure and pore pressure (Fig. 4).

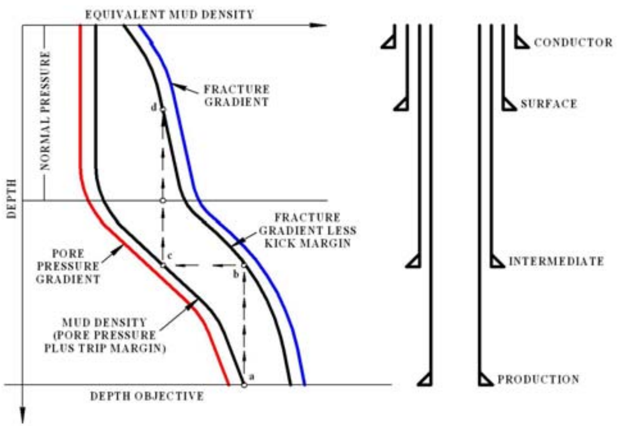

Figure 4. The selection of depth for casing setting should proceed from bottom to top (gradually through the points: a – production casing; b – intermediate casing; c – surface casing; d – conductor casing); thus, between the pore pressure curve (formation pressure + margin of formation pressure) and the fracture pressures curve (+ margin of fracture pressure)

On the right of the figure, after exceeding the fracture pressure values there is the risk of losing circulation of the drilling fluid. Also, in case of lower well pressure (e.g. low density of drilling fluid) than the pore pressure (on the left), there is the risk of blowouts/kicks (Fig. 5).

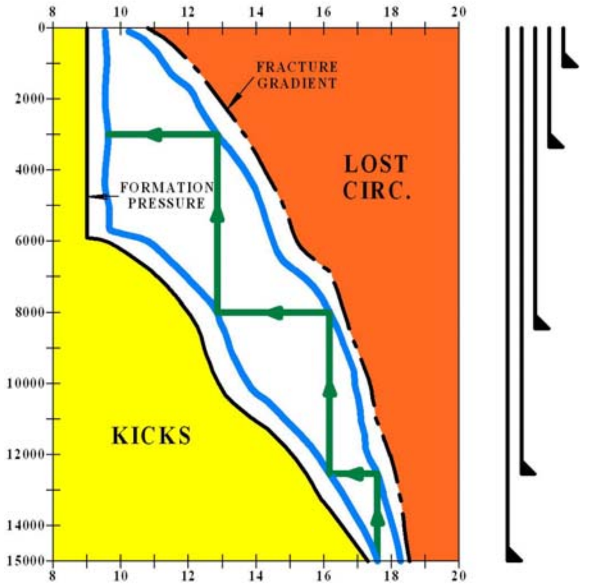

Figure 5. The suitability of depth for casing setting (marked with a green line)

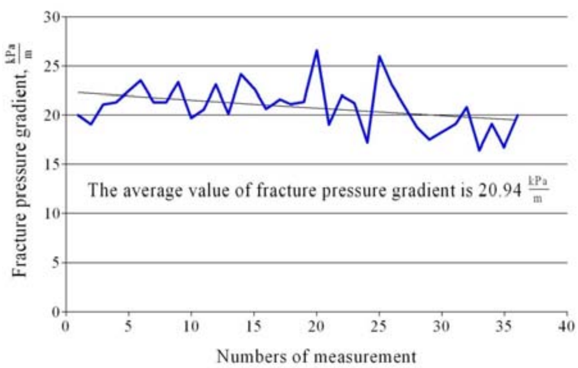

Figure 6. The graph of fracture pressure gradient in the Vienna Basin

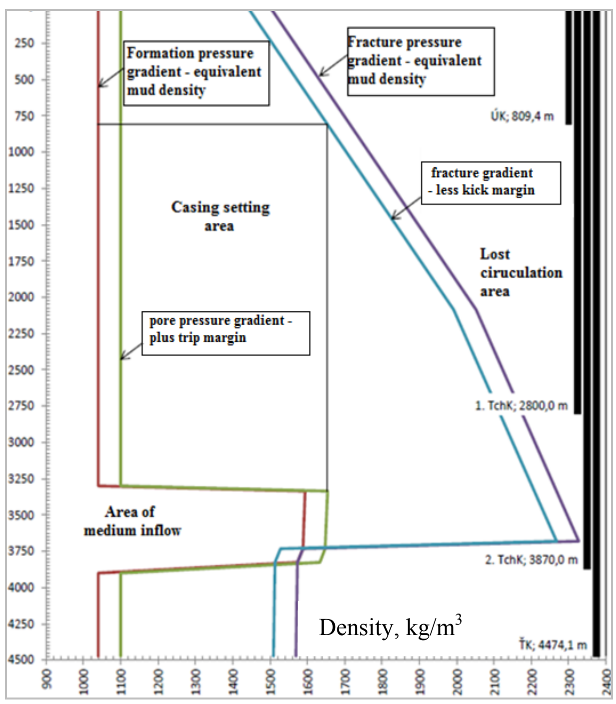

Figure 7. The selection of depths for casing setting of gas deposit Kúty

4. THE DETERMINATION OF FRACTURE PRESSURES OF THE VIENNA BASIN

The Slovak Republic's natural gas is located and also extracted in two regions, i.e. in the Vienna Basin area and in the East Slovakian Neogene Basin, where the geological exploration is currently taking place. In both areas, the fracture pressure values of some wells have been calculated and observed, as well as, the casing depth depending on equivalent mud density. The values of the Vienna Basin wells are listed in Table 1 and the graphical representations of cased boreholes are shown in Figures 6 – 9.

Table 1. The calculated values (observed values) of fracture pressures in the Vienna Basin wells

The name of the borehole	Depth of casing shoe (H)	Density of drilling fluid (ρ_{kvap})	Fracture pressure below the casing shoe ($P_{š}$)	Injection pressure at top of the borehole (P_i)	Fracture pressure gradient	Equivalent mud density ($\Delta_{\rho max.\ d}$)
	m	kg/m^3	MPa	MPa	kPa/m	kg/m^3
Malacky Z 102	155.98	1120	3.108	1.440	19.926	2031
Suchohrad 64	197.52	1150	3.771	1.650	19.092	1946
Jakubov 70	298.88	1130	6.287	3.141	21.035	2144
Jakubov 73	300.07	1125	6.410	3.167	21.362	2178
Jakubov 71	302.02	1120	6.802	3.610	22.522	2296
Jakubov 72	305.11	1110	7.181	4.000	23.536	2399
Jakubov 67	350.42	1130	7.504	3.700	21.414	2183
Jakubov 66	351.33	1130	7.524	3.500	21.416	2183
Jakubov 69	354.41	1130	8.287	4.550	23.383	2384
Gajary 148	354.52	1145	7.022	3.130	19.807	2019
Suchohrad 66	354.70	1120	7.287	3.543	20.544	2094
Gajary 134	375.02	1120	8.711	4.665	23.228	2368
Gajary 133	375.06	1130	7.587	3.500	20.229	2062
Gajary 132	384.98	1150	9.338	4.800	24.256	2473
Gajary 136	388.00	1140	8.884	4.600	22.897	2334
Gajary 139	388.48	1120	8.075	3.896	20.786	2119
Záhorská Ves 5	391.98	1100	8.452	4.380	21.562	2198
Vysoká 37	398.51	1080	8.439	4.387	21.176	2159
Dúbrava 52	399.44	1125	8.549	4.327	21.402	2182
Dúbrava 50	399.87	1140	10.689	6.330	26.731	2725
Záhorská Ves 3	400.00	1140	7.667	3.310	19.168	1954
Vysoká 36	400.05	1100	8.829	4.600	22.070	2250
Jakubov 65	430.00	1165	9.194	4.300	21.381	2180
Láb 134	450.07	1120	7.825	3.100	17.386	1772
Gajary 147	458.50	1120	11.940	6.500	26.041	2655
Jakubov 68	461.19	1120	10.650	5.860	23.092	2354
Závod 95	498.44	1120	10.398	4.510	20.861	2127
Gajary 148	647.43	1085	12.724	5.840	18.866	1923
Jakubov 73	689.83	1115	12.171	4.938	17.643	1799
Malacky Z 102	699.86	1080	12.825	5.714	18.325	1868
Suchohrad 64	746.50	1115	14.337	6.633	19.206	1958
Gajary 136	791.72	1110	16.535	8.200	20.885	2129
Gajary 131	791.98	1115	13.154	4.850	16.609	1693
Gajary 133	793.44	1080	15.230	7.200	19.195	1957
Gajary 134	816.98	1090	13.795	5.683	16.885	1721
Gajary 139	818.02	1065	16.272	8.000	19.892	2028

The formation pressures trend is slightly over-hydrostatic (Fig. 8). The formation pressure gradient of the Šaštín sands is the single case, where this gradient is in the range of 1.6 SG. Below this interval, once again the formation pressure is slightly over-hydrostatic.

Determination of depths for casing setting according to this graphical method is not clear and the selection of casing setting depths is based on drilling parameters (length of open hole interval without casing).

5. DETERMINATION OF FRACTURE PRESSURES OF THE EAST SLOVAKIAN NEOGENE BASIN

Also, the fracture pressure values of some wells in this area have been calculated and observed, as well as the casing depths of casing strings depending on the equivalent mud density and accordingly, the values for the East Slovakian Neogene Basin wells. The calculated values are listed in Table 2 and the graphical representations of cased boreholes are in Figures 10 and 11.

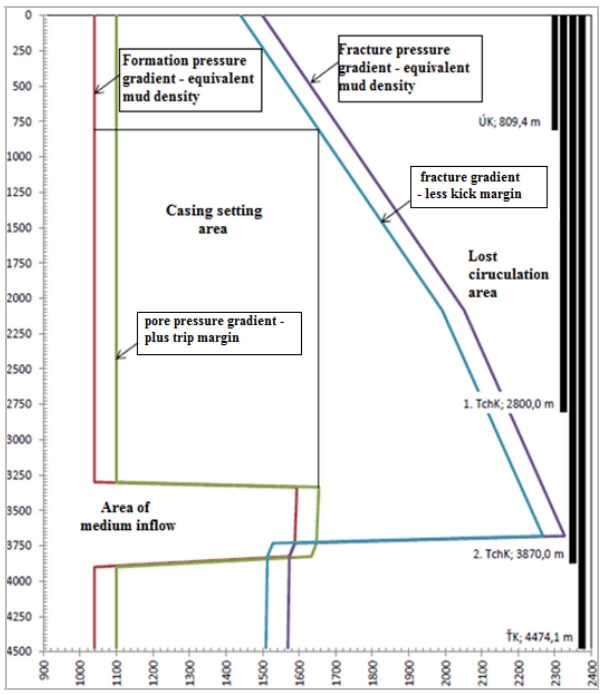

Figure 8. The selection of depths for casing setting of gas deposit Závod

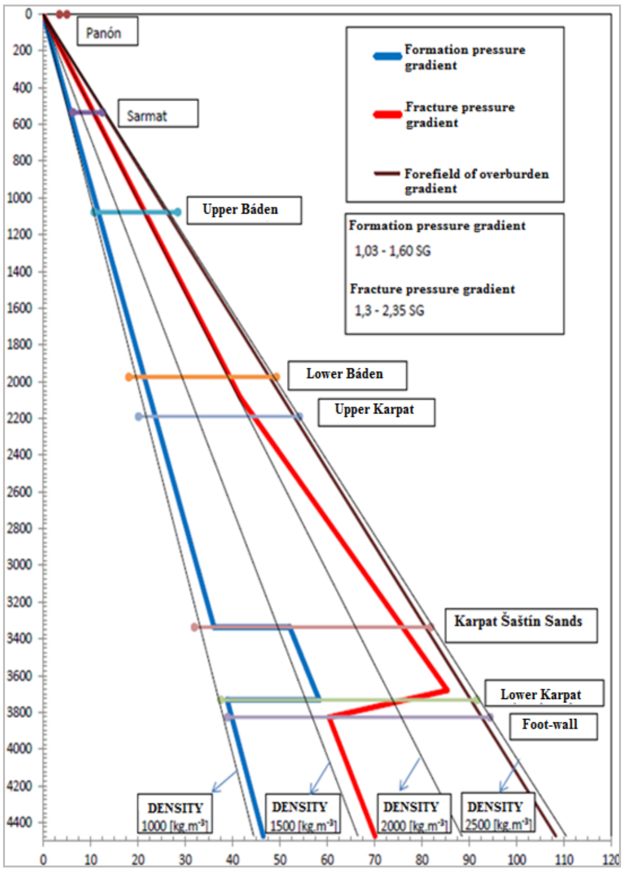

Figure 9. Pressure conditions in the wellbore of gas deposit Závod

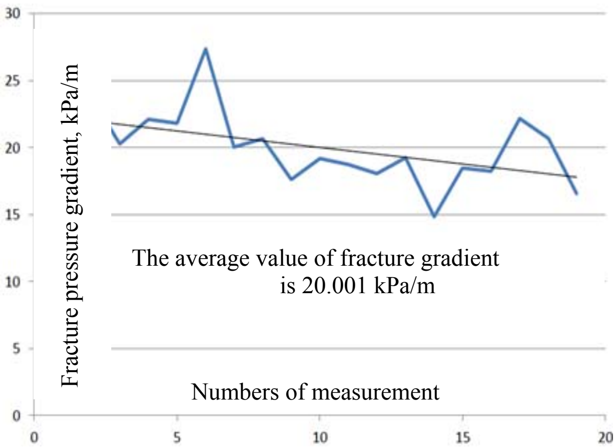

Figure 10. The graph of fracture pressure gradient of the East Slovakian Neogene Basin

6. CONCLUSIONS

Geological exploration for oil and gas is increasingly transferred to more challenging geological areas and environments. Therefore, the knowledge of pressure conditions during drilling operation is becoming a more and more important factor. Also, the knowledge and understanding of the principal stresses in wellbore are essential to wellbore stability problems. It is possible to obtain information about principal stresses during drilling by carrying out tightness tests of rock mass.

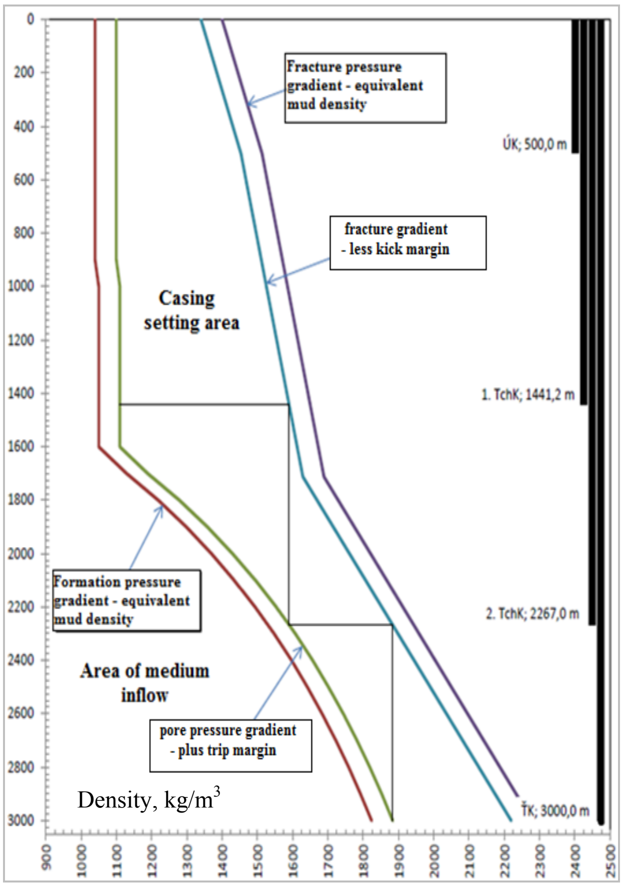

Figure 11. The selection of depths for casing setting of gas deposit Pavlovce

These pressure testing systems – mainly Leak-Off Test (LOT) and Extended Leak-Off Test (ELOT) – have been carried out in the oil and gas industry for several decades. The obtained data are used to evaluate the pressure or strengths of rock mass to verify the quality of cementation and also to estimate the magnitudes of principle stresses.

This interpretation provides the basis for vital decisions such as selection of depths for casing setting the maximum permissible values of mud density method of drilling and the tightness verification of cement and cementation work. Incorrect estimates can result not only in an increasing cost of wellbores but also can cause potentially hazardous situations such as lost circulation of drilling fluid, problems with managing the boreholes, borehole stability problems and also blowouts.

Therefore, the proper identification of principal stresses of wellbore will lead to reduction of non-productive time as well as the cost-reduction in drilling operations and consequently to greater operational safety. Acquisition of fracture pressures in wellbores appears to be economically savvy (the fracture pressures tests below the casing shoe are not required) particularly in the case when geological exploration is already carried out in the known geological area where the drilling activities were previously conducted. LOT (Leak-Off Test – The method for obtaining fracture pressures in wellbores) was also carried out in this area in the past.

Table 2. Fracture pressures calculated values of the East Slovakian Neogene Basin wells

The name of the borehole	Depth of casing shoe (H)	Density of drilling fluid (ρ_{kvap})	Fracture pressure below the casing shoe ($P_{š}$)	Injection pressure at top of the borehole (P_i)	Fracture pressure gradient	Equivalent mud density ($\Delta_{\rho max. d}$)
	m	kg/m^3	MPa	MPa	kPa/m	kg/m^3
Stretava 56	101.10	1210	2.035	0.810	20.129	2052
Zemplínska Široká 3	124.83	1180	2.970	1.500	23.792	2426
Bánovce 37	299.54	1110	6.077	2.960	20.288	2068
Pozdišovce 15	301.00	1180	6.653	3.200	22.103	2253
Michalovce 2	305.75	1150	6.666	3.380	21.802	2223
Moravany 1	309.61	1140	8.473	5.180	27.367	2790
Vrbnica 1	354.00	1180	7.094	3.110	20.040	2043
Vrbnica 2	361.00	1130	7.460	3.650	20.665	2107
Zemplínska Široká 1	393.36	1180	6.934	2.500	17.628	1797
Palín 1	398.50	1180	7.649	3.200	19.194	1957
Zemplínska Široká 6	437.74	1100	8.206	3.500	18.746	1911
Zemplínska Široká 2	448.15	1180	8.099	3.100	18.072	1842
Zemplínska Široká 4	449.33	1180	8.642	3.600	19.233	1961
Pavlovce 4	502.50	1180	7.458	3.600	14.842	1513
Sliepkovce 3	552.82	1190	10.216	4.000	18.480	1884
Stretava 56	800.00	1200	14.582	5.380	18.228	1858
Pozdišovce 15	1001.82	1150	22.194	11.300	22.154	2259
Zemplínska Široká 3	1006.59	1180	20.823	9.600	20.687	2109
Pavlovce 4	1712.00	1200	28.356	unknown	16.563	1688

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ABSTRACT (IN UKRAINIAN)

Мета. Метою даної статті є опис методу обсадження нафтових і газових свердловин у Словацькій Республіці.

Методика. Мабуть немає загального методу або процедури, за допомогою яких можна визначати оптимальне місце розташування свердловин. Дана стаття є спробою визначити оптимальне розташування башмака обсадної колони. Потенційні вигоди дозволять підвищити безпеку та економічність експлуатації. Методи прогнозування градієнтів руйнування для більш глибоких свердловин вже існують. У статті описаний метод прогнозування градієнтів руйнування для неглибоких свердловин. Даний метод поєднується з критерієм опору породи руйнуванню, щоб отримати метод вибору глибини встановлення обсадної колони. Крім того, було досліджено зміну тисків руйнування на різних глибинах.

Результати. Два основні чинники визначають глибину встановлення башмака обсадної колони, тобто тиск руйнування і поровий тиск. Третім фактором є літологія, оскільки бажано розмістити башмак обсадної колони у відповідному інтервалі сланцю. Практичне значення полягає у застосуванні цього методу при проектуванні обсадної колони в глибоких свердловинах.

Наукова новизна. Унікальність даного методу полягає в тому, що в процесі обсадження свердловин важливе значення має визначення необхідної довжини обсадної труби з урахуванням всіх параметрів безпеки й міцності.

Практична значимість. Дана інтерпретація є основою для прийняття важливих рішень, таких як вибір глибини встановлення обсадної колони, гранично допустимих значень густини бурового розчину, способів буріння, контролю герметичності цементування та тампонажних робіт. Неправильна оцінка може призвести не тільки до збільшення вартості спорудження свердловини, але й до потенційно небезпечних ситуацій, таких як втрата циркуляції бурового розчину, проблеми з управлінням поглиблення свердловин, проблеми стійкості стовбура свердловини, а також викиди.

Ключові слова: *обсадна колона, тиск руйнування, поровий тиск, градієнт руйнування, буріння глибоких свердловин*

ABSTRACT (IN RUSSIAN)

Цель. Целью данной статьи является описание метода обсадки нефтяных и газовых скважин в Словацкой Республике.

Методика. Пожалуй, нет общего метода или процедуры, с помощью которых можно определять оптимальное месторасположение скважин. Эта статья является попыткой определить оптимальное расположение башмака обсадной колонны. Потенциальные выгоды позволят повысить безопасность и экономичность эксплуатации. Методы прогнозирования градиентов разрушения для более глубоких скважин уже существуют. В данной статье описан метод прогнозирования градиентов разрушения для неглубоких скважин. Этот метод сочетается с критерием сопротивления породы разрушению, чтобы получить метод выбора глубины установки обсадной колонны. Кроме того, было исследовано изменение давления разрушения на разных глубинах.

Результаты. Два основных фактора определяют глубину установки башмака обсадной колонны, то есть давление разрушения и поровое давление. Третьим фактором является литология, поскольку желательно разместить башмак обсадной колонны в соответствующем интервале сланца. Практическое значение состоит в применении этого метода при проектировании обсадной колонны в глубоких скважинах.

Научная новизна. Уникальность данного метода заключается в том, что в процессе обсадки скважин важное значение имеет определение необходимой длины обсадной трубы с учетом всех параметров безопасности и прочности.

Практическая значимость. Данная интерпретация является основой для принятия важных решений, таких как выбор глубины установки обсадной колонны, предельно допустимых значений плотности бурового раствора, способов бурения, контроля герметичности цементирования и тампонажных работ. Неправильная оценка может привести не только к увеличению стоимости строительства скважины, но и к потенциально опасным ситуациям, таким как потеря циркуляции бурового раствора, проблемы с управлением углубления скважин, проблемы устойчивости ствола скважины, а также выбросы.

Ключевые слова: *обсадная колонна, давление разрушения, поровое давление, градиент разрушения, бурение глубоких скважин*

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ABOUT AUTHORS

Ján Pinka, Doctor of Philosophy, Faculty of Mining, Ecology, Process Control and Geotechnology, Technical University of Košice, 9 Letná Ave., 04200, Košice, Slovakia. E-mail: bfdek@ccsun.tuke.sk

Oleg Vytyaz, Candidate of Technical Sciences, Director of the Institute of Petroleum Engineering, Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska Ave., 0-524, 76019, Ivano-Frankivsk, Ukraine. E-mail: o.vytyaz@gmail.com