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# DETECTION AND ESTIMATION OF OVERPRESSURES IN GAS RESERVOIRS WHILE DRILLING

## 1. INTRODUCTION

As part of rotary – hydraulic drilling method (the most common method for drilling the wells) the rock is displaced by the action of drilling bit, being removed from the bottom and brought to the surface, through the drilling fluid. Besides this function, the drilling fluid creates a backpressure against the borehole walls, overcoming the collapse of the poorly consolidated rocks as well as the fluids influx from the formations crossed by the well.

In order to fulfil these functions of the drilling fluid, it must be a correlation between the pore fluid pressure from the crossed formations and the wellbore pressure, as follows:

$$p_p \le p_m \le p_f \tag{1}$$

where:

$p_p$ – fluid pressure contained in the rock pores,
$p_m$ – hydrostatic pressure of the well drilling fluid (drilling mud),
$p_f$ – fracturing pressure of the rocks from the wellbore.

The ***pore pressure of the fluids*** contained in rocks, $p_p$ can be assimilated with the pressure exerted by a column of reservoir water from that depth to the surface [5]. This thing is possible when there is a communication through the pores or fractures network with the surface or when an equilibrium in time has been established.

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In this case, the reservoir pressure is considered to be a „normal'' pressure and is expressed by relation:

$$p_p = \rho_w g H \tag{2}$$

where:

$p_p$ – normal pore fluid pressure,
$\rho_w$ – density of the reservoir water,
$H$ – depth of the fluids in the reservoir.

In this context, a normal pore pressure gradient of the fluids, is generally considered 0.107 bar/m [1].

When the pore pressure is lower or higher than the theoretical hydrostatic pressure, for a certain depth, we discuss about the pressure anomalies which can be negative (subnormal) or positive (supernormal or overpressures).

In many gas basins there are positive pressure anomalies which can reach the values of about 90–95% from the lithostatic pressure [4], and if these are unexpected or not detected in due time they can determine most serious complications during the drilling process Therefore, in situation when the opened formations by the wells are unknown, detection and estimation in real time of the pore overpressures is required.

In Figure 1 is presented the variation of the lithostatic pressure and pore fluids pressure with depth.

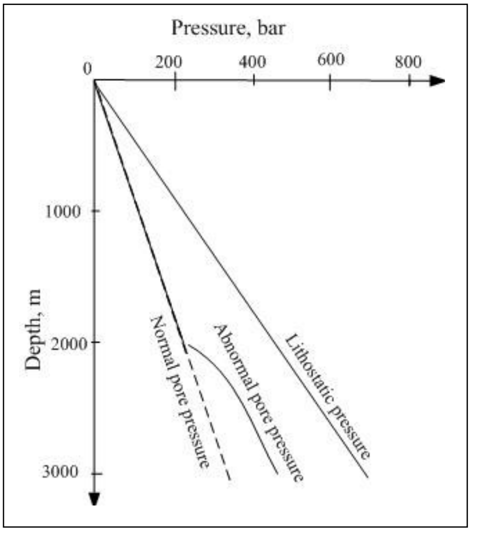


**Fig. 1.** The lithostatic and the pore pressure with depth

The ***fracturing pressure*** is the value of the wellbore pressure at a certain depth, $H$, which induces a fracture, with variable orientation, from vertical to horizontal, in the borehole walls.

The ***wellbore fluid pressure*** in certain point inside the borehole, represents the hydrostatic pressure of the respective fluid column, which height is equal with the vertical from that point to the surface. As in the normal conditions most part of the fluid is circulated inside the wellbore, the pressure conditions along the well interval, and especially at the bottom are modified. So, during the fluid circulation, the pressure drop from the annulus overlaps the hydrostatic pressure exerted by the fluid, and the effect is the pressure increasing at the well bottom.

## 2. ESTIMATION OF THE PORE FLUID PRESSURE

The pore fluid pressure is a very important parameter, which has to be taken into account both in designing and also in the execution phase of drilling jobs. An incorrect estimation of the pore pressure can determine a wrong designing of the mud density, which can cause difficulties and complications during drilling. We are taking about walls instability of the borehole, circulation losses, the drilling string stuck by differential sticking and last but not least the undesired influx of the fluids contained in the formation pores crossed by the well (blowouts, kick). All these phenomena increase the well costs, and sometimes can determine the wells abandonment before reaching the targets.

In this context, can be concluded that the accuracy of the pore pressure value estimation depends on the drilling execution in conditions of safety and efficiency.

The estimation of the pore fluids pressure, in the designing stage of the exploration wells on new fields, is made based on the analysis of all seismic data, geological and also those based on the information provided by the correlation wells. If the well is drilled on a known structure, the pore pressure estimation can be done with more accuracy, based on geophysical investigations, production tests and pressure measurements of the wells drilled previously in the same sedimentary basin (Fig. 2).

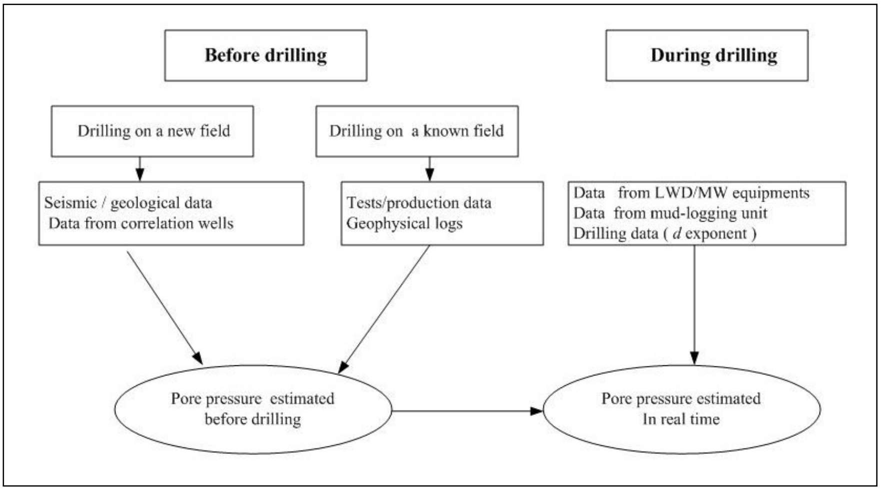


**Fig. 2.** The diagram of pore pressure estimation

During drilling, it's recommended, to review in real time the pore pressure, in order to eliminate/minimize any risk factor generated by strata – well disequilibrium. The real time analysis of the pore pressure during drilling can be performed by using LWD (logging-while drilling) devices or MWD (measurement-while-drilling), based on the mud – logging data or by monitoring the drilling parameters [4].

## 3. THE METHODS FOR DETECTING AND EVALUATION OF PORE OVERPRESSURES WHILE DRILLING

The methods for detecting and quantitative evaluation of the overpressures encountered while drilling, are based on the assumption that the overpressured formations are less compact, having a higher porosity than a formation located at the same depth, but with a normal pressure. On the other hand, the porosity in clays decreases exponentially with depth, which in graphical plot in semi-logarithmic coordinates is represented by a line with a normal compaction trend.

So the result is that for a certain lithostratigraphic sequence can be drawn a line of normal compaction trend of the clays, based on some records and interpretations of the rate of bit penetration or on some physical properties of rock dependent of porosity and notification of some deviation from this trend, can signify the presence of an overpressure zone. Moreover, knowing the normal values and those of deviation from the normal compaction trend at a certain depth, can be also quantitatively evaluated these abnormal pressures.

Starting from this reasoning, for estimation the pore overpressure while drilling, some methods have been developed, the most common being: the *d* exponent method, the method of proportionality and the method of equivalent depth.

The ***d exponent method*** is based on monitoring and analysis of the drilling regime parameters, the relationship between the rate of penetration and factors which influence this rate (weight on bit, rotation, hydraulic regime, strata – well differential pressure , the rock strength, rock compaction etc.)

The expression of *d* exponent resulted from rate of penetration is presented below [3]:

$$d = \frac{\lg \dfrac{0.05465\, ROP_a}{R}}{\lg \dfrac{0.665W}{D_b}} \tag{3}$$

where:

$ROP_a$ – average rate of penetration, m/h,

$R$ – bit rotation, rot/min,

$W$ – weight on bit, tf,

$D_b$ – bit diameter, mm.

In case of a normal compaction of rocks and in the conditions of a normal pore pressure gradient of fluids, *d* exponent increases with depth. The decreasing trend of *d* exponent means a possible interception an overpressured layer.

Based on the practical observations, it was found that a correction of *d* exponent can be made, taking into account the circulation equivalent density [2]. This correction is made by using the relation:

$$d_c = d \frac{\rho_w}{\rho_m} \tag{4}$$

where:

$d_c$ – corrected *d* exponent,

$\rho_w$ – reservoir water density from that area,

$\rho_m$ – mud density.

The graphical plot of the corrected values of *d* exponent, is more relevant for entering in a zone with abnormal pressures, increasing also the accuracy degree for a quantitative estimation of the pressures values.

In order to estimate the pore pressure based on *d* exponent, Eaton relation [3] can be used:

$$p_p = p_l - (p_l - p_{pn})\left(\frac{d_{c0}}{d_{cn}}\right)^{1.2} \tag{5}$$

where:

$p_l$ – lithostatic pressure,

$p_{pn}$ – normal pore fluid pressure,

$d_{c0}$ – real value of $d_c$ exponent,

$d_{cn}$ – value of $d_c$ exponent measured on line of normal compaction.

The ***method of proportionality*** is based on the assumption that between the parameter which expresses the rock compaction degree and the pore pressure is a direct proportionality and in this situation the following relation [2] can be written:

$$p_p = p_{pn} \frac{x_n}{x_o} \tag{6}$$

where:

$x_n$ – normal value of the monitored parameter which represents the compaction degree of the rock,

$x_o$ – observed value of the parameter which represents the compaction degree of the rock.

The above proportionality was more noticeable for *d* exponent, while in case of other parameters the method is less accurate.

The ***method of equivalent depth*** is based on the assumption that clays with equivalent physical properties, have the same compaction degree, therefore resulting that the pressure from the solid frame on vertical direction (the contact pressure between the rock grains) is the same.

The computing relation of the pore pressure for this method is [3]:

$$p_p = \rho_w g H_{ec} + \rho_{ar} g \left(H - H_{ec}\right) \tag{7}$$

where:

- $p_p$ – pore fluid pressure at depth $H$,
- $\rho_w$ – density of the reservoir water,
- $\rho_{ar}$ – apparent rock density,
- $H$ – depth of the point where you wish to calculate the pore pressure,
- $H_{ec}$ – depth at which the compaction degree at the desired depth is equivalent on the line of normal compaction trend.

The equivalent depth $H_{ec}$ is determined by drawing a parallel from the point in which is wanted to calculate the pore pressure, to the depths scale, on which are represented the resistivity values, conductivity, apparent density, propagation time of the sonic waves or the values of $d_c$ exponent, and represent the intersection point of this parallel with the line of normal compaction trend.

## 4. CASE STUDY REGARDING THE QUALITATIVE AND QUANTITATIVE ESTIMATION OF THE PORE OVERPRESSURES

### 4.1. The qualitative estimation of overpressures for the well X

The well X was designed as a vertical preliminary exploration well, having the target 2500 m depth. The well purpose was verifying the gas indications from Sarmatian [6]. Based on the drilling parameters recorded by the *mud-logging unit*, were computed the values of $d_c$ exponent, starting with 500 m depth, until the final depth, for each meter drilled. The obtained results were plotted having in ordinate depth in a normal scale, and in abscissa $d_c$ exponent in a semi – logarithmic scale [2].

The interpretation of the $d_c$ exponent plot has been correlated with the lithological column performed for the well X based on the percentage description of the cuttings collected on the interval 400–2500 m, with the gas analysis from the drilling fluid and also with daily drilling reports [6]. After this interpretation, it was estimated that on the interval

2240–2464 m, it would be possible to have subcompact layers with higher pore pressure gradients than the normal ones, based on the following arguments:

- from this depth the $d_c$ exponent doesn't follow the trend of normal compaction of clays (Fig. 3a),
- at 2243 m depth, the formation gas was 43.4%, the mud density introduced in the well was 1.28 kg/cdm, and the mud density out 1.26 kg/cdm,
- at 2252 m the formation gas was 88.8%, the mud density introduced in the well was 1.34 kg/cdm , and the mud density out 1.30 kg/cdm,
- the connection gas occurence at the following depths: 2253 m (25.98%), 2262 m (29.12%), 2271 m (24.84%),
- at 2424 m depth after drifting, the trip gas was 40.2% and the fluid density decreased from 1.48 kg/cdm to 1.44 kg/cdm.

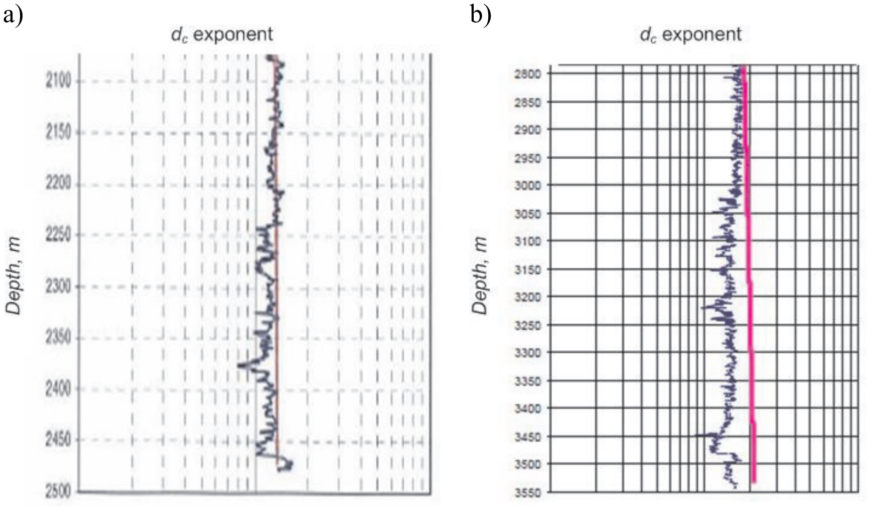


**Fig. 3.** Plot of $d_c$ exponent and the normal compaction trend (fragments):
a) well X; b) well Y

### 4.2. The quantitative estimation of overpressures for the well Y

The prospective – exploration well Y had as target verification of the hydrocarbons content of some Sarmatian and Badenian reservoirs, in the depth limit of 3500 m [6]. For this well there were also quantitative estimations of the values of reservoirs overpressures, by using for this purpose the Eaton relation (5) and relations (6) and (7) applied for $d_c$ exponent [2].

In order to verify these estimations, by comparison with the real pressure data recorded after performing the production tests, have been selected the depth intervals effectively perforated and tested and where the abnormal high pressures have been recorded (Tab. 1).

**Table 1**

The pore pressure values in the well Y determined based on d exponent and production tests

| Interval | | $d_{co}$ | $d_{cn}$ | $H_{ec}$ | $p_l$ | Pore pressure, $p_p$ | | | | Fluid type |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | The method of proportionality | The method of equivalent depth | Eaton method | Production tests | |
| | m | | | m | bar | bar | bar | bar | bar | |
| I | 2987–3005 | 1.6087 | 1.9184 | 2428 | 704 | 381 | 421 | 384 | 406 | Clean gas |
| II | 3037.5–3039.5 | 1.5977 | 1.9352 | 1880 | 714 | 393 | 431 | 395 | 387 | Clean gas |
| III | 3069–3072 | 1.4770 | 1.9482 | 2425 | 722 | 433 | 508 | 442 | 415 | Clean gas |
| IV | 3229–3231<br>3233–3235<br>3238–3240 | 1.4547 | 2.0137 | 2796 | 761 | 478 | 537 | 471 | 468 | Clean gas |
| V | 3378–3381<br>3384–3387<br>3389–3392 | 1.4590 | 2.0740 | 1560 | 799 | 515 | 583 | 503 | 605 | Salt water with gas shows |

## 5. CONCLUSIONS

Detecting and estimation the pore fluid pressures while drilling is a decisive factor for anticipating and avoiding some complications which could occur while drilling, especially in case of geological research wells, where could occur discrepancies related to the project, not only regarding the values of pressures estimated based on the correlation wells, but also with depths of intercepting some formations.

The estimation of the pore overpressures while drilling, based on *d exponent*, is an efficient method, economical and useful, due to the fact that overpressures detecting and evaluation can be done just while drilling, as the bit is progressing, allowing drilling process to be managed in conditions of efficiency and safety.

The accuracy of the obtained results by applying the presented methods, is largely depending on drawing a more precise line of normal compaction trend, which assumes the selecting of those intervals containing clean marls, with thickness of at least 5–7 m.

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