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Considerations Regarding the Damage of Natural Gas Formations as a Result of Their Opening by Drilling

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Abstract

During the drilling of a well, the productive formation gets in touch with the drilling fluid that produces a damage of a limited area in the vicinity of the well's wall. Highlighting the degree of damage and assessment of its impact on the well productivity is a key element in optimizing operational performance of that formation. One of the most common and effective ways to combat the damage of the porous medium is the acidification of productive formations, especially in the case when these formations contain large percentages of carbonate rocks. However it is preferably to prevent damage by using drilling fluids with fewer solids and their filtrate to be compatible with the formation and deposits fluids.

Key words: *damage, drilling fluid, permeability, productivity index, skin.*

Introduction

Exploitation of natural gas involves the achievement, with drilling operations, of some communication paths (wells) between productive formations, at different depths in the crust and at surface. All operations that are executed for this purpose lead to contamination of the layers opened by drilling, a phenomenon which has the effect of modifying/damage of the physical properties associated to permeable porous medium.

Thus, as a result of the contamination, around the well there are two areas with different permeabilities (fig. 1). The area I, delimited by the radius r, called the contaminated area, characterized by a permeability k_1, lower than the original one or the one existing in the rest of the reservoir, noted k_2. Area II consists of the rest of the reservoir, to r_e well's drainage radius and is called reference area as flow elements in this area are taken as points of comparison for the contaminated area.

Thus, existence of the contaminated area leads to reducing the fluid flow capacity through the rock surrounding the well, with negative impact on its productivity. For formations which respond well to treatment with acid (typically true for carbonate rocks), and if the radius of the contaminated area is small, this is not too severe, because the damage can be repaired afterwards by treatment of the formation with an acid solution. But for formations that do not respond well to acid (usually valid for sandstone), damage could be permanent. In addition, the products resulting from the reaction of the constituent minerals of reservoir rocks can lead to higher rates of damage.

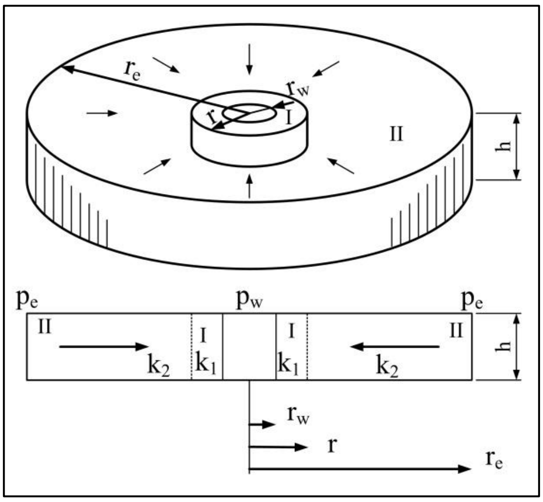

Fig. 1. Illustration of the contaminated area and reference area (uncontaminated) around the well: r_w - wellbore radius; r - radius of the contaminated area; r_e - well's drainage radius; h - reservoir thickness; I - contaminated area; II - uncontaminated area; k_1 – permeability of the contaminated area; k_2 - permeability of uncontaminated area; p_w - wellbore flowing pressure, p_e - reservoir pressure at $r = r_e$.

Mechanisms of Productive Formations Damage during Drilling

During drilling, as the productive formation is open, it comes into contact with drilling fluid filtrate that affects its permeability in a certain area in the vicinity of the well wall. The depth and damage extent of the formation are determined by the nature and composition of the drilling fluid, the well-layer differential pressure, duration of contact between fluid and rock and by the rock characteristics.

Damage to the productive formation as a result of contact with the drilling fluid occurs through the following mechanisms [1, 2]:

- the interaction between the liquid phase filtered through the well walls with clay minerals from the formation;
- invasion of solid particles from drilling fluid into the pores of the formation;
- precipitation and adsorption of some chemicals from drilling fluid to the surface of pores.

Interaction of the aqueous phase filtered from the drilling fluid with clay minerals contained in the productive formation is considered the main cause of reduction in rocks permeability. In reservoir rocks, clay minerals can be found in varying proportions, most commonly between 1 - 10%, rarely more than 10% and very rarely less than 1% [1]. A sand containing percentages of clays between 1% and 5% is usually called clean sand and one which contains between 5 to 20% clay is called dirty sand. Carbonate rocks may also contain clays.

The drilling fluid filtrate is usually water containing different types of positive and negative ions, and surfactants at various concentrations as well. The filtrate is forced upwards in the porous area around the well hole by the well-layer differential pressure displacing or mixing with the fluid existing in the rock. Following to filtered water - clay contact, the balance between clay and reservoir water is changed. Clay minerals retain water by adsorption at their crystalline lattice. In the case of planar water adsorption occurs a surface hydration (water is retained in the crystalline lattice of the clay minerals through hydrogen bonds), as well as an osmotic hydration, which is related to the adsorbed water as a result of the difference in the concentration of cations. The immediate effect of hydration is swelling, dispersion and migration of clay particles, with drastic effects on the permeability of the productive layer.

The invasion of mud solids in the formation pores occurs over a certain depth, determined primarily by the ratio between the particles diameters and the pores ones. Solids may be: weighting materials or filtration control materials, fine particles of dislodged rock, flow loss control materials, solids from drilling etc.

Speed and viscosity of drilling fluid, differential pressure well-layer, nature, concentration and solid particles shape, pore diameter and tortuosity have an influence on the depth of penetration of solid particles, and so on the formation damage.

Precipitation and adsorption of some chemicals from drilling fluid on pore surface occurs when aqueous solutions of minerals existing in pores become saturated due to changes in composition, pressure or temperature. By precipitation and recrystallization, sometimes, a crust on the surface of pores is formed, which changes the wettability and permeability of the reservoir rock.

Precipitated substances are sulfates (calcium, barium, magnesium), carbonates (calcium, magnesium) and some gels (iron hydroxide and silica).

Deposits occur mainly when are coming into contact two incompatible fluids: drilling fluid filtrate with pore fluids.

Assessment of Damage Effect by Hydrodynamic Wells Investigation

Characterization of any changes in gas wells production capacity due to contamination may be done with their hydrodynamic investigation, in steady or unsteady state, after which can be determined the parameters showing productivity characteristic affected by damage: productivity index *IP* and effective permeability k_1, respectively productivity ratio, skin factor, extra pressure drop.

a. Steady - state case

When researching a well in steady – state flow, the dependence $(p_e^2 - p_w^2)/q$ on the well flow rate q translates a straight line with slope B and ordinate at origin A, with which we can find the parameters that we are interested in assessing damage [4]:

- productivity index:

$$PI = \frac{1}{A} \tag{1}$$

- real effective permeability:

$$k_1 = \frac{\mu Z p_0 T_r \ln\frac{r_e}{r_w}}{\pi A h T_0} \tag{2}$$

where:
μ – dynamic viscosity of the gas;
Z – gas compressibility factor;
T_r – reservoir temperature;
T_0, p_0 –temperature, respectively reference pressure.

After comparing the real productivity index of a contaminated well *PI* with the well productivity index value taken as a reference (characterized by identical conditions but without contamination) PI_o the damage degree duet of contamination of the analysed formation productivity is obtained:

$$E = \frac{PI}{PI_0} \tag{3}$$

On the other hand using as reference the effective gas permeability value in an uncontaminated formation, determined from laboratory analyzes based on cores collected at the stage of the respective formation opening by drilling, k_2 represents the damage in the form of a ratio between the two permeabilities:

$$\varepsilon = \frac{k_1}{k_2} \tag{4}$$

Damage effect of the area in vicinity of the wellbore on productivity index is shown in Figure 2. It can be seen that even very superficial damage can cause a substantial reduction in productivity.

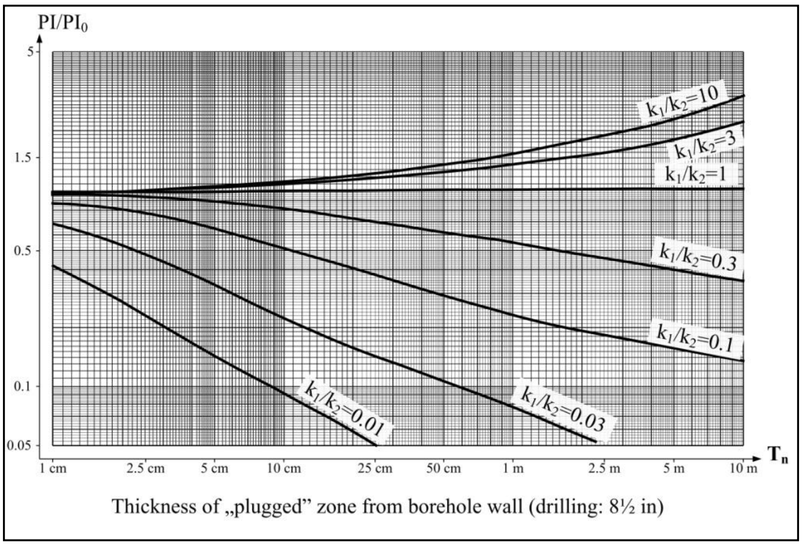

Fig. 2. Effect of damage in area in vicinity of the wellbore on the productivity index [3]

b. Unsteady – state case

Considering that (μZ) is constant (the case when the reservoir pressure is less than 140 bar) when researching in an unsteady-state, pressure is recorded in a shut in well and the well build – up pressure curve is drawn.

From the resulting diagram one can determine the slope of the linear part i, initial pressure p_i, square pressure one hour after well shutting in $p^2_{\Delta t} = 1h$, and with their help can calculated the parameters required in assessing damage [4]:

- real effective permeability:

$$k_1 = \frac{(k_1 h)}{h} = \frac{2.3 q \mu Z p_0 T_z}{2 h \pi i T_0} \tag{5}$$

- skin factor:

$$S = 1.151\left(\frac{p^2_{\Delta t=1h} - p^2_{\Delta t=0}}{i} - log\,\frac{k_1}{m\mu\beta r_w^2} - 0.351\right) \tag{6}$$

- additional pressure drop:

$$\Delta p_s^2 = 0.87 S i \tag{7}$$

- real productivity index:

$$(IP)_r = \frac{q}{p_i^2 - p^2_{\Delta t=0}} \tag{8}$$

- ideal productivity index:

$$(IP)_i = \frac{q}{p_i^2 - p_{\Delta t=0}^2 - \Delta p_s^2} \tag{9}$$

- productivity ratio:

$$PR = \frac{(IP)_r}{(IP)_i} \tag{10}$$

where:
t – the apparent production time;
Δt – time period corresponding to pressure $p\ \Delta t$;
q – flow rate before well shutting in;
m – porosity;
β – total compressibility.

Following experiments it was concluded that the positive values of skin factor ($S > 0$) mean that there is a reduced permeability zone (damaged area) around the well and negative values of skin factor ($S < 0$) may indicate a higher permeability zone around the well obtained by a stimulation operation. A classification of the wells according to the value of the skin factor is shown in table 2 below.

Table 2. Classification of wells according to the value of skin factor

Well situation	**Value of skin factor**
Ideal well	0
Severe damaged well	+20 to 500
Moderately damaged well	+5 to +20
Well with initial good completion, unstimulated	+2 to -1
Slightly acidified well	0 to -2
Well with natural fracturing or slight fracturing	-3.0 to -5.0
Well with major fracturing in low permeability formations	-6.0
Well with maximum stimulation	-7.0

Case Study on Evaluating the Well Damage by Investigation during Unsteady-state

Well X Tazlau (Neamt county) has been designed and drilled as vertical exploitation well for intensifying production from Oligocene. The final depth was 1220 m, for crossing the productive layer the inhibiting drilling fluid was used, treated with specials additives, with the density 1.01 – 1.04 kg/dm^3 [5].

When drilling the well, the reservoir was highly depleted, with a static reservoir pressure of approximately 40 bar, whereas initial pressure was 148 bar.

The well has been brought in production at the lower Oligocene, being perforated selectively at 1195 – 975 m, where it produced with an average flow rate of 2500 Scm/day [5]. Because production results from this interval were not satisfying, the well entered a recompletion operation program.

During recompletion operations, the interval 1031 – 1039m has been tested by performing hydrodynamic investigations. Saphir program was used to process the data from the build-up pressure curves, having the results shown in Figures 3-5.

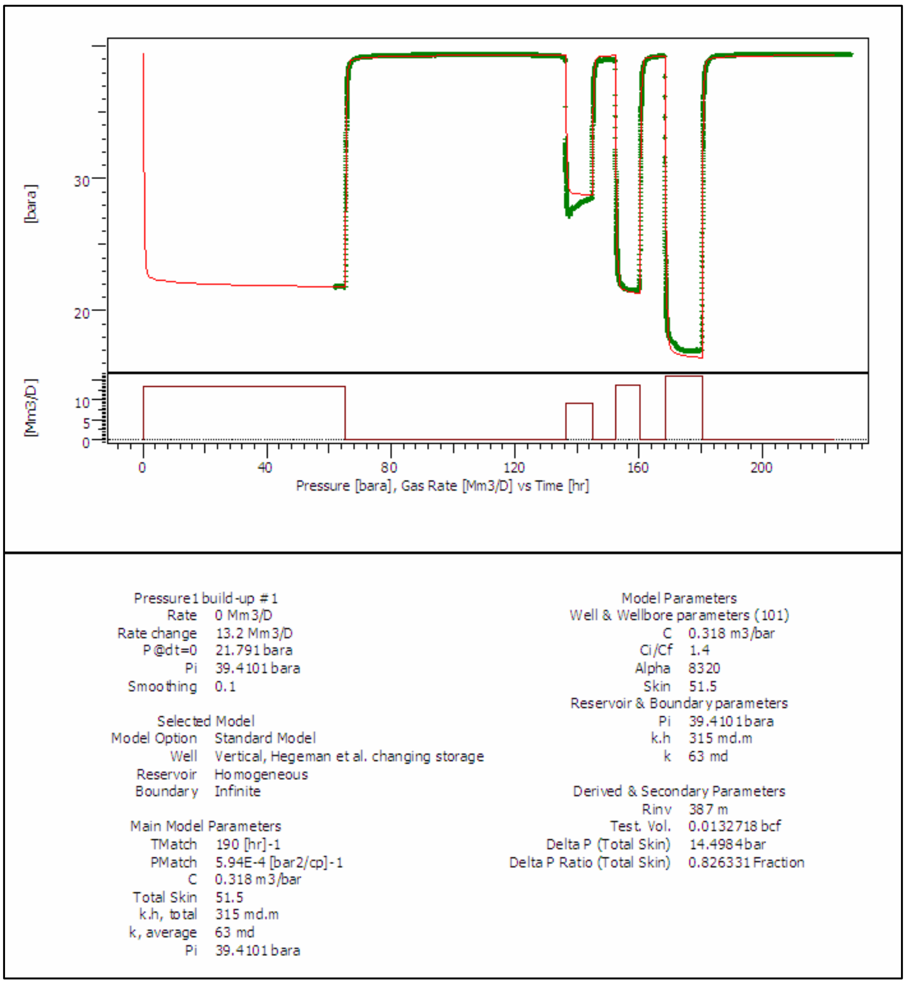

Fig. 3. Program for testing interval 1039-1031m, well X Tazlau

The results of the hydrodynamic investigation in an unsteady-state indicate a high damage degree of the layer-well inflow area (values of the *skin* factor over 50, obtained both from the interpretation of the derivative curve graph and of the semilog graph) even if the density of the drilling fluid was maintained at values close to those of the reservoir water. The pressure drop caused by this mechanical blockage contributed with about 82% to the total layer-well pressure drop.

This is explained because the productive layer, being highly depleted (pore pressure gradient of about 0.4 bar/10m) had to bear a differential pressure of about 60 bar, that led to a strong invasion of the drilling fluid filtrate in the layer.

Moreover, starting with 995 m and up to final depth of 1220 m this pressure imbalance caused, during drilling, a partial and even total loss of flow resulting in a high quantity of drilling fluid reaching in the productive layer [5].

After additional perforations of other productive layers the total flow rate was 9,500 Scm/day, considerably below the average flow rate of the wells drilled on the field, this being caused by the damage of the productive units in the layer-well inflow area.

Under these conditions, for unlocking the productive layer a re-perforation has been performed followed by an acidizing operation, having thereafter an increased flow rate at values exceeding 40,000 Scm/day.

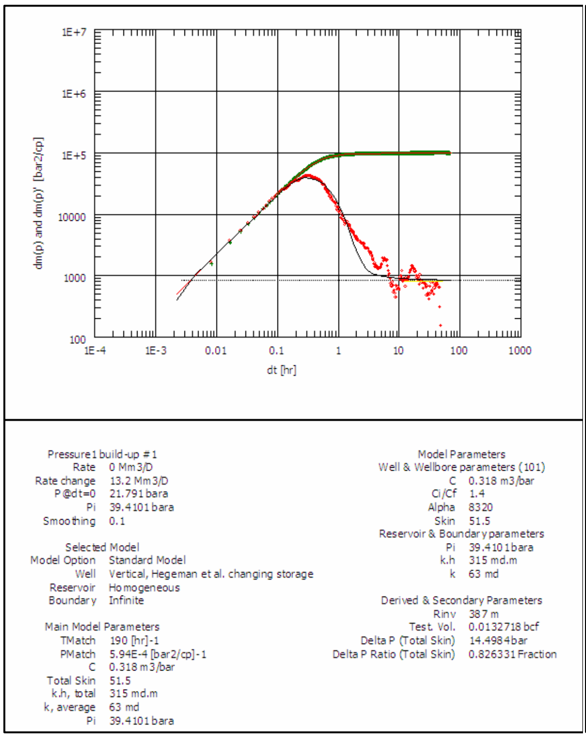

Fig. 4. Graph of the derivative function and its interpretation

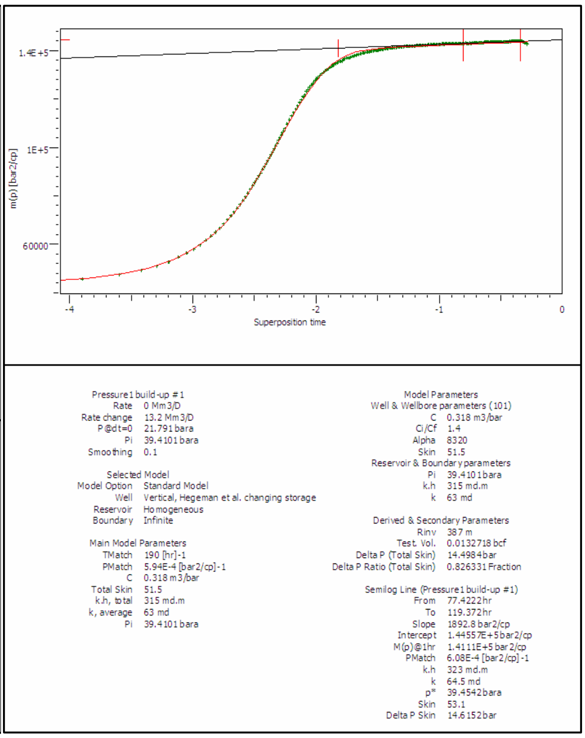

Fig. 5. Semilog graph and its interpretation

Conclusions

Highlighting the damage level and assessing its impact on physical properties of a productive formation is a key element in optimising the production performances.

Knowing that there is a damaged area near the well has undesirable operational and economic implications, therefore measures may be taken to minimise the damage degree by applying the appropriate well drilling technology. Moreover, the quantitative assessment of damage effects enables to perform technical-economic analyses to substantiate the decisions that have to be made.

When drilling gas wells, especially in case of depleted reservoirs, it is necessary to prevent damage of the layer-well inflow area by using proper drilling fluids as reaching the interest area. A very high drilling speed may be also beneficial and a reduced overpressure on the target area in order to limit the filtrate quantity invading the productive formation.

The ideal situation for preventing damage would be to have in the well a fluid with fewer solids, whose filtrate to be compatible with the formation and the reservoir fluids. When using a fluid with solids it would be preferable to use riskless solids (for example no barite) that can be easily destroyed by acidizing.

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Consideraţii privind deteriorarea formaţiunilor productive de gaze naturale ca urmare a deschiderii lor prin foraj

Rezumat

În timpul forajului sondelor, formaţiunea productivă intră în contact cu fluidul de foraj care produce o deteriorare a unei zonei limitate din vecinătatea peretelui sondei. Punerea în evidenţă a gradului de deteriorare şi evaluarea impactului acestuia asupra productivităţii sondei reprezintă un element cheie în optimizarea performanţelor în exploatare a respectivei formaţiuni. Una dintre cele mai utilizate şi eficiente metode de combatere a deteriorării mediului poros al formaţiunilor productive o reprezintă acidizarea, mai ales în cazul când aceste formaţiuni conţin procente mari de roci carbonatice. Este de preferat însă prevenirea deteriorării prin utilizarea de fluide de foraj cu cât mai puţine solide şi al cărui filtrat să fie compatibil cu formaţiunile și fluidele din zăcăminte.