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Performance Analysis of Hydrocarbon Wells Based on the Skin Zone

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Abstract. The purpose of this research is to study the area near the bottom of the hydrocarbon well, which is usually affected by drilling and development operations, and to find a modern method that improves the transfer of fluid from the reservoir to the well.
The area near the wellbore of an oil and gas formation is a very active and unstable zone. Field studies have shown that during the process of drilling the first well into the pay zone, a new area of disturbed permeability and porosity forms around the wellbore. This disturbed area is called the skin zone and is characterized by different properties. The skin zone can also form during the completion processes of hydrocarbon wells.
In terms of well test processing for any hydrocarbon well, the term "skin effect" should be understood as the effect of changes in the lower wellbore zone (i.e., changes in rock properties, changes in formation fluid, formation structure, geologic section, etc.) on bottom wellbore pressure. This indicates a change in the permeability of the bottom zone of the borehole during drilling and development.
In this paper, a new computational method is proposed in which the investigation of hydrocarbon well condition can be performed in two ways. The first way represents replacing the true radius of the wellbore (rw) with an effective radius (rwe). Under this condition, the skin factor term reflects only the effect of changes in the bottom wellbore zone. The second way is that the skin factor indicates not only the amount of change in the bottom wellbore zone, but also the effect of hydrodynamic imperfection of the hydrocarbon well performance during production, while maintaining the value of the well radius. After evaluating these parameters, it is possible to conclude the effectiveness of the implemented measures in the bottom wellbore zone of the formation. At the same time, the value of the skin factor after the performed works regarding the impact on the bottom zone can determine the positive or negative impact on the operation of the hydrocarbon well.
Keywords.Skin effect, Bottomhole zone, Hydrocarbon well condition, Wellbore radius, Hydrodynamic imperfection.

1. Introduction

The There is no industry in which minerals are not extracted from the rock without drilling a well. These are oil, gas, water, metals dissolved in acid, and other elements. The method of drilling a well is very cost-effective and is widely used in mining and commercial production [1-3]. The rock structure, rock pressure, synclines and anticlines, and mineral composition of the rock largely affect the process of hydrocarbon accumulation in a porous medium. The increase in rock pressure also affects the flow process of liquid and gas [4,5].

Hydrocarbons can accumulate in various rocks. According to their structure and characters, these rocks may be sandstone, dolomite, and limestone. The rocks sometimes differ in their granulometric or mechanical composition [6-8]. The reservoir properties of rocks also affect the process of oil accumulation. Thus, the normal type of reservoirs includes carbonate rocks, the grains of which consist largely of shells, grain fragments and oolites. The cement of sandstone is very diverse (marl, calcareous, clay, siliceous, ferruginous and so on) [9-11]. The cementing material may be both primary, deposited with the sand grains and chemically deposited as a result of the diagenetic process between and around the grains, and secondary, deposited from aqueous solutions that have penetrated the rock after deposition. Note that as the cement content increases, the rock may gradually changes to a chemogenic rock. This process may degrade the reservoir properties of the rock and gradually transform it into unproductive rock, creating a skin zone in the bottom zone of the production well [12-14].

The nature of the structure and the size of the rock cavities have a great influence on the reservoir properties of the rocks and the amount of hydrocarbon accumulation. Rock structure and voids (cavities) are classified as large, small and subcapillary. Hydrocarbons generally accumulate in capillaries, i.e. small cavities [15, 16].
Pressure affects the structure of the rock and the degree to which it is saturated with hydrocarbons. However, the resulting pressure (called hydrostatic reservoir pressure) has specific differences from the pressure generated by the rock (geostatic pressure). Hence, it is necessary to consider two groups of hydrocarbon accumulations [17-19]:

(a) under normal reservoir pressure and
(b) under abnormal reservoir pressure.

However, during drilling or completion of hydrocarbon wells, additional resistance occurs in the bottom wellbore zone. The appearance of a new zone partially reduces the permeability of this zone. To solve this problem, we consider the simplest case when the entire reservoir can be divided into two sharply defined zones based on permeability, rock structure, porosity, etc. The coaxial well is intended to serve as a boundary between formation zones with different physical properties. There is an abrupt change in rock properties between the wellbore and the target zone. Note that in real conditions, the deterioration of the wellbore zone can be caused by the influence of low-grade clay mud when drilling a productive formation and developing a wellbore, washing the bottom with various fluids (water, acid, steam), clogging the pores of the formation and so on [20, 21].

The following very useful conclusions follow from this: Disturbing of the hydrodynamic perfection of the production well and disturbing the near-bottom zone of the well do not prevent the determination of reservoir permeability throughout the well's drainage area. However, the wellbore bottom disturbance and the hydrodynamic perfection of the well have a strong influence on the magnitude of downhole pressure drop [22, 23]. Since this downhole pressure changes as a function of given wellbore flow rate, this affects the value of the coefficient of hydrocarbon well productivity.
Note that if the hydrocarbon well has a disturbance in the bottom-hole zone, the size of that zone will differ from the size of the formation.

Authors of works [24, 25] introduced the concept of «skin effect». The English word "skin" literally means "outer layer", "shell". The addition of this parameter reflects the main idea of these authors. This parameter quantitatively characterizes the skin effect of the lower zone of the borehole, which is briefly called the skin factor index.
Based on the above, it was necessary in this investigation to find and improve a new calculation method for the production specifications for this area.

2. Methods of research

Based on the approaches used to study hydrocarbon well conditions, a new calculation method was derived and performed. In the first approach, the true wellbore radius (rw) is replaced by the effective radius rwe. In the second approach, the skin factor term reflects only the effect of changes in the lower wellbore zone. In the second approach, the value of the true wellbore radius was retained and the skin factor indicates not only the amount of change in the lower wellbore zone but also the effect of hydrodynamic imperfection of hydrocarbon well performance during production.

3. Results and discussions

It is known that the general equation - the law of flow - can be represented as:

$$v = \frac{d_{eff}^2 Sl}{\mu} \cdot \frac{dP}{dr} \tag{1}$$

Where d_{eff} is the effective diameter of the particles composing the porous medium, Sl is the dimensionless coefficient (Slichter number), V is the velocity of the fluid flow, μ is the fluid viscosity ,*dp/dr* is the pressure gradient [26].

The effective particle diameter d_{eff}can be calculated by:

$$d_{eff} = \sqrt[3]{\frac{\sum n_i d_i}{\sum n_i}} \tag{2}$$

Where ni is the number of i^{th} fraction, d_i is the average diameter of the i fractions, determined by the formula:

$$d_i = \frac{1}{2}\left(d_i' + d_i''\right) \tag{3}$$

$d_i' + d_i''$ - Arithmetic mean of the extreme diameters

The dimensionless coefficient (Slichter number), SI, is a value that depends not only on the porosity but also on the structure of the pore space, which is determined by the shape of the particles and the degree of roughness of their surfaces [27-29]. We thus solve this problem for a one-dimensional radial flow of an incompressible fluid.

To do this, we take the cross-sectional area of the reservoir to be

A=2πrh,

where r is the formation radius, h is the formation thickness:

$$vA = 2\pi rh \frac{d_{eff}^2 Sl}{\mu} \cdot \frac{dP}{dr} \tag{4}$$

According to the linear flow law, we obtain:

$$dP = \frac{Q\mu}{d_{eff}^2 Sl} \frac{1}{2\pi h} \frac{dr}{r} \tag{5}$$

Where Q is the fluid flow rate .

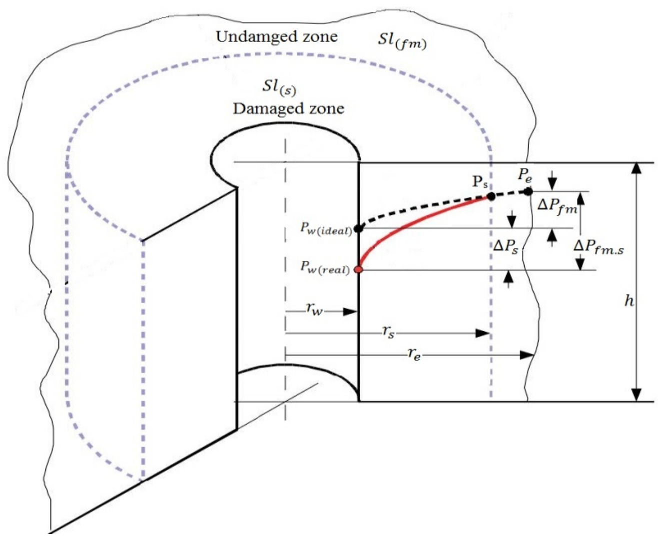

Figure 1. Diagram of the near-wellbore region of a heterogeneous formation: ΔP_{fm} - Reservoir pressure drop during fluid flow into an ideal wellbore (with natural $Sl_{(fm)}$) of the reservoir); $\Delta P_{fm.s}$- Total reservoir pressure drop during fluid flow into a real wellbore (considering the skin layer with $Sl_{(s)}$ of the formation); ΔP_s - Pressure drop at the wellbore bottom in the skin layer as a result of formation degradation.

Based on Fig. 1, which describes the skin and formation zones around the well, we assume the following boundary conditions using (1):

$$\int_{P_w}^{P_e} dP = \frac{Q\mu}{2\pi h}\left[\int_{r_w}^{r_s} \frac{1}{d_{eff(s)}^2 Sl_{(s)}} \frac{dr}{r} + \int_{r_s}^{r_e} \frac{1}{d_{eff(fm)}^2 Sl_{(fm)}} \frac{dr}{r}\right] \tag{6}$$

Where $deff_{(s)}$ and $deff_{(fm)}$are the corresponding effective diameter of the skin zone and formation;
Sl(s) and $Sl_{(fm)}$ are the Slichter numbers for the skin zone and formation, respectively;
P_w - bottom-hole pressure;
P_e- external pressure;
r_w and r_e - the radius of the borehole and formation, respectively;
r_s - the radius of the skin zone.
Integrating (6) , we obtain:

$$P_e - P_w = \frac{Q\mu}{2\pi h}\left[\frac{1}{d_{eff(s)}^2 Sl_s} \ln\frac{r_s}{r_w} + \frac{1}{d_{eff(fm)}^2 Sl_{fm}} \ln\frac{r_e}{r_s}\right] \tag{7}$$

By rearranging, adding and subtracting the value $\ln\frac{r_s}{r_w}$ we get:

$$P_e - P_w = \frac{Q\mu}{2\pi h\, d_{eff(fm)}^2 Sl_{fm}}\left[\frac{d_{eff(fm)}^2 Sl_{fm}}{d_{eff(s)}^2 Sl_s} \ln\frac{r_s}{r_w} + \ln\frac{r_e}{r_s} + ln\frac{r_s}{r_w} - ln\frac{r_s}{r_w}\right] \tag{8}$$

$$P_e - P_w = \frac{Q\mu}{2\pi h\, d_{eff(fm)}^2 Sl_{fm}}\left[\ln\frac{r_s}{r_w}\left(\frac{d_{eff(fm)}^2 Sl_{fm}}{d_{eff(s)}^2 Sl_s} - 1\right) + \ln\frac{r_e}{r_w}\right] \tag{9}$$

By introducing the concept of skin factor:

$$S = \ln\frac{r_s}{r_w}\left(\frac{d_{eff(fm)}^2 Sl_{fm}}{d_{eff(s)}^2 Sl_s} - 1\right) \quad (10)$$

In the final form, we then obtain:

$$P_e - P_w = \frac{Q\mu}{2\pi h\, d_{eff(fm)}^2 Sl_{fm}}\left[S + \ln\frac{r_e}{r_w}\right] \quad (11)$$

From this formula, the value of the volumetric fluid flow rate can be obtained:

$$Q = \frac{2\pi h\, d_{eff(fm)}^2 Sl_{fm}}{\mu(S + \ln\frac{r_e}{r_w})} \quad (12)$$

With these formulas, it is possible to assess the influence of the skin factor on the pressure drop in the well bottom and the fluid flow rate. Numerous observations have shown that the skin effect assumes values smaller than S = - 6 in practice [30- 32]. With this value of the skin factor, a theoretically conceivable extreme case is considered, namely,

$$\frac{d_{eff(fm)}^2 Sl_{fm}}{d_{eff(s)}^2 Sl_s} = 0 \quad (13)$$

Field observations showed that this value of skin factor was reached after hydraulic fracturing, but only on the basis of the calculations performed can a positive effect of hydraulic fracturing be concluded. In processing of numerous field studies, it was found that the value of the skin effect was very often large and positive. This indicates that the properties of the bottom wellbore zone deteriorate during drilling or well development. The analysis shows that after carrying out special works related to the effects on the bottom wellbore zone, the new values of skin effect were lower than the previous ones.

4. Conclusion

Considering the above, it can be shown that the skin effect provides an assessment of the condition of the lower wellbore zone depending on various parameters such as the structure of the pore space, the shape of the particles and the degree of roughness of their surfaces. These parameters must be taken into account when planning measures to improve the operation of a production well.
The change in the value of the skin factor can be used to assess the success of the work carried out in the lower borehole zone.
This method of calculation makes it possible to judge the imperfection of wells in two ways. First, replace the true well radius with the effective radius. In this case, the value of the skin factor reflects only the effect of changes in the zone of the well bottom.
The second method is that the skin factor indicates not only the amount of change in the well bottom, but also the effect of the hydrodynamic imperfection of the production well during production, while preserving the value of the well radius.

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