Application of skin factor in low water cut stage of tertiary oil recovery

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Abstract. The application of skin factor can evaluate the change of formation seepage capacity, and the positive and negative value of skin factor can effectively judge the pollution situation of formation skin area. Combined with well test data, this paper analyzes and applies skin factor change of central well after tertiary oil recovery enters low water cut stage. The skin factor is used to classify well test curves, qualitatively analyze well test curves, evaluate single well productivity, and put forward relevant opinions and measures. Furthermore, the change of formation permeability can be judged by the change range of skin factor, and the productivity of fracturing measures can be quantitatively evaluated by referring to the relevant technical limits of fracturing measures. It achieves the degree of using skin factor to evaluate productivity, and achieves good effect of increasing oil and reducing water after being applied to single well evaluation.

1. Introduction
At present, the positive and negative values of the skin factor can be used to effectively judge the pollution in the stratum skin area. Skin factor is an important parameter to analyze formation damage degree and evaluate the difference between formation permeability and formation permeability near wellbore. Skin factor is often used to judge formation pollution and evaluate the effect of measures[1]. The skin factor is used to express the degree of perfection near the bottom of a well:

\[ S = \left( \frac{k}{k_s} - 1 \right) \ln \frac{r_s}{r_w} \]  

(1)

In the formula:  
- \( k \)—Effective permeability of formation, \( \mu \text{m}^2 \);
- \( k_s \)—Effective permeability of contaminated formation, \( \mu \text{m}^2 \);
- \( r_s \)—Radius of imperfect pollution area, m.

According to the formula and field practice, when the formation near the wellbore is polluted, the permeability of the polluted area will be less than the deep permeability of the reservoir, and the pressure drop will be positive. The skin factor \( S \) is greater than 0, which indicates that the formation is polluted. The larger the \( S \) is, the more serious the pollution is, and the faster the permeability decreases near the well. When the fluid flows into the well, the energy loss is large, even if there is still a large amount of flowing oil in the formation, it will lose its development value. If the measures are taken, the seepage condition of the reservoir near the wellbore can be effectively improved and the production can be increased, \( S \) value decreases. \( S = 0 \), it is not polluted or reformed, but the well test interpretation is affected by many parameters. In general, it is not equal to 0. The additional pressure drop is negative when the perforation is over perfect or the formation is reformed, the skin factor is
less than 0.

2. Qualitative evaluation and analysis of skin factor

2.1. The relationship between skin factor and productivity

Formation pollution or improvement caused by drilling and completion, this creates additional resistance. It is assumed that the wellbore has a skin, the additional resistance produced by fluid flowing through it is just equal to the additional resistance produced by permeability change near the well. After the introduction of skin, it can be considered that the permeability of near well formation has not changed, the difficulty of mathematical treatment caused by the change of permeability near the well zone is avoided. The additional resistance caused by skin is expressed by skin factor S. With the increase of skin factor, the production of oil well decreases gradually[2]. The definition is as follows:

\[
Q_w = \frac{2\pi kh \lambda (p_r - p_w)(1 - f_w)}{\ln \frac{r_h}{r_w} + S}
\]  

(2)

2.2. Classification of skin factor in well test curve

Well test curve model and research method. According to the actual situation of field application of tertiary oil recovery, the basic model of typical block is selected for analysis, which is shown in formula 3. The basic model is single-phase flow in homogeneous reservoir. The inner boundary condition is with wellbore and skin factor, and the outer boundary condition is infinite. Well test data are mainly fitted by double logarithm, supplemented by semi logarithm.

\[
\begin{cases}
\frac{\partial^2 p}{\partial t^2} - \frac{1}{r} \frac{\partial p}{\partial r} - \frac{\partial p}{\partial r} + \frac{\partial p}{\partial r} (r_D, 0) = 0 \\
p (\infty, t_D) = 0 \\
C_D \frac{d p_w}{d t_D} - \left( \frac{\partial p}{\partial r} \right)_{r_D} \left( r_D = 1 \right) = 1 \\
p_w = \left( p - S \left( \frac{\partial p}{\partial r} \right) \right)_{r_D = 1}
\end{cases}
\]  

(3)

The average permeability level of the model is 380md, and the average formation pressure is 10.2MPa. According to the shape of well test curve and well test interpretation parameters in low water cut stage of oil reservoir. In this paper, permeability less than 380md is defined as low permeability, and formation pressure less than 10.2MPa is defined as low pressure. If there is no special explanation below, it is defined as this. The well test curves are divided into 5 types, and the classification criteria are shown in Table 1.

Table 1. Main types and classification criteria of well test curves.

| Curve type          | Normal Curve | Pollution blockage | High pressure and low permeability | Low pressure and low permeability | Low permeability with pollution |
|---------------------|--------------|--------------------|-----------------------------------|----------------------------------|---------------------------------|
| Permeability (md)   | ≥380         | ≥380               | <380                              | <380                             | <380                            |
| Skin factor         | <3.0         | ≥3.0               | <3.0                              | <3.0                             | ≥3.0                            |
| Pressure (MPa)      |              |                    | ≥10.2                             | <10.2                            |                                 |
2.3. Classification and analysis of well test curves

2.3.1. Normal Curve. On the double logarithmic curve, the curve is smooth. When the pressure line and the derivative line bifurcate, the derivative curve has no hump or the hump is very small, the derivative line appears 0.5 horizontal line quickly; The half logarithmic curve has a short afterflow section, and the radial flow straight line section is obvious, and the slope of the straight line section is small. This kind of oil well has no pollution. The skin factor is small and the permeability is high, so it is difficult to predict fracturing effect from well test curve. Take well X3-T1-SW65 as an example, the skin factor is -3.0.

2.3.2. Pollution blockage. On the double logarithmic curve, there is a large hump on the derivative curve. The larger the hump, the more serious the pollution. The half logarithmic curve has short afterflow and small slope. After fracturing, the pressure curve and derivative curve begin to separate in the early stage. The hump decreases and the curve tends to be flat. After fracturing, the skin factor is generally less than -4.0, the fracturing effect is good. Take the well test data comparison chart of X3-T2-SW64 well before and after the measures as an example.

2.3.3. High pressure and low permeability. On the double logarithmic curve, the derivative curve appears 0.5 horizontal line for a long time or does not appear 0.5 horizontal line. Lengthening of afterflow section of semi logarithmic curve, shortening of straight section of radial flow, the slope of the straight line is large. After fracturing this kind of well, reservoir permeability increases. In the early stage, the afterflow section was significantly shortened, and the radial flow appears earlier. The straight line becomes longer, and the slope of the curve decreases, and the flow coefficient increases, which has gained a good fracture result.

2.3.4. Low pressure and low permeability. On the double logarithmic curve, the derivative does not appear 0.5 line segment. Length of afterflow section of semi logarithmic curve, the straight section of radial flow is very short or no straight section appears. This kind of oil well is short of energy supply, so measures have little potential. The formation pressure of the well is 9.79MPa, and the skin factor was -3.07. Combined with dynamic and static data, we adjusted the sporadic scheme of well group.

2.3.5. Low permeability with pollution. On the double logarithm curve, the derivative curve has a large hump, and the 0.5 level line appears for a long time or does not appear. Length of afterflow section of semi logarithmic curve, the straight section of radial flow is short, and the slope of the straight line is large. After fracturing with large linear slope, on the double logarithm curve, hump reduction of derivative curve, the curve tends to be flat. The slope of the semi logarithmic curve decreases, permeability increase, the fracturing effect is the best. That is to say, it can improve the pollution near the well, it can also increase reservoir permeability.

Well test interpretation is always a difficult problem in well test research. The accuracy and reliability of the parameters are not high, so it directly affects the judgment of this kind of oil well. For example, the calculated formation pressure of some oil wells is lower than that at the end of shut in. For this kind of curve, combining the results of fine geological research, we analyze and judge whether the fracturing horizon is effectively connected with the surrounding wells. In addition, the effect of oil well fracturing is affected by many factors such as construction quality, and the potential of measures should be comprehensively analyzed and judged.

3. Determination of the relationship between skin factor and fracturing effect

In order to eliminate the influence of skin factor data inaccuracy, the research object is the central well of the third oil recovery in the well test curve type, analyze the single well that has completed fracturing measures. The permeability of this kind of well is relatively high, which is less affected by other reasons. The fractured wells are divided into three grades according to the average daily oil
production in the effective period, they are A, B and C respectively. Among them, the average daily oil 
increase of grade A is more than 10t/d, and the average daily oil increase of grade B is 8~10t/d, and the 
average daily oil increase of grade C is less than 8t/d. Determine the relationship between skin factor 
and permeability, and the correlation expression between fracturing effect and skin factor S is 
determined finally.

In order to analyze the influence of skin factor S on fracturing effect, the distribution range and 
variation of skin factor S of 30 fractured wells are analyzed and compared, as shown in Table 2.

Table 2. Changes of skin factor s before and after fracturing.

| Fracturing effect | Number of wells | S average value before fracturing | S average value after fracturing | S drop value (ΔS) |
|-------------------|-----------------|----------------------------------|----------------------------------|-----------------|
| A                 | 6               | 0.6                              | -3.4                             | 4.0             |
| B                 | 19              | 0.2                              | -3.2                             | 3.4             |
| C                 | 5               | -0.1                             | -2.1                             | 2.0             |

As can be seen from Table 2, the average skin factor of type A well is the largest before fracturing, 
then the decline is the largest after fracturing. From static data, Class A well has high permeability, it is 
located in the main channel zone. Before fracturing, the skin factor of class B and class C decreased in 
turn. After fracturing, the skin factor decreases gradually. Because of the low permeability, the skin 
factor is inconsistent with the static and dynamic data. According to the statistical law, there is a 
parabolic relationship between the decrease of skin factor and skin factor before compression. The 
larger the skin factor is, the greater the decrease is, the more obvious the effect of daily oil increase is 
after fracturing. It shows that oil well fracturing can effectively remove the pollution.

Empirical relationship between skin factor decrease and skin factor before measures:

\[ -\Delta S = 0.0757S^2 + 1.416S + 2.9375 \]  \hspace{1cm} (4)

Empirical formula of oil production increase caused by skin factor decrease:

\[ \frac{\Delta Q}{Q} = 2.5035 \ln(-\Delta S) + 5.0317 \]  \hspace{1cm} (5)

Theoretical analysis and practical results show that, skin factor before fracturing is one of the 
important parameters to determine fracturing effect. According to the statistical data of well test and 
fracturing effect, the skin factor before the measure is judged properly, calculating oil production 
growth. For oil wells with skin factor greater than 0 and large interval value and large increase, 
priority should be given to measures.

4. Application of skin factor in field practice

The above conclusions are applied in well selection, the skin factor S of fracturing well X1-123-W55 is 
1.192 before the measure. Compared with the previous year before the measures, the S value of -3.440 
changed greatly. From negative to positive, on the double logarithmic curve, the derivative curve 
appears 0.5 horizontal line for a long time, the hump is steep. Lengthening of afterflow section of semi 
logarithmic curve, the slope of the straight line is large. It belongs to high pressure and low 
permeability type, as shown in Figure 1. After substituting Formula 1 and 2, the skin factor was 
predicted to decrease to -3.54, and the oil was predicted to 12.5t. In addition, the well is in line with the 
technical limit of fracturing well and layer selection in low water cut stage. At present, the fracturing 
scheme has been worked out.
5. Conclusion

(1) The application of well test curve can evaluate the effect of measures. After fracturing, the curve hump of double logarithmic derivative disappears and the influence of afterflow weakens, which is one of the characteristics of fracturing efficiency improvement in low water cut stage.

(2) Well selection principle for fracturing in low water cut stage: Before the measure, the skin factor is greater than 0; On the double logarithmic curve, the hump is larger; On the semi logarithmic curve, the afterflow section is longer.

(3) In the stage of low water cut, comprehensive use of dynamic and static data analysis, clear measure potential is the prerequisite for effective tapping remaining oil.

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