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Stimulation for minimizing the total skin factor in carbonate reservoirs

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ABSTRACT

Carbonate reservoir is characterized by natural fractures and vugs. Reservoir damage can be easily caused by drilling and completion processes that bring high total skin factor and additional pressure drop. To improve the well productivity, it is necessary to decompose the total skin factor and implement mechanism oriented actions to minimize the skin factor. To eliminate the reservoir damage, this work first aims at optimizing drilling and well completion technologies. Then, a fracture network acidizing technique that can remove "non-radial & network-like" damage by making full use of natural fractures and minimizing the skin factor is proposed to maximize the well productivity.

1. Introduction

In recent years, with the continuous exploration and development of deep marine carbonate reservoirs, China has ensured great oil and gas resources, such as the Puguang gas field and Longwangmiao gas reservoirs in Sichuan province. Due to the wide distribution of natural fractures and vugs, carbonate reservoirs easily suffer from reservoir damage caused by drilling and completion. The high total skin factor and additional pressure drop depress fluid conductivity around the wellbore.

The total skin factor of oil and gas wells is controlled by many factors, which typically includes petrophysical properties, fluid properties, degree of formation damage and stimulation, well geometry, well completion, number of fluid phases, and fluid flow velocity (Darcy or non-Darcy). There are plenty of models studying the total skin factor. Odeh (1980) considered skin factor as restricted entry caused by plugged perforations or insufficient number of perforations; Vrbik (1991) thought that pseudo-skin factor arises because only a portion of the pay zone allows the flow of oil into the wellbore, i.e. the so-called partial well completion. Samaniego (1996), Economides et al. (2000) and Yildiz (2006) presented how to put the individual skin factors together and correctly predict the total skin factor. Previous researches on skin factor mainly studied the reservoir damage, perforation and completion theoretically. Studies integrating field application to discuss how to minimize total skin factor are very rare. Problems including decomposition of total skin factor from the perspective of production stimulation and proper methods to reduce them, as well as effective engineering solutions for high skin factor need to be solved. All of these will be discussed in the following sections.

In this paper, based on the binomial deliverability equation, the authors prove that it is feasible to increase production by minimizing the skin factor from a few aspects. Specifically, on one hand, the total skin factor is decomposed into components associated with drilling and well completion techniques which can be further optimized to prevent damage from the root; on the other hand, in view of the preexisting natural fractures and vugs in carbonate reservoirs, fracturing and acidizing techniques are optimized to reduce the skin factor by connecting the hydraulic fractures with them to form high conductive networks.

2. Stimulation mechanisms in reducing skin factor

For oil and gas wells drilled in carbonate reservoirs, the total skin factor before stimulation represents the overall degree of damage and seepage resistance in the near wellbore area. The

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greater the skin factor, the more serious damage and the more seepage pressure drop are. According to the binomial deliverability equation, Li et al. (2003) and Guo et al. (2014) described the relationship between total skin factor and productivity as follows.

$$P_e^2 - P_{wf}^2 = AQ_g + BQ_g^2 \tag{1}$$

where,

$$A = \frac{8.48 \times 10^4 \mu_g ZTP_{sc}}{KhT_{sc}} \left(\lg \frac{r_i}{r_w} + 0.434S \right) \tag{2}$$

$$B = \frac{1.966 \times 10^{-8} \beta \gamma_g ZTP_{sc}^2}{h^2 T_{sc}^2 R} \left(\frac{1}{r_w} - \frac{1}{r_i} \right) \tag{3}$$

$$\beta = 1.873 \times 10^8 \frac{hr_w \mu_g T_{sc} R}{\gamma_g P_{sc} K} D \tag{4}$$

Based on the field data of an oilfield in Sichuan basin in China, the IPR (inflow performance relationship) curves with different skin factors are drawn in Fig. 1. Every drop of 5 in the skin factor adds more than 20% in the open-flow capacity. When the reservoir is damaged with total skin factor of 15, the production is $480 \times 104\ m^3/d$. If the total skin drops to 0 through optimized design of drilling and completion, then the production will increase by over 65%. Acid fracturing is able to further reduce the skin factor to −15, in that case, the production will increase by more than 80%. Therefore, by optimizing the drilling and completion design and implementing acid fracturing treatment, the skin factor can be significantly reduced and thus high productivity can be achieved.

The total pressure drop in completed wells can be expressed as.

$$\Delta P = \frac{141.2 Q_g \mu_g B_g}{Kh} [\ln(r_e/r_w) + S] \tag{5}$$

which gives the productivity index,

$$J_c = \frac{Kh}{141.2 \mu_g B_g [\ln(r_e/r_w) + S]} \tag{6}$$

Total skin factor can be estimated from production well testing data. For the wells with high total skin factor, to minimize the skin factor, it is essential to decompose the total skin factor into components associated with the root causes of the damage.

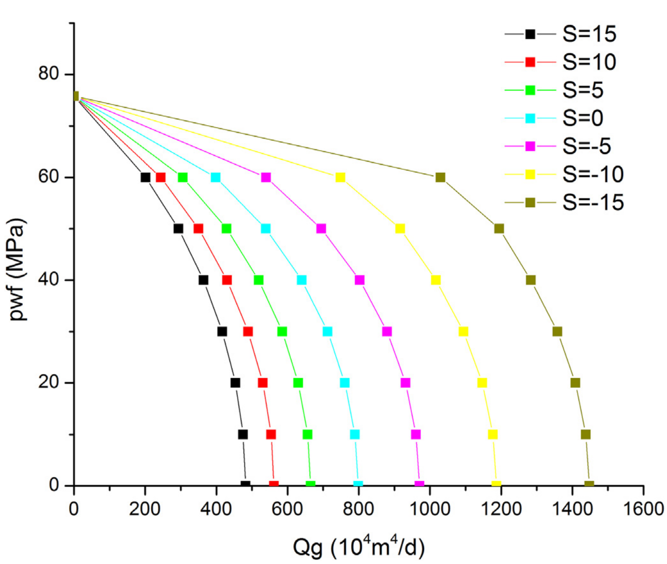

Fig. 1. Gas well IPR curves under different total skin factors.

Table 1
Expressions of total skin factor and its components (Yildiz, 2006).

Vrbik (1991)	$S_t = S_d + S_{pp} + S_p + S_\theta + S_f$
Daltaban and Wall (1998)	$S_t = S_d + S_{pp} + S_\theta$
McLeod (1983)	$S_{pdc} = S_d + S_{pp} + S_\theta$
Bell et al. (1995)	$S_t = S_d + S_{pp} + S_\theta$
	$S_t = S_{pp} + \frac{h}{h_p}\left[\frac{S_{pdc}}{\gamma} + \left(9 + 11\frac{h}{h_p}\right)S_\theta\right]$
	$S_{pdc} = S_d + (K/K_d)(S_p + S_{cz} + S_x)$
Jones and Slusser (1974)	$S_{pd} = S_d + (K/K_d)S_p$
	$S_t = (h/h_p)S_{pd} + S_{pp}$
Penmatcha et al. (1995)	$S_t = (h/h_p)S_{pd} + S_{pp} + S_p + S_{cz} + S_\theta$
Golan and Whitson (1991)	$S_t = (h/h_p)(S_d + S_p) + S_{pp} + S_{cz}$
Samaniego and Ley (1996)	$S_t = (h/h_p)(S_d + S_p) + S_{pp} + S_\theta + S_f$
Economides et al. (2000)	$S_t = S_d + S_p + S_{\theta pp}$

3. Decomposition of total skin factor

Combination of the mechanical skin, completion pseudo-skin, and perforation pseudo-skin and geometrical pseudo-skin makes the total skin factor for a well. Many studies expressed the total skin factor as a linear summation of the individual skin factors.

$$S = S_d + S_{PT} + S_{PF} + S_\theta + S_b + S_{tu} + S_A \tag{7}$$

where S is the total skin factor, S_d is mechanical skin factor due to drilling damage, S_{PT} is completion pseudo-skin due to partial penetration, S_{PF} is perforation pseudo-skin factor, S_θ is geometrical pseudo-skin due to well inclination, S_b is mobility change pseudo-skin factor, S_{tu} is non-Darcy pseudo-skin factor due to high velocity flow and S_A is the pseudo-skin factor related to drainage area shapes.

Aside from Equation (7), many other publications present the total skin equations in different forms, as listed in Table 1.

3.1. Mechanical damage skin factor

Also known as drilling and completion damage skin factor, mechanical damage around the wellbore leads to additional pressure drop and reduces fluid production. Hawkins (1956) proposed that the damaged zone can be considered as a concentric cylinder

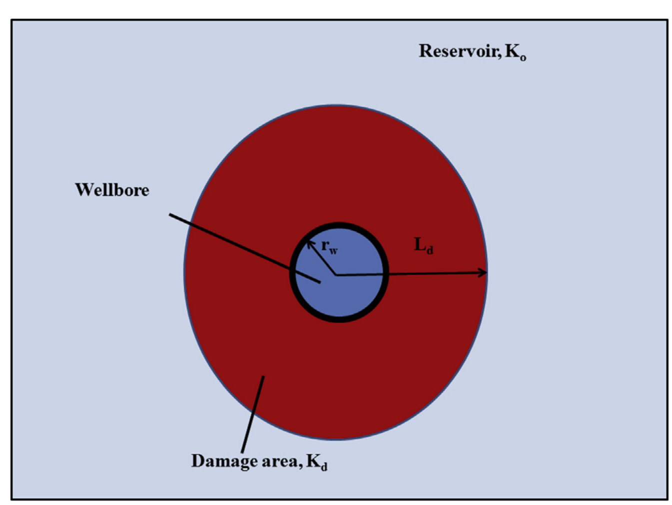

Fig. 2. Concentric damage zone around an open hole well.