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Research Article

Modeling of Fluid Filtration around a Perforation and Wellbore and Investigating its Effect on Skin Factor

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ABSTRACT

In this paper, a mathematical model is presented for a water based mud filtration into a perforation and wellbore and its effect on reducing the relative permeability and damage of the formation. The proposed model includes fluid invasion, filter cake buildup, and relative permeability, formation damage model and skin factor. The penetration of solid particles into the formation was avoided. Filter cake and mud filtration models were developed based on a mass balance equation of cake deposition and erosion and Darcy's equation. The invasion flow of mud filtrate into the formation was considered radial. A convection dispersion equation was solved numerically to characterize filtrate invasion.

Keywords: Numerical simulation; Mud filtrate invasion model; Mud filtration distribution model; Formation damage model; Skin factor

INTRODUCTION

The mud cake thickness and the filtration velocity depend on the overbalance pressure, formation permeability, mud cake characteristics and the invasion time. The effective permeability distribution and the depth of invasion are the keys to estimating the damage caused by fluid invasion. Damage radius and skin factor predicted by the model are in agreement with published results [1].

Using computational fluid dynamics, the invasion flow of mud filtrate into a perforation and well was modeled and the effect of perforation geometry on the invasion rate was simulated. The skin factor is considerable with increasing the length of perforation to 20 cm [2].

The filtration rate actually indicates the ability of the mud filtrate to pass through the mud cake and the formation. In fact, the deposition of solid mud particles is a mass balance of the rate of sedimentation of particles and their rate of removal from the wall of the well [3]. By integrating the Darcy relation, thefiltration can be achieved under a certain pressure difference.

The distribution of fluids in the invasion zone is a function of the filtration concentration of the mud. The invasion of mud filtrate into the formation and its propulsion is a two phase displacement. Assuming the formation is hydrophilic, the saturation of the wetting fluid (water) increases, which reduces the relative oil permeability around the well. Therefore, the most important mechanism of damage due to the invasion of drilling mud filtrate is related to saturation changes due to invasion of mud filtrate. Many models have been proposed to predict the degree of damage [4].

Donaldson, et al.; Windarto, et al.; Colins, et al.; Hermia, et al.; Nerveres, et al.; Willis, et al.; Sherman Sherwood, et al.; Civan and Engler, et al.; Civan, et al.; Parn-anurak, et al.; Liu, et al.; Tien, et al.; Yen, et al. and Ghazanfari, et al. simulated the invasion of drilling mud flow into the formation and the damage around the wellbore by considering the sub-model hypotheses [5].

- Drilling mud in static/dynamic condition.
- Considering/without considering the compaction of the mud cake.

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- With/without considering the penetration of solid particles into the formation.
- The invasion flow of mud into the formation as linear flow or radial flow.
- The invasion flow of mud into the formation following the Darcy/non-Darcy law.

MATERIALS AND METHDOS

In this paper, the distribution of drilling mud filtrate and its penetration rate around the horizontal wellbore were modeled by considering the radial flow and non-penetration of solid particles into the formation in the static state and the permeability changes around the wellbore and the damage rates of the formation were simulated [6].

Mud filtrate invasion model

Single phase flow is assumed to be radial. Displacement is immiscible, bottom hole pressure and reservoir pressure are constant. The penetration of solid particles is avoided.

Assuming that no solid particles penetrate into the formation, all solid particles deposit in the inner wall of the well. Mud cake formation depends on the density of the drilling fluid [7].

The rate of mud cake formation is related to the rate of sedimentation and erosion rate, which is due to the shear force caused by the movement of drilling mud in the well. The sedimentation rate also depends on the volume of mud that penetrates into the formation. As the mud cake thickens, its formation rate decreases until a state of equilibrium is established between the erosion rate and the sedimentation rate. At that time the thickness of the mud cake is fixed [8].

Mud filtration distribution model

Flower effluent concentration depends on factors such as formation heterogeneity, formation porosity, mud filtrate invasion rate and time, and can change radially. Assuming no change in porosity and incompressible fluid, Civan, et al. stated the following equation [9].

$$\frac{1}{r}\frac{\partial}{\partial r}\left(rD\frac{\partial C}{\partial r}\right)-\frac{u}{\emptyset(1-S_{or})}\frac{\partial C}{\partial r}=\frac{\partial C}{\partial t} \quad \text{(Eq. 1)}$$

Permeability and skin factor in the damaged formation

Drilling mud is assumed to be water-based, so increasing the amount of mud filtrate indicates an increase in water saturation. As the water saturation increases, the relative permeability of the displaced phase (oil) decreases. This process damages the reservoir and ultimately reduces production from the reservoir.

Water saturation change is a function of mud concentration and residual oil saturation and irreversible water saturation, which is calculated from the following equation.

$$S_{mud}(r)=C_f(r)\left(S_{w\cdot max}-S_{w\cdot min}\right)+S_{w\cdot min} \quad \text{(Eq. 2)}$$

A change in saturation that causes a change in relative permeability causes damage to the reservoir due to trapping or blocking of the oil phase. Therefore, this damage due to the relative permeability change in the reservoir is different due to the difference in the saturation of the mud filtrate. The following equation is used to estimate reservoir damage.

$$s=k_{eff}\int_{r_w}^{r_d}\left(\frac{1}{rk_{d\cdot eff}(r)}\right)dr-\ln\left(\frac{r_d}{r_w}\right) \quad \text{(Eq. 3)}$$

$$S=\frac{k_{eff}}{\bar{k}_{D\cdot eff}}\ln\left(\frac{r_d}{r_w}\right)-\ln\left(\frac{r_d}{r_w}\right) \quad \text{(Eq.4)}$$

RESULTS AND DISCUSSION

Validation

To determine the accuracy of the proposed model, two comparisons are performed using the data of Yan, et al. In the first comparison, the penetration depth of mud effluent in 30 minutes in 13 samples from a reservoir is determined and the results were compared with the results of experimental data of Yan et al. In the second comparison, the penetration depth and skin factor for a horizontal well are calculated and the model results and experimental results are compared (Figures 1-3). In both cases, there is no rotation of the mud and the mud is at static condition [10].

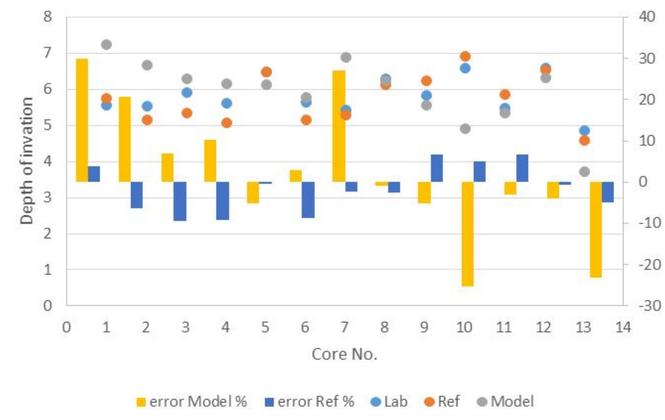

Figure 1: Comparison diagram of invasion depth of drilling mud filtrate based on experimental data (Yan model, et al.) and the presented model.

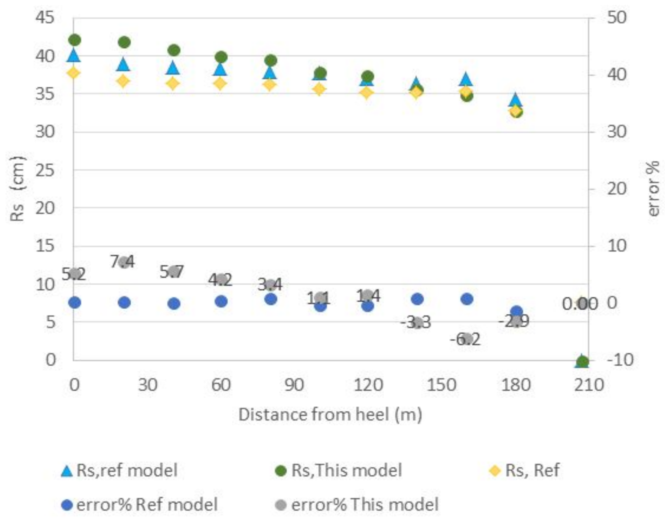

Figure 2: Comparison diagram of the damage radius of the proposed model and reference for a horizontal well in static condition.

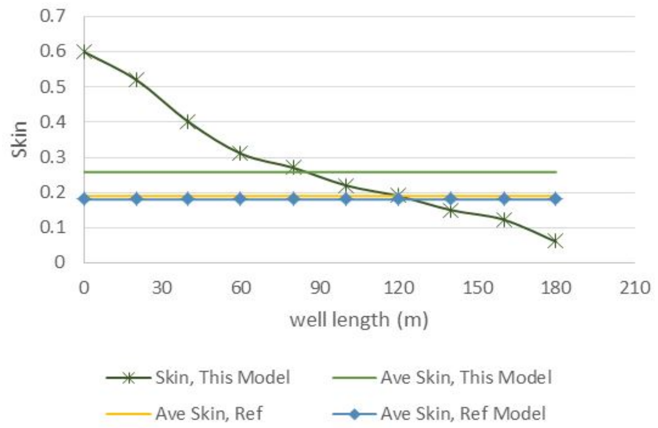

Figure 3: Profiles of concentration and penetration rate of drilling mud filtrate around a perforation with time.

Simulation results

By solving the drilling mud concentration distribution model around a perforation, we estimate the amount of damage caused by drilling mud penetration into the perforation tunnel and porous media. Figure 4 shows the desired perforation geometry. The perforation is filled with gravel particles. The permeability of the formation is about 63 md. The perforation permeability filled with gravel is equal to 560 md. The only way to connect the drilling mud and the formation is through the perforation entrance (Figure 5).

In order to determine, the formation damage due to drilling mud filtration, drilling mud invasion rate was simulated during 20 minutes for different perforation depth. Then, according to the damage relationship of the formation, the amount of skin factor was calculated. Figure 6 shows the skin factor diagram. Although increasing the channel length reduces the skin factor, but due to the penetration of drilling mud, skin factor increases. Because with increasing perforation length, the contact surface of drilling mud with the formation increases (Figure 7).

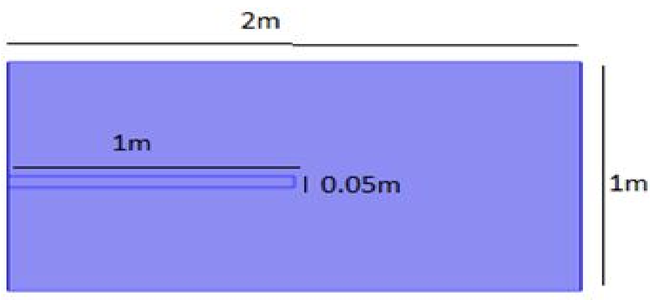

Figure 4: perforation geometry to study the concentration distribution of drilling mud.

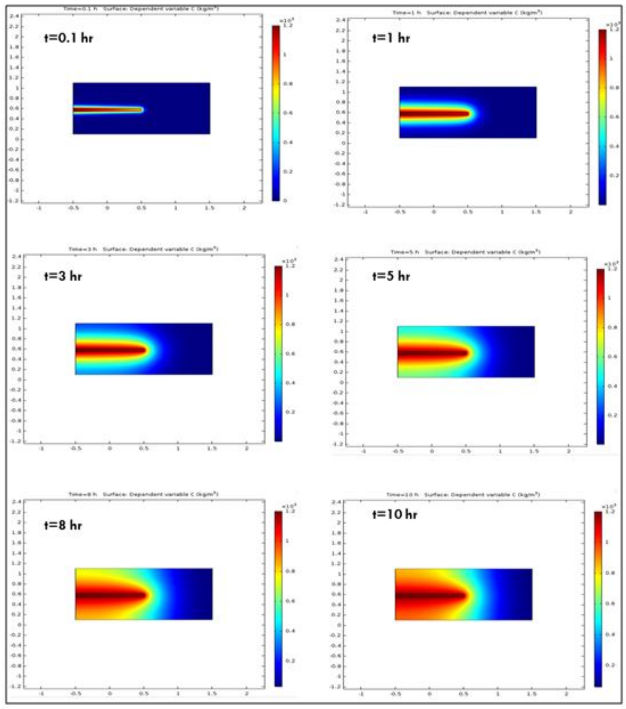

Figure 5: Distribution of drilling mud concentration penetrates around a perforation *vs.* time.

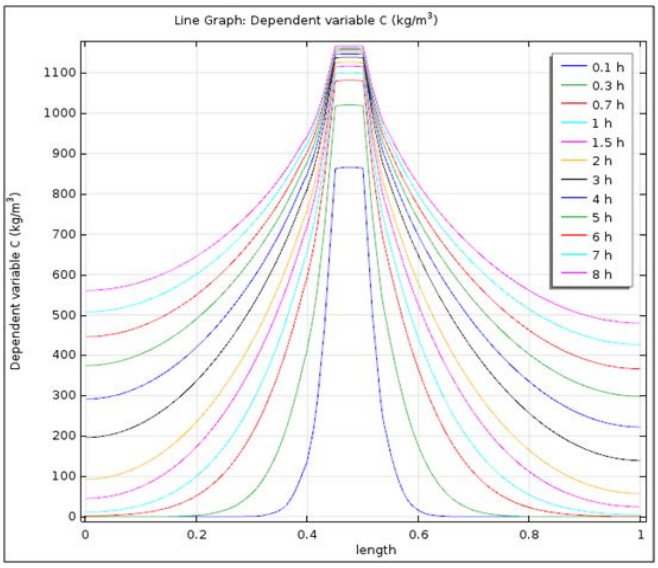

Figure 6: Profiles of concentration and penetration rate of drilling mud filtrate around a perforation with time.

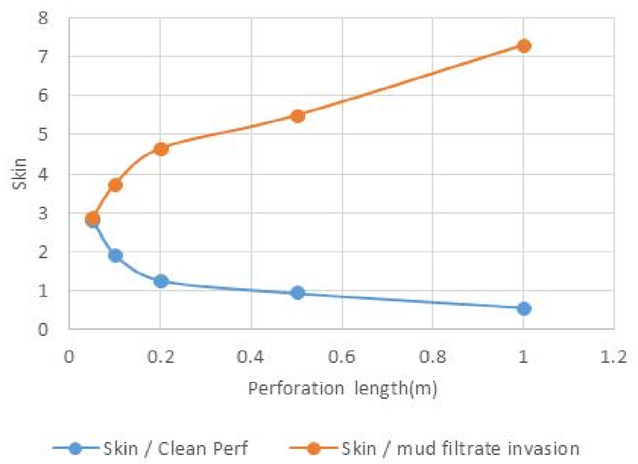

Figure 7: Changes skin factor with increasing perforation depth in two modes of clean channel/channel under the influence of drilling fluid penetration into it and porous media.

CONCLUSION

Modeling of invasion of water based drilling mud into the formation and its effect on the formation damage was done.

The penetration depth of drilling mud was validated with laboratory data of the articles, which has an acceptable degree of validity from the proposed model.

Radial flow was considered for the penetration of drilling mud into the formation. The penetration of solid particles into the formation has been neglected

Penetration rate to the formation is a function of the amount of over balance pressure, permeability of the formation, the amount of time the drilling mud contact with the formation and characteristics of mud filtrate including porosity, density and permeability.

The effect of perforation geometry on drilling mud penetration and formation damage was simulated. The amount of damage of the formation is considerable with increasing the perforation depth to 20 cm. Data and results related to filtration conditions, can be predicted the conditions of the invasion area and the thickness of the mud filtrate cake in oil and gas wells when using water based drilling mud.

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