Modeling of Induced Formation Damage due to Capillary Blocking and Mud Filtration During Drilling Operations

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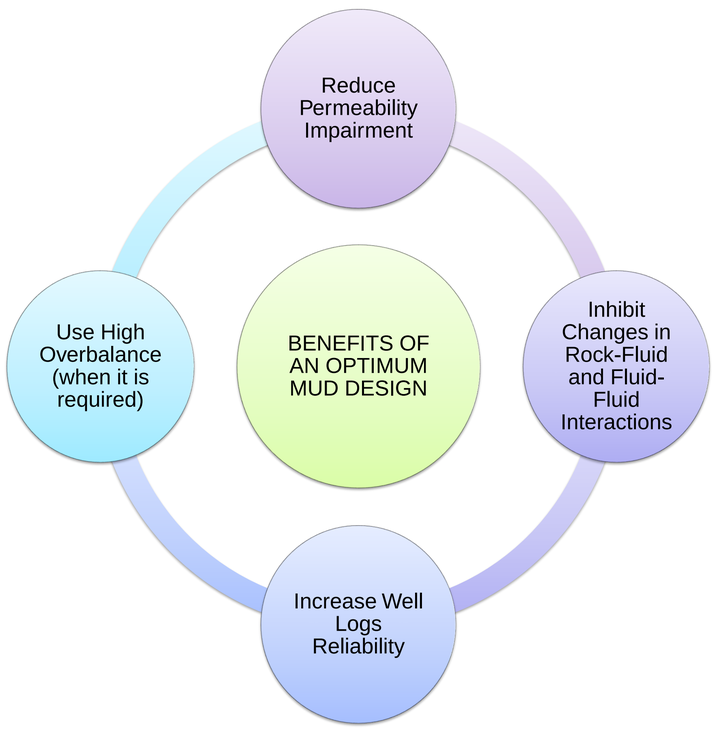
MODELING OF INDUCED DAMAGE AND MUD FILTRATE IMPACTS

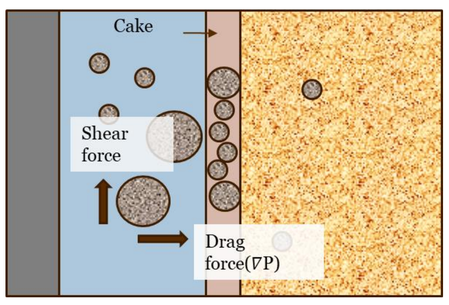
Well drilling remains one of the most critical operations that contribute to formation damage. Based on a phenomenological model, a software tool was built to predict the effects along the invaded zone, and thus optimize both mud formulation and operative conditions.



CONCEPTUAL, MATHEMATICAL AND NUMERICAL MODEL

Understanding each of the following phenomena allows them to be integrated and combined into a single model:

- Filter cake growth by particle accumulation



Cake thickness controls the filtration rate (inner boundary condition) and it is determined by balancing forces (axial and radial forces) and petrophysical characterization. Cake growth is treated explicitly and is updated at every step.

$$\frac{dh_c}{dt} = C_{d1}\left(u_x - \frac{Y}{\alpha c_{sm}}\right)$$

- Oil, gas, water and species flow in porous media

For oil-based muds, emulsified droplets were similarly modeled to polymers in water-based muds. Unlike solids, droplets and polymers are exclusively used to model the cake properties.

$$\frac{\partial}{\partial t}\left(\varepsilon_p\, \rho_p\, w_{i,p}\right) + \vec{\nabla}\left(w_{i,p}\, \rho_p\, \overrightarrow{u_p}\right) + \dot{q_{i,p}} + \sum_{op=1}^{Np} \dot{m}_{i,op\to p} = 0$$

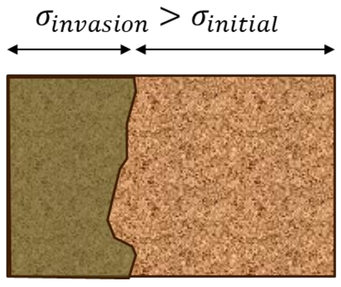
Unknowns associated with Black-Oil Model and solids trapping and entrainment are solved implicitly.

- Pore throat trapping (PTT) and interfacial tension changes (IFT)

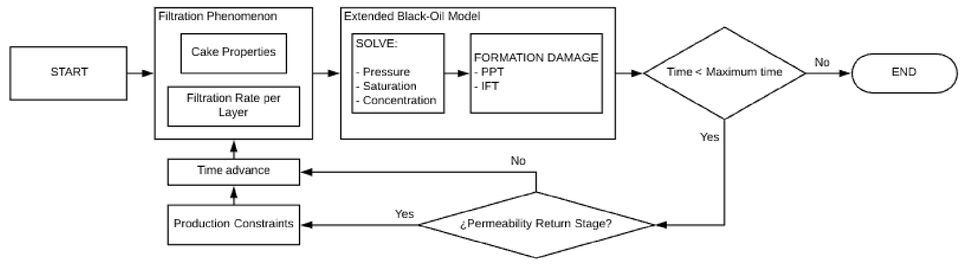
PPT has the most potential formation damage. Moreover, high IFT mud filtrate increases capillary pressures, blocking narrowest pores and reducing well productivity.

PPT: $$\frac{d\sigma_i}{dt} = \frac{u_p}{\emptyset S_p}\left(\lambda_{1s} c_{t,i} - \lambda_{2s}\sigma_i\right)$$

IFT: $$P_c = \frac{2\sigma\cos(\theta)}{r}$$



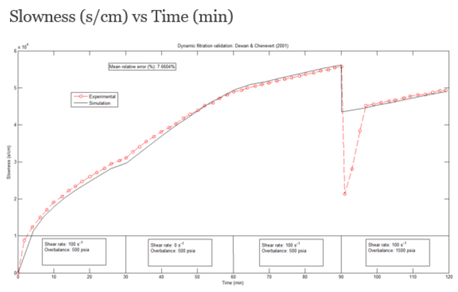
The numerical model uses a Newtonian linearization method, building and solving a Jacobian matrix and its Residual vector.



RESULTS

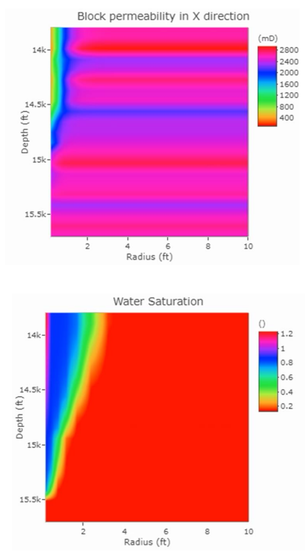
The whole simulation model was successfully validated with experimental data reported in the literature and tests performed in the laboratories at Universidad Nacional de Colombia.

Laboratory Validation

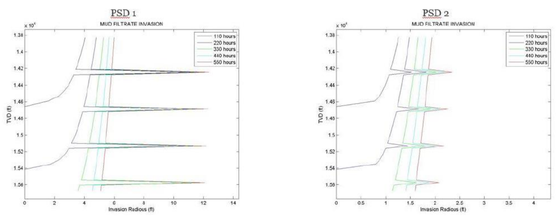


Experiments allow us to observe the response of filtration rate and cake properties to changes in mud formulation, rock properties, and operative conditions. Parameters are calibrated with filtrate rates and volumes.

Field-scale performance:



Radial applications involve field variables such as mud density, overbalance pressure and pump rate. The grid permits the presence of high permeability channels (discrete fractures). Optimizing particle size distributions for a specific case, invasion radius could be reduced up to 70%. Furthermore, production constraints effect on permeability return can be assessed with final skin/permeability profiles along the well.



CONCLUSIONS

- This work endeavors to quantify the effect of production constraints and mud formulation on permeability return with a full implicit and flexible simulator.
- The assessment of mud filtrate effects efficiently and economically optimizes classical formulations, as well as modifies physical and manageable variables including particle size distribution curves, pumping rate, overbalance and additives concentrations.

FORTHCOMING RESEARCH

Being flexible, the software is able to incorporate novel additives and the impacts on rock productivity, continuous fractured systems, stress sensitive rocks and well-strengthening applications.

References:

• Lohne, Arild, and others. «Formation Damage and Well Productivity Simulation.» SPE Journal (SPE), 2010: 751-769.
• Dewan, J.T., y M.E. Chenevert. «A Model for Filtration of Water-base Mud During Drilling: Determination of Mudcake Parameters.» Petrophysics, 2001: 237-250
• Civan, Faruk. «A Multi-Phase Mud Filtrate Invasion and Wellbore Filter Cake Formation Model.» Society of Petroleum Engineers, 1994: 399-412.

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