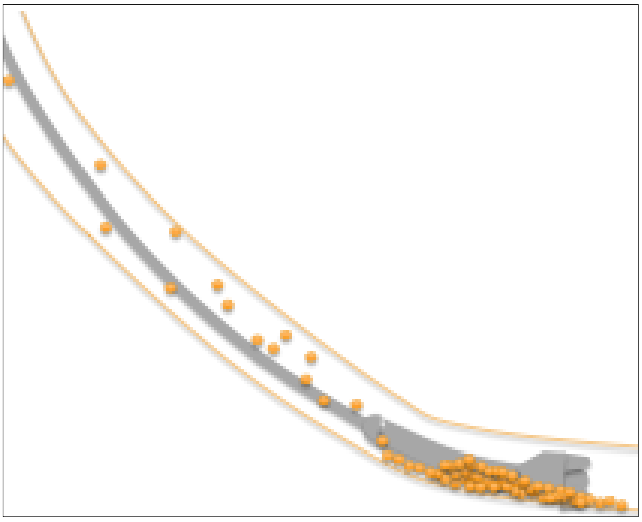
Agglomeration and transport of drilling generated particles in the oilwell
European Study Group with Industry ESGI102

Background: Process Description

When drilling an oilwell, produced drilling cuttings are transported to the surface by the use of drilling fluid. Such a fluid is also known as drilling mud, due to the historical use of water with large clay content. Using powerful pumps, the drilling fluid is pumped from the surface through the hollow drill pipe, through the drill bit, and subsequently up the annulus of the well back to the surface, where the cuttings are separated from the drilling fluid using machinery known as shale shakers, containing one or multiple screens through which the drilling fluid is passed.



The drilling fluid is normally oil-based or water based, although synthetic fluids are also applied. The oil-based fluid consists of a water-in-oil emulsion, with the base oil as the main component. Water based drilling fluids are normally brine-clay solutions, where there also may be a smaller oil component present, forming an emulsion with the brine. The main additives are emulsifiers, solids weight material and viscosifiers such as clays and polymers. Due to the particle additives, the drilling fluids have non-Newtonian shear-thinning rheology characteristics which are beneficial for the transport. These fluids will also gel when static, enabling support of particles in fluid suspension. Another important mechanism for transport is the wetting of the cuttings particles in suspension, which may be influenced by the same chemicals used as emulsifiers [Caenn, 2011].

An oilwell may have significant inclination, as shown in the figure. The mechanisms governing the characteristics of cuttings transport depend on the inclination of the wellbore. Multiple mechanistic models exist for describing the behavior in the various sections of different inclination in the well [Kamp, 1999] [Pilhevari,1999] [Ramadan, 2005].

Agglomeration and transport of drilling generated particles in the oilwell
European Study Group with Industry ESGI102

In order to drill an oilwell, strands of drill pipe must be continuously added as the well grows longer. In conventional drilling operations this requires stopping the mud-pumps to enable connection of the new strand to the top of the drill pipe. When the well is static the drilled cuttings may fall to the bottom (wall) of the inclined well, forming what is known as a cuttings bed. Through interaction with the drill pipe, drill bit and fluid flow, such cuttings beds may cause sticking of the drill pipe and packing off of the well, further leading to fracturing of the formation, fluid loss, and potential loss of the well. The drilling fluid composition and resulting properties shall both help avoid forming of cuttings beds, and further help move or dissolve these should they occur [Clark,1994] [Nazari,2010] [Cayeux,2014].

The mechanisms of the cuttings bed are poorly understood. Both fluid flow and drill pipe rotation help break up cuttings beds, but only qualitative mechanistic models exist for interpreting and predicting transport behavior in the well [Azar,1997] [Walker, 2000]. Further, the observed difference in cuttings bed and transport behaviour in oil-based and water-based drilling fluids is poorly understood. A better understanding of these mechanisms will help improve the quality, efficiency and success rate of drilling operations.

Problems to be explored

1. **Arrive at a physical and mathematical understanding of the problem through development of a complete mathematical description.**
2. **Analyse the characteristics of the problem and suggest initial asymptotic solutions through problem simplification.**
3. **Explain the key differences between oil-based and water-based drilling fluids for cuttings bed formation, dissolution, and cuttings transport.**

Possible mathematical simplifications

- We look on the fragment of the wellbore (last stand). Diameter of well could be considered as a constant (~50cm). Diameter of the pipe is ~12.5cm in its narrow part and ~25cm in its wide part.

- The system could be considered as a horizontal or slightly inclined tube with external and internal boundaries.

- The external boundaries correspond to the oil-well boundaries. The internal boundary is a rotating drilling pipe. The “left” boundary condition is outflow and the “right“ boundary condition is inflow.

- The source (fluid and cuttings) is located on the right boundary. The pipe rotates with approximately constant speed, than stops rotation and renews it after certain time -- this is a continuous process. The pipe drills for ~30m, stops for 5-15 min and restarts rotation and drilling.

Agglomeration and transport of drilling generated particles in the oilwell
European Study Group with Industry ESGI102

Physical properties of the modeled process

- Cuttings in the suspension are advected and fall to bottom at the rate depending on viscosity density of the drilling fluid.

- Horizontal symmetry cannot be employed, as the gravitation force must be taken into account.

- Eccentricity of pipe should be considered as it exercises a force on the cutting bed.

- Two types of the drilling fluid should be considered: Water-Based and Oil-Based. Drilling fluids have varying rheology as a function of temperature, pressure and composition. Other features of the fluid are shear thinning, yield stress behaviour and gel formation. Common yield stress behaviour models: yield with linear plastic viscosity and yield with power law combined.

References

Azar, J. J., & Sanchez, R. A. (1997, January 1). Important Issues in Cuttings Transport for Drilling Directional Wells. Society of Petroleum Engineers. doi:10.2118/39020-MS

Caenn, R., Darley, H.C.H., & Gray, G.R., (2011, August). Composition and Properties of Drilling and Completion Fluids, Gulf Professional Publishing; 6 edition (August 29, 2011), ISBN-10: 0080445152, ISBN-13: 978-0123838582

Cayeux, E., Mesagan, T., Tanripada, S., Zidan, M., & Fjelde, K. K. (2014, March 1). Real-Time Evaluation of Hole-Cleaning Conditions With a Transient Cuttings-Transport Model. Society of Petroleum Engineers. doi:10.2118/163492-PA

Clark, R. K., & Bickham, K. L. (1994, January 1). A Mechanistic Model for Cuttings Transport. Society of Petroleum Engineers. doi:10.2118/28306-MS

Kamp, A. M., & Rivero, M. (1999, January 1). Layer Modeling for Cuttings Transport in Highly Inclined Wellbores. Society of Petroleum Engineers. doi:10.2118/53942-MS

Nazari, T., Hareland, G., & Azar, J. J. (2010, January 1). Review of Cuttings Transport in Directional Well Drilling: Systematic Approach. Society of Petroleum Engineers. doi:10.2118/132372-MS

Ozbayoglu, M. E., Ettehadi Osgouei, R., Ozbayoglu, A., & Yuksel, E. (2010, January 1). Estimation of Very-Difficult-to-Identify Data for Hole Cleaning, Cuttings Transport and Pressure Drop Estimation in Directional and Horizontal Drilling. Society of Petroleum Engineers. doi:10.2118/136304-MS

Pilehvari, A. A., Azar, J. J., & Shirazi, S. A. (1999, September 1). State-of-the-Art Cuttings Transport in Horizontal Wellbores. Society of Petroleum Engineers. doi:10.2118/57716-PA

Ramadan, A., Skalle, P., & Saasen, A., (2005). Application of a three-layer modeling approach for solids transport in horizontal and inclined channels, Chemical Engineering Science, 60, (2005) 2557-2570, doi:10.1016/j.ces.2004.12.011

Walker, S., & Li, J. (2000, January 1). The Effects of Particle Size, Fluid Rheology, and Pipe Eccentricity on Cuttings Transport. Society of Petroleum Engineers. doi:10.2118/60755-MS