Validation of a CFD Non-Newtonian Eulerian-Eulerian Multiphase Model for Predicting Wellbore Filter Cake Formation

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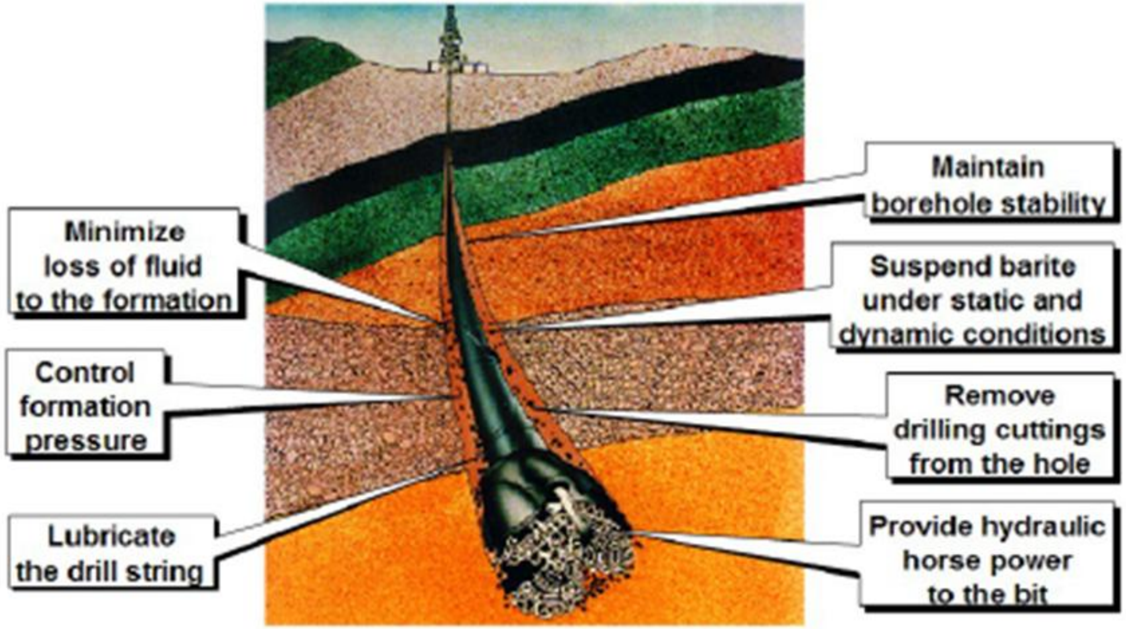
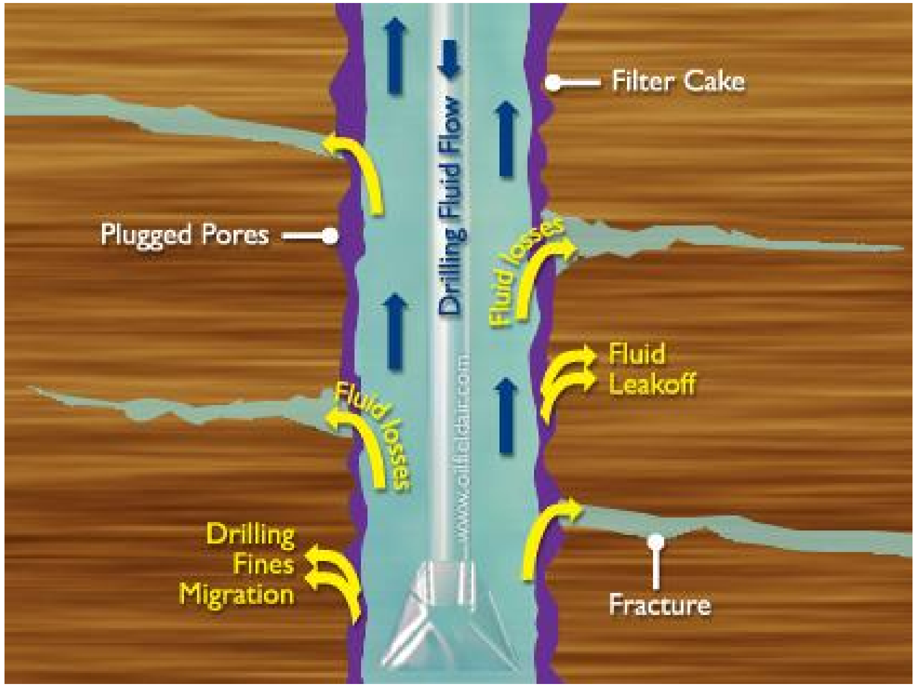
Problem Definition

Filter Cake Formation in Oil & Gas Wellbore Drilling





Problem Definition
A CFD Modelling Approach

In order to optimize the wellbore drilling process, good predictions of the filter cake formation is necessary. CFD modelling is used to approach this problem.

CFD Modelling Approach

Multi-Fluid Flow Model

- Eulerian-Eulerian Fluid/Granular Flow
- Non-Newtonian Viscosity Model
- Heat Transfer Model

Filtration Model

- Flow in Porous Material

Statistical Data Analysis Model

- Regression model
- Qualitative data comparison model

Modelling Approach
Model Structure in ANSYS FLUENT

- **Multi-Fluid Model (Eulerian-Eulerian)**
  - Primary phase: Liquid
  - Secondary phase: Granular (drilling fluid particles)
  - Tertiary phase: Granular (rock debris)
  - Laminar flow / Turbulent flow (*k-ε* model)

$$\nabla.(\alpha_l \rho_l \vec{v_l}\,\vec{v_s}) = -\alpha_l \nabla P + \nabla.\overline{\tau_1} + \alpha_l \rho_l \vec{g} - \{K_{sl}\,(\vec{v_l} - \vec{v_s})\}$$

$$\nabla.(\alpha_s \rho_s \vec{v_s}\vec{v_s}) = -\alpha_s \nabla p - \nabla p_s + \nabla.\overline{\tau_s} + \alpha_s \rho_s \vec{g} + \{(\quad K_{ls}(\vec{v_l} - \vec{v_s}))\}$$

- **Non-Newtonian Viscosity Model (Power Law)**

$$\tau_1 = \alpha_l \tau \overline{\dot{\gamma}_l} + \alpha_l \left(\lambda_l - \frac{2}{3}\tau\right) \nabla.\vec{v_l}\,\bar{I} \qquad \tau = k\left|\overline{\dot{\gamma}_l}\right|^{n-1}$$

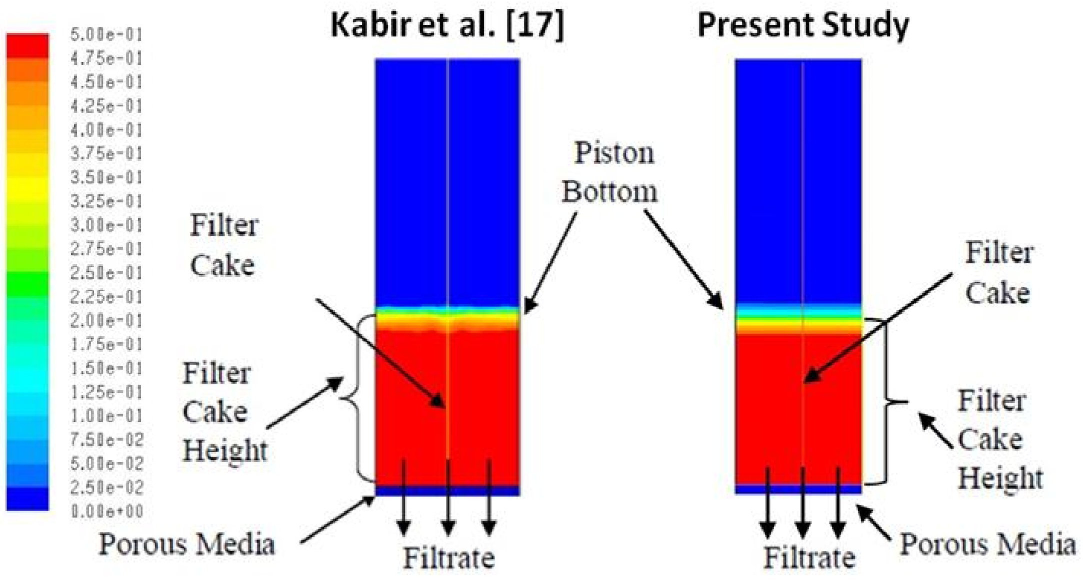
- **Porous Material**

$$\nabla P = -\frac{\mu}{K_p} v \qquad K_p = \frac{{D_p}^2}{150}\frac{\varepsilon^3}{(1-\varepsilon)^2}$$

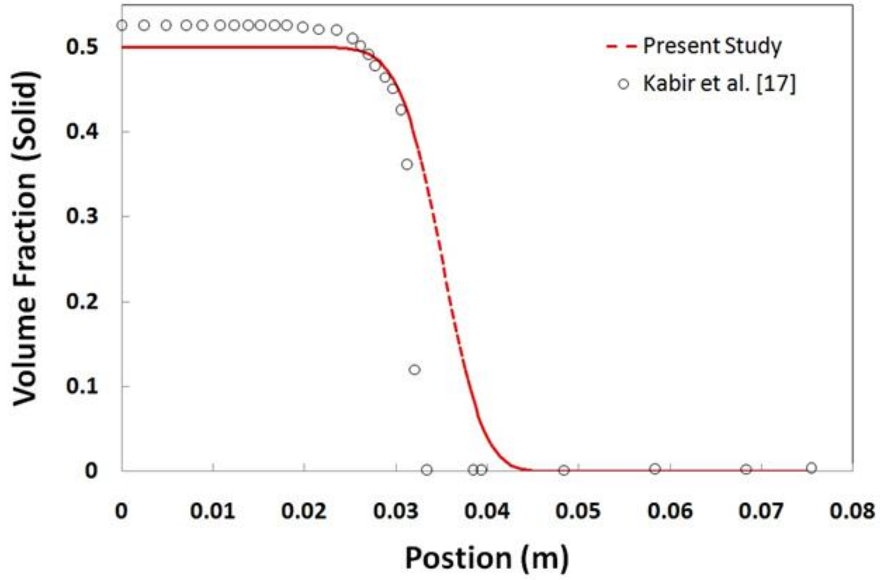
- **Heat Transfer Model**

$$\nabla.\left[\alpha_q \rho_q \overrightarrow{u_q} h_q\right] = \overline{\tau_q} : \nabla \overrightarrow{u_q} - \nabla.\overrightarrow{q_q} + \sum_{p-1}^{n} \left[\overrightarrow{Q_{pq}}\right]$$

Modelling Approach
Validation

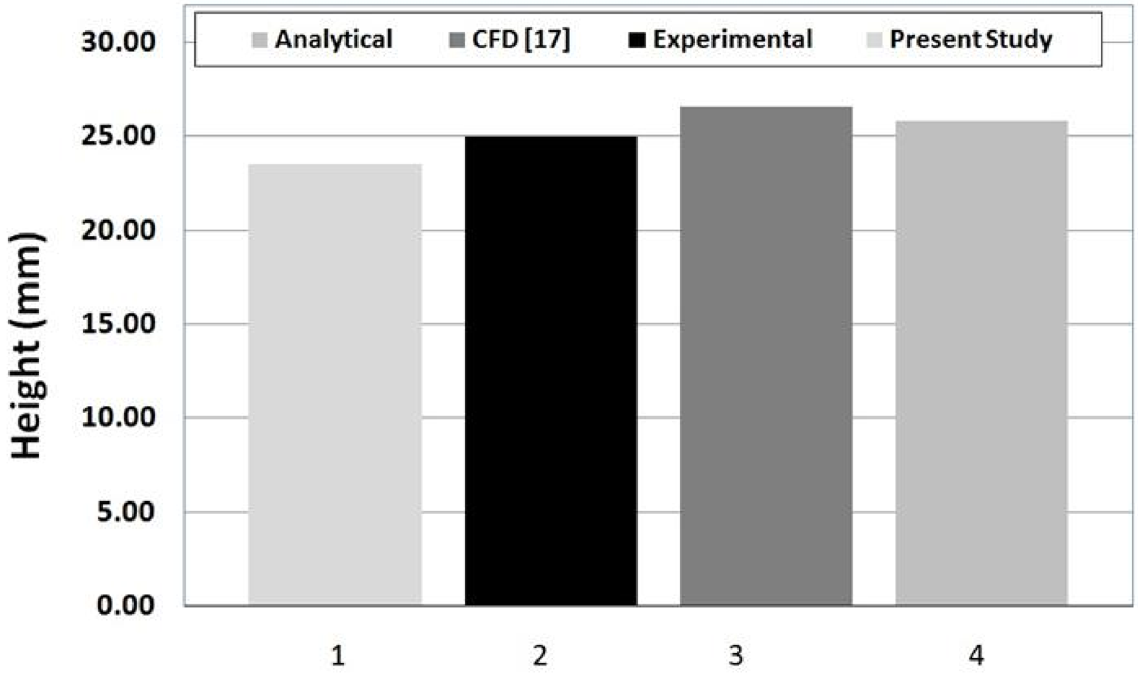


Filter cake formation represented by solid volume fraction distribution for the present study and kabir el al. [17]



Quantitative solid concentration profile along the vertical axis

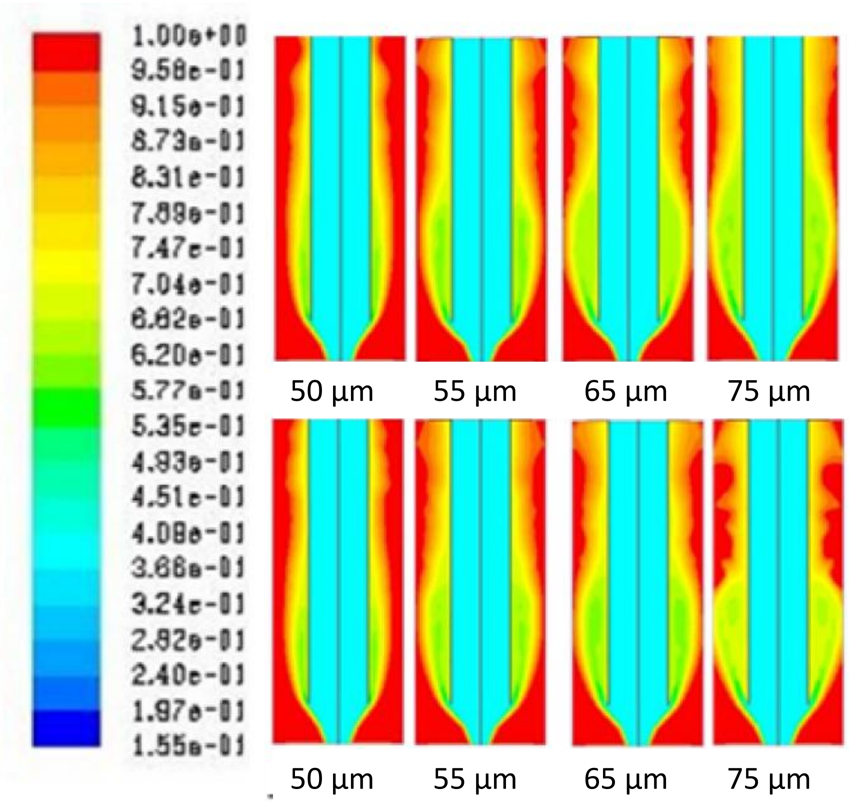
Modelling Approach
Validation



Comparison of filter cake thicknesses dervied from different methods including the present model

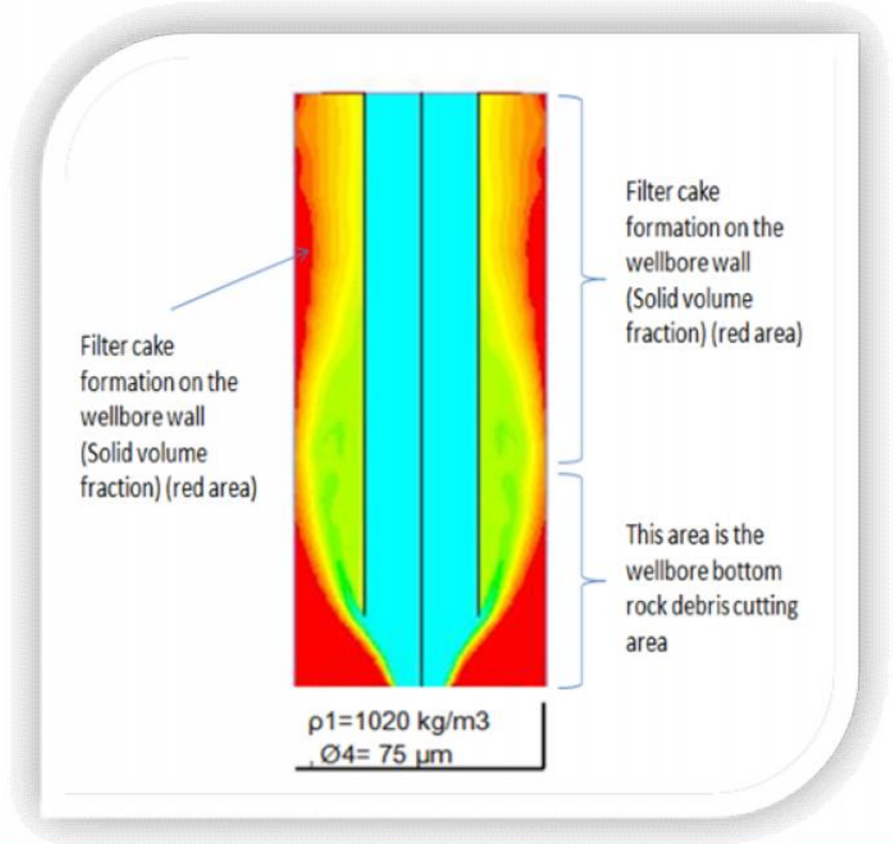
Modelling Filter Cake Formation

Deep drilling (175 MPa, 443 K) with different fluids

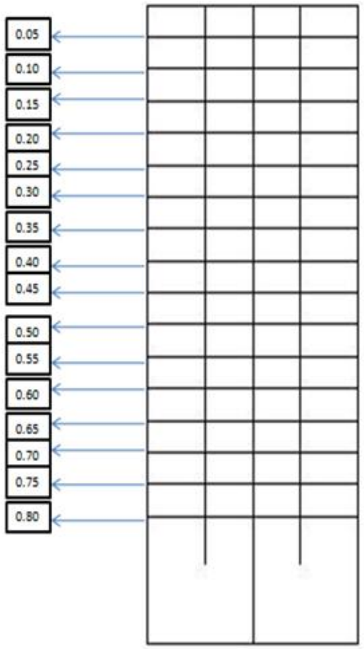


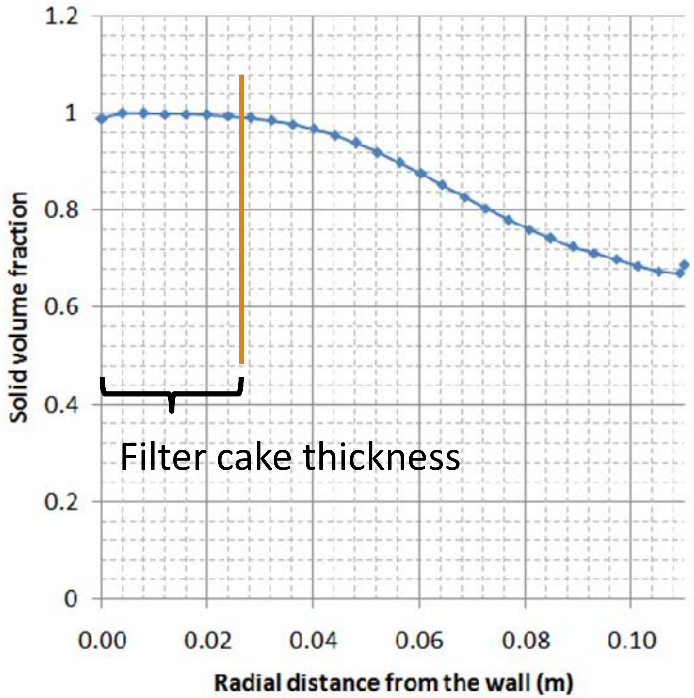
P = 1020 kg/m^3

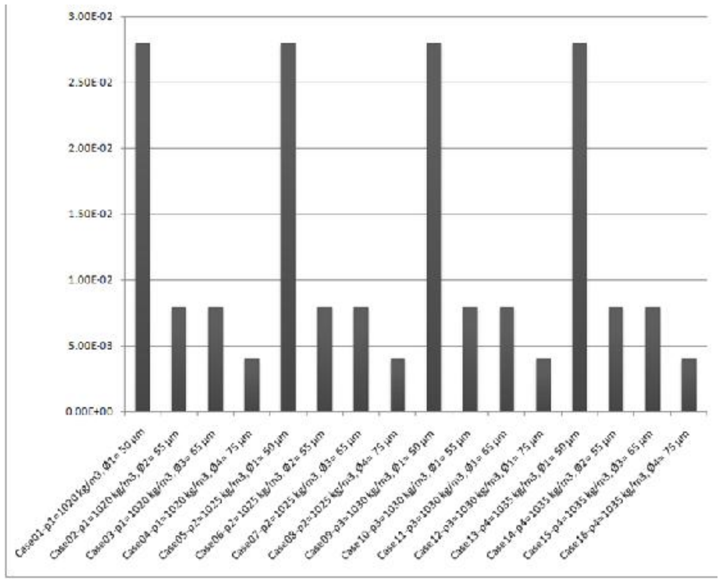
P = 1025 kg/m^3



Filter Cake Thickness
Calculation method from CFD Results





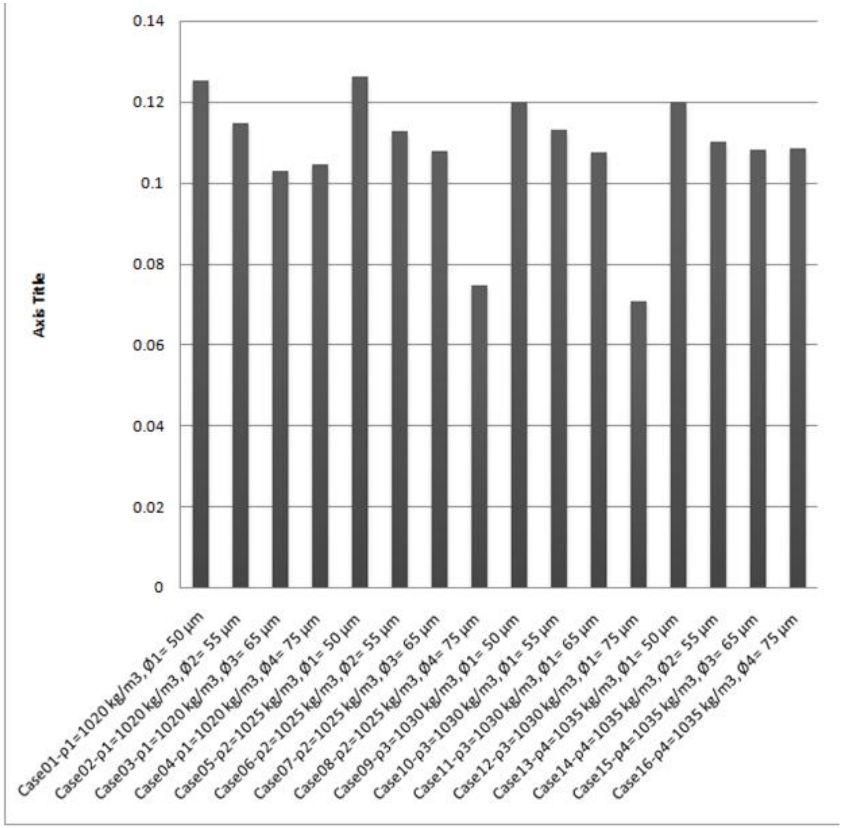


The solid volume fraction was calculated at 16 stations along the domain

The average radial profile solid volume fraction was plotted for each case

This was repeated for all cases

Filter Cake Uniformity
Calculation method from CFD results



The standard deviation (σ) was calculated for the 16 data set from every case. The less σ, the better the filter cake.

The range of σ was found to be within 0.05 to 0.123. This range of values shows that the predicted filter cake profiles were acceptably uniform in comparison with actual measurements.

Conclusion

- A multi-fluid model for simulation filter cake formation during oil & gas wellbore drilling was successfully built, tested and validated using ANSYS FLUENT CFD package.
- The model was successfully used to compare the filter cake formation, in terms of thickness and uniformity, for different drilling fluids (base fluid density and particle size)
- This model will enable better optimization for drilling processes to be carried out.