CORE DERIVED DATA IN NEAR WELLBORE MODELLING

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ABSTRACT

Core analysis is well established as a process that enables accurate simulation of formation damage mechanisms and geomechanical rock properties. Core analysis tests are normally undertaken on small core plug samples and the results of these tests must be interpreted to replicate reservoir scale. This scaling up of core analysis test data is relatively well proven for deep reservoir, away from the well, but in the past little attention has been paid to the specific conditions near to wells and at the wellbore – reservoir boundary.

Return permeability formation damage tests have improved in quality and increased in quantity over the last two decades. There is no doubt that there is great value in appropriate laboratory testing and that they can assist in the process of fluid and completion choices and in damage mitigation. Upscaling of laboratory return permeability testing to near wellbore and reservoir scale has been neglected. High quality core testing is conducted and then the results sometimes extrapolated using the most basic and inaccurate inflow models.

The ever advancing speed and capacity of computational power available has led to a revolution in the detail that can be captured in inflow modelling. Precise, numerical models with millions of connected volumes can be used to represent near wellbore geometry down to millimetres of resolution. These models can be built to accept the detail available from core tests and thus upscale with accuracy and significantly improve the validity of well inflow performance prediction and the prediction of the impact of formation damage. Modelling techniques such as computational fluid dynamics (CFD) are now being used to model the near wellbore and capture the value of core analysis testing by applying appropriate physical laws to represent the reservoir and fluids.

Prediction of the strength or integrity of wellbores under varying conditions of stress is enhanced by real measurements on real core. Upscaling of core data to near wellbore scale has been challenging in the past. But advances in computing power and in software has enabled accurate translation of laboratory core data in to real well failure predictions. Processes such as finite element (FE) numerical modelling improve prediction of sand production and guide sand management decisions.

This paper will present examples of both CFD and FE modelling and demonstrates the

value of core analysis testing and translation in the prediction of formation damage impact and potential sand production. Core analysis testing is of great value to critical well engineering decisions if it is properly translated.

INTRODUCTION

Core testing is unique in that it enables direct measurements of rock properties of oil and gas reservoirs. These direct measurements, sometimes underestimated, can provide a strong pillar on which we can build models that attempt to predict the performance of wells. All other reservoir data or measurements are indirect and require correlation or interpretation. Core data can be used to derive important rock properties such as rock strength, permeability and susceptibility to formation damage. Of course the core must be carefully cut, retrieved to surface, handled and selected. And the measurements must be carefully made in order to provide the best simulation of rock properties under real reservoir and well conditions. Properly derived, directly measured core data are invaluable as input data to analytical and numerical models of reservoirs and wells. These models are built in order to predict well performance and the potential for rock failure, sand production and flow restriction. Using these models, important decisions on well construction such as completion type, sand control selection and stimulation options are made. Without the measured core data the rigour of these models is compromised and decisions made are less reliable.

Two different examples of the use of core derived data in near wellbore modelling are presented in this paper. The first illustrates the use of core derived formation damage parameters in a finite volumes numerical model of well inflow. The second shows how core derived rock strength data can be used to predict rock failure in specific well geometries. In both cases the reliability of the model is greatly enhanced through the use of appropriate laboratory core test data.

EXAMPLES OF THE USE OF CORE DATA IN MODELLING

Core Data and Prediction of Formation Damage Impact

This example evaluates the selection of the optimum drilling fluids for a planned well. This was realized through the following workscope.

- Laboratory testing was undertaken to identify magnitude and depth of potential formation damage from the various drilling fluid options
- A predictive model was constructed using computational fluid dynamics (CFD) in order to predict the impact of different mud systems on well performance.

The data generated from the reservoir conditions core testing were used to determine the depth and permeability of the filtrate damage and mud cake zones (Table **1**). The percentage change from base permeability of the effective permeability after spin down was taken to represent the permeability of the filtrate damage zone. The mud cake permeability was determined using a relationship between the effective permeability with the drilling mud cake still in place and after it was removed. The pore volume and sample length were used to calculate the depth of the filtrate damage zone.

Table 1. Core Flood Test Results

Sample	Fluid Applied	Total filtrate volume loss, cc	Base Oil Perm, mD	After drawdown (mD)	After offload minus drilling mud cake, (mD)	After Spindown, (mD)
1A	Mud 1	2.75 (0.499 PV)	39.7	27.4 (-31.0%)	30.9 (-22.2)	33.3 (-16.1)
2B	Mud 2	3.270 (0.542 PV)	37.6	22.6 (-39.9%)	25.8 (-31.4)	28.3 (-24.7)
3C	Mud 3	11.8 (1.986 PV)	39.7	22.6 (-42.6%)	24.6 (-38.3)	25.9 (-35.1)

These data were input in to the 3D numerical model (see Figure **1**) which consists of a deviated well connected to the reservoir.

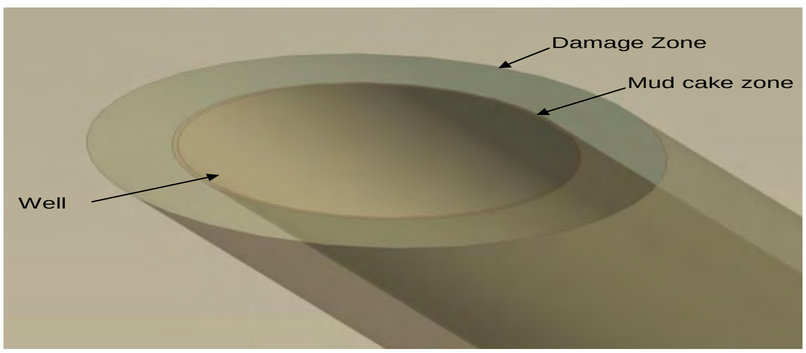


Figure 1. Model Geometry

The results are presented in the table below.

Table 2. Results of Sensitivities

CASES	Q, Stb/d
Open hole No Damage	6300
Open hole + Perforation + Crushed zone + No damage	6600
Open hole + Perforation + Crushed zone + Mud 2	6500
Perforated case + Crushed zone + Mud 2	5200

The table above shows that the maximum production rate was obtained with open hole and perforations. The data also show that even when the formation damage measured in the core flood tests is taken in to account that there is considerable advantage in perforating with an uncemented liner in place.

The example presented is merely a demonstration of the use of CFD modelling to upscale return permeability test data. It presents a steady state case based on end point laboratory experiments but of course transient two, three and even four phase (including solids movement) modelling can be undertaken.

Numerical Modeling for Sanding Prediction

Geomechanics has an important contribution to make in the solution of challenges such as wellbore stability and sand prediction in the oil industry. For some of these challenges, the use of advanced modelling techniques using numerical analysis is required. Numerical analysis is optimised if it is calibrated and verified using laboratory core test data. Once it is guaranteed that the numerical technique is capable of accurately modelling these experiments, it can be extended to the real well.

Rock strength is dependent on triaxial stress state. Therefore a description of the rock behaviour involves performing experiments where this condition is replicated. The triaxial stress state in laboratory testing is usually obtained by applying to a cylindrical sample an axial force together with a lateral hydrostatic pressure that is held constant.

Two models for predicting the onset sanding for open hole wells are presented as examples of how the rock constitutive model is enhanced by real core measurements.

Material Calibration

In order to calibrate the open hole sanding model, a finite element model was built to simulate the triaxial test, representing the laboratory conditions. The model simulates the geometry of the rock sample. Pressure loading on the external surface of the model (axial stress and radial confining pressure) was specified and increased to a preset level prior to the axial compression. The axial compression was increased further until failure has occurred, keeping the radial confining pressure constant. The axial loading of the model is applied using the triaxial test velocity to the nodes on the top of the model.
The rock behaviour is based on the use of an elasto-plastic model to fit the stress-strain curves observed in the triaxial compression tests. Elastic behavior was modeled as linear elastic using the generalized Hooke's law. An extended Drucker-Prager model, which includes hardening, was applied. The yield criterion, which defines the surface in stress space where plasticity is initiated, has a linear form. Additionally, the model is provided with isotropic hardening hence plastic flow causes the yield surface to change size uniformly with respect to all stress directions.

The available stress-strain laboratory data for the two examples and the simulated curves (theoretical curves) using Drucker-Prager criterion are presented in Figure 2a (Case 1) and Figure 2b (Case 2). A good match was obtained between experimental and numerical data and therefore the constitutive model and the critical plastic strains were estimated from these data. This information allows the elastic and plastic parameters of the rock to be used for the formation failure model.

Failure Criterion

The results from the sand prediction simulations are limited to stress, strain and pore pressure in the formation near the well. To evaluate whether sanding onset will take place or not, a failure criterion must be applied to this results. The critical plastic strain limits were calculated from each of the triaxial stress-strain curves and a value of 5 millistrains (5×10^{-3}) for Case 1 and 2 millistrains (2×10^{-3}) for Case 2 were used.

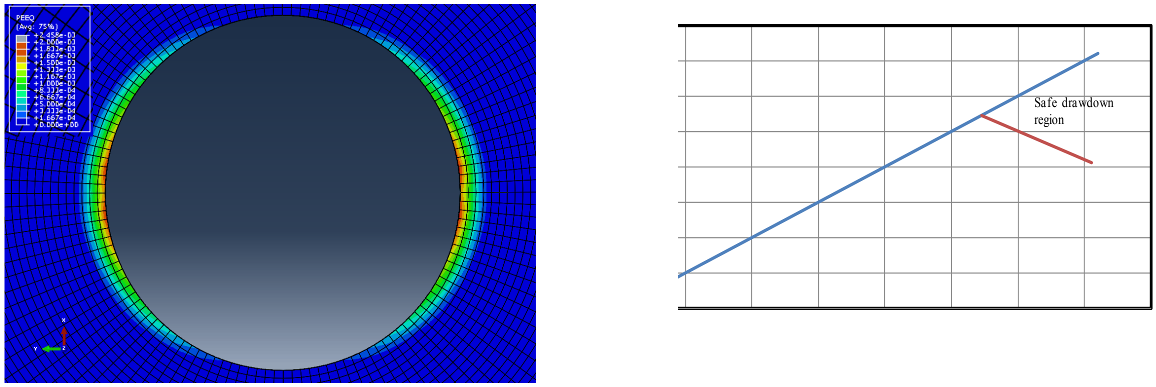
(a) (b)

Figure 2. Strain – stress curves – a) Case 1: Confinement pressures of 2.5, 5 and 7.5 MPa. b) Case 2: Confinement pressures of 5, 10 and 15 MPa.

<u>Sanding Onset Failure Model</u>

A constitutive model of the material that describes the behavior of the rock and a failure criterion was obtained after matching experimental triaxial data and these were used to model the well behavior. Plane strain conditions were assumed. This assumption is frequently used in problems that are very long in one dimension while assuming a uniform cross section with finite dimensions. Initial stresses and pore pressure are applied within the domain. In situ effective stress fields are applied to the external boundaries of the domain in order to assure the equilibrium. The next stage is the drilling process where a borehole was generated and a mud pressure was applied. Drawdown pressures were applied after the drilling process in order to assess their impact in the rock integrity.

Models for Case 1 and Case 2 were constructed, and the relevant load and boundary conditions applied. For Case 1, the simulations indicate that the maximum plastic strain is less than the critical plastic strain during the well productive life, and therefore formation failure is not expected, even under the abandonment conditions. For Case 2, Figure 3a shows the distribution of plastic strain generated when a drawdown of 15 MPa is applied in the open hole model for a horizontal well at initial conditions. In this case, the limit of the plastic strain (2×10^{-3}) was exceeded and hence onset of sanding is expected for drawdowns higher than 15 MPa. Figure 3b illustrates the formation failure envelope for Case 2, where pressure conditions above the failure line, shown in red, are expected to allow sand free production.



(a) (b)

Figure 3. a) Plastic Strain for Case 2 in an open hole horizontal well oriented parallel to Shmax; b) drawdown of 15 MPa applied at initial conditions, b)

Constitutive models for Case 1 and Case 2 which comprise most of the characteristics of the rocks under triaxial stress conditions have been presented. A reasonable agreement is achieved when numerical predictions are compared with experimental results for different loading conditions hence these results were used for simulating the horizontal well condition. Onset of sanding is expected to happen at initial conditions in Case 2 if the drawdowns exceed 15 MPa. There is no safe drawdown region when reservoir pressures are lower than approximately 27 Mpa. Critical plastic strains are not likely to take place even at final reservoir pressure of the productive life of the horizontal well in Case 1.

CONCLUSIONS

Complex numerical modelling can enhance our understanding of well behaviour and complex phenomena such as sand production and the impact of formation damage on well inflow performance. The modelling is greatly enhanced by using data derived from measurements made on reservoir core samples. Core data is critical to the prediction of well inflow and of well stability and is an integral part of modern numerical well and reservoir modelling.

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