INTERACTION OF COMPLIANT STRUCTURE WITH A FILTER CAKE

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1 Introduction

During the drilling of an oil well, the borehole contains drilling fluid. The drilling fluid density is adjusted so that the downhole hydrostatic pressure is slightly higher than the pressure within the pores of the surrounding rock. This avoids hole collapse due to earth stresses and prevents the ingress of gas or other fluids to the hole. The differential pressure drives liquid from the wellbore into the rock. Drilling fluid particles, which are too large to enter the rock pores, create a low-permeability filter cake at the rock interface; see figure 1. An engineering problem for analysis is the sealing or isolation of different parts of the well by flexible structures and the interaction of these structures with the cake and the resulting sealing efficiency. This paper describes a multi-dimensional calculation framework to analyze the interaction of a rubber structure called a “packer” with a filter cake.

In this paper we have assumed that the filter cake is composed of homogeneous Bingham fluid, noting that in practice the cake would be highly inhomogeneous, being more compacted at the well/rock formation interface and special calculation procedures should be adopted for more detailed analysis of filter cake dynamics. The emphasis is on the coupling of the dynamics of the structure with the fluid flow. We will study the impingement of the end of a rubber cylinder with a Bingham fluid. A related squeeze flow under the action of a rigid disc has been reported by Matsoukas and Mitsoulis [1].

Figure 1 – Schematic of filter-cake
2 Implicit fluid-structure coupling algorithm

2.1 Fluid flow and structural dynamics solvers
To be explained is an algorithm in which the fluid flow and structural dynamics codes exchange boundary condition values at their common domain interfaces. The fluid dynamics code used for this work, CAFFA (Computer Aided Fluid Flow Analysis) [2], is based on the finite volume approach with Lagrangian/Eulerian moving mesh formulation. The dependent variables are the velocity components and pressure. The structural dynamics code used for this work, DLEARN [3], is based on the finite element method with Lagrangian formulation. Here the dependent variables are displacements.

2.2 Coupling method
Figure 2 shows pictorially the procedure used for the coupling during a complete time step for the flow past a flexible beam, and shown are the operations carried out during a single fluid structure interaction iteration. Several such iterations are carried out during a time step. At the end of the time step, the forces at the domain interfaces are in equilibrium; that is the fluid forces acting on the solid oppose exactly the solid forces acting on the fluid. The fluid flow solver determines the forces at the shared interfaces; these forces are used as boundary conditions for the structure. The structure solver determines interface coordinates that are used to update the fluid domain geometry. Typically, for stiff problems several hundred fluid structure interaction iterations may be required.

For each time step:-

1. Re-mesh calculation domain

2. Solve flow
   → determine interface forces

3. Solve structure
   \[ M \dot{\mathbf{x}} + C \mathbf{x} + K \mathbf{x} = \{ F(t) \} \]
   → determine interface coordinates

4. Under-relax interface coordinates
   Go to 1 if not converged

Figure 2 - Flow and structure coupling scheme

The present algorithm is an extension of the algorithm developed for rigid structure-fluid interaction developed in a separate paper [4].
2.3 Impingement of rubber cylinder end with filter cake
Consider a rubber packer of right cylindrical form, shown in figure 3, impinging a filter cake with its end face. As the packer impinges it will deform and there will be flow of the filter cake outwards in the radial direction.

![Figure 3 - Rubber packer impinging the filter cake](image)

This coupled process was calculated using the present algorithm. The initial separation between the packer and well/formation interface was 5mm. The packer, of diameter 60mm, was pushed against the interface with a constant velocity of 1.0mm/s. Effective contact of the packer with the well/formation interface was assumed when the packer reached 0.5mm from the interface. The packer outer surface (cylindrical) was constrained from radial movement, but axial strain was permitted.

Figure 4 shows the pressure fields for the two domains during the process at two instants.

3 Discussion
The implicit algorithm used for the calculations shown in this paper is effective for the analysis of "stiff" problems, but can be expensive when an elevated number of fluid-structure interaction iterations are required for convergence. Future developments of such an algorithm could include the replacement of the fixed-point method used for the fluid-structure interaction iterations by a gradient method and/or the implementation of various methods used to study nonlinear problems including automatic calculation of time step size [5].

References


Figure 4 - Solid and fluid pressure fields and velocity vectors at two instances during impingement