3.2.4 The Post-Penetration Wellbore Flow

In the current SNL model, it is assumed that the gas and spalled waste particles are mixed with drilling mud in the bit cavity forming a slurry; and the slurry is carried up through the wellbore to the surface by the circulating drilling mud. The motion of slurry, which contains mud, gas, salt, and waste particles, in the wellbore is governed by a compressible mixed Navier-Stokes equation. The equations are:

Mass balance equation,

$$\frac{\partial}{\partial t}(\rho V) + \frac{\partial}{\partial z}(\rho V u) = S_{mass} \, ,$$

Momentum balance equation,

$$\frac{\partial}{\partial t}(\rho V u) + \frac{\partial}{\partial z}(\rho V u^2) = -V\left(\frac{\partial p}{\partial z} - \rho g + F\right) + S_{mom} \, ,$$

The equation of state of constituents is:

For the mud, $\rho_m = \rho_{0(m)}[1 + c_m(p - p_0)]$,

For the gas, $\rho_g = \rho_{0(g)} \dfrac{p}{p_o}$,

and, For the salt and waste particles, $V_{s,w} = \dfrac{m_{s,w}}{\rho_{0(s,w)}}$.

In the above equations, u is the velocity of flow, ρ is the density of slurry, and V is the volume of slurry, i.e.,

$$V = V_{salt} + V_{waste} + V_{mud} + V_{gas} \, .$$

The effects of pipe friction, type of flow (laminar or turbulent), and slurry viscosity on the flow property are also taken into consideration in the calculation.

The ideal gas law is used in the formulation, the cavity is assumed to grow with drilling, and there is no momentum transfer between the gas and the mud during mixing. These assumptions are certainly reasonable.

The mass-transport formulation above addresses both the down-going and up-going mud columns in a continuous fashion. Implementation can be likened to a conveyor belt where the first half of the belt is the down-going column and the second half is the up-going. At post-penetration, gas will be released from the repository and enter the mud-column. If spalling occurs, waste material will also enter the stream. It is important to note here that both the down-going and up-going mud columns are subject to the same boundary conditions within the cavity after post-penetration. This is the correct way to do it.

The model is sufficiently robust to adequately address the ballistic model of waste release as an extreme case. Should the repository gas pressure be sufficiently high, it is conceivable that the down-going flow could be choked off at the bit. Under this condition, there would be no mud supply to mix with the gas and waste entering the stream from the cavity. The up-going mud column would be supported only by a gas-waste column. This condition is sometimes referred to as a blow-out condition in oil field drilling.

The panel’s opinion is that the above formulation is indeed proper for describing the release of spalled particles from the repository by the circulating mud during drilling. It is sufficiently robust to address all realistic scenarios.

Signature Page

for

Spallings Conceptual Model Peer Review Report

Revised

Section 3.2.4, The Post-Penetration Wellbore Flow

February 20, 2004

I acknowledge by my signature below that I concur with the attached revised Spallings Conceptual Model Peer Review Report Section 3.2.4, Post-Penetration Wellbore Flow.

Ching Yew

Ching Yew, Ph.D., Chairman

02/21/04

Date

Jonathan Hanson, Ph.D.

Date

Lawrence Teufel, Ph.D.

Date

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Jonathan Hanson, Ph.D. | Date

Lawrence W. Teufel

Lawrence Teufel, Ph.D. | 02/23/04 Date

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Lawrence Teufel, Ph.D. — Date