CTES, L.C
9870 Pozos Lane
Conroe, Texas 77303
phone: (936) 521-2200
fax: (936) 5221-2275
www.ctes.com

Fill Removal Modeling

Subject Matter Authority: Bharath Rao

May 10, 1999

Summary

Operations involving fill removal or wellbore cleanouts are the most common of coiled tubing applications. The “wash” fluid is pumped through the CT at a sufficient rate for a certain period of time in an effort to clean out the wellbore. The fluid returning in the annulus carries the fill particles (usually sand, drilled cuttings, or other wellbore debris) to the surface, where the particles settle out in surface tanks. Common wash fluids include foams, water, brines, light oils, and polymer gels.

This document presents a simple model for the fill removal operation based on a steady-state analysis.

In recent years, fill removal (also referred to as wellbore cleanout) ranks as one of the primary applications of coiled tubing [Sas-Jaworksky II (1993)]. The operation involves circulation of a fluid through the coiled tubing down to the fill (sand/drilled cuttings) in the wellbore. The fluid mixes with the sand particles and carries the particles up to the surface through the annulus formed between the coiled tubing and the production tubing/casing.

The cleanout operation should be designed so that the flow rate in the annulus is sufficiently high to transport the fill (usually sand) up to the surface while maintaining pressure in the coiled tubing below the maximum working pressure. The pressure during the operation should also have no adverse effect on the reservoir, formation, and wellbore. For horizontal or deviated wells, a sand bed may form at the lower side of the annulus, which may result in incomplete cleanouts, and may sometimes even cause the coiled tubing to become stuck. Therefore, a successful design of a fill removal operation involves optimum selection of various parameters such as pump rate and fluid type in order to ensure a complete cleanout with the least possible time under safe operating conditions.

In the past decade, a few articles [Pursell and Moore (1992); Sas-Jaworsky II (1993); Appah and Ichara (1994); Gu *et al.* (1994); Walton (1995)] on fill removal in coiled tubing applications have been reported in literature.

Many important aspects of the fill removal operation can be captured by a simple analysis based on steady state flow. The fill removal model in Cerberus is based on such a steady-state analysis and is presented below.

The amount of fill that is picked up for any given flow rate in a cleanout operation is expressed in terms of the lifting ablility of the fluid. The lifting ability of the fluid (L_A) is defined as

$$L_A = Q\lambda, \qquad \textbf{Eq 1}$$

where Q is the flow rate and λ is the maximum loading (maximum concentration of paticles in the fluid medium) for that particular flow rate. Variables are in consistent units here and throughout this document, except where noted. The penetration rate (R_P) can be found from the lifting ability as

$$R_P = \frac{L_a}{(1-\varphi)\rho_P A_F} \qquad \textbf{Eq 2}$$

where ρ_P is the density of the fill particle, φ is the porosity (represents the void volume fraction), and A_F is the fill cross-sectional area. The term (1 - φ)ρ_P in Eq 2 is sometimes referred to as the fill packing density (ρ_{PD}) and is provided as an input along with ρ_P, φ, and λ.

Once the fill particles are suspended in the fluid medium, it is important that they remain suspended and be carried all the way up the annulus. In order to ensure this, the magnitude of the annular fluid velocity must be sufficiently greater than the terminal settling velocity (v_{TV}) of fill particles. A popular "rule of thumb" is that, in vertical wells, the fluid velocity in the annulus must be atleast twice the terminal settling velocity of fill particles. For horizontal wells, this factor is close to 10 to prevent bed formation and maintain particle motion in the flow direction [Sas-Jaworsky II (1993)]. Again, this is by no means a scientifically sound analysis and, therefore should be treated accordingly.

Moore (1974) has proposed a correlation for determining v_{TV} from a particle Reynolds number (Re_P) defined for non-Newtonian fluids as

$$\mathrm{Re}_P = \frac{\rho v_{TV} D_e}{\mu_a} \quad \text{EQ 3}$$

where $\mu_a = K\gamma^{n-1}$. Here, n is the behavior index, K is the consistency index, and γ is the shear rate. The expression for v_{TV} in Moore's (1974) work is obtained from Stokes law as

$$v_{TV} = \left[\frac{4}{3}\frac{g}{C_d} d_P \frac{\rho_P - \rho}{\rho}\right]^{\frac{1}{2}} \quad \text{EQ 4}$$

where d_P is the diameter of the fill particle (assumed to be spherical) and C_d is the drag coefficient. The value of C_d is dependent on the magnitude of Re_p and is determined as follows.

$$C_d = 1.5 \quad (\mathrm{Re}_p > 300;\ \text{turbulent flow}) \quad \text{EQ 5}$$

$$C_d = \frac{40}{\mathrm{Re}_P} \quad (\mathrm{Re}_p \le 3;\ \text{laminar flow}) \quad \text{EQ 6}$$

$$C_d = \frac{22}{\sqrt{\mathrm{Re}_P}} \quad (\text{intermediate region}) \quad \text{EQ 7}$$

Settling velocities may also be estimated by use of the correlation [Chien (1994)]

$$v_{TV} = 0.0002403e^{5.030\alpha}\left(\frac{\mu}{d_P\rho}\right)[B-1]$$

Eq 8

where

$$B = \sqrt{1+920790.49e^{-5.030\alpha}d_p\left(\frac{\rho_P}{\rho}-1\right)\left(\frac{d_P\rho}{\mu}\right)^2}$$

Eq 9

In Eq 8 and Eq 9, units of μ and d_p are centipoise and inches respectively, and ρ and ρ_p are in pounds per gallon. In addition, α is called the sphericity and refers to the roundness of the fill particle. It is defined as the ratio of the surface area of a shape having the same volume as the particle to the surface area of the particle. Both Moore's (1974) and Chien's (1994) correlation are incorporated in Cerberus to determine the particle terminal settling velocity.

The magnitude of particle settling velocity obtained from these correlations is compared with the required annular velocity in a particular well. As mentioned earlier, depending upon whether the well is vertical, horizontal, or deviated, a suitable velocity factor (range between 2 and 10) is used to determine the minimum annular velocity for a complete cleanout. The minimum flow rate and system pressures that satisfy the annular velocity requirements are subsequently determined.

Nomenclature

C_d	drag coefficient
d_P	diameter of fill particle (ft)
K	consistency index (lbf-s^n/ft^2)
L_A	lifting ability of fluid (lbm/s)
n	flow behavior index
R_P	rate of penetration (ft/s)
v_{TV}	terminal settling velocity of particles (ft/s)

Greek Symbols

α	sphericity
γ	shear rate (1/s)
μ	viscosity of fluid (lbf-s/ft^2)
φ	porosity
ρ_P	density of fill particle (lbm/ft^3)
ρ_{PD}	packing density (lbm/ft^3)

Subscripts

F	fill
p	particle
TV	terminal velocity

References

1. Appah, D. and Ichara, M.: “Empirical Model Determines Energy to Clean Sand from Wellbore,” *Oil and Gas J.,* (Feb. 28, 1994) 36-38.

2. Chien, S. F.: “Settling Velocity of Irregularly Shaped Particles,” SPE 26121 presented at the 69th Annual Technical Conference and Exhibition, New Orleans, LA (Sept. 25-28, 1994).

3. Gu, H., Walton, I.C., and Brady, B.H.G.: “A Computer Wellbore Simulator for Coiled Tubing Cleanout Operations,” *Computer methods and Advances in Geomechanics*, Balkema, Rotterdam, Netherlands (1994) 3, 2059-64.

4. Moore, P. L.: *Drilling Practices Manual*, Petroleum Publishing Co., Tulsa (1974).

5. Pursell, J. C. and Moore, B. K.: “How to Sand Wash Large Tubulars with Coiled Tubing*,” Petroleum Engineer Intenational*, (Aug. 1992) 42-45.

6. Sas-Jaworsky II, A.: “Coiled Tubing …Operations and Services, Part 4,” *World Oil’s Coiled Tubing Handbook*, Gulf Publishing Co. (1993), 28-34.

7. Walton, I. C.: “Computer Simulator of Coiled Tubing Wellbore Cleanouts in Deviated Wells Recommends Optimum Pump Rate and Fluid Viscosity,” paper SPE 29491 presented at 1995 Production Operations Symposium, Oklahoma City, OK, (Apr. 2-4, 1995).

CTES