Fill Removal with Foam in Horizontal Well Cleaning in Coiled Tubing

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Abstract: Coiled Tubing (CT) services are extensively used in oil industry to clean out the fill produced from wellbore. Recently, the use of foam as cleaning agent has become more popular due to its low density and high viscosity which are desirable in many cleaning operations. The present study is carried out to investigate the suspension of fines in the annulus of CT during cleaning operations. Solid particles were uniformly injected at annulus inlet and sand concentration at each point in the annular was calculated along the horizontal wellbore section. The motion of the particles is calculated under the effect of drag, buoyancy, rotational and virtual mass forces to analyze the settlement of the particles. The foam quality and foam velocity are found to be the deciding factors for the particle depositional pattern. The fill removal efficiency and frictional pressure loss are affected by both the velocity of the annular flow and the quality of the foam.

Keywords: Coiled tubing, fill concentration, flow velocity foam quality, pressure drop

INTRODUCTION

A typical operation of service in an oilfield is the removal of fill, such as the production of sand, scale or fines from a production well. The fill is removed from a well primarily to regain the oil or gas well's productivity. Furthermore, it is vital to remove the fill so that operational tools can pass through and the choking material can be removed in order to complete operations. The use of Coiled Tubing (CT) is one of more frequently used operations for fill removal. Coil tubing is used to circulate the solids out of the well by way of carrying fluids. Presently, removal of fill is the greatest application of CT consisting of approximately 50% of all CT operations (Li and Green, 2011).

Two modes of circulation are available with coiled tubing for the removal of solid particles. These modes are presented in Fig. 1 and are known as the forward circulation mode and the reverse circulation mode. During the operation of the forward circulation mode, fluid is pumped in by way of the coiled tubing and then recalculated to the surface mud pad by way of the annulus. During this process, solids that have been captured at the bottom are carried along with the returning fluid. This method is the most oftenly used cleanout operation. Contrary to that is the reverse circulation mode. In this mode, fluid is pumped down the tubing annulus and the fluid/solid suspension is rerouted to the surface mud pad reservoir by way of the coiled tubing string (Li and Luft, 2006).

Fill removal is a major issue in high angle and horizontal wells (Walton, 1995) as shown in the Fig. 2.
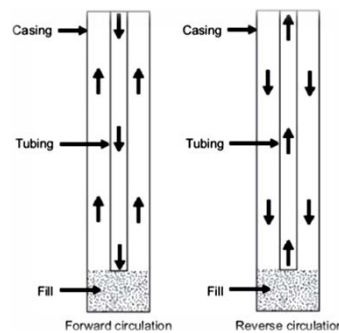

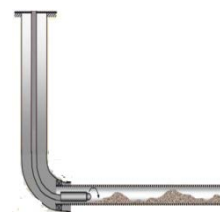Fig. 1: Two type of fill cleaning circulation mode (Li et al., 2010)

Fig. 2: Fill removal from horizontal well (Li et al., 2008)

In these situations, there is a tendency for the fluid-solid mixture to deposit a solids bed in the lower part of the annulus. The velocity of cleanout fluid is a critical factor in sand removal. To achieve the necessary cleanout velocity for high head in horizontal well, high surface pumping pressure and high fluid flow rate are required. However, the pump head cannot be continuously sustained at high pressure beyond a certain period due to overheating.

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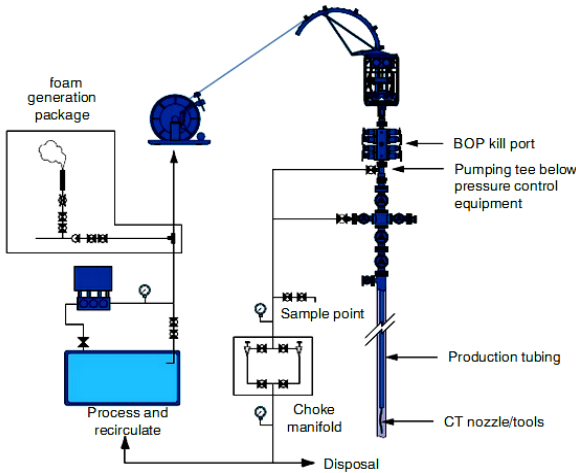
Fig. 3: Typical foam equipment configuration for fill removal (Lane, 2005)

Presented in Fig. 3 is a common equipment configuration for foam being used in the removal of fill? The foam has to be prepared in advance before the operation; giving the foam enough residence time for the required foam characteristics to be achieved. The foam is created by mixing in a gas phase; normally with nitrogen, which is mixed with a foaming agent and a base fluid. Water and oil are the most typical kind of base fluids. The foaming agent (0.5 to 1% by volume) is a surfactant. It is used to lower the surface tension between the gas and the base fluid (Li *et al.*, 2010).

The rheological behavior of foam has a vital role to play in the calculation of the solid transport efficiency. Over the past three decades, several rheological models have been formulated. Beyer *et al.* (1972), Blauer *et al.* (1974) and Phillips *et al.* (1987) put a lot of effort into the calculation of the rhetorical model. They investigated the properties of foam and found that they were dependent upon the foam quality; that is the concentration of the volume fraction of the gas to the total volume fraction.

The liquid-phase composition is the determining factor for the viscosity of the foam. It has been found that as pressure increases with the depth thenit causes the linear increase in the viscosity of foam. It was noted that when the quality of the foam increases to 98%, the viscosity of the foam decreased. This resulted in the lowering of the carrying ability of foam. It was reported by Saintpere *et al.* (2000) that the Herschel Bulkleyviscosity model could give a good indication of the efficiency of the foam-solid transport.

It was investigated by Li *et al.* (2010) that for the case of a vertical well, in order to achieve a successful cleaning, the velocity of the foam fluid should be in accordance with Eq. (1) and (2) .

$$V_F \geq 1.1 V_t \qquad (1)$$

Table 1: Rehologicalmodel parameters

Liquid Phase	Parameters	Quality (%)		
		70	80	90
Water	τ_0(Pa)	0.0004	0.000009	0.001379
	K(Pa.s)	0.6894	1.999	2.8268
	n	0.53	0.45	0.42

$$V_t = \left[\frac{gD_S^{n+1}}{18K(1.02431+1.44798n-1.47229n^2)}(\rho_S - \rho_F) \right]^{\frac{1}{n}} \qquad (2)$$

where,

V_t = The terminal velocity
D_s = The diameter of the particle of sand, is the sand's Density
ρ_F = The foam's density
n = The exponen

It is hard to achieve an efficient CT cleaning operation without an adequate understanding of the transportation of the fill particles. The aim of this present study has been to carry out an analysis to calculate the critical annular foam velocity for fill removal when tubing is stationary. Also the pressure drop for different qualities of foam at different velocities.

METHODOLOGY

ANSYS-CFX-14 was utilized to investigate theremoval of sand in the horizontal section of wellbore. Similar approach has been used by Bilgesu *et al.* (2002) to investigate the cutting transport efficiencies in vertical well.

The flow isassumed to be in pseudo-steady state condition. The inner tube is concentric during cleanup operation. Inner wall of casing and outer wall of tubing is assumed as smooth wall i.e., there is no roughness. It is also assumed, that particle shape is spherical having 3 mm diameter. Herschel Bulkley viscosity model is assumed for the foam behavior. The rheological relation can be written as:

$$\tau = \tau_0 + K\gamma^n \qquad (3)$$

where,

τ = The shear stress
τ_0 = The yield stress
K = The consistency index
γ = The shear rate
n = The power index for non-Newtonian fluid

Herschel-Bulkely model parameters for water base foam was investigated by Miska *et al.* (2003) as shown in Table 1, as their values are assumed valid in the present study.
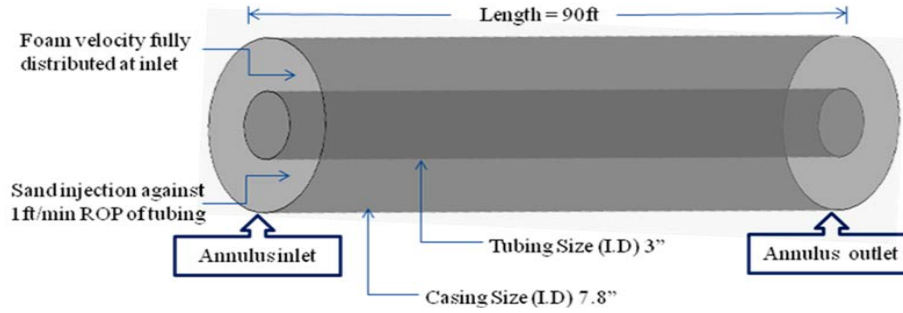
Fig. 4: Schematic well diagram

Figure 4 shows the schematic diagram of the horizontal well model. The annular section of wellbore is taken as 90 ft long with casing size (I.D) of 7.8" and tubing size (I.D) of 3". Analysis is carried out in the horizontal section of the wellbore with foam quality of 70%, 80% and 90%. The foam velocities applied at annulus inlet are varied from 3-6 ft/sec. Atmospheric pressure is assumed at outlet. The rate of penetration of tubing inside the fill is taken 60 ft/h. Flow rate of solid particles are calculated using the following equation:

$$Q = \rho V A \tag{4}$$

where,
Q = The mass flow rate
ρ = The density of fill
V = The velocity of particle which is a assumed as a reaction of fill particles when tubing penetrates into fill surface
A = The area of annulus

The CFX Lagrangian particle transport multiphase module that can model the distribution of solid particles in a continuous fluid phase was used for the analysis. The Lagrangian model tracked a few individual solid particles through the continuous fluid starting at the area of injection until the particles were out of the area of interest. The particle tracking was performed by creating a set of regular equations in time for individual particles. These equations were then integrated by making use of a simple integration scheme for calculating the behavior of the particles as they moved through the flow area.

The displacement of the particle is calculated using forward Euler integration of each particle velocity over time step as given below:

$$x_i^n = x_i^o + v_{pi}^o \delta t \tag{5}$$

where,
x = The particle displacement
n = The new position of sand particle
o = The old position of particle
V_p = The particle velocity

δt = The time ste

The particle velocity is defined as:

$$v_p = x_f + (v_p^o - v_f)\exp(-\frac{\delta t}{\tau}) + \tau F_{all}\left(1 - \exp(-\frac{\delta t}{\tau})\right) \tag{6}$$

where,
v_f = The foam velocity
τ = The shear stress
F_{all} = The sum of all forces

The forces which acted on the particle are drag (F_d), buoyancy (F_b), lift (F_l) and virtual mass forces (F_{vm}) to analyze the settlement of the particles are defined as:

$$m_p \frac{dUp}{dt} = FD + FB + FR + FVM \tag{7}$$

where,
m_p = The mass of the solid particle
dUp/dt = The particle velocity
FD = The drag force acting on the particle
FB = The buoyancy force
FR = The force due to tube rotation
FVM = The virtual mass force
FP = The pressure gradient

The interaction between these forces affects the solid particle transport during fluid circulation.

VERIFICATION OF MODEL

Chen *et al*. (2007) performed experiments to study drilling cutting concentration in the horizontal annulus versus foam velocities with three foam qualities. Their test section consisted of annulus with 5.76" outer casing and a 3.5" drill pipe inside. Inner pipe was rotated up to a speed of 250 RPM. Their experimental model is used as the validation example for the present study.

Figure 5 presents the effects of different velocities of 70% quality foam on fill transport along horizontal
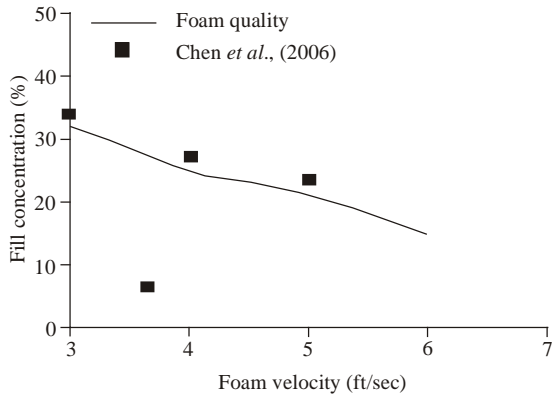
Fig. 5: Fill concentration at different velocities in horizontal well for 70% quality foam
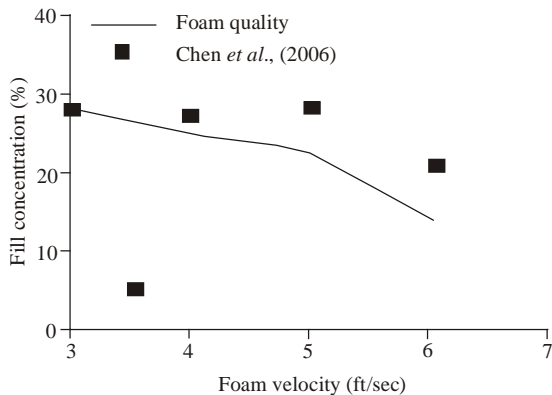

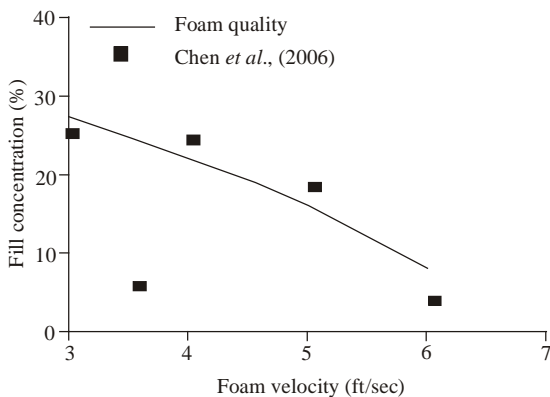Fig. 6: Fill concentration at different velocities in horizontal well for 80% quality foam

Fig. 7: Fill concentration at different velocities in horizontal well for 90% quality foam

wellbore. It was observed in the present study that fill particles removal rate is approximately matching with experimental data. It can be investigated that there is around 24 % concentration of particles at 5 ft/sec for both experimental and present study.

In Fig. 6 is the rate of the removal of the fill for the foam quality of 80%. Present study has shown that at

lower annular velocities e.g., 3 and 4 ft/sec, removal of solid particle is according to experimental data.It can be observed from present study that as velocity is increasing, fill concentration is decreasing as concentration of particles is inversely proportional to the velocity of the fluid. At this point, fill concentration is increasing in the experimental data which must decrease. May be this outlier in the trend is due to data accusation problemto calculate the particles concentration in the experimental set up. The difference of particles concentration at 5 and 6 ft/sec is high but the trend of present study is same as experimental study.

Figure 7 presents the effect of different velocities on the removal of the fill for the foam quality of 90%. In the present study, It has been analyzed that fill removal rate was according to the experimental data. As the velocity was increased, it was noted that there was a decrease in the concentration of the fill according to experimental data.

RESULTS AND DISCUSSION

Fill distribution along the horizontal annulus: In Fig. 8, the concentration of the fill was plotted along the longitudinal direction of the horizontal well for foam velocities ranging from 3-6 ft/sec for the 70% foam quality. It was found that removal of fill concentrationis inversely proportional to the fluid velocity.

Fill concentration was 45% along the wellbore at lower velocity e.g., 3 ft/sec. Furthermore, 32% fill concentration was seen with a further1 ft/sec increase in the foam velocity along the annulus.It can be noticed that there was 20% concentration of fill at 5 ft/s. At 6 ft/sec the suspension of the fill particles was comparatively good with respect to other velocities. At a higher velocity, e.g., 6 ft/sec, there was a 9% concentration of the fill along the annulus. During the continuous fluid circulation along the well, it is acceptable to have a less than 10% particle concentration.

Figure 9 shows that the concentration of the fill is 30% at a low velocity, e.g., 3 ft/sec. Moreover, for velocities that are higher, such as between 5 and 6 ft/sec, it has been observed that very good cleaning has taken place. It was investigated that there is a good fill removal at 5 ft/sec for 80% foam quality as compared to 70% foam quality At a higher velocity, e.g., 6 ft/sec, there was a 8% concentration of the fill along the annulus. The concentration of fill along the annulus for the 90% foam quality is shown in Fig. 10. It can be seen that the 90% foam quality had a greater suspension even at lower velocities. Highest cleaning efficiency is observed at velocity around 6 ft/sec. It can be noticed
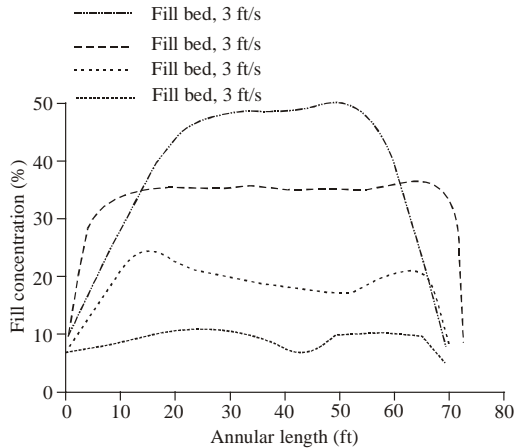
Fig.8: Fill bed along horizontal annulus for 70% quality foam
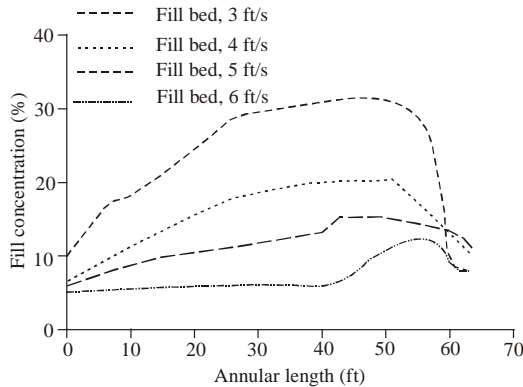

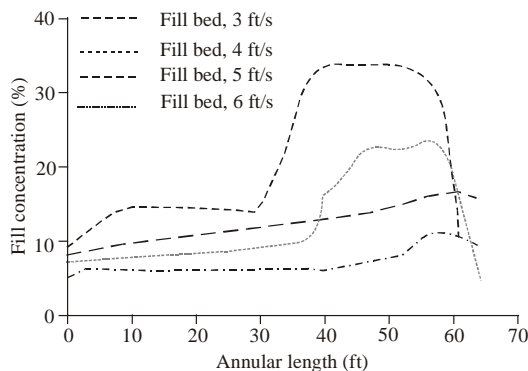Fig. 9: Fill bed along horizontal annulus for 80% quality foam

Fig. 10: Fill bed along horizontal annulus for 90% quality foam

that amount of fill concentration is less than 7% along the annulus for highest quality of foam.

Fill bed formation along lower side of the annulus: In Fig. 11, the concentration of the fill was noticed along each point of the horizontal well at foam velocities ranging from 3-6 ft/sec for the 70% foam quality. The contour is showing the settlement of fill along the lower side of the annulus. There is higher settlement of fill particles at low velocity of foam e.g.,

3 ft/sec, therefore fill bed formation occur at low velocity. As gravity overcome the buoyancy of the fill, so particles settle down and form a continuous solid bed. As the distance grew, the removal of the fill at lower velocities became more difficult and a fill bed was formed as the particles started settling down along the wellbore. At 6 ft/sec a greater suspension of the fill particles was obtained, with a 9 % concentration of the fill along the annulus. There is reduction of fill bed formation at higher velocity simply because the momentum of the foam is sufficient to counter the settling of particles due to gravity.

Figure 12 shows that the settlement of fill particle increased with the passage of time and the concentration of the fill became 30% at lower velocity e.g., 3 ft/sec which indicated the formation of a fill bed at the lower side. It was investigated that for further 1 ft/sec increase in velocity resulted in 20% concentration of particles along the annulus. Moreover, for velocities that are higher, such as between 5 and 6 ft/sec, it has been observed that very good cleaning has taken place due to suspension of particles. It was investigated that there is a good suspension of particles at 5 ft/sec for 80% foam quality as compared to 70% foam quality. As the suspension of fill increased, then concentration of particles reduced to around 8% for 6 ft/sec foam velocity.

The settlement of fill along the annulus for the 90% foam quality is shown in Fig. 13. It can be seen that the 90% foam quality had a greater suspension even at velocities that were low so there is a less concentration of particles. As the distance increased, removing the fill become harder; moreover, particles dropped down the wellbore due to gravity along the lower side for velocities of lower values, e.g., 1-2 ft/sec. The most efficient clean up was noted at the velocity around 6ft/sec, highest suspension was achieved because bouncy force overcome the gravitational force along the lower side of wellbore. Highest cleaning efficiency is observed at velocity around 6 ft/sec. It can be noticed that amount of fill concentration is less than 7% along the annulus for 90% quality of foam because of highest suspension of the particles.

Pressure gradient vs. flow velocity: The pressure gradient along the annulus for a foam-fill flow at the 70, 80 and 90% aqueous foam quality is presented in Fig. 14. When the results were analysis, it could be seen that the drop in the pressure increased when the velocity of the foam increased. It can also be observed that the flow rate of the fluid had an effect on the pressure drop of the fluid, directly. For a high flow rate, There was a higher drop in pressure. The trend of the pressure drop was an increase related to the use of a higher quality of foam caused by the high shear rate inside the walls. This frictional pressure gradient comparison of all three qualities of aqueous foam has
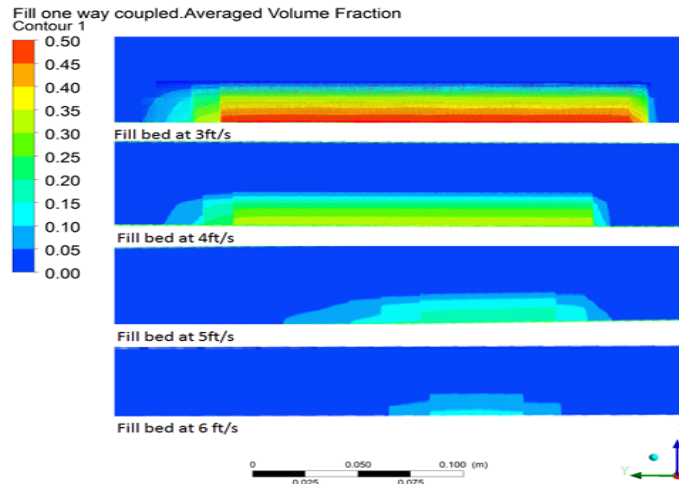
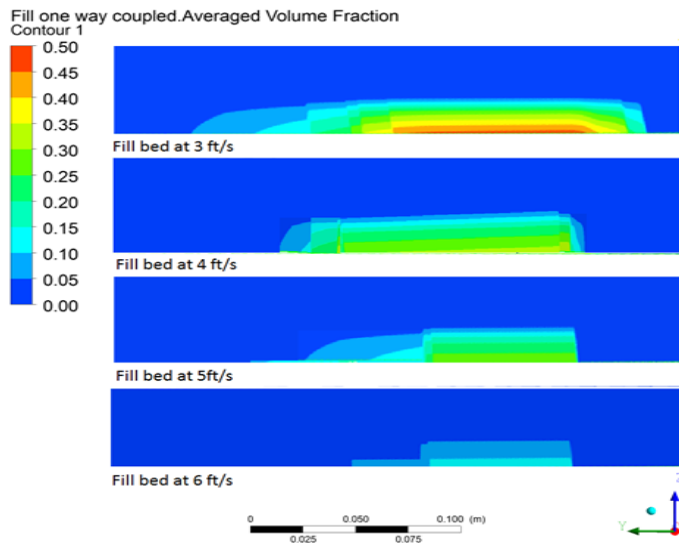Fig. 11: Fill bed along bottom of the annulus for 70% quality foam

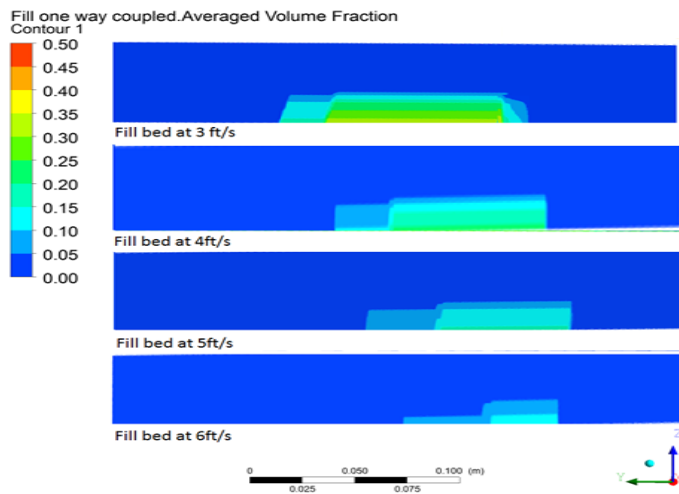Fig. 12: Fill bed along bottom of the annulus for 80% quality foam

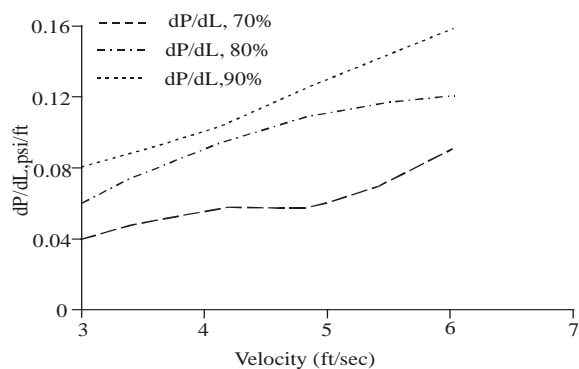Fig. 13: Fill bed along bottom of the annulus for 90% quality foam

Fig. 14: Annular pressure gradient vs. flow velocity

been studied at critical velocity of foam solid transport e.g., 6ft/sec.

CONCLUSION

Fill removal is anvital part of Coil Tubing service to enhance the production of oil/gas wells. Predicting the behaviors of foam solid transport during the CT cleanout operation is a big concern because there are numerous parameters which influence the cleaning operation resulting in loss of fill removal efficiency and rise in the cost of well services. Foam fluid has low density and high viscosity so it has high blocking ability. It reduces the leaking of fluid into fractured formation especially in low pressure wells and enhances sand cleanout efficiency. The flow of foam-solid transport in the horizontal annulus is analyzed in the present study. The foam quality, velocity and viscosity are identified as the deciding factors to improve the fill removal rate. For all qualities of foam an increase in the velocity results in the reduction of fill concentration. Highest fill removal rate was observed with 90% quality foam.Friction pressure losses increases when the quality of the foam increases andfriction pressure loss decreases with the decrease in the quality of foam.

ACKNOWLEDGMENT

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