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Fill Removal in Wellbore Using Coiled Tubing

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Abstract. Coiled Tubing (CT) services are widely applied in oil field to remove fill from wellbore. Its function is to restore the productivity of oil and gas well since fill such as sand will regularly block the production line especially at the well bottom. Predicting the behaviors of cleaning fluid and particle transports during the CT cleanout is a major challenge because there are many variables which affect the cleaning operation resulting in loss of cleaning efficiency, waste of cleaning fluid and increase in cost of well services. The objective of this study is to perform detailed analyses of both flow pattern of cleaning fluids and particle transports in wellbore during cleaning process at different cleaning operating conditions and well geometries. In order to achieve the objective, the problem is broken down into two parts; namely the well string and the well bottom/annulus. The well string, which is the coiled tubing itself, is first solved semi-analytically to obtain the exit velocity of the flow nozzle and the accompanying surface pump operating conditions. Once the exit velocity in the coil tubing is known, the value is used as an inlet velocity boundary condition for the bottomhole and the well annulus for the subsequent CFD analysis. Simulating the cleaning process along the entire well span is impractical due to limitation in computational resources. Hence, only a limited section in the bottomhole and annulus were considered, where the calculated transport properties there is sufficient to inform the likelihood of fill being circulated to the surface. The present study identified that diameter ratio of CT and annulus, properties of the cleaning fluid, design of downhole nozzle are the three most important factors influencing the cleanout. The result of this study is a linearized CT parameters design chart that allows user to plan for cleaning operation.

Introduction

Operations of fill removal from production well are commonly been practiced in the oilfield. The services are essential in order to restore the productivity of the oil or gas well, to permit the passage for operational tools as well as to remove the choking material for completion operations. One of the fill cleanout methods is by using Coiled Tubing (CT). This technology have been in existence for over four decades and today account for approximately more than 30% of worldwide well services [1].

During the fills cleanout process, the fluid could be circulated in two different modes: forward circulation and reverse circulation as shown in Fig. 1. In the forward circulation mode, the carrying fluids are pumped through the CT down to bottom and flowed back to surface in the casing annulus. On the other hands, for the reverse circulation, fluids are pumped down the casing annulus and circulated back via the coil [2].

The principle of the cleaning process involves the circulation of a fluid through the CT to the fillface where the fill is picked up by the jetting action of the nozzles. It is then transported to the surface through the annulus between the CT and annulus casing. A simple configuration of CT cleaning operation set up can be seen in Fig. 2. An important consideration in designing cleanout operations is the proper selection of the fluid and pump rate [3]. Examples of typical cleaning fluids are water, brine, and diesel. They should be chosen so that bottomhole pressure does not exceed the safe operating limits, and the sand or fill will be efficiently conveyed to the surface. This can be done by ensuring the buoyancy force of the cleaning agent is higher than the gravity force of the fill particles.

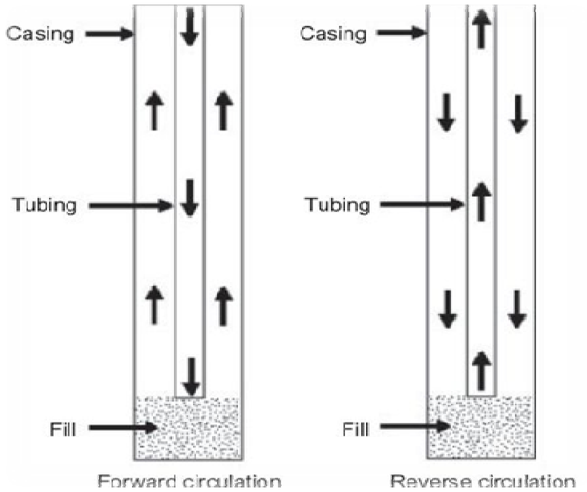

Fig. 1: Two type of fill cleaning circulation mode [1]

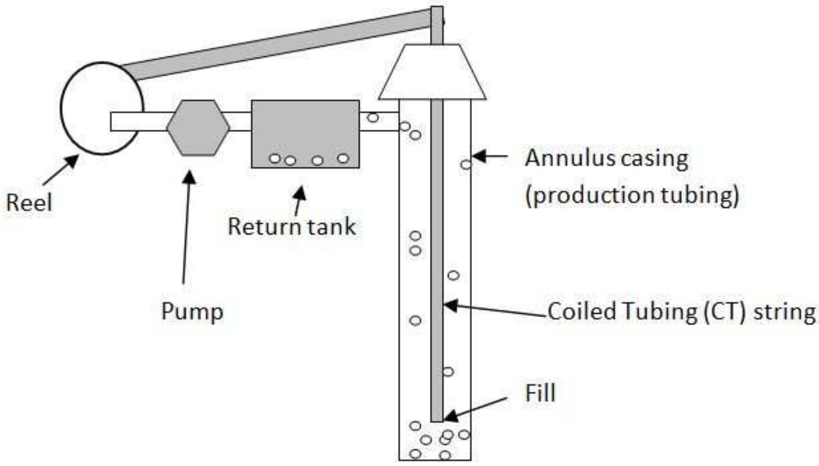

Fig. 2: Configuration of CT forward circulation cleanout operation

There are other factors that affect the cleanout operation. Those are fill type, formation type, reservoir pressure, temperature, well deviation angle, flowrate, circulation time at total depth (TD), and completion size or CT size [4]. Predicting the behavior of cleaning fluid and particle transport in wellbore is a major challenge during the CT cleanout process. This becomes more complex when there are field uncertainties which affect the operational efficiency. An efficient CT cleaning job is hard to achieve without a good knowledge on the fill particles transport. The objective of the present study is to analyze the flow and transport parameters during CT cleanout operation to gain a deeper understanding of the parameters critical to downhole transport.

Methodology

The CT and the associated cased annulus is investigated in two parts, as shown in Fig. 3. In the first part, semi-analytical solution for the flow in the CT is solved to obtain the exit velocity and downhole pressure. The bottomhole and the cased annulus flow parameters are solved using the CFD software, FLUENT. In other words, the solutions from the first analysis are used as the boundary conditions for the second analysis. The limitation of such resolution is that the flow in the CT is tacitly assumed pseudo-steady state. The only reason for breaking down the problem into two parts is because of computational resource limitation. The present approach resulted in approximately an hour per simulation time. The detail of the methodology now follows.

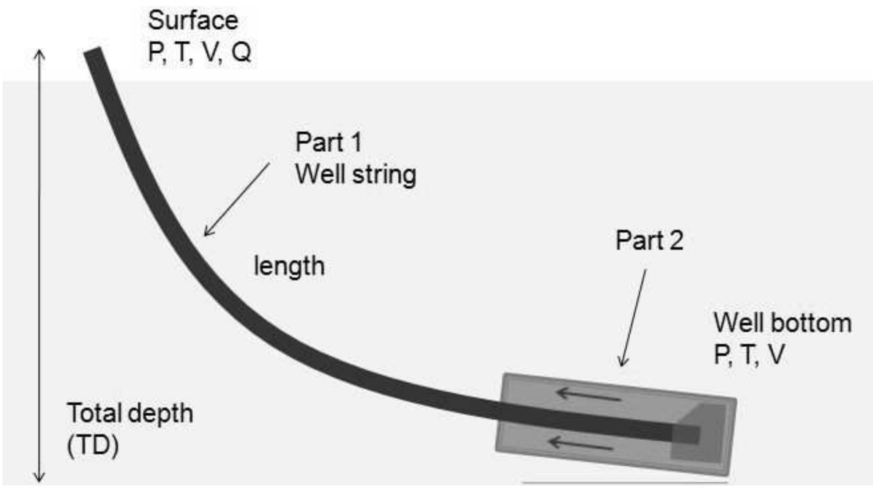

Fig. 3: Simple well configuration

Pressure in the Coiled Tubing. The pressure along the CT and the annulus are first estimated using Bernoulli's equation assuming pressure loss due to friction at the string's wall and at the bottom of the well.

$$p_1 + \frac{\rho v_1^2}{2} + \rho g z_1 = p_2 + \frac{\rho v_2^2}{2} + \rho g z_2 + \Delta p_f \tag{1}$$

where p is the pressure, v is the velocity; z is the elevation, ρ the density of fluid and Δp_f is pressure loss due to friction. For power law fluids, the following equations are employed for pipe flow and annulus flow, respectively to compute the friction pressure loss, Δp_f.

$$\Delta p_f = \frac{f \rho v^2}{25.8 d_i} \Delta L \tag{2}$$

$$\Delta p_f = \frac{f \rho v^2 \Delta L}{21.1\left(d_{2a} - d_{1a}\right)} \tag{3}$$

where f is the friction factor, d_i internal CT diameter; d_{1a} external CT diameter, d_{2a} internal annulus diameter; and ΔL is the length of the pipe or the annulus. Assuming the CT pipe and the casing wall are smooth pipe, Colebrook's friction factor function can be applied to determine the friction factor along the pipe [5, 6]

$$f = \frac{0.0791}{N_{\mathrm{Re}}^{0.25}} \tag{4}$$

Transport Simulation in the Bottomhole. On the other hands, the fill transport behavior at the well's bottomhole will be solved separately using the FLUENT to obtain the fills transport flow pattern and bottomhole pressure loss during the cleaning process. The CT and annulus exit velocities which are calculated from Eq. 1 is used as the boundary conditions for the nozzle. The simulation utilizes the FLUENT Eulerian-granular multiphase module as its basis. Equation (5) shows the granular phase momentum equation involved in this model.

$$\frac{\partial}{\partial t}\left(\alpha_s \rho_s \vec{u}_s\right) + \nabla \cdot \left(\alpha_s \rho_s \vec{u}_s \vec{u}_s\right) = -\alpha_s \nabla p_f + \nabla \cdot \tau_s + \sum_{s=1}^{n}\left(\vec{R}_{fs} + \dot{m}_{fs} \vec{u}_{fs}\right) + \vec{F}_s \tag{5}$$

where α_s is the solid volume fraction, ρ_s solid density, $\vec{u}_s$ is the solid velocity, p the fluid pressure, $\vec{\tau}_s$ solid stress tensor, $\dot{m}_{fs}$ is the rate of mass transfer and $\vec{F}_s$ is the external force.

The model also applies Gidaspow kinetic theory which is suitable for dense fluidized bed, in this case to solve for the phase interaction between fill and cleaning fluid in the wellbore. Figure 4 illustrates the structure of the well's bottomhole model.

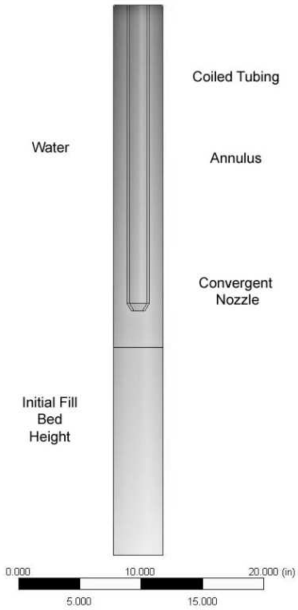

Fig. 4: Model of the well bottom for simulation

The initial condition in the sand bed is such that the sand is assumed spherical shape with diameter of 1mm, and a volume fraction of 0.5 sand volume per unit of total volume. The annulus outlet boundary condition is obtained by solving for pressure loss in Eq. 1 in the annulus.

Verification

The CT flow model was verified with a 10,000 ft vertical well data. The internal diameter of the casing is 7” while the internal and the external diameter of the CT are 4.5” and 4.68”, respectively. The cleaning fluid is assumed to be water for simplicity sake, with viscosity of 1 cP. The cleaning fluid is circulated at the rate of 66 gpm. Cleaning fluid’s pressure change when it is circulated in the well based on the results calculated is shown in Table 1. The predicted downhole pressures are relatively close to the actual measurement even though the present model is greatly simplified. The difference between the calculated and measured pumping pressure (~ 30%) is because the present model does not include a pump model. Thus the calculated pump’s pressure is the minimum pressure required. Its value needs to be calibrated against type of pump used and is not the main focus of the present study.

Table 1: Verification for CT fluid flow model

Location	Calculated Pressure [psi]	Measured Pressure [psi] [7]
CT Inpipe inlet	69.5	95
CT nozzle outlet	4471.5	4600
Annulus bottom	4420.8	4550
Annulus outlet	0.0	0.1

Simulation and Parametric Studies

Figure 6 showed snapshots of the sand volume fraction at different time using the well configuration mentioned in previous section. From the change of sand volume fraction, it is possible to find out the time when fill pick-up begins and estimate the rate of fill pick-up. This is important during the early stage of cleanout to inform the operator if fill is being transport efficiently or bedding is occurring.

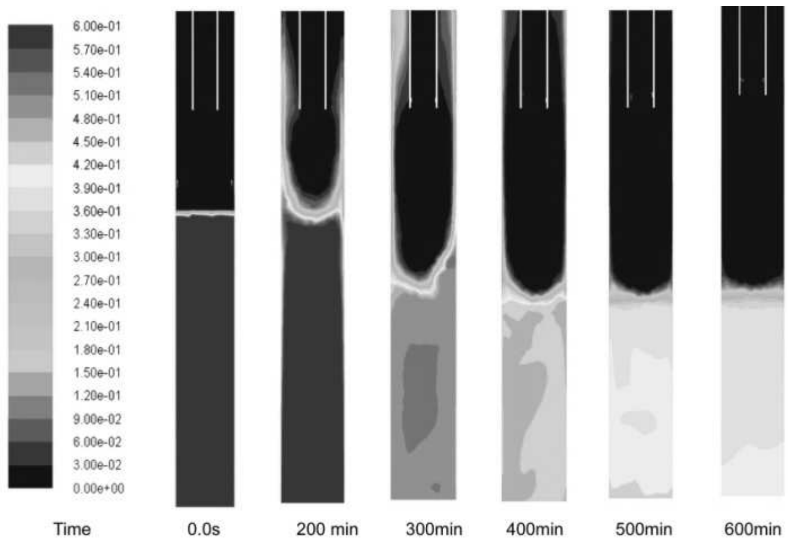

Fig. 6: Fill volume fraction against time

Using the FLUENT model that has been created, six parameters that are thought to be affecting the wellbore cleaning process were tested. These parameters are diameter ratio between CT and annulus, height of CT nozzle from the sand bed and its head size, fill's thickness, fluid velocity, viscosity and density. The nozzle used in the studies is modeled as a simple convergent nozzle. Figure 7 shows the influence percentage for each parameter against the rate of fill removal. Out of six factors, diameter ratio, fluid velocity, fluid viscosity and nozzle size are identified as critical parameters which produce significant change to the rate of fill removal. Diameter ratio, fluid velocity and fluid viscosity are directly proportional to the rate of fill removal while nozzle size is inversely proportional to the rate of fill removal.

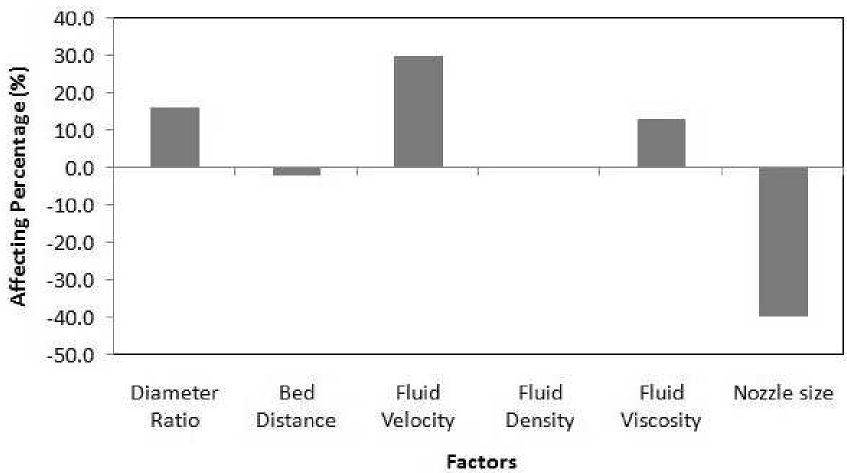

Fig. 7: Affecting percentage of factors on fill removal rate at wellbore

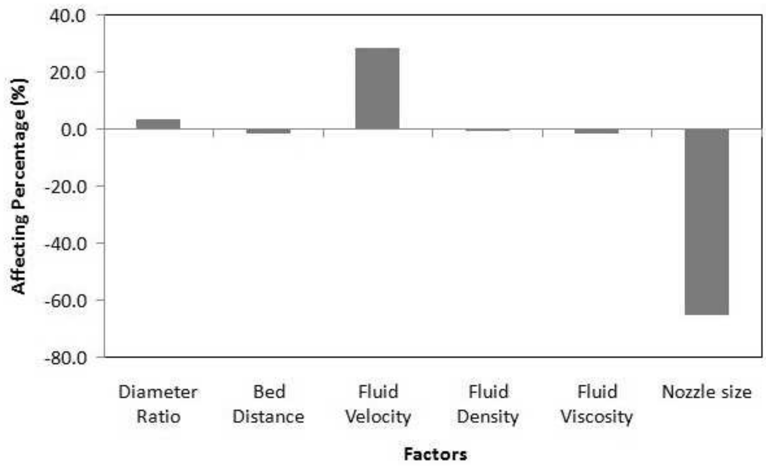

Fig. 8: Affecting percentage of factors on pressure loss at wellbore

Figure 8 showed that fluid velocity and nozzle size are the only two factors which influence the pressure loss at the well bottomhole. Other parameters, even though affecting pressure loss, their effects are relatively insignificant. Thus, smaller nozzle head's size and higher fluid velocity will significantly cause higher pressure loss during cleaning operation of well bottom.

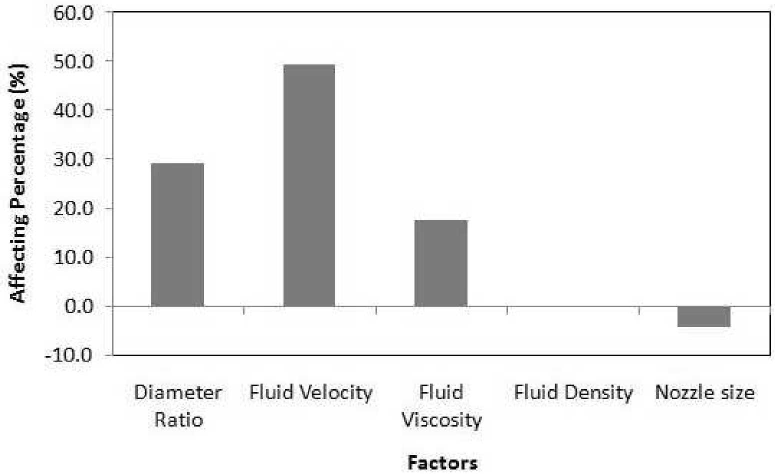

Fig. 9: Affecting percentage of factor on overall pumping pressure required

One of the main operational parameter in the field is the back circulation pressure, which is the pump head required to circulate the fill out from the bottomhole. Fluid exit velocity is identified as the major influence over the pump's head as shown in Fig. 9. Interestingly, fluid density does not seem to play a significant role. This is probably due to the isothermal assumption of the present study. A simple 'back-of-the-envelope' calculation showed that the density change due to pressure is in the order of 10^{-4} kg/m^3 for the range of the pressure under investigation. Other variables affecting the pumping pressure are the diameter ratio and fluid viscosity. Although increasing the value of these three factors can help improving the fill removal efficiency, it will increase the pump pressure substantially. Higher pump pressure is needed to overcome the pressure loss due to friction along the wall of casing and pipe as discussed in Eq. 3 and 4.

Coiled Tubing Screen Chart

Screen chart is a graphical information map that is typically used in engineering services to fast-track field engineers to zoom-in preliminary design solution when there is insufficient data. Figure 10 showed a preliminary CT screen chart which could be used to predict the required performance of CT well cleaning operation. The charts listed the required fill concentration per minute in the annulus against the minimum pumping pressures, depending on diameter ratio of CT and annulus and required exit velocity of the nozzle. The chart has been linearised and is only intended for preliminary design purpose. It is not suitable for operational optimization. Further work is required to calibrate the chart and to fit in more field related information, such as minimum pump head per ft of total vertical depth, well inclination etc.

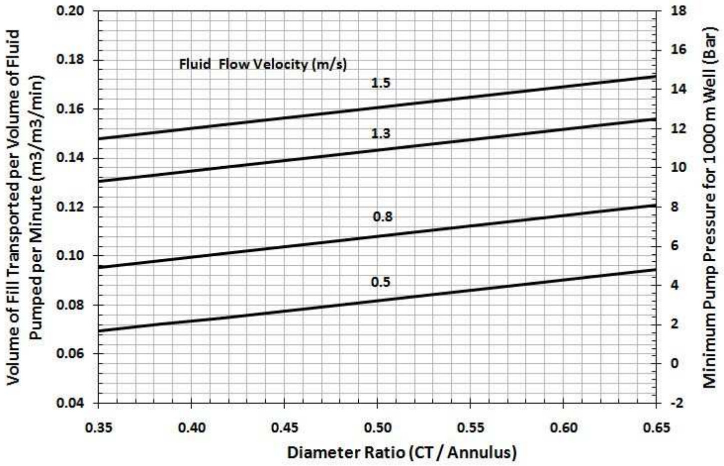

Fig. 10: CT diameter ratio and cleaning fluid velocity versus fill removal rate and pump pressure required

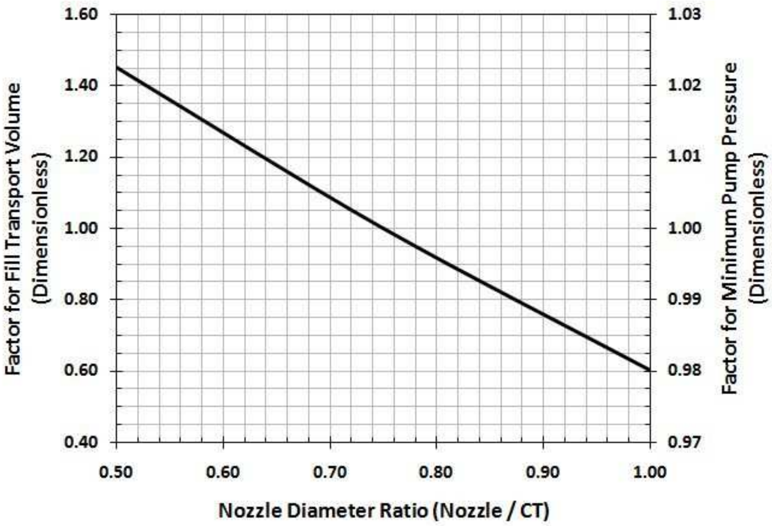

Fig. 11: Nozzle diameter ratio versus the factor for fill transport volume and pump pressure required

In Figure 10, the relation between the diameter ratio between CT and annulus of the well and the velocity of the cleaning fluid are shown. The left vertical axis of the chart shows the fill concentration changes where it is represented by the volume [m^3] of fill being transported by a cubic meter of cleaning fluid per minute. Meanwhile, the right axis of the chart represents the minimum pressure required for the pump to achieve a complete circulation for 1000 m well.

Since the pump pressure has a linear relation with the depth of the well, the minimum pumping pressure for CT cleaning operation at other well depth can be estimated by multiplying the pressure value from Fig. 10 with the ratio of other well's depth and the chart standard well's depth of 1000 m. Since Fig. 10 is only considering the diameter and the velocity factors, other variables which are nozzle diameter ratio and viscosity of the cleaning fluid are kept constant at 0.5 and 1 centiPoise respectively.

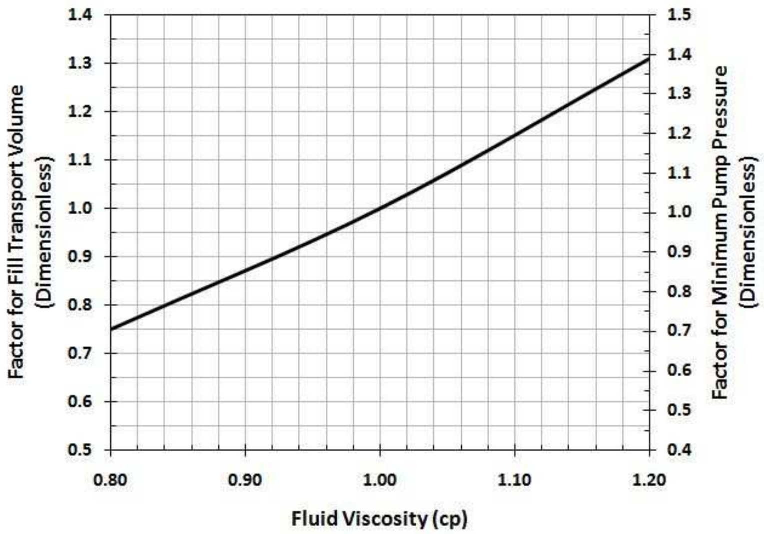

Fig. 12: Chart C- Chart on viscosity of cleaning fluid versus factor for fill transport removal and pump pressure required

In order to predict the effects for size of nozzle and viscosity of the fluid on the cleaning efficiency, Fig. 11 and Fig. 12 have to be used together with Fig. 10. Figures 11 and 12 showed the changing factor for both fill volume concentration change rate and pumping pressure in Fig. 10 with respect to the change of the size of nozzle and viscosity of the fluid respectively. The values of the factor obtained from Fig. 11 and Fig. 12 are to be multiplied with the values obtained from Fig. 10 to predict the final fill removal rate and pump pressure required. These screening charts are useful to fast-track the preliminary operational parameters required when there is a lot of unknown data. It can be helpful to CT crew in-situ without the need of detail simulation model.

Conclusions

Downhole fill removal is an important part of oilfield CT service to restore the productivity of oil/gas wells. Understanding the fill transport can enhance the efficiency of the well cleanup process. In the present study, fill removal using CT is studied using a two stages approach. The fluid flow in the CT is analysed semi-analytically using Bernoulli's equation while the downhole fill transport is modeled using FLUENT. Parameters associated with CT and fill transport efficiency are studied. The diameter ratio, fluid velocity, viscosity and nozzle size are identified as the main factors affecting the rate of fill removal. On the other hand, nozzle exit velocity and nozzle size will cause a significant effect to the downhole pressure loss. The back circulating pressure is influenced by nozzle exit velocity, diameter ratio, and fluid viscosity. Further work is in progress to produce a screening chart for CT operational parameters to be used in the oilfield service.

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