FLUSHING WATER FLOW RATE CALCULATION METHODOLOGY – A CASE STUDY

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Abstract:

This article deals with sediment transport for non-cohesive material. A 16” produced water header, which has 2” inlet line from sand treatment package, allows some sand particles settle in it. The sand deposition is more serious when there is no flow in produced water header. Therefore, it was thought to install a water flushing line upstream of tapping of 2” inlet line from sand treatment. This article explains that flushing water flow rate and water channel velocity is to be maintained to avoid sand deposition in pipe line and thus can be used as a guideline in any sediment transport application for liquid / solid system.

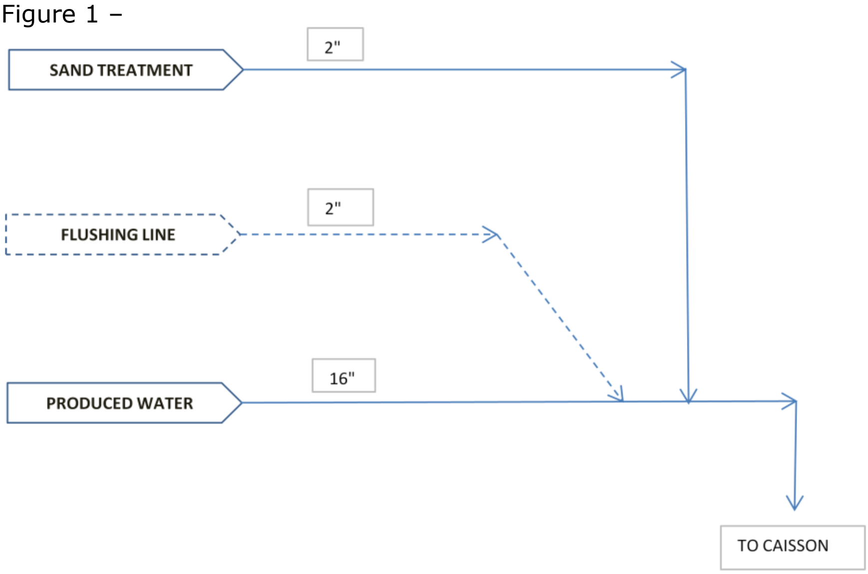
Case Study:

A 16” GRE line collects produced water from different units of the offshore production platform. It has a downward slope of 1:100 and finally enters the caisson. During sand treatment package sand disposal sequence sand slurry is routed to the drain caisson from the 2" sand disposal line via the 16" produced water disposal line. Slurry velocity at the 2" sand disposal line is high and acceptable however at the 16" produced water disposal line velocity drops due to larger pipe cross section and during no water flow condition.

It is suggested that a flushing line is to be installed, so that any deposited / settled sand particles shall be displaced and removed from the 16" line.

While 16” produced water line is flowing water, it is not anticipated that sand shall deposit because it would simply flow with the water. However, when there is no produced water flowing through the line, then sand shall deposit in the 16” header and might get hardened over a period of time and become impossible to get displaced using the produced water flow. In order to tackle this issue, a flushing water line is envisaged. This shall work when sand disposal sequence is on. Refer figure 1 for the schematic.

Figure 1 –



Notation:

A	: Flow cross sectional area	: m^2
d	: Sand particle equivalent size	: m
D	: Produced water header diameter	: m
h	: Average water channel depth	: m
H_r	: Sand bed depth	: m
n	: Manning's roughness coefficient	: Dimensionless
P	: Wetted perimeter	: m
Q	: Flushing water flow rate	: m^3/hr
R	: Hydraulic radius (A/P)	: m
s	: Relative density (p_s/p_{water})	: Dimensionless
S	: Channel (pipe) slope	: m/m
S_*	: Sediment - fluid parameter	: Dimensionless
$u_{*,c}$	: Critical friction velocity	: m/s
V	: Channel flow velocity	: m/s
θ_c	: Critical shields parameter	: Dimensionless
θ	: Arc angle	: Degree
$t_{b,c}$	: Critical bottom shear stress	: N/m^2
t_b	: Shear stress	: N/m^2
$þ$	: Water density	: kg/m^3
μ	: Kinematic viscosity	: m^2/s

Introduction:

The movement of sand and sediments in horizontal pipeline has been the topic of study for some years now. The sand / sediments deposited create various problems, such as restricting the flow, corrosion, erosion, cracks etc. Not a single factor or criterion or equation well defines the flow characteristic of sand particle transportation in fluid pipe and thus the method of determining flushing velocity has been debated by many researchers. This article explains the methodology to calculate the flushing line velocity such that solid deposition is averted.

Basis and Assumptions:

Following basis and assumptions were considered for the case study.

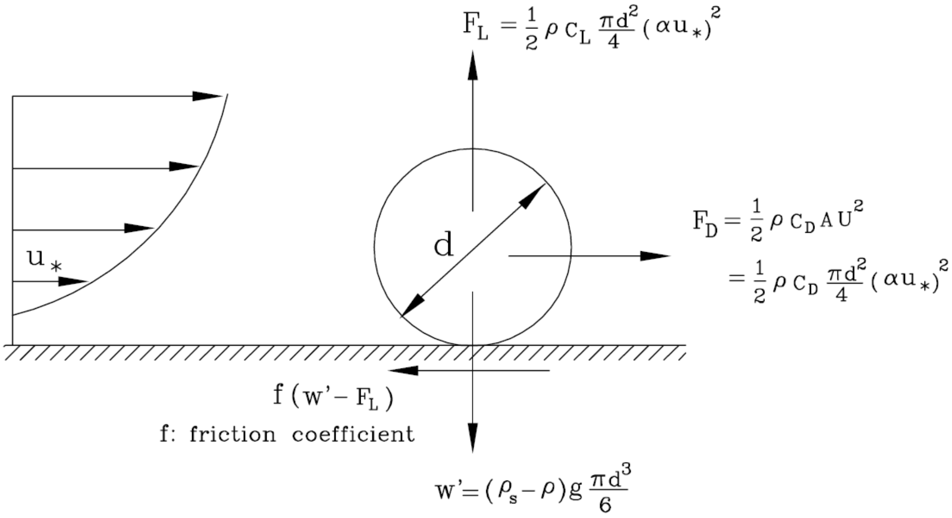
There is no flow in 16" line, apart from the flushing line flow.

d	: Sand particle equivalent size	: 0.004 m
D	: Produced water header diameter	: 0.38734 m
H_r	: Sand bed depth	: 0.005 m
n	: Manning's roughness coefficient	: 0.01
s	: Relative density (p_s/p_{water})	: 2.711
S	: Channel (pipe) slope	: 0.01 m/m
μ	: Kinematic viscosity	: 0.000001 m^2/s
$þ$	: Water density	: 1000 kg/m^3

Methodology:

During steady flow over the bed composed of cohesionless sand particles. The forces acting on the particle is shown in figure 2 [1].

Figure 2 -



At critical friction velocity ($u_{*,c}$), when the particle is about to move, the drag force is equal to the friction force, i.e.

$$\frac{1}{2}\rho C_D \frac{\pi d^2}{4}(\alpha u_{*,c})^2 = f\left((\rho_s - \rho)\, g \frac{\pi d^3}{6} - \frac{1}{2}\rho C_L \frac{\pi d^2}{4}(\alpha u_{*,c})^2\right)$$

This can be re-arranged as;

$$\frac{u_{*,c}^2}{(s-1)\, g\, d} = \frac{f}{\alpha^2 C_D + f\, \alpha^2 C_L}\frac{4}{3\,\alpha^2}$$

Shields parameter is defined as;

$$\theta = \frac{u_*^2}{(s-1)\, g\, d}$$

Therefore the conditions for sediment movement is when

- Friction velocity, (u_*) is more than critical friction velocity, ($u_{*,c}$); [$u_* > u_{*,c}$) or
- bottom shear stress is greater than critical bottom shear stress; [$\tau_b > \tau_{b,c}$]

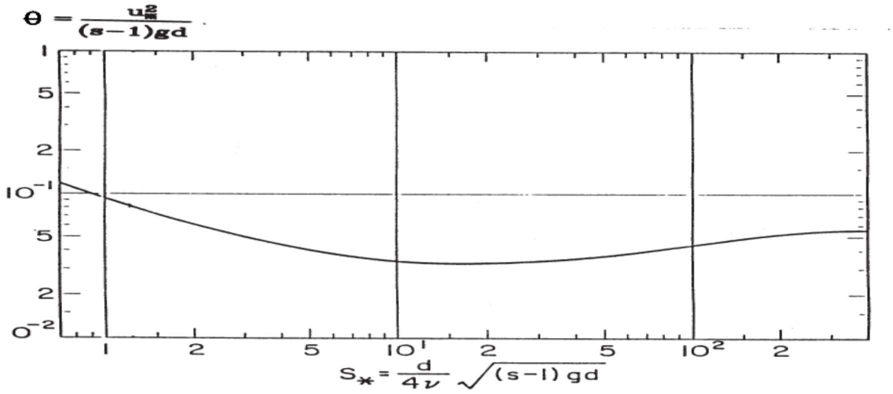
  $\tau_{b,c} = \rho\, u_{*,c}$ or
- Shields parameter (θ) is more than critical Shields parameter (θ_c); [$\theta > \theta_c$]

  $$\theta_c = \frac{u_{*,c}^2}{(s-1)\, g\, d}$$

Figure 3 shows the graphical relation between the critical Shields parameter, θ_c and sediment-fluid parameter S_*.

$$\boxed{S_* = \frac{d\sqrt{(s-1)gd}}{4\mu}}$$

Figure 3 –



- Friction velocity ensures that the sand particles start to move. This velocity can also be termed as minimum water channel velocity.

When flushing water enters the 16" line, the flow turns into the channel flow. The actual water channel velocity is ensured to be 1.5 times the minimum water channel velocity. The flushing water flow rate is assumed and geometry of the channel is calculated using Manning equation.

$$Q\frac{n}{1.49}S^{-1/2} = AR^{2/3}$$

Assuming the flushing water flow rate, *Q*, LHS of above equation is calculated. Using the formula for wetted perimeter, *P* and flow cross sectional area, *A* (as given below), arc angle, *θ* is calculated by trial and error to satisfy LHS of above equation.

$$P = \theta\frac{\pi}{180}r$$

$$A = 0.5\left(\theta\frac{\pi}{180} - \sin\theta\right)r^2$$

Average water channel depth, H_r is calculated using below equation.

$$H_r = \frac{D}{4} - \frac{\cos(\theta/2)}{4}.D$$

The actual water channel velocity, *V* is calculated from below equation.

$$Q = AV$$

If it is less than 1.5 times the minimum water channel velocity, then higher flow rate is to be considered and calculations are to be repeated.

Case Study Results:

Following results were obtained for the case study.

A	: Flow cross sectional area	: 0.007 m^2
h	: Average water channel depth	: 0.036 m
Q	: Flushing water flow rate	: 23.2 m^3/hr
S_*	: Sediment - fluid parameter	: 259
$u_{*,c}$	: Critical friction velocity	: 0.06 m/s
V	: Channel flow velocity	: 0.92 m/s
θ_c	: Critical shields parameter	: 0.055
θ	: Arc angle	: 71.1°
$t_{b,c}$	: Critical bottom shear stress	: 3.7 N/m^2

Conclusions:

- The flushing water flow rate and channel velocity calculation method discussed above is a quick and reliable method for ensuring sand or other non-cohesive particles are displaced along with the water flow in channel.
- This can be used as a quick guide for any sediment transport application in a horizontal liquid pipeline, storm water drainage, sea water outfall and sewer system etc.

References:

[1] "Sediment Transport", Zhou Liu, Aalborg University, January 2001.