Pressure losses across Bore-Hole Assembly (BHA) and Wellbore Cleaning Performance.

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Abstract

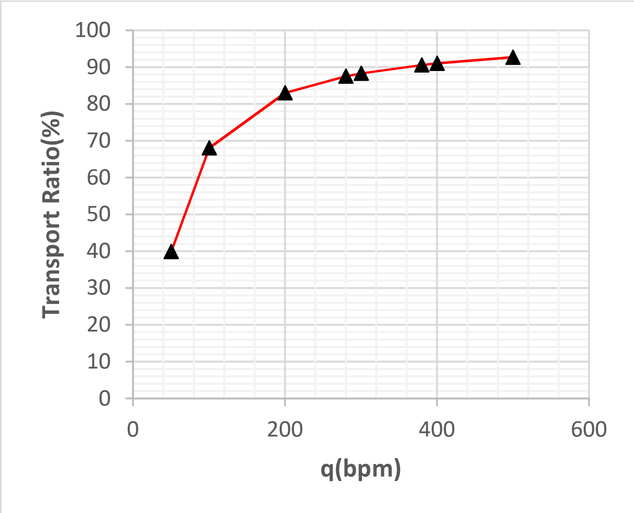
In order to accurately design and operate oil production facilities in an optimized means, it is necessary to predict the behavior of the two-phase flow of hydrocarbon in pipes with different angles. It would be desired to apply a more unified model to every conceivable condition such as inclination angles, pipe diameters, flow rates and pressures practically. Some of such models are available in technical literature. Practically all oil well production design involves evaluation of flow lines under two-phase flow conditions. However, the uncertainties in flow regime determination greatly affect the pressure drop predictions. A technique is thus required for accurate calculation of pressure losses.

Problem statement

A well diagram with following input data is being considered for calculating pressure losses across the assembly. Furthermore, eccentricity and deviation factor is also being considered. To calculate the pressure losses, transport ratio (hole cleaning performance) and graphically show sensitivity analysis by considering multiple factors.

Effect of Stand pipe scenario on hole cleaning

A vertical pipe rising along the side of derrick which joins the discharge line leading from the mud pump to rotary hose and through which mud is pumped going into the hole. Of the many functions that are performed by the drilling fluid, the most important is to transport cuttings from the bit up the annulus to the surface. If the cuttings cannot be removed from the wellbore, they will soon impede drilling. Following is the transport ratio calculated for different flow rates:

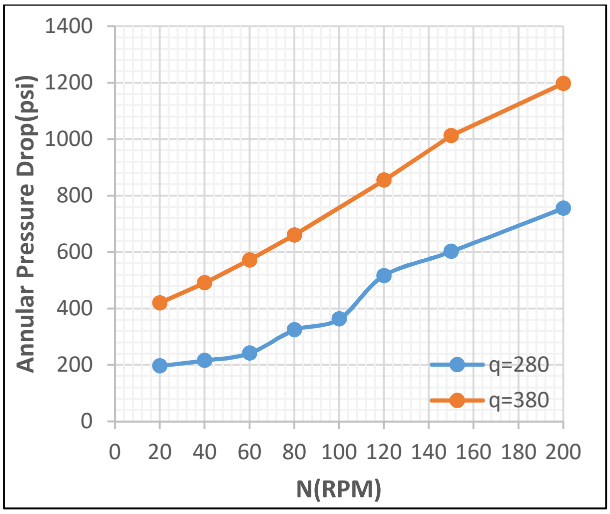


Graph 1:- Influence of flowrate on cuttings transport

Any increase in flow rate shows improved transport ratio for the same standpipe. The reason behind this improved transport ratio is as the flow rate increases, the flow behavior of fluid shifts from laminar to turbulent flow. Turbulent flow has higher capacity of lifting the cuttings.

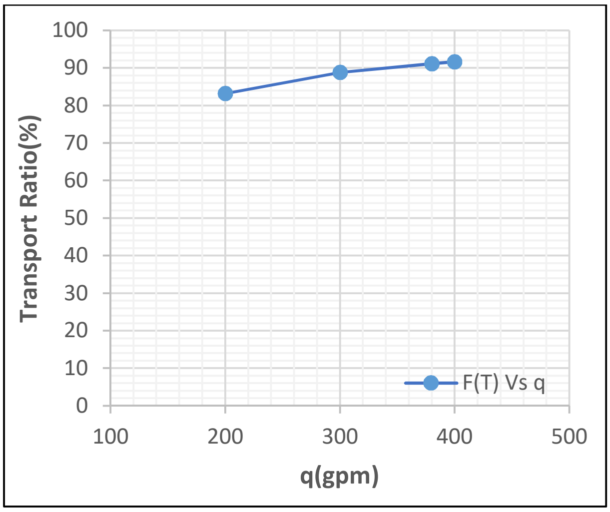
Effect of Drill pipe rotation and Eccentricity on Hole cleaning

Over the years a number of studies have been conducted to know the influence drill pipe rotation on frictional pressure losses and the performance of hole cleaning (wellbore cleaning). Delwiche et. al. and Marken investigated the effect of drill pipe rotation on real wells and found that the pressure losses increased if rotation to drill pipe in the annulus is applied. With drill pipe dynamic influence, the annular frictional pressure losses are the combined result of shear-thinning effect and drill pipe rotation. McCann et al. emphasized that pipe rotation speed and eccentricity strongly affect the pressure loss in narrow annuli. Potter et al. mentioned that as a fluid is flowing through an annulus with inner pipe (drill pipe) rotating, the flow regime may be turbulent even though the Reynolds number in the axial direction shows a laminar flow because of effects of drill pipe rotation.

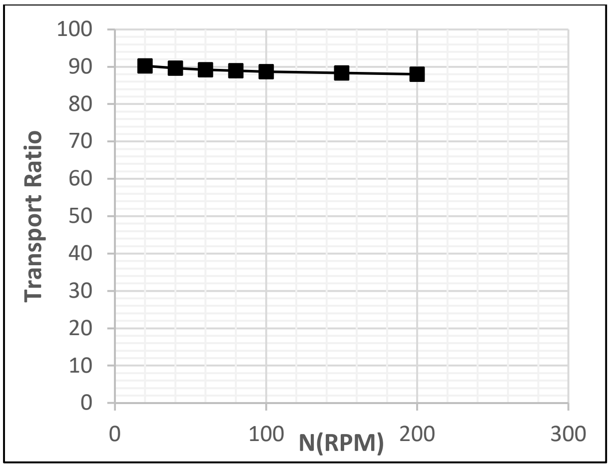


Graph 2:-Influence of rotation on Pressure Losses at different flowrates.

Because of drill pipe rotation, fluid flowing in the annulus (drill pipe-open hole, drill pipe-cased hole and drill collar-open hole) will become turbulent and makes the frictional pressure loss to increase, causing an increased stress on the drill cuttings. Moreover, this increased shear is the reason behind the transport of cutting from bottom. It is also seen that the flow rate has a good influence the cuttings transport as shown in next graph, **graph 3**.



Graph 3:- Influence of Flowrate on cuttings transport when rotation is applied.

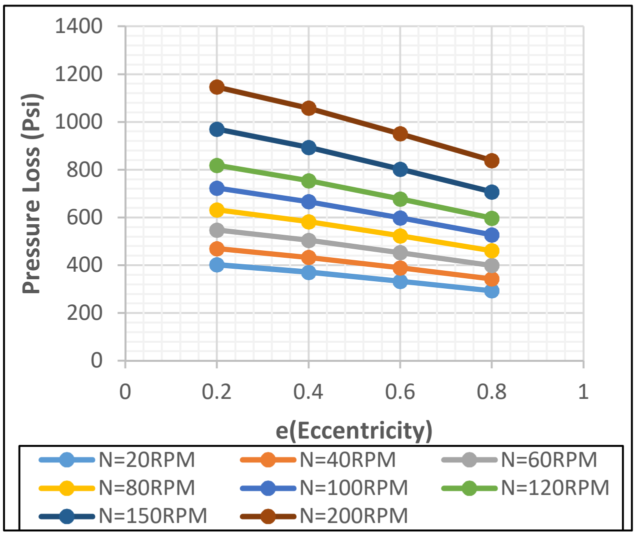


Graph 4: Slight change in cuttings transport when rotation is applied.

The methodology and the formulae we have used here have been discussed in the appendix. It has been observed that increasing eccentricity and rotation causes an earlier transition from laminar to turbulent flow. Increasing eccentricity decreases pressure losses as shown in **graph 5.**

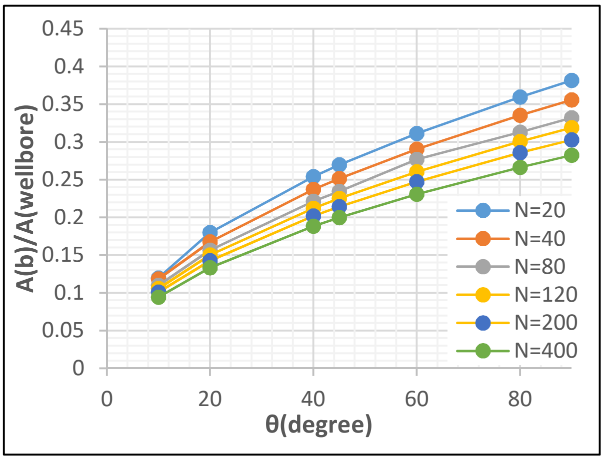
Effect of wellbore inclination and drill pipe rotation on hole cleaning

The problem of cuttings transport or hole cleaning cannot be totally represented by cuttings transport ratio, especially for deviated wells or horizontal wells. The definition of cuttings transport ratio was first defined for slightly inclined or vertical wells. In highly inclined wellbores or horizontal wellbores, the concept of transport ratio is not a good way to evaluate hole cleaning because of the packing and deposition of cuttings as shown in **fig 1.** Thence, for such scenarios, use of cuttings volumetric concentration or equivalent bed height is

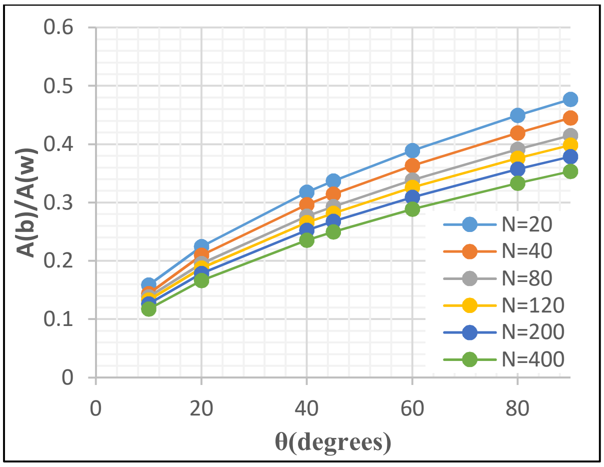


Graph 5: effect of eccentricity on Pressure losses.

a better way to evaluate the hole cleaning situation. The effects of drill pipe rotation on cuttings transport are different for different parts of the wellbore. In highly inclined wellbores, rotation of drill pipe sways cutting bed tangentially and shakes cuttings out of lower side of the annulus, which is helpful for cuttings to be carried away by high speed fluid flow in the upper region of the annulus. Also, it is important to note that if the outer diameter of pipe increases there will be less space for the cuttings to move freely through the annulus in turn increasing the volumetric cuttings concentration or increases the cuttings bed height and consequently this phenomenon may cause stuck-pipe problems. We showed such phenomenon by calculating the volumetric concentration in both drill pipe-open hole and drill collar-open hole annuli where it is certain that the OD. of drill collar is more than OD. of drill pipe and the significant changed are shown in **graph 6 and 7** respectively.



Graph 6: Influence of wellbore inclination on cuttings bed at different rotation speeds (drillpipe annulus)



Graph 7: Influence of wellbore inclination on cuttings bed at different rotation speeds (dillcollar annulus)

At intermediate inclined angles, the cuttings also tend to settle to the lower side of the annulus. Since the inclination angle in this position is less than in the highly inclined part, the settling force (mainly caused by gravity) is smaller at this position. Cuttings can be carried back to the surface easily, so the effect of drill pipe rotation is not significant in this region. in nearly vertical wells the drill pipe rotation has negligible effect on cuttings concentration.

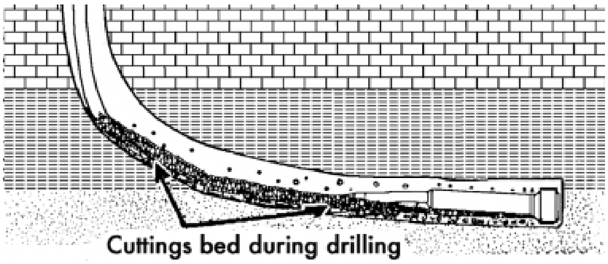
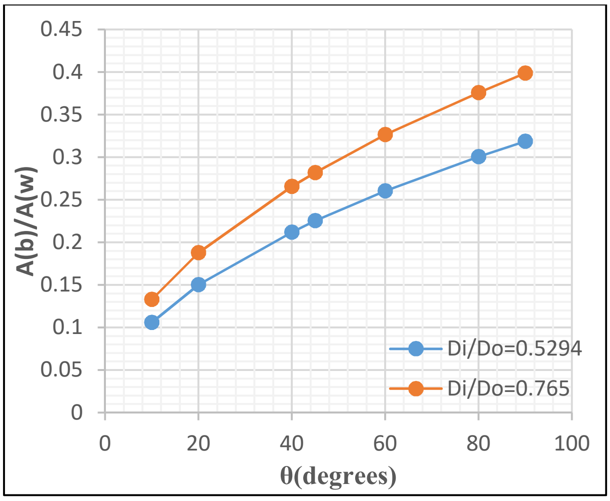


Fig 1: cuttings bed formation in typical horizontal drilling[10].



Graph 8:-Influence of Diameter ratio on cuttings bed thickness with inclination.

Conclusions

The following conclusions were made from our analysis:

a. In standpipe conditions, flow rate has significant influence on cuttings transport and increases as flowrate increases.
b. When pipe rotation is applied in vertical wellbore, there is no significant influence on cuttings transport but has significant increase in frictional pressure losses due to the change in flow regime to turbulent.
c. When the wellbore inclination is increased, there is a buildup of cuttings bed and

however as the pipe rotation is applied, the cuttings bed decreases as we increase the rotation speed.

d. We observed there is also an influence of change in pipe(rotating) outer diameter. We observed that as the diameter ratio increases; meaning that the diameter of the inner pipe is increased in horizontal wells there is a significant cuttings bed formation.

It is recommended that high drillpipe rotation helps cuttings to be suspended and transported easily to the surface.

APPENDIX

GIVEN DATA

SG(cuttings)=	2.65	
ρ(cuttings)=	22.0851	lbm/gal
dia(cuttings)=	0.25	inch
$Ø_{600}$	65	
$Ø_{300}$	39	
$Ø_{3}$	3	
$Ø_{100}$	20	
n=	0.7365378	
ρ(mud)=	12.5lb/gal	
K=	201.27057pa.sec^n	

$\mu_p = 24cp$ and yield stress is 12lb/100sft

Dimensions

Drill Pipe

Pipe		
Di	3.78	in
Do	4.5	in
Length	5000	ft

Drill Collar & Drill Collar Annulus

Drill Collar		
Ddci	2.5	in
Ddco	6.5	in
Length	600	ft
Dhole	8.5	in

Pressure Drop Across Nozzle

Dn1	11
Dn2	11
Dn3	12

Formulae:

1. **For continuous pipe[1]:**

$$\bar{v} = \frac{q}{2.448d^2} ft/s$$

$$N_{Re} = \frac{89100\rho\bar{V}^{2-n}}{K}\left(\frac{0.0418d}{3+1/n}\right)^n$$

$$\frac{1}{\sqrt{f}} = \frac{4}{n^{0.75}}\log\left(N_{Re}f^{1-\frac{n}{2}}\right) - \frac{0.395}{n^{1.2}}$$

For laminar flow;

$$\frac{dP_f}{dL} = \frac{KV^n\left(\frac{3+\frac{1}{n}}{0.0416}\right)^n}{144000D^{1+n}} psi.$$

And for turbulent flow;

$$\frac{dP_f}{dL} = \frac{f\rho v^2}{25.8D} psi.$$

2. **For Annular section[1]:**

$$\bar{v} = \frac{q}{2.448({D_o}^2 - {D_i}^2)} ft/s.$$

$$N_{Re} = \frac{109000\rho\bar{V}^{2-n}}{K}\left(\frac{0.0208(d_2-d_1)}{2+1/n}\right)^n$$

$$\frac{1}{\sqrt{f}} = \frac{4}{n^{0.75}}\log\left(N_{Re}f^{1-\frac{n}{2}}\right) - \frac{0.395}{n^{1.2}}$$

For laminar;

$$\frac{dP_f}{dL} = \frac{KV^n\left(\frac{2+\frac{1}{n}}{0.0208}\right)^n}{144000({D_o}^2 - {D_i}^2)^{1+n}} psi.$$

For turbulent flow;

$$\frac{dP_f}{dL} = \frac{f\rho v^2}{21.1(Do - Di)} psi.$$

Finally, transport ratio is given by:

$$F_T = 1 - \frac{V_{sl}}{V_a}.$$

3. **Considering drill-pipe rotation[2]:**

$$N_{ReT} = N_{Rea} + N_{Rer}$$

Where,

$$N_{Re_a} = \frac{757\rho v_a(D_o - D_i)}{\mu_{ea}}$$

$$N_{Re_r} = \frac{2.025\rho N(D_o - D_i)D_i}{\mu_{er}}$$

$$\mu_{er} = K\left(\frac{1}{n}\right)^n (\xi)\left(\frac{1}{N}\right)^{1-n} cp$$

$$\xi = \left(\frac{{D_o}^2 - {D_i}^2}{{D_o}^2}\right)\left(\frac{15}{\pi}\right)^{1-n}\left(\frac{1}{\left(1-\left(\frac{Do}{Di}\right)^{-2/n}\right)}\right)^n$$

finally,

if NRe(T)<3000,

$$f_f = 8.274{N_{Re_a}}^{-0.9075} + 0.00003N_{Re_r}$$

if 3000<NRe(T)<7000,

$$f_f = 0.0729{N_{Re_a}}^{-0.3017} + 0.000011N_{Re_r}$$

If 7000<NRe(T)<10000,

$$f_f = 0.006764{N_{Re_a}}^{-0.0286} + 0.00001N_{Re_r}$$

If 10000<NRe(T)<25000,

$$f_f = 8.28{N_{Re_a}}^{-0.7258} + 0.000001N_{Re_r}$$

If 25000<NRe(T)<40000,

$$f_f = 0.06188{N_{Re_a}}^{-0.2262}$$

If NRe(T)>40000,

$$f_f = 0.03039{N_{Re_a}}^{-0.1542}$$

Pressure losses and cutting transport ratio are calculated using the formulae presented in section 2 (depending on the flow regime).

4. **For eccentric wellbore[6]:**

Laminar flow;

$$R_{lam} = 1.0 - 0.072\frac{e}{n}\left(\frac{D_{pipe}}{D_{hole}}\right)^{0.8454} - 0.5e^{2\sqrt{n}}\left(\frac{D_{pipe}}{D_{hole}}\right)^{0.1852} + 0.96e^{3\sqrt{n}}\left(\frac{D_{pipe}}{D_{hole}}\right)^{0.2527}$$

$$\left[\frac{\Delta P}{\Delta L}\right]_{eccentric} = \left[\frac{\Delta P}{\Delta L}\right]_{concentric}.R_{lam}$$

Turbulent Flow;

$$R_{turb} = 1.0 - 0.048\frac{e}{n}\left(\frac{D_{pipe}}{D_{hole}}\right)^{0.8454} - \frac{2}{3}e^{2\sqrt{n}}\left(\frac{D_{pipe}}{D_{hole}}\right)^{0.1852} + 0.285e^{3\sqrt{n}}\left(\frac{D_{pipe}}{D_{hole}}\right)^{0.2527}$$

$$\left[\frac{\Delta P}{\Delta L}\right]_{eccentric} = \left[\frac{\Delta P}{\Delta L}\right]_{concentric}.R_{turb}$$

5. **For Wellbore Inclinations and including Rotation effects[5]**

In order to solve for this scenario where the volumetric cuttings concentration is a function;

$$\frac{\boldsymbol{V_{bed}}}{\boldsymbol{V_{wellbore}}} = \frac{\boldsymbol{A_{bed}}}{\boldsymbol{A_{wellbore}}} = \boldsymbol{f(D_{annulus}, C_c, \theta, \rho_m, v_a, v_{tang}, g, N, \mu_m, d_c)}$$

Thus, applying **Buckingham's PI theorem** we can deduce as:

$$\frac{\boldsymbol{A_{bed}}}{\boldsymbol{A_{wellbore}}} = \Pi_1^{\boldsymbol{a1}}.\Pi_2^{\boldsymbol{a2}}.\Pi_3^{\boldsymbol{a3}}.\Pi_4^{\boldsymbol{a4}}.\Pi_5^{\boldsymbol{a5}}\Pi_6^{\boldsymbol{a6}}\Pi_7^{\boldsymbol{a7}}\Pi_8^{\boldsymbol{a8}})$$

Where,

$$\Pi_1 = \frac{\boldsymbol{D_i}}{\boldsymbol{D_o}}$$

$$\Pi_2 = \boldsymbol{C_c}$$

$$\Pi_3 = \frac{\boldsymbol{\rho_m v_a D_{annulus}}}{\boldsymbol{\mu_m}}$$

$$\Pi_4 = \frac{\boldsymbol{\rho_m v_{tang} D_{annulus}}}{\boldsymbol{\mu_m}}$$

$$\Pi_5 = \frac{\boldsymbol{v_a}^2}{\boldsymbol{gD_{annulus}}}$$

$$\Pi_6 = \frac{\boldsymbol{ND_{anuulus}}}{\boldsymbol{v_a}}$$

$\Pi_7 = \boldsymbol{\theta}$ and,

$$\Pi_8 = \frac{\boldsymbol{\rho_m v_a d_c}}{\boldsymbol{\mu_m}}.$$

Now, the constants are arbitrary depending on the group data generated and from the well data.

Also,

$$D_{annulus} = D_o - D_i$$

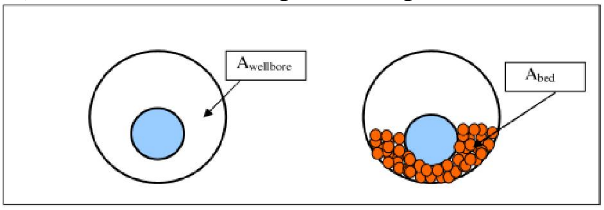
$$\rho_m = C_c \rho_c + (1 - C_c)\rho_f$$

$$\mu_m = (1 + 2.5C_c + 10.05{C_C}^2 + 0.00273exp(16.6C_c))\mu_f$$

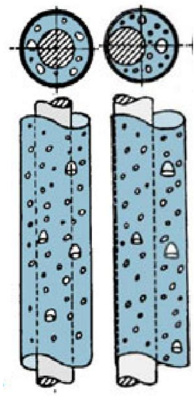
$$v_{tang} = \frac{k^2 D_o N}{(k^2 - 1)({D_o}^2 - {D_i}^2)} \times \left\{ \left(\frac{{D_o}^3 - {D_i}^3}{3D_o} \right) - ({D_o}^2 - D_o D_i) \right\}.$$

Schematic for wellbores:

(a) horizontal: cuttings bed height [3]



(b) vertical: concentric and eccentric wellbore



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