

Well planning for optimal hole cleaning

Annular Velocity and **Mud Properties** are the two major variables in the process of cleaning solids from the wellbore during drilling and tripping (**i.e. hole cleaning**).

They are however only one part of an integrated process to achieving full hole cleaning optimisation. Other variables if not fully examined, evaluated and considered will result in a damaging effect on other well processes. *E.g. Drilling and cost efficiency, bit/bottom hole cleaning, solids removal, wellbore stability, stuck pipe and hole problem prevention.*

Table: Hole cleaning variables

Hole cleaning (transport) variables	Major	Moderate	Minor
Annular velocity*	Ö		
Mud rheology	Ö (vertical & horizontal wells)	Ö (high angle)	
Bit & bottom hole cleaning	Ö		
Cuttings-size, shape, density		Ö	
Mud weight		Ö	
Mud type		Ö (water based)	Ö (OBM&synthetic)
Pipe reciprocation		Ö	Ö
Pipe rotation-mode, speed, effect		Ö	Ö
Drillstring & hole size		Ö (<17 ½ hole)	Ö (>17 ½ hole)
Hole and pipe eccentricity			Ö
Drilling rate			Ö
Drilling operation		Ö (Rotary)	Ö (Sliding)
* Annular velocity is determined by (flowrate, wellbore and drillstring geometry.)			

In reality a compromise of all hole-cleaning variables, in the well planning, engineering and operational circumstances must be investigated and accounted for. Engineers must use well engineering design and planning tools, offset information, and consider specific rig and down hole equipment aspects to be able to best develop the most suited balance of drillstring / bottom hole assembly configurations to be run.

Hole sizes, hole angle, casing setting depths, well conditions and formation characteristics must also be suitably planned, engineered and accounted for. The following guidelines have therefore been compiled to support hole cleaning in the well planning and operational phases of drilling operations.

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Well Planning

- **Trajectory** - The choice of well trajectory is often limited by other wells in the area, the choice of target and economics. Plan and consider the implications of choosing certain trajectories. *e.g. 17.5" holes at inclinations >55° are best avoided if possible.*
- **Hole angle** - Deviated wells will require higher annular velocities than Vertical wells
- **Hole size** - Minimise hole size where possible to maximise hole cleaning *e.g. 16" instead of 17 1/2" increases annular velocity by approximately 20%, Plan large diameter hole sections closer to vertical. Avoid unnecessary rotation, e.g. backreaming that may under cut the top side of the wellbore.*
- **Wellbore Stability** – Engineer and ensure best practices are utilised to maintain a gauged and consolidated wellbore.
- **Hole enlargement** - Every effort should be made in well planning to avoid enlargement of the open hole. *Mud weights, formation characteristics, fluid and drillstring dynamics are critical considerations to be accounted for in the planning process. Study offset well data for signs of over gauge hole, which may need to be included in minimum flow rate calculations.*
- **Pump rates** - Use hydraulic programmes to determine minimum flowrates to clean each section (*based on ROP, cuttings size & weight, hole angle, mud properties, BHA/Drillstring design etc.*) and maximum mud flow rates (*Equipment & pressure ratings available*)
 - **Minimum annular velocities** required to clean the open hole/ drillpipe sections. *This process is especially important in hole angles of over 30° when cuttings beds start to form.*
 - **Maximum annular velocities attainable** *E.g. calculated from No. of mud pumps, liners required, surface equipment, large diameter dp (in open hole), restrictions in mwd / motor / collars etc.*

As a rule of thumb guide, the annular velocity necessary to get cuttings moving in a well inclined at 30° is about 20% higher than in a vertical well. Between 50° and 60°, the annular velocity needs to be about twice that in vertical holes.

- **Mud properties and flow rates** - should be planned to ensure the hole is cleaned as fast as it is drilled. This is a primary criteria (*total pump capacity*) to consider when selecting the rig.
- **Bit Hydraulics** - Select nozzles to balance ROP optimisation, bit / bottom hole cleaning and annular velocity available to remove solids from the hole.
- **Slide / Oriented drilling** – Plan to optimise use of rotary drilling
Note; Type of bit and BHA selected for directional work can effect this significantly.
- **Casing Programme** - Plan minimum rat-holes consistent with safe running of casing
- **Floating Vessels & long marine riser length** - The use of a booster line is recommended when high solids' loading in the riser and BOP's is expected *i.e. where annular velocities may be significantly less than optimum.*
- **Planning Tools** - Use PC applications / Hole Cleaning Charts / Guidelines / Stuck pipe handbooks that are available.
- **Plan for typical operating conditions** - It is recommended that hydraulic and hole-cleaning simulations are run for each wells. This enables mud properties and flow rates to be optimised to provide adequate hole cleaning in all sections of the well.
- **ECD's in Higher angle and horizontal sections** – ECD increase over section length must be taken into account *e.g. formation breakdown gradients will remain the same in horizontal section.* Critical circulating pressures, swab/surge must be accounted for in well planning considerations.

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- **Hole-cleaning problems** do not necessarily occur near total depth, but can occur further up in the hole where enlargement or increase in casing diameters, reduce mud velocities. Simulation of cleaning efficiency at several points in the annulus can determine areas of inadequate cleaning.

Table 12 : Typical flow rates

Hole Size	Typical Flow Rates
17 ½"	Aim for 1100 gpm +.
12 ¼"	Typically 750 - 1150 gpm.
8 ½"	Aim for 500 gpm.
Note : It is important to calculate minimum flow rates required for hole and wellbore conditions, <i>i.e. hole angle, casing setting depth, mud properties, anticipated ROP's etc.</i> If not achievable, then ensure that drillstring engineering, BHA design, drilling & tripping procedures are in place to best manage cuttings beds that may form.	

- **Surface equipment** - This covers rig pumps, flow lines and shakers. The surface equipment is essential for obtaining good hole cleaning.
- Drillstring & Bottom hole assembly (BHA) design
- Time allocations (*especially 'circulating hole clean' times*)
- Correct mud gradient selection
- Casing setting depths

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Equipment considerations

- **Mud Pumps** - Determine flow rate and horsepower requirements for all critical sections.
- **Surface pressure losses**
- **Surface equipment** - 5000 or 7500psi rated
- **Drillstring components, BHA and drillstring design** : Design on a run what you need basis. Design to maximise rotation and minimise sliding *e.g. Bit selection, hydraulics, stabiliser, bent sub, optimisation etc.*
- **BHA** - Select simple BHA with high bypass area to assist tripping in & out of hole
- Smaller hole e.g. < 8 ½", consider running two jet bits vs. three to improve bottom hole cleaning and ROP. (*Two jets being less likely to plug than three smaller ones for same total flow area (TFA).*)
- **On-line drillstring simulator** using data from drilling mechanics sub is capable of calculating the variations in friction factors and can provide early indications of hole cleaning problems.
- **Downhole torque and downhole WOB monitoring** has proved to be an important tool in qualitatively assessing hole cleaning efficiency. Trend analysis can indicate the condition of the hole while drilling, as well as the effectiveness of any remedial action such as reaming, circulating and wiper tripping.
- **Solids control equipment** – Ensure shakers are fitted with correct screens for section. Run centrifuges only as required.
- **Floater**s. The use of a booster line is recommended when high solids loading in the riser and BOP's is expected.

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Mud properties

- **Oil-based and synthetic-based fluids** - mud-rheology used in the modelling process should be based on downhole conditions, not surface conditions.
- **Mud Chemistry** - Ensure chemical compatibility to prevent cuttings swelling
- **Mud weight** - Increased mud weight provides buoyancy, reduces the effective weight of cuttings with effective transport occurring at lower annular velocities. Mud weight is governed by other drilling considerations (*e.g. well control, wellbore stability and losses*).
- **Mud gel** - Elevated low end rheology (*i.e. high gels*) assists in Hole Cleaning. *It does this by preventing cuttings from settling into a cuttings bed.*

Rule of thumb : 3 fann rheometer minimum of 12-15

- **Flow Regimes** - Generally use thick mud's in laminar flow (*unless ECD is critical*)
- **Typical ranges of fluid properties for a selection of hole sizes** - are specified by either the Yield Point (*based on Bingham Model*) or the Power Law Index (n) as illustrated below.

Table 23 : Typical range of fluid properties

Hole Size	Recommended YP Limits (lb/100 ft ²)	Recommended "n" Range	Flow Regime
17½"	28 Min	0.5 - 0.7	Laminar
12 ¼"	21 Min	0.5 - 0.75	Laminar
12 ¼"	5 - 10 Max	0.5 - 0.95	Turbulent*
8 ½"	22 Min	0.5 - 0.7	Laminar
8 ½"	5 - 12 Max	0.5 - 0.9	Turbulent*

Note : In general higher viscosity muds pumped in laminar flow are preferred.

* May result in hole washout/enlargement especially around BHA components.

- **Mud Rheology** - Select mud's with high YP/PV ratios and enhanced low shear viscosity
- **Pump Rate** - Use hydraulics programmes to determine minimum mud flow rate
- **Drill pipe rotation** - is more pronounced in viscous muds and in smaller holes
- **Hole cleaning pills** - Circulating mud properties must be optimised to provide adequate hole cleaning. Under certain conditions, it may be necessary to supplement hole cleaning with "viscous" pills. Excessive use of pills should be avoided since they can contaminate the mud system. Generally a high viscosity (and preferably high weight) pill is effective at removing accumulated cuttings. Low viscosity pills can also be effective in smaller hole sizes (12-1/4 inch and below).

Low and high viscosity pills can also be pumped in tandem. The maximum volume of the pills should be based on hole size and changes in hydrostatic. Similar improvements in hole cleaning have been achieved using lost circulation material (LCM) pills.

- **Viscous Pills** - Use only when essential. Take special care with low viscosity pills to maintain high flow rate
- **Dense Pills** - Use only when essential. Limit volume to avoid fracturing formation

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Table 34 : Recommended sweep size

26" & 36" Intervals	17½, 16" Intervals	12¼" Intervals	8½ Intervals
80 + bbl	60 + bbl	30 - 50 bbl	20 bbl

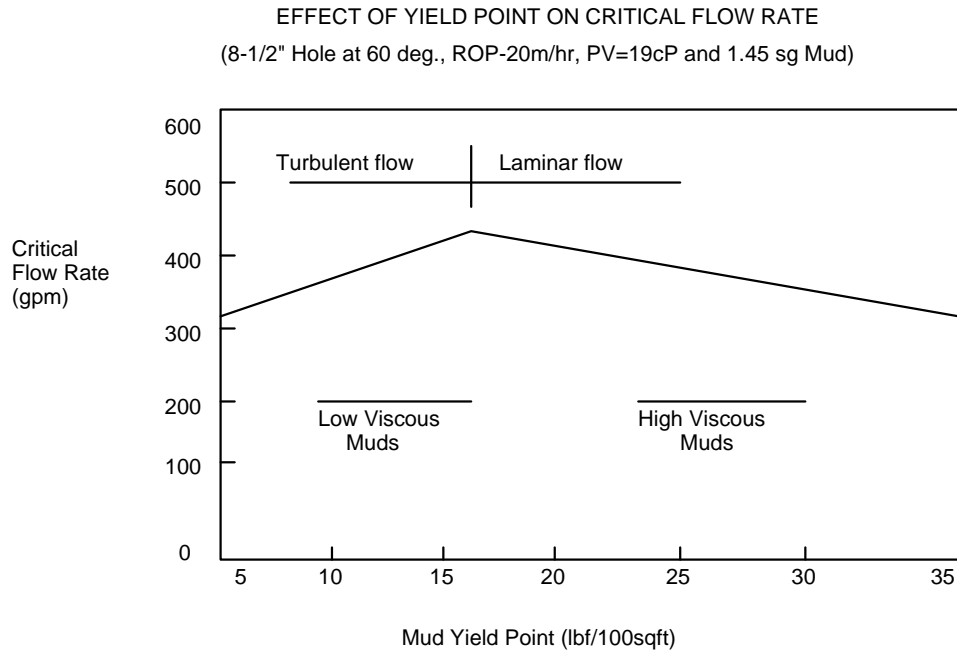


Figure 1 : Effect of yield point on critical flow rate

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Drilling Practices

- **Vertical holes** - reciprocate rather than rotate the pipe during circulation prior to tripping - this helps remove cuttings from stagnant zones near the wellbore wall.
- **Vertical holes** - Poor hole cleaning is generally indicated by cuttings fill at the bottom of the hole. Increase sweep size and frequency if drilling riserless with seawater *e.g. 40-60bbls every 10m*. If drilling with mud, improve rheology.
- **ROP** - Higher penetration require higher flow rates to clean the hole. Instantaneous ROP must be pre-determined and maintained to avoid overloading annulus with cuttings. *Mud properties and flow rates should be adjusted to ensure the hole is cleaned as fast as it is drilled.*
- **Pump Failure** - Stop drilling and circulate until full pump capacity is restored
- **Slide Drilling** – Orientate directional BHA to high side when wiping string and circulating. Consider rotary wiper trip after prolonged periods of sliding as hole cleaning conditions dictate.
- **Tripping** - Circulate the hole clean prior to tripping. a single bottoms up is not sufficient
- **Drags** – Abnormal drags should be attempted to be wiped out mechanically. If they persist on subsequent trips, a increase in mud weight may assist. Note: It is not advised to systematically ream, backream or circulate through trouble spots as this can result in deteriorating hole condition (instability, washout, enlargement that should be avoided if possible.)
- **Allowable drag** - Agree to a maximum allowable drags in advance with the Company Man. Do not go immediately to the maximum allowable drag, but work to this value progressively ensuring that the pipe is free in the opposite direction on every occasion.
- **Backream** - Avoid precautionary backreaming. Understand the nature and causes of any problems encountered on tripping. **Only backream when essential.**
- **Pipe movement** - Avoid sudden mechanical or hydraulic shocks (swab and surge) which may cause cuttings to avalanche.
- **Control tripping rates** - to avoid pulling rapidly into a cuttings beds or causing excess swab/surge pressure.
- **Stop and circulate** - the hole clean if drags continually increase and cuttings beds are suspected.
- **Drill pipe rotation/reciprocation** - Will mechanically disturb cutting beds and assist hole cleaning. Downward and stationary rotation are most effective rotating modes helping to equalise fluid velocities on the low and high side of the hole.
- **Backreaming does not achieve this !** The influence of drill pipe rotation is more pronounced in viscous muds and in smaller holes < 17 ½ In cases of slide drilling, cuttings beds may form are more difficult to remove. Under these special circumstances, increased flow rate or changes in operation practices, wiping every stand to achieve normal drag may be necessary to improve cuttings bed management and overall hole cleaning and ease of tripping.
- **Drill pipe reciprocation** helps hole cleaning by causing surges in the AV and is the best practice to establish drag trends that will be first indicator to poor hole cleaning and cuttings bed forming. *If the drillstring is rotated continuously you will not see this.*
- **Record pickup, slack off and off-bottom rotating torque regularly** - at connections to establish actual trends for comparison to predicted trends. Always wipe stand prior to connection and if necessary ream stand down. (*Avoid upward rotation.*)
- **Horizontal hole** – As circulating ECD increase with section length, control pipe movement to minimise wab and surge and resultant ECD's.

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- **Horizontal hole** – Minimise formation damage consists of keeping the invasive fluids and solids within a tight radius of the borehole axis, either by tight time constraints or **careful drilling practices**.
- **Horizontal hole** - Avoid circulating for extended periods with the same stand, to prevent undercutting wellbore. As a rule of thumb, keep pipe moving and lay out a stand every half hr to prevent hole deterioration.
- **Data Acquisition** - Trend sheets should be used to log all hole cleaning parameters for future use, *i.e. flow rate, rpm, mud rheology Vs depth and evidence of dirty hole on trips etc.*
- **Trip procedures** - should be prepared in advance with guidance on tripping intervals, such procedures can be modified over the well as necessary.
- **Cuttings returns log** - can provide valuable information on trends in cuttings returns versus ROP by measuring the amount of cuttings over the shakers at regular intervals

Table 45 : Well inclination / Circulating factors

Well inclination	Section length factor*			
	Range	17 ½ hole	12 ¼" hole	8 ½ hole
	0° - 10°	1.5	1.3	1.3
	10° - 30°	1.7	1.4	1.4
	30° - 60°	2.5	1.8	1.6
	60° +	3.0	2.0	1.7
* Factor = Bottoms up factor				

- **Avoid hole enlargement and/or washouts** – Prevention rather than cure is paramount in this case *e.g. If hole washout increases from 17 ½" to 20", the volume of rock increases by 166% over that area. The pump rate at this stage drops by 281%. Hole cleaning is now a problem.*

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Rig Site Indicators

- **Cutting size & shape** - Rounded cuttings indicate poor carrying capacity
- **The volume of cuttings generated** - is a function of hole size and ROP. The table below illustrates the amount of cuttings generated for given hole sizes and ROP

Table 56 : Cuttings volume generated

Cuttings Generation Rates		
Hole size	Average ROP's	Tonnes / hour
17 ½"	30 m/hr (100 ft /hr)	12 tonnes / hour
	60 m/hr (200 ft/hr)	24 tonnes / hour
	90 m/hr (300 ft/hr)	36 tonnes / hour
12 ¼"	30 m/hr (100 ft /hr)	5 tonnes / hour
	60 m/hr (200 ft/hr)	10 tonnes / hour
	90 m/hr (300 ft/hr)	15 tonnes / hour
8 ½"	15 m/hr (100 ft /hr)	0.5 tonnes / hour
	30 m/hr (200 ft/hr)	1.0 tonnes / hour
	45 m/hr (300 ft/hr)	1.5 tonnes / hour

- **Cuttings Return** - Use average ROP's to estimate anticipated cuttings rate at shakers for hole size being drilled
- **Torque & Drag** - Use to predict torque and drag. Look for deviations from trend
- **Erratic Torque / SPP** – Formation related or Indicator of cuttings beds & hole packing-off
- **Tripping Analysis** - Compare drag trends with subsequent trips to indicated possible presence of cuttings beds
- **Hole drag & fill** - Monitor string weights for indications of drag and fill on bottom before and after each connection and while tripping in/out of the hole. Ensure trouble spots trends are recorded, handed over and monitored.
- **Formations being drilled** – will result in variable drilling indicators and changing hole cleaning efficiencies. *E.g. while drilling mudstones inefficient hole cleaning is indicated by an increasing drag trend with very little increase in drilling torque.* However, both torque and drag may increase with poor hole cleaning while drilling some sandstone reservoir sections. A straightforward analysis is therefore not always possible, *e.g. a decrease in wellbore lubricity with increasing sandstone cuttings may play a vital role in the drilling mechanics response required.*
- **Shale Shaker monitoring** - The shakers will indicate the effectiveness of the hole cleaning and provide an early warning sign to a hole cleaning problem. *Are volumes of cuttings right for the ROP? Do slugs of cuttings appear followed by very few cuttings? Etc.*

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