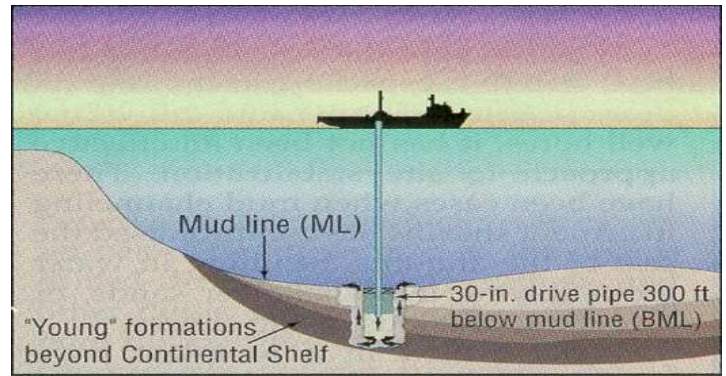


Optimising riser-less Drilling

What is riserless drilling?

"Riserless" drilling refers to offshore drilling from a drill ship or semi submersible, rather than a floating drilling rig, or "riser." A hole is drilled from the mud line below the seabed with the cuttings returning to the seabed. A subsea wellhead is run back to the rig with a blow out preventer and a marine riser is added at this point. This allows the rest of the well to be drilled with weighted drilling, which is needed to maintain control over the pressure in the well as it is drilled deeper. The deeper drillings now bring the drilling fluid and cuttings back to the added marine riser.



1. 17 1/2" Riserless drilling Optimisation example

Based on offset data from > 100 wells drilled riserless in SE Asia, this worksheet illustrates how 17 1/2" 'riser-less' drilling rates can theoretically be optimised based on sedimentary formation characteristics, fluids present, and drilling parameters. The optimized rates are equated to field results.

It reviews effects of annular

- drilled cuttings concentration to prevent pack-off, mud rings and hole cleaning difficulties
- pressure constraints that may result in formation (fracture) breakdown or well flow.
- hole size, length, rates of penetration, formation density/characteristics presented.

1.1 Cuttings Concentration

Cuttings concentration (C_a) while circulating and drilling an annulus volume of a specified section length is dependent upon the following;

- Rate of penetration, (ROP), ft/hr.
- Porosity (ϕ_h %) & density (F_d , lb/gal) of formation drilled.
- Flow rate pumped (Q , gal/min).
- Transport efficiency of drilled solids (E_t , %).
- Drilling fluid density (ρ , lb/gal).
- Wellbore diameter (D , in)
- Section length drilled (SL , ft)

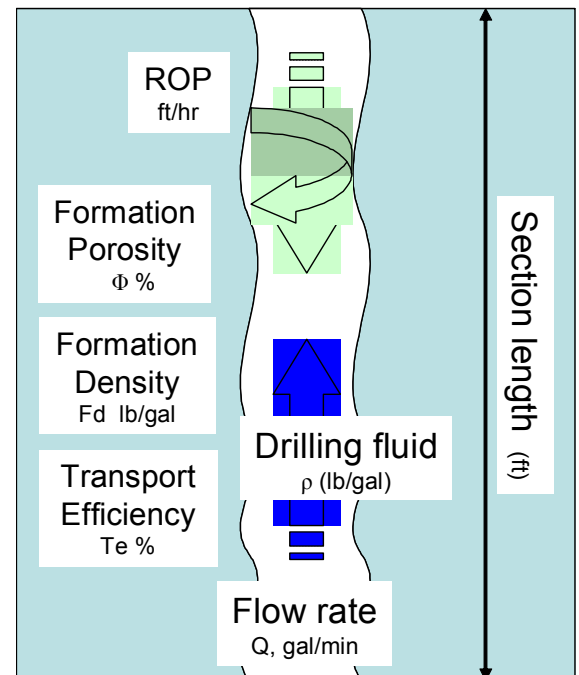
Note: Cuttings drag, shape, formation type, pipe rotation, hole angle, slip velocity, are not considered in the worksheet calculations presented.

Based on the parameters as input, the concentration of cuttings (C_a) in the fluid annulus can be calculated using equations as defined in this worksheet.

Drilling Notes:

- 75% of offshore sedimentary formations drilled are shales.
- **In 100% soft shales sequences;** it has been shown that a concentration of cuttings (i.e. A C_a of > 6% - 8%) by volume can result in hole cleaning problems, mud rings and/or wellbore pack-off occurring. Therefore this cuttings concentration may prove to be the drilling limit for shale formations.
- **In predominant sand or silt sequences.;** Cutting concentration effects in the annulus may be limited to the fracture gradient of these formations. Where if exceeded, fracture, instability and loss of the wellbore may occur.

Note. Wells considered were in an average water depth of 1500m, 4,921ft. At the seabed, formations will have a porosity of (70% fluid and 30% formation) that will decrease and increase in proportion based on depth, burial, compaction and sedimentary formations present. Hence 40- 50% is assumed as a reasonable figure for this base line evaluation. This would be changed as better geo-mechanical understanding of sediments drilled were gained.



Initial Input data;

Hs :=	36	in	phi := 45%
	30		
	26		
	23		
	17.5		
	14.75		
	12.25		Fd := 16 lb/gal
			bb1 := 42gal

1.1.1 Hole size.

For various hole sizes, formation porosity and density as input. The first calculation determines the cuttings volume concentration (Cd) per foot (Ah_p) drilled, *Note: for non circulating conditions.*

Step # 1: Calculate the volume of cuttings drilled for hole size, (Hs inches), average porosity (φ_h, %) in terms of area (Ah, in²) and volume per foot drilled (Ah, ft³/ft)

$$Ah := \frac{\pi \cdot (1 - \phi_h) \cdot H_s^2}{4}$$

$$Ah = \begin{pmatrix} 3.888 \\ 2.7 \\ 2.028 \\ 1.587 \\ 0.919 \\ 0.653 \\ 0.45 \end{pmatrix} \text{ft}^2 \quad Ah = \begin{pmatrix} 3.888 \\ 2.7 \\ 2.028 \\ 1.587 \\ 0.919 \\ 0.653 \\ 0.45 \end{pmatrix} \frac{\text{ft}^3}{\text{ft}}$$

1.1.2 Cuttings concentration

Step # 2: Calculates the cuttings concentration (Cd, lb/ft) based on hole volumes per foot drilled (Ah, bbl/ft) and formation density (Fd, lb/ft),

$$Cd := Ah \cdot Fd$$

$$H_s = \begin{pmatrix} 36 \\ 30 \\ 26 \\ 23 \\ 17.5 \\ 14.75 \\ 12.25 \end{pmatrix} \text{in} \quad Cd = \begin{pmatrix} 465.315 \\ 323.135 \\ 242.71 \\ 189.932 \\ 109.956 \\ 78.113 \\ 53.878 \end{pmatrix} \frac{\text{lb}}{\text{ft}}$$

Step # 3: Converts the cuttings concentration (Cd, lb/ft) into a more identifiable drilling measurement value *i.e. relative to a drill pipe single (3ft) or drilling stand (93ft) for the various hole sizes (Hs, inches) as input.*

*Note: Consider the **significance of the cuttings volumes generated in the larger hole sizes.** e.g. These will impact wellbore (fracture!) pressures and hole cleaning characteristics considerably.*

$$H_s = \begin{pmatrix} 36 \\ 30 \\ 26 \\ 23 \\ 17.5 \\ 14.75 \\ 12.25 \end{pmatrix} \text{in} \quad Cd = \begin{pmatrix} 1.396 \times 10^4 \\ 9.694 \times 10^3 \\ 7.281 \times 10^3 \\ 5.698 \times 10^3 \\ 3.299 \times 10^3 \\ 2.343 \times 10^3 \\ 1.616 \times 10^3 \end{pmatrix} \frac{\text{lb}}{30\text{ft}} \quad Cd = \begin{pmatrix} 4.327 \times 10^4 \\ 3.005 \times 10^4 \\ 2.257 \times 10^4 \\ 1.766 \times 10^4 \\ 1.023 \times 10^4 \\ 7.265 \times 10^3 \\ 5.011 \times 10^3 \end{pmatrix} \frac{\text{lb}}{93\text{ft}}$$

2.1 Riserless surface hole drilling of soft sedimentary formations

This second worksheet is valid for **Vertical wellbores** or wellbores up to 30degree inclination. Calculations further evaluate cuttings concentrations, at various drilling rates of penetration (ROP, ft/min), accounting for fluid density (Fd), transport efficiency (φ, %), hole size (D) and drillstring dimensions (d) as input below.

Data Input.

ROP = rate of penetration, (ft/min)

Q = drilling pumping flowrate (gal/min)

ρ = Mud weight (lb/gal)

φ = average porosity for section (%)

Fd = density of cuttings, (lb/gal)

D = hole size drilled (inches)

d = drillstring diameter (inches)

$$ROP := \begin{pmatrix} 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{pmatrix} \frac{\text{ft}}{\text{min}}$$

$$ROP = \begin{pmatrix} 120 \\ 180 \\ 240 \\ 300 \\ 360 \end{pmatrix} \frac{\text{ft}}{\text{hr}}$$

$$\rho := 8.66 \frac{\text{lb}}{\text{gal}}$$

$$Fd := 16 \frac{\text{lb}}{\text{gal}}$$

$$Q := 850 \frac{\text{gal}}{\text{min}}$$

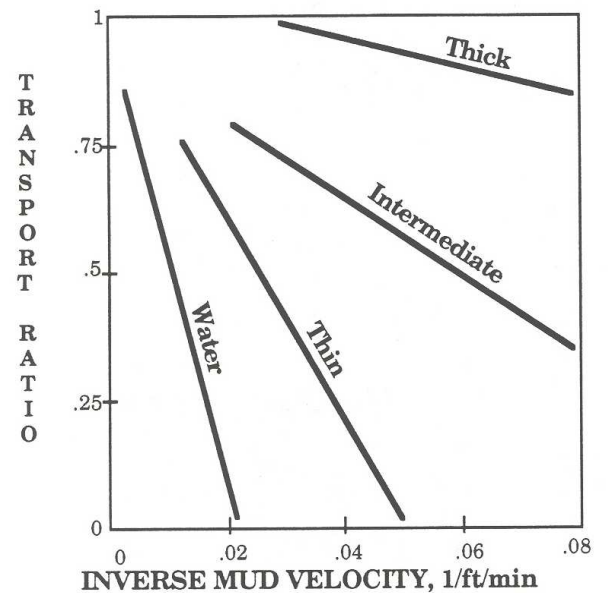
$$\begin{pmatrix} D \\ d \end{pmatrix} := \begin{pmatrix} 17.5 \\ 5.0 \end{pmatrix} \text{in}$$

$$\phi := 40\%$$

Notes: Drilled cuttings are transported dependant upon fluid properties, flow & drilling rates, and influenced by wellbore & drillstring geometry and overall transport efficiency relationships. From Siffermans table as shown and when considering a thin or intermediate drilling fluid for the riser-less drilled section.

The first evaluation determines the transport ratios, that is then used to calculate cuttings concentration and pressure effect in the drilled annulus.

SIFFERMAN'S TRANSPORT RATIOS



2.1.1 Transport efficiency

Step # 1; Calculate annular velocity (A_v , ft/min) based on flowrate (Q , gal/min), wellbore (D) and drillstring dimensions (d) input.

$$A_v := \frac{Q}{D^2 - d^2}$$

$$A_v = 58.178 \frac{\text{ft}}{\text{min}}$$

Step # 2; Assuming a thin fluid* and then using annular velocity obtained in step#1. Determine the inverse of annular mud velocity ($1/A_v$) from Siffermans transport ratio's table above

$$\frac{1}{A_v} = 0.017 \frac{\text{min}}{\text{ft}}$$

* A thin fluid is assumed as most practicable because as the soft 'riser-less sedimentary formations' are drilled drilled seawater will now contain a mix of predominantly dispersed clay that in essence has become a weighted fluid system and thus a more efficient transport medium!.

Step # 3; From Siffermans graph by plotting the inverse mud velocity ($1/A_v$) to intersect with the drilling fluid used (i.e. thin) and from this intersection then determine the transport ratio, E_t , %.

$$E_t := 63\%$$

2.1.2 Cuttings concentration

Step #4; Calculate the volumetric concentration of drilled cuttings (C_a) in the annular interval using the following equation for varying rates of penetration as input;

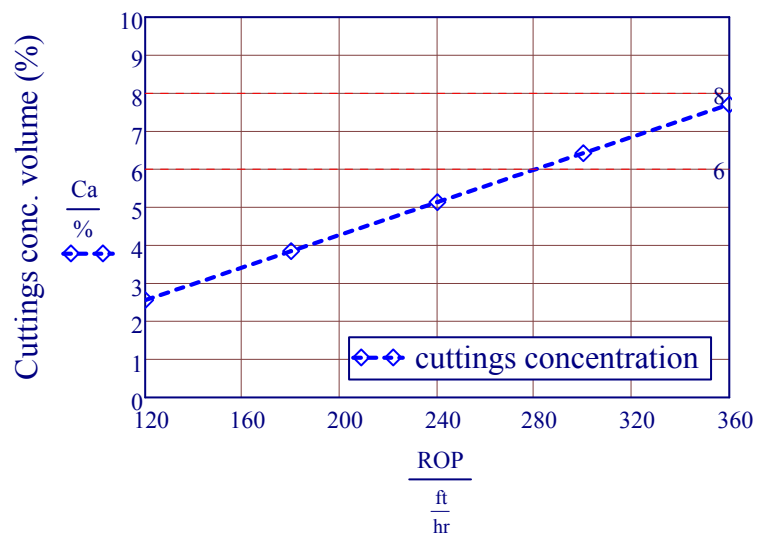
Note: This now evaluates and determines effects of drilling, circulating rate, dimensions & transport efficiency.

$$C_a := \frac{\text{ROP} \cdot \pi \cdot (1 - \phi) \cdot (D^2 - d^2)}{4 \cdot E_t \cdot Q}$$

$$C_a = \begin{pmatrix} 2.57 \\ 3.86 \\ 5.14 \\ 6.43 \\ 7.71 \end{pmatrix} \%$$

$$\text{ROP} = \begin{pmatrix} 120 \\ 180 \\ 240 \\ 300 \\ 360 \end{pmatrix} \frac{\text{ft}}{\text{hr}}$$

Cuttings concentration vs drilling rate



Drilling, rate of penetration

Note. For the wellbore hole size drilled (i.e. 17 1/2" in this case), formation and drilling parameters input. It can be concluded from the relationship graph above that a cuttings concentration C_a of 6-8% would theoretically occur at rates of penetration in excess of 280 and 360+ft/hr

- Well data and field drilling experience would assist in optimising this process.

2.1.3 Annular pressure (fracture) effects

Step #5; Based on cutting concentration determined in 2.1.2 step#4 . Calculate the effective weight due to cuttings concentration (ρ_e , lb/gal), being generated in the drilled annulus as illustrated below.

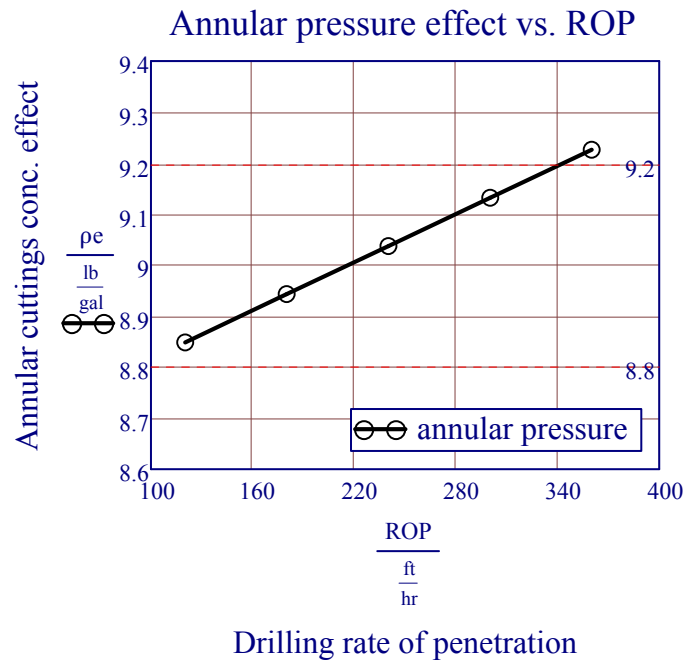
$$\rho_e := Fd \cdot (Ca) + \rho \cdot (1 - Ca)$$

$$\rho_e = \begin{pmatrix} 8.85 \\ 8.94 \\ 9.04 \\ 9.13 \\ 9.23 \end{pmatrix} \frac{\text{lb}}{\text{gal}} \quad \text{ROP} = \begin{pmatrix} 120 \\ 180 \\ 240 \\ 300 \\ 360 \end{pmatrix} \frac{\text{ft}}{\text{hr}}$$

Discussion; From working through calculations for different input parameters, it should be now understood that flow rates and rates of penetration effect cutting concentration. Also that effective mud weights can exceed formation breakdown pressures. All these factors therefore needing to be understood and evaluated in order to optimise a drilling process or prevent operational problems from occurring.

Note. For the wellbore hole size drilled (i.e. 17 1/2" in this case), formation and drilling parameters input. It can be concluded from the relationship graph above that formation flow or fracture (based on 'on bottom total depth' limits as input in graph) would theoretically occur at rates of penetration below 100ft/hr and at a maximum rate of 340ft/hr.

- Well data and field drilling experience would assist in optimising this process.



Conclusion; Drilling rate, mud ring and pack off concerns is evaluated as the recognised constraint vs pressure and fracturing risk.

3. Section length considerations, SI (ft)

$$SI := 4000\text{ft}$$

3.1.1. Hole volume for hole size(s) and section length drilled.

Step #1; If a specified section length (SI, ft) is now considered to be drilled. The following worksheet steps calculate the hole volume theoretically drilled (Hv, bbl) for various hole sizes (Hs, in) input, including a hole enlargement or wash-out factor (W_{out} , %)

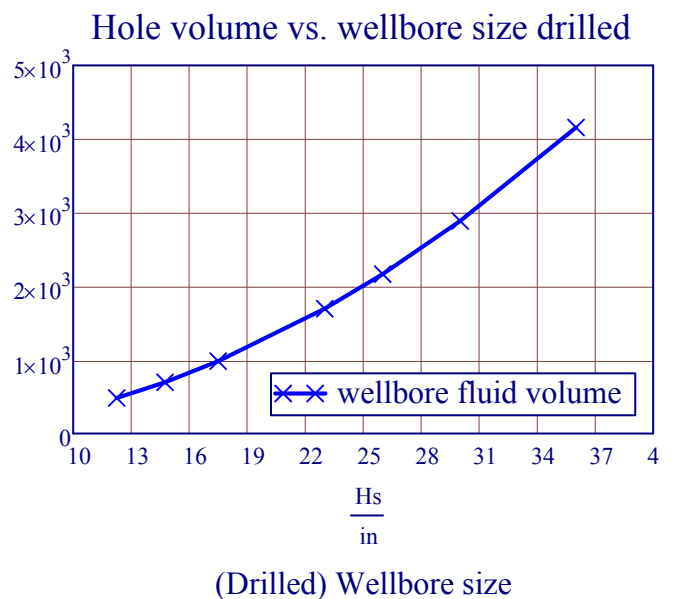
Hole enlargement or wash-out

$$W_{out} := 150\%$$

$$Hv := SI \cdot Ah \cdot W_{out}$$

$$Hv = \begin{pmatrix} 4155 \\ 2885 \\ 2167 \\ 1696 \\ 982 \\ 697 \\ 481 \end{pmatrix} \text{ bbl} \quad Hs = \begin{pmatrix} 36 \\ 30 \\ 26 \\ 23 \\ 17.5 \\ 14.75 \\ 12.25 \end{pmatrix} \text{ in}$$

Hole volume
 $\frac{Hv}{bbl}$



Note. For the wellbore hole sizes drilled, it can be concluded from the relationship graph above that as drilled 'hole size' increases wellbore volumes increase, where the physical magnitude of cuttings would in turn result in greater annular pressures and hole cleaning effects.

So hole size will effect the maximum riser-less rates that can be achieved.

3.1.2 Hole size and Section length effect.

Step #2; Calculates cuttings bottoms up time (Tds) based on hole volume, flowrate and transport efficiency. *Note: In reality transport efficiency would change considerably for each hole size and flow rate used or available.*

$$Tds := \frac{Hv}{Q} \cdot \frac{1}{Et}$$

$$Hs = \begin{pmatrix} 36 \\ 30 \\ 26 \\ 23 \\ 17.5 \\ 14.75 \\ 12.25 \end{pmatrix} \text{ in}$$

$$Tds = \begin{pmatrix} 326 \\ 226 \\ 170 \\ 133 \\ 77 \\ 55 \\ 38 \end{pmatrix} \text{ min}$$

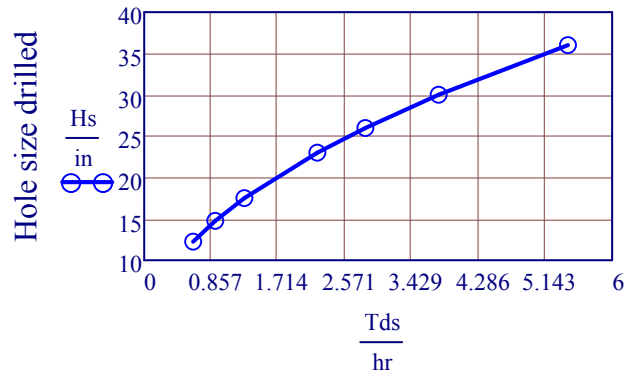
$$Tds = \begin{pmatrix} 5.43 \\ 3.77 \\ 2.83 \\ 2.22 \\ 1.28 \\ 0.91 \\ 0.63 \end{pmatrix} \text{ hr}$$

Discuss the impact of cuttings concentration when the section length and resulting hole volume for flowrate and rate of penetration is less than or exceeds one hour duration?

Note. When considering a specific section length for varying hole sizes at a given pump rate and transport efficiency as illustrated in the relationship graph above. It can be concluded that as the drilled 'hole size' increases the time required to clean the wellbore will also increase. Therefore as the wellbore cannot be physically cleaned faster than it can be drilled, there comes a point where when bottoms up will takes more than 1hr rates of penetration and an equivalent factor will then have to account for the time required.

So in effect, section length will affect the maximum riser-less drilling rates that can be achieved and is in itself a function of hole volumes, flowrate, transport efficiency and time.

Hole size vs. bottoms up time



Theoretical 'Bottoms up' time

3.1.3 Cuttings concentration and section length

Step #3; Calculate cuttings concentration for example in a 17 1/2" hole accounting for section volume at various rates of penetration drilled.

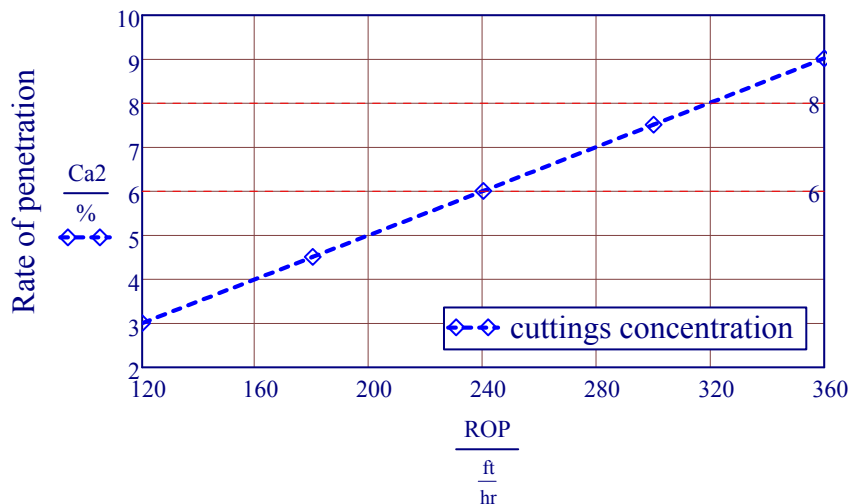
'Bottoms up' time

$$Tds2 := 1.17 \text{ hr}$$

$$Ca2 := \frac{ROP \cdot \frac{\pi \cdot (1 - \phi) \cdot (D^2 - d^2)}{4} \cdot Tds2}{Et \cdot Q} \cdot \frac{1}{hr}$$

$$Ca2 = \begin{pmatrix} 3 \\ 4.5 \\ 6 \\ 7.5 \\ 9 \end{pmatrix} \%$$

$$ROP = \begin{pmatrix} 120 \\ 180 \\ 240 \\ 300 \\ 360 \end{pmatrix} \frac{\text{ft}}{\text{hr}}$$



Rate of penetration

Note. When accounting for section length, flowrate and volumes, where bottoms up time can be > 1hr, the drilling rate boundaries are **now reduced to 240 and 320ft/hr** due to time effects required to clean the wellbore. Conversely if bottoms up time (section length) was less than 1hr drilling rates could be increased accordingly.

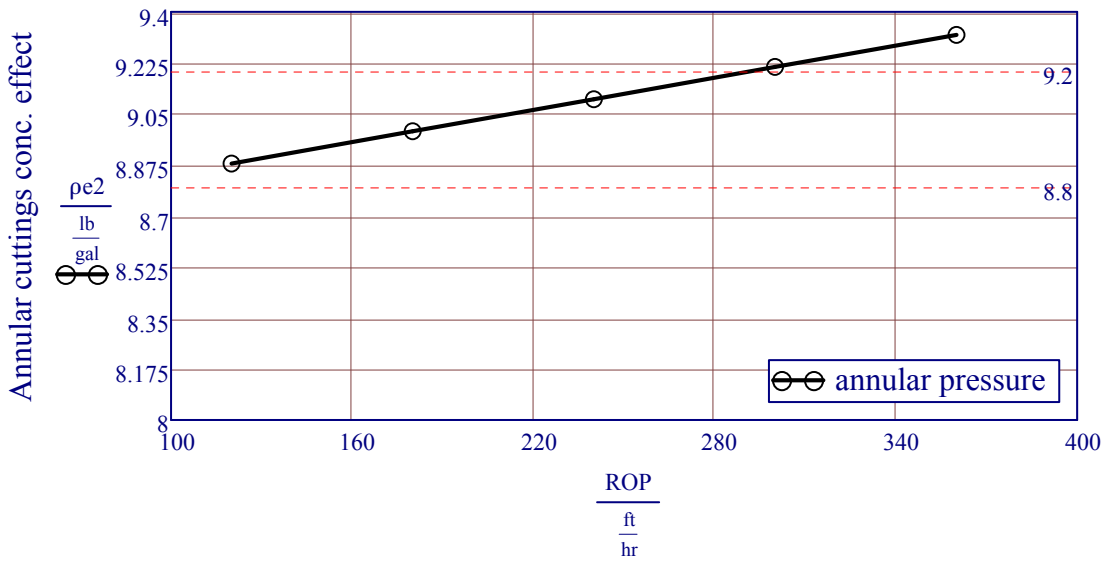
Step #4; Based on cutting concentration (Ca2) as determined in step #11. Calculate now the effective weight due to cuttings concentration (ρ_{e2} , lb/gal), as illustrated below.

$$pe2 := Fd \cdot (Ca2) + \rho \cdot (1 - Ca2)$$

$$\rho e2 = \begin{pmatrix} 8.88 \\ 8.99 \\ 9.1 \\ 9.21 \\ 9.32 \end{pmatrix} \frac{\text{lb}}{\text{gal}}$$

$$ROP = \begin{pmatrix} 120 \\ 180 \\ 240 \\ 300 \\ 360 \end{pmatrix} \frac{\text{ft}}{\text{hr}}$$

Annular pressure vs. ROP



Drilling rate of penetration

Note. Similarly for this 17 1/2" wellbore assumed drilled and considering the formation and drilling parameters input. It can be concluded from the relationship graph above that formation flow or fracture (based on 'on bottom total depth' limits as input in graph) and section length would theoretically occur at rates of penetration **below 100 and above 300 ft/hr.** Considerably less than section 2.1.2 when no section length and bottom up time was accounted for.

4. Concluding remarks.

- In this area one well was known to be drilled at < 100ft/hr, what resulted was a shallow water flow.
- Similarly based on 100wells drilled, drilling experience evolved that drilling at rates > 300ft/hr resulted in drilling difficulties (pack off, mud rings, occurring).
- This worksheet illustrates why this is so and how such a process can be used to optimise future drilling campaigns

Final Note: A drilled section cannot be achieved without stopping circulation in order to add either a drillpipe single or stand every 31ft or 93 ft drilled. In reality cuttings will slip through the drilling fluid during this 'no circulation period' and must therefore also be accounted for. This would become most critical when bottoms up time exceeded 1hr as sections length deepened.

Mr. Aird's consulting business and for-sale worksheets can be found at the [Kingdom Drilling Web Site](http://www.kingdomdrilling.co.uk/), <http://www.kingdomdrilling.co.uk/>. The Web Site offers extensive information on the process, tools, and practice of drilling wells. The site has been developed to educate & develop interactively with a world-wide audience the best practices, technical ingenuity, and experience that exists in the industry today.