Material Mass Balance

Measure

Flow Rate & Density

Going in and out of the well

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Material Mass Balance

What does it mean?

Measure Flow Rate & Density going in and out of the well in real time – directly at the flow line (bell nipple) and at the mud pump suction line

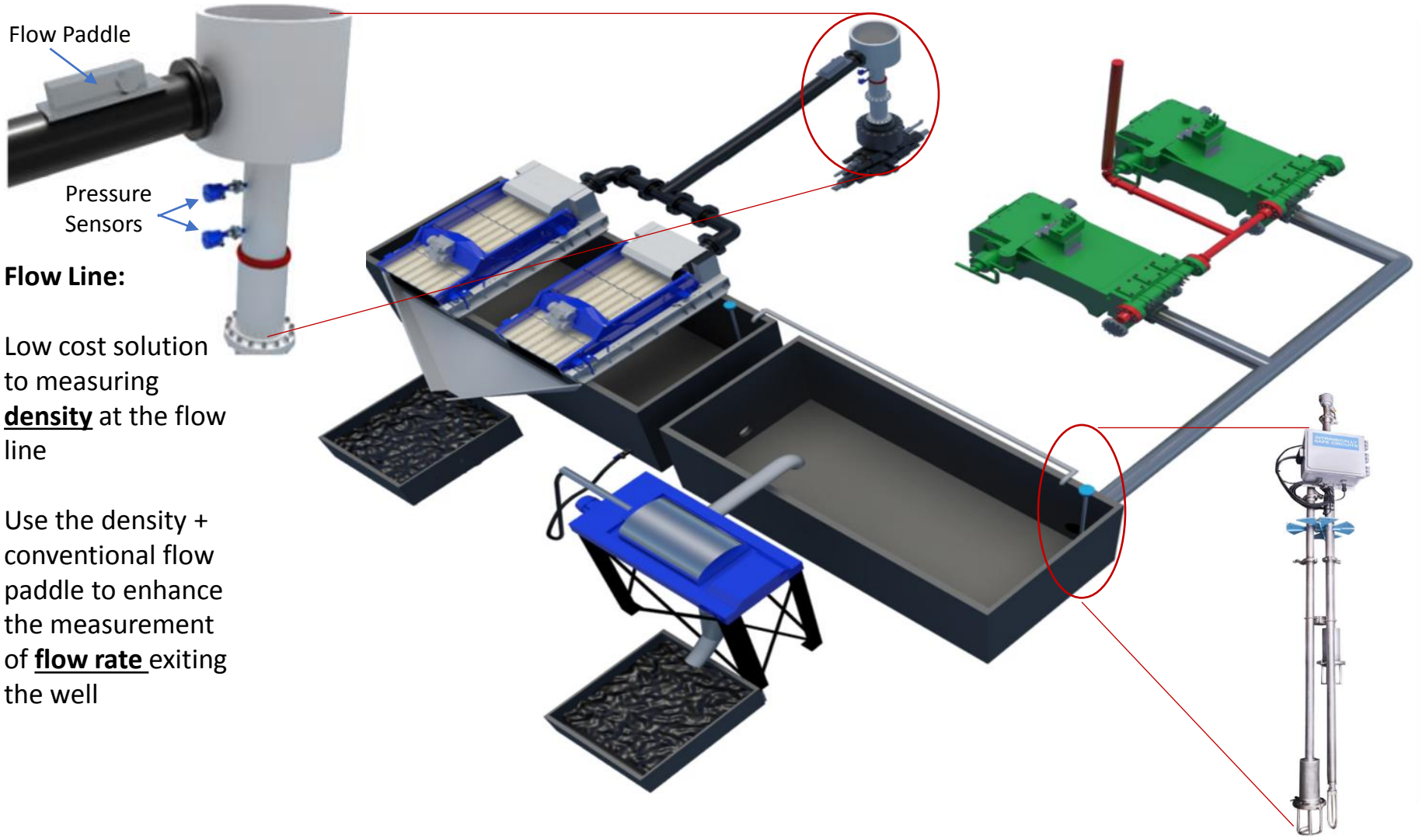
What value can be delivered using the data?

Key Performance Indicators:

- Early Kick detection vs Ballooning vs Losses – quantify those gains and losses
- How much cuttings has been generated vs how much has been removed – quantify the efficiency
- Circulating bottoms up, sweep efficiency, sloughing shale, hole cleaning efficiency
- Barite sag index, cementing efficiency, wellbore displacement efficiency

Drilling Fluids Instrumentation – Phased Approach

Density First – Mass Balance Enabler



Flow Line:

Low cost solution to measuring **density** at the flow line

Use the density + conventional flow paddle to enhance the measurement of **flow rate** exiting the well

Use the conventional stroke count data from each mud pump to calculate **flow rate** going into the well

Suction Line:

Pressure Differential Density sensor lowers in through the top of any mud tank.

Measure **density** going into the well

Measure Flow Rate & Density

Mass Balance Theory:

Measure

SUCTION LINE SENSOR

MF_{IN} – 6000 lb/min

$Density_{IN}$ – 12 ppg

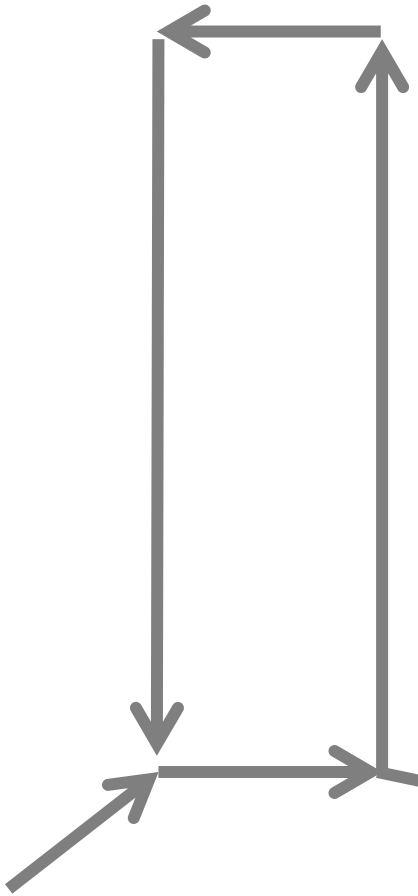
$Flow\ Rate_{IN}$ – 500 gpm

FLOW LINE SENSOR Measure

MF_{OUT} – 6100 lb/min

$Density_{OUT}$ – 12.1 ppg

$Flow\ Rate_{OUT}$ – 495 gpm



Algorithms / Calculations

Early Kick Detection vs Ballooning

Formation Fluid Loss Severity

Hole Cleaning Efficiency

Quantify Sweep Efficiency

Algorithms / Calculations

Circulating bottoms up excessively long

Lag Time / Lag Volume Calculations

Barite Sag Monitoring

Cement Top Verification

Calculate

CUTTINGS GENERATED

$MF_{CUTTINGS}$ – 150 lb/min

$Density_{CUTTINGS}$ – 18.35 ppg

$Flow\ Rate_{CUTTINGS}$ – 4 gpm

FORMATION LOSSES Calculate

MF_{LOSSES} – 50 lb/min

$Density_{LOSSES}$ – 12 ppg

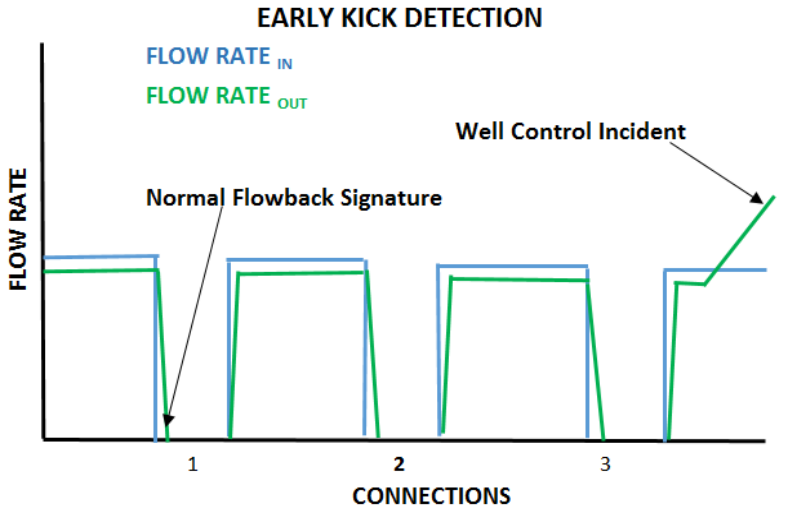
$Flow\ Rate_{LOSSES}$ – 5 gpm

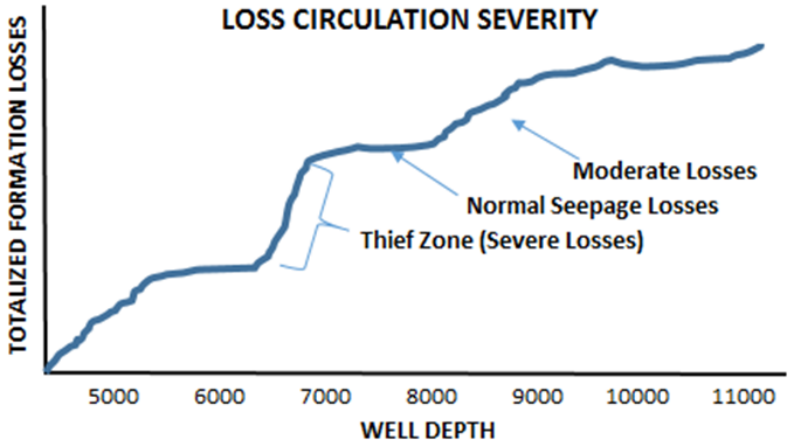
Deliverable – Identify Gains & Losses

AFH Installation - Well Control & Loss Circulation

Problems occur when either too much fluid (Kick) or too little fluid (Loss Circulation) is exiting the well at any given time

- Diagnostic *Fluid Gains and Losses* is used to monitor the process
- Interpreting what the real time data is telling us will be where the true value comes from, as an example, identifying every well control incident early and quantifying any loss circulation is fundamental to all drilling operations
- The AFH at the flow line removes all doubt from the process





Additional AFH Benefits – Mass Balance

The real value of mass flow data

Once the AFH sensor is installed and the system is providing validated mass flow data entering & exiting the well in real time, an additional benefit can come from the development of enhanced diagnostics using pseudo-code already written for the following drilling applications:

Material Mass Balance Algorithms (patented):

- Hole Cleaning Efficiency
- Sweep Efficiency
- Quantify the effectiveness of a Bottoms up prior to a trip
- Identify sloughing shale
- Wellbore displacement monitoring
- Barite sag index calculation
- Monitoring cementing operations

Material Mass Balance

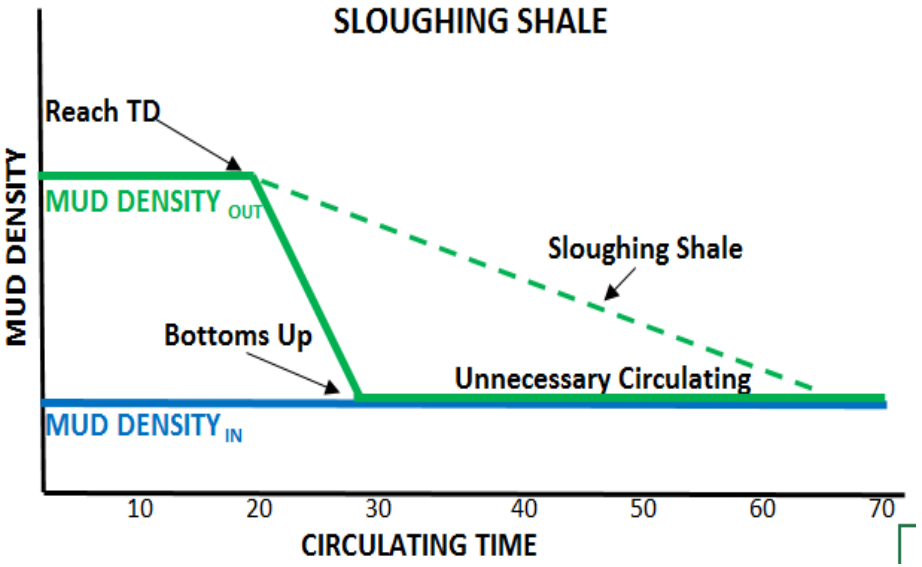
Quantify the effectiveness of a bottoms up

Problems occur when either there is too much drilled cuttings or too little drilled cuttings exiting the well at any given time

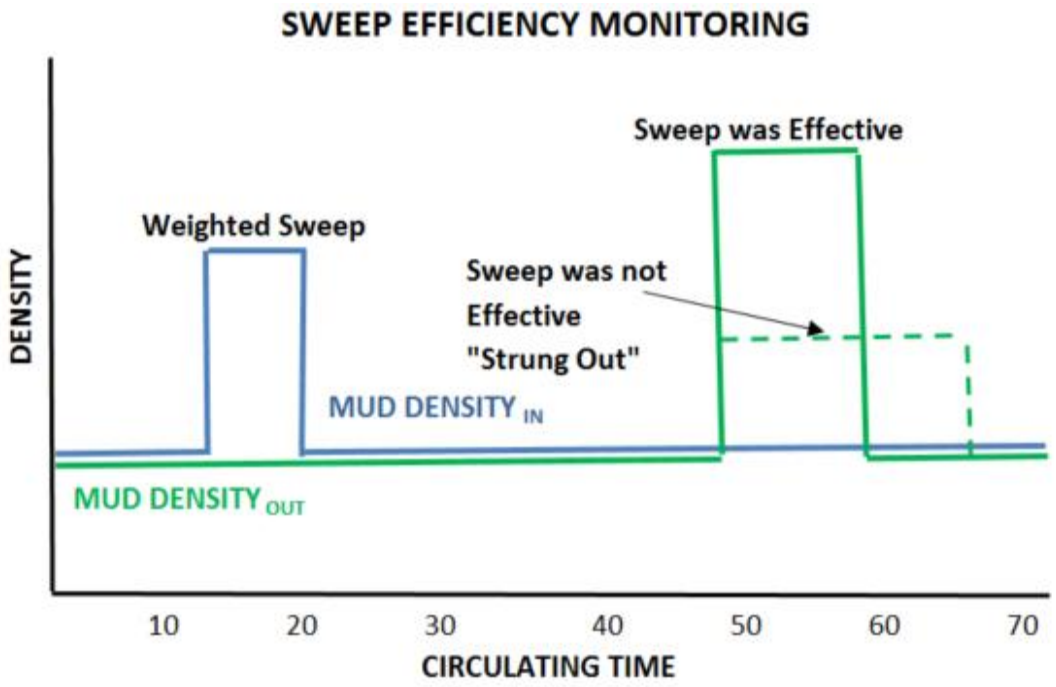
- Diagnostic *Material Mass Balance* is used to monitor the drilled cuttings removal process.

- Hole cleaning efficiency is undeniably one of the most important parameters to monitor during the drilling process

- There are a dozen KPI's that we can monitor using material mass balance data just by measuring flow rate & density going in and out of the well in real time

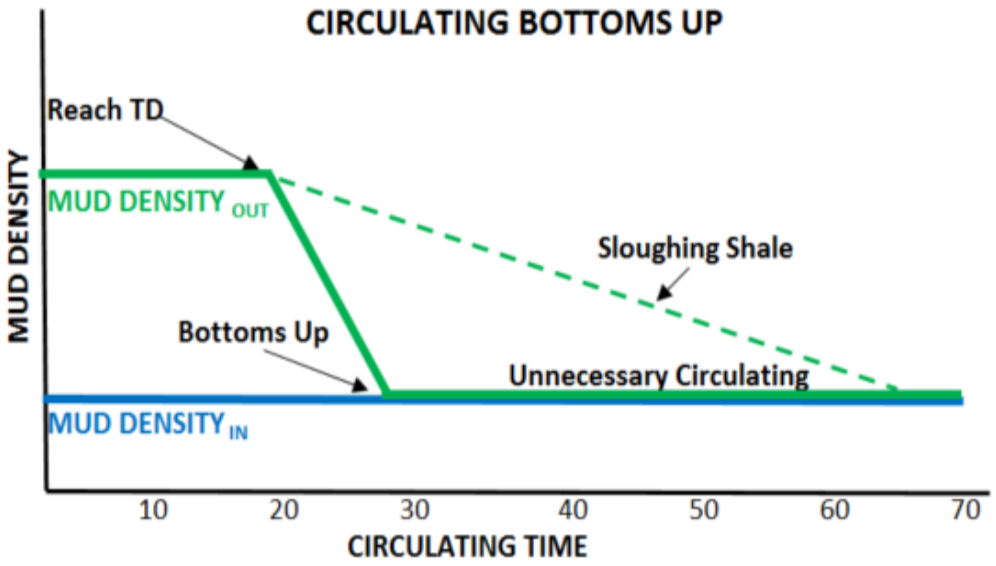


Sweep Efficiency



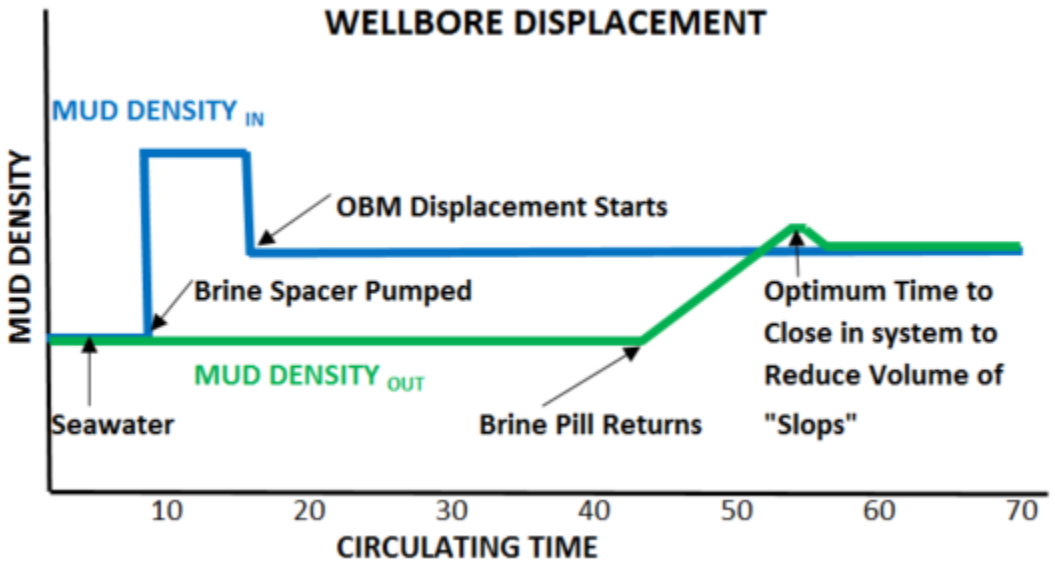
- Plot density in & out on the same graph, any increase in density out should be indicative of the sweep providing some level of effectiveness.
- The data will show if the sweep came out of the well fully intact or if the sweep got "strung out" due to inadequate hydraulics.
- Quantify this effectiveness by capturing the volume & density before and after a sweep is pumped.
- Utilize a text box called "Sweep Effectiveness", use Integration to calculate the area under the curve. Eff = 1 - (Area1 / Area2)

Bottoms Up Circulating Time



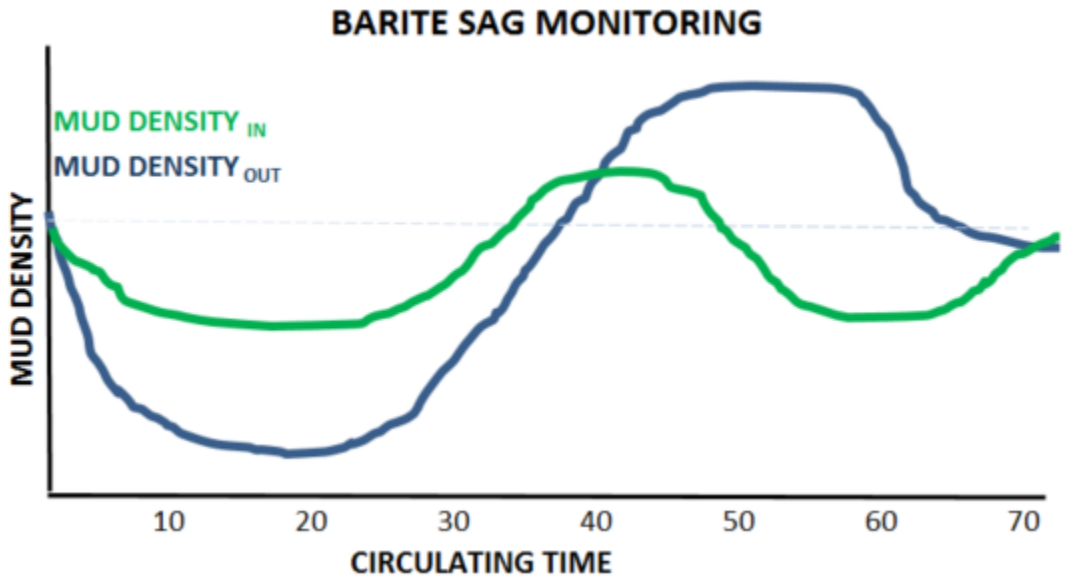
- A sharp decrease in density at Bottoms Up would be indicative of good hole cleaning prior to a trip.
- If it takes a long time to get the density out to drop to the same as density in, indicative of sloughing.
- Quantify the volume of cuttings exiting the wellbore immediately after “bottoms up”.
- "Bottoms Up Effectiveness" provides an indicator as to how effective was the circulating after there were no additional cuttings generated.
- Quantify the effectiveness by determining:
  % Eff = 1 - (Time after BU / BU Time)

Oil Based Mud Displacement



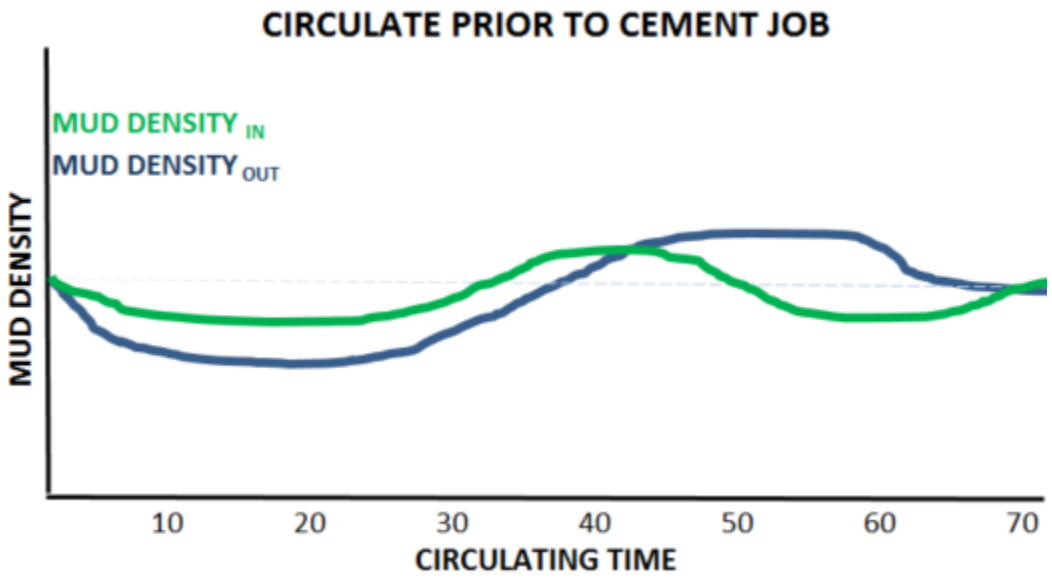
- Monitor MW in & out during the oil based mud displacement will help reduce the volume of “slops” generated from the water and oil interface.
- Monitor precisely when the brine spacer is at surface, close in on the active immediately to minimize the volume of slops.
  - Slops will need to be disposed of or reconditioned at a cost
- Identify the point at which the Brine spacer & SBM is at its highest density. At that point, derrickman to close the system in on the active.

Barite Sag Index



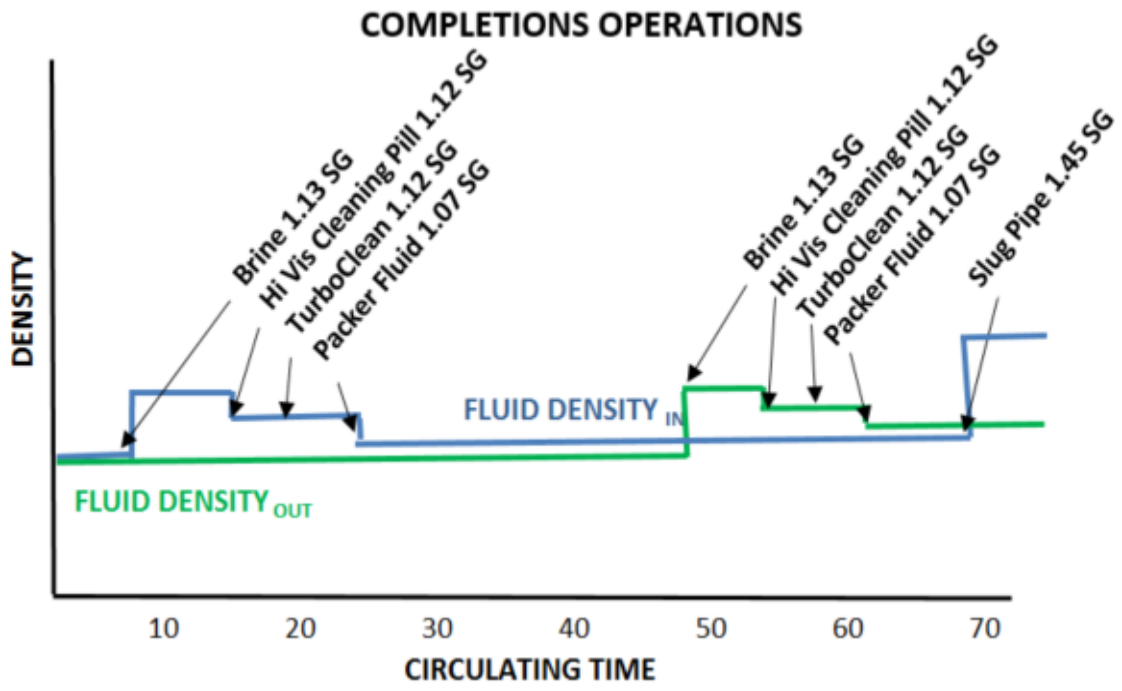
- After a trip or any long period of time without circulating, a density variation from the baseline density is indicative of Barite Sag.
- It will be easy to see when measuring MW in & out plotted on the same graph.
- We can monitor the total circulating time and alert the driller if there is a wide discrepancy in density throughout the total circulating volume.
- Barite Sag Register = 10 x ΔMW / Circulating MW

Cementing Operations



- Monitoring MW in & out prior to a cement job will ensure that there is an even MW all the way around which will be critical to achieving a good zonal isolation.
- Monitoring MW also helps in better understanding the effectiveness of the spacer pumped ahead of the cement.
- Monitor if adequate filter cake was removed from the wellbore wall prior to cement job indicative of a slight increase in density due to solids being removed from the wall of the well.

Completions Operations



- Monitoring Fluid Density in and out during completions operation can be critical to achieving maximum production rates.
- Monitor spacer train cleanliness as each return to surface
- Monitor kill weight to keep the well at minimum over balance at all stages of operations
- Add inline NTU & TSS sensors to quantify the effectiveness of the completion