Kick Detection at the Bit: Early Detection using Borehole Geophysics

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What is the Problem?

- Unexpected formation fluid invasions into the borehole ("kicks") represent a persistent threat during the drilling process
- If left unabated, kicks can grow in intensity and become blowouts, which can result in catastrophic damage to life, materials, and the environment
- The most-commonly used kick detection techniques (e.g. monitoring mud return) are inherently imprecise and time-consuming
- Drilling challenges from abnormal formation pore pressure and wellbore instability events cost the industry ~$8 Billion/year[1]
- 44% of non-productive time was associated with geopressure and wellbore instability problems[1]
- Ecosystem damage from catastrophic petroleum releases may be quite extensive and take years for recovery

Our Solution

- Detecting kicks as early as possible offers the best chance for the driller to regain well control
- Sensitive geophysical instrumentation is deployed on the drillstring to make formation measurements (e.g. logging-while-drilling, measurement-while-drilling)
- Some instruments measure the fluid-filled annulus to correct formation measurements - annular measurements are usually unused beyond this purpose
- Pure drilling fluid physical properties are distinctly different from the physical properties of drilling fluid mixed with kick fluid
- Geophysical instrumentation is able to resolve the contrast between pure and kick-mixed drilling fluids
- We propose using the real-time annular measurements from a suite of geophysical tools together with an algorithm to provide early kick detection and to identify kick fluids

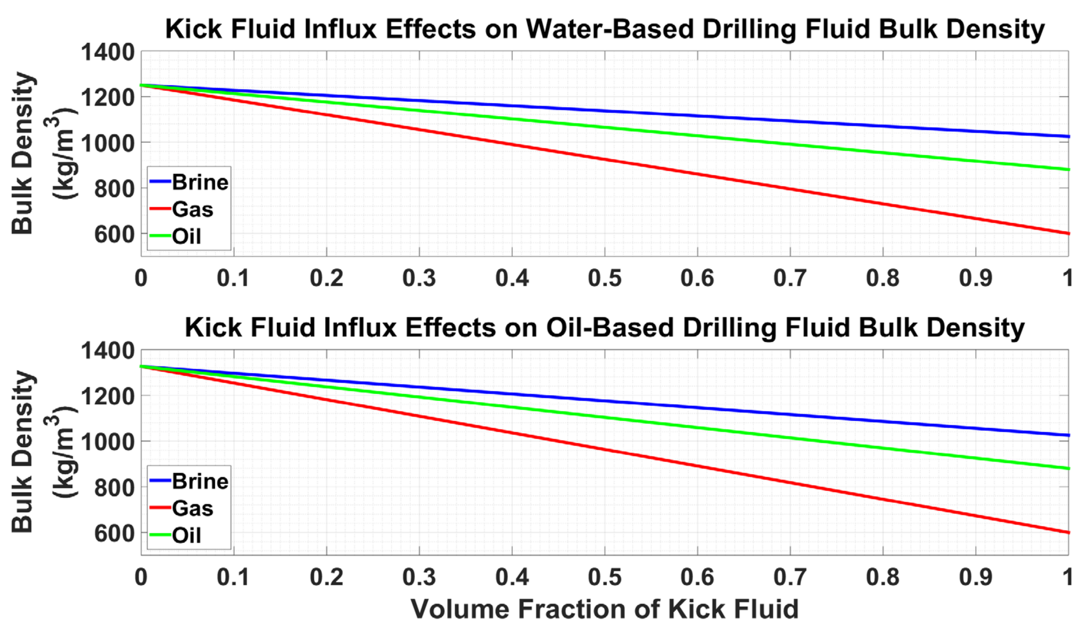
[1]https://www.landmark.solutions/Drillworks-Geomechanics

Results: Proof-of-Concept

I. Bulk Density

Mixture bulk density described by: $\rho_{mix} = \varphi_{DF}\rho_{DF} + \varphi_{KF}\rho_{KF}$

Kick Fluid Mixing Effects on Drilling Fluid Bulk Density



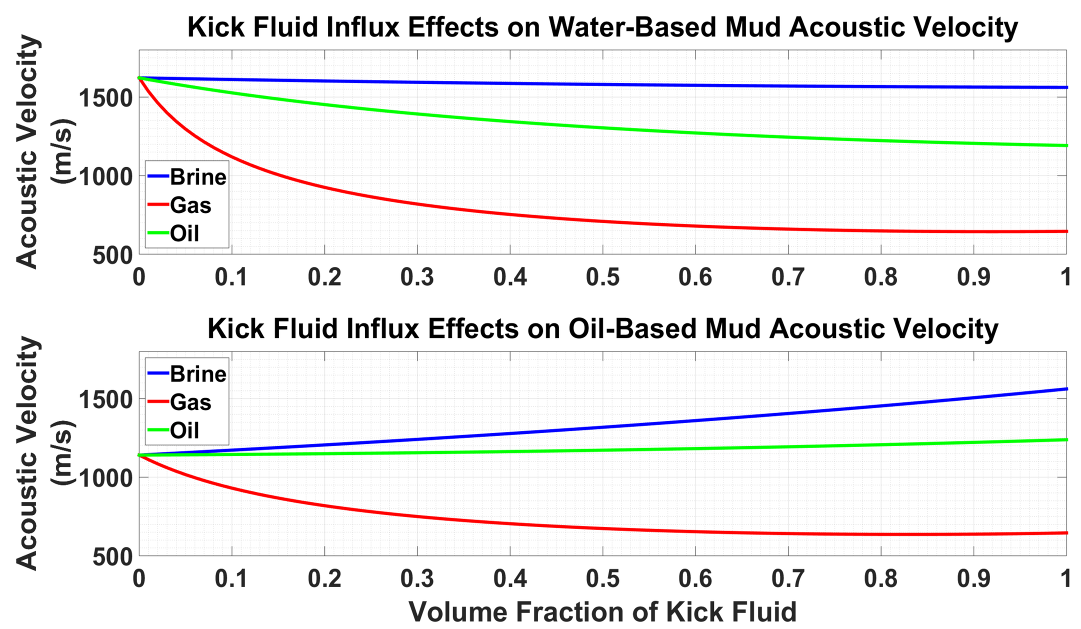
Algorithm to Describe Kick Fluid Mixing Effect on Drilling Fluid Bulk Density

Drilling Fluid Base	Typical Drilling Fluid Density Range (g/cm³)	Formation Fluid (Kick)		
		Brine (1.0 to 1.1 g/cm³)	Liquid Petroleum (0.6 to 0.85 g/cm³)	Natural Gas (0.01 to 0.7 g/cm³)
Water	1.0 to 2.6	If $\rho_{KF} > \rho_{DF}$: Increase If $\rho_{KF} < \rho_{DF}$: Decrease	Density Decrease	Density Decrease
Oil	0.8 to 1.8	If $\rho_{KF} > \rho_{DF}$: Increase If $\rho_{KF} < \rho_{DF}$: Decrease	If $\rho_{KF} > \rho_{DF}$: Increase If $\rho_{KF} < \rho_{DF}$: Decrease	Density Decrease

II. Compressional (*p*-wave) Velocity

Compressional wave velocity described by: $V_{pm} = \sqrt{\frac{K_m + \frac{4}{3}\mu}{\rho}}$ Mixture bulk modulus described by: $\frac{1}{K_m} = \frac{\varphi_{DF}}{K_{DF}} + \frac{\varphi_{KF}}{K_{KF}}$

Kick Fluid Mixing Effects on Drilling Fluid Acoustic Velocity



Algorithm to Describe Kick Fluid Mixing Effect on Drilling Fluid Acoustic Velocity

Drilling Fluid Base	Typical Drilling Fluid Acoustic Velocity Range, m/s	Formation Fluid (Kick)		
		Brine (Acoustic Velocity ≈ 600 to 1900 m/s)	Liquid Petroleum (Acoustic Velocity ≈ 900 to 2300 m/s)	Natural Gas (Acoustic Velocity ≈ 200 to 750 m/s)
Water	1,300 to 1,600	Depends on salinity; decrease occurs beyond a critical depth	Depends on composition; decrease occurs beyond a critical depth	Velocity decrease
Oil	1,000 to 1,300	Depends on salinity; decrease occurs beyond a critical depth	Depends on composition; decrease occurs beyond a critical depth	Velocity decrease

Is this method faster than a kick?

- ✓ **YES** - First-order calculations based on worst-case scenarios for kick travel time and data telemetry time show that our method is effective for wells greater than 1,000 feet deep
- Kick warning time increases with increasing well depth - deeper wells provide more advance warning to the driller

"Kick Fingerprinting"

- Specific drilling fluid/kick fluid mixtures result in unique physical properties (e.g. density, velocity, electrical resistivity)
- It is possible to correlate instrument responses to specific kick fluids

Accomplishments

- NETL Technical Report Series internal publication
- Non-provisional US Patent Application: 14/852,845 (filed: 9/14/2015)
- Focus of two external news articles
  - Hart's E&P article (March 2015)
  - Journal of Petroleum Technology article on Early Kick Detection (August 2015)

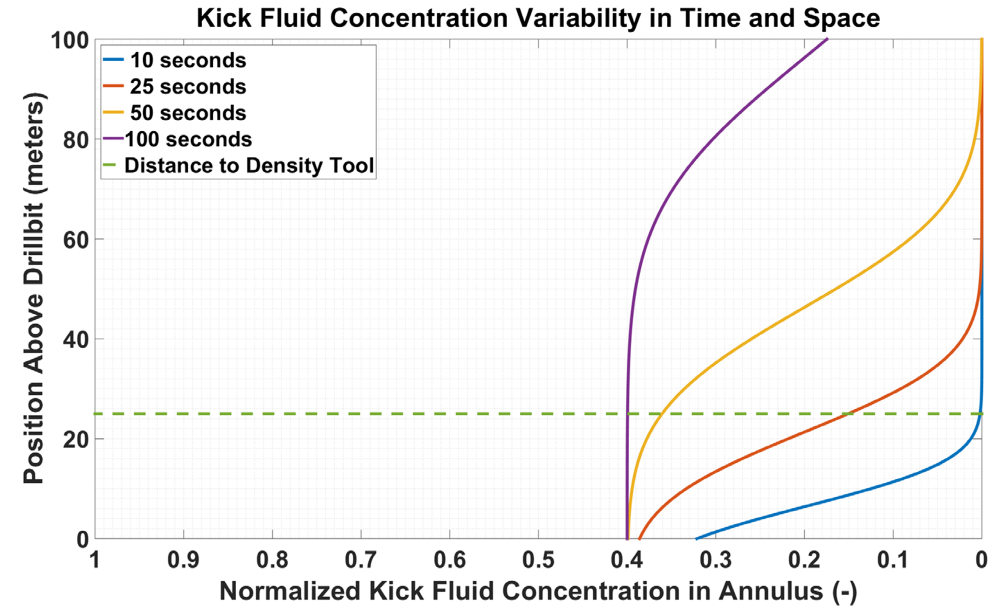
Work In-Progress: Computational Modeling

I. Determining Realistic Constraints on Kick Fluid Transport using the Advection-Dispersion Equation

How much kick fluid will be where? When?

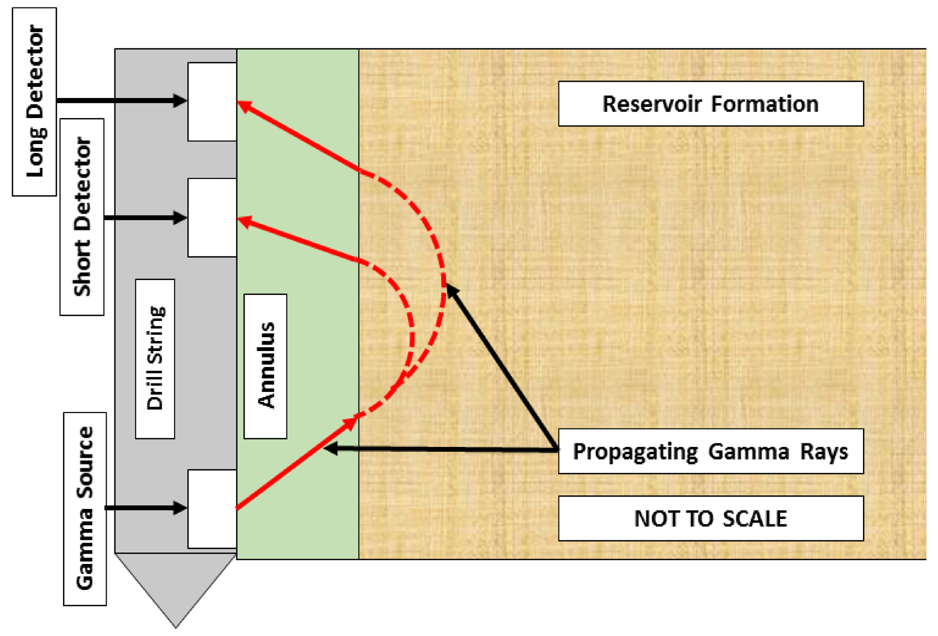
$$\frac{\partial C}{\partial t} + V\frac{\partial C}{\partial x} = D\frac{\partial^2 C}{\partial x^2}$$

C = Kick fluid concentration
V = Advecting fluid velocity
D = Dispersion coefficient



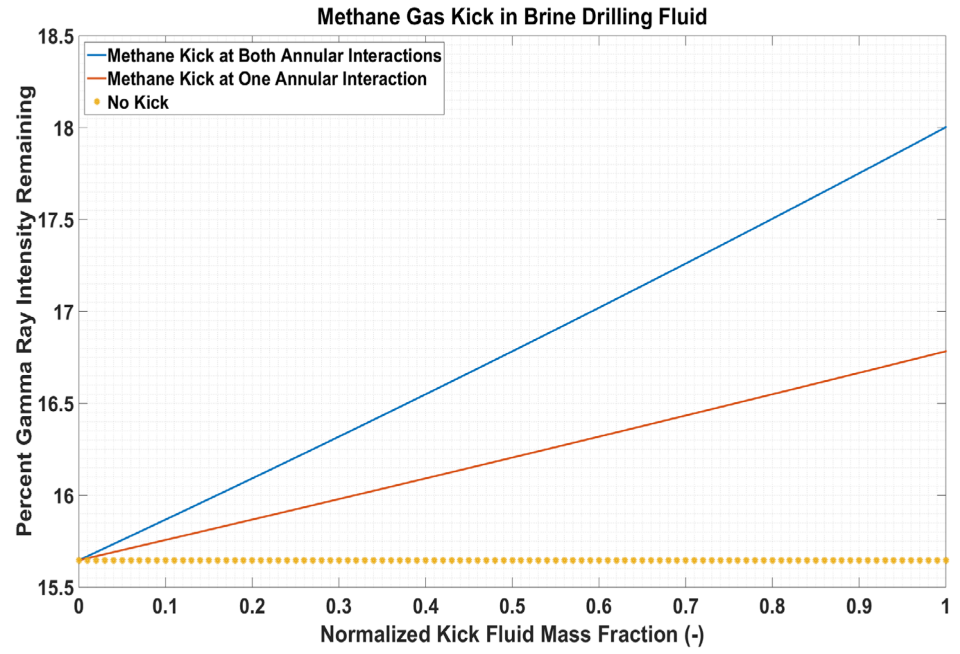
II. Modeling Instrument Responses to Kicks to Generate Synthetic Well Logs

How do instruments respond to kick fluid invasions? How much kick fluid is enough to sense a kick?



$I = I_o e^{-\rho\mu d}$

I_o = Initial gamma ray intensity
ρ = Material bulk density
μ = Material attenuation coefficient
d = Material thickness



This work was completed as part of National Energy Technology Laboratory (NETL) research for the U.S. Department of Energy's Complementary Research Program under Section 999 of the Energy Policy Act of 2005. The authors wish to acknowledge Roy Long (NETL Strategic Center for Natural Gas and Oil) and Elena Melchert (DOE Office of Fossil Energy) for programmatic guidance, direction, and support.

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