# Live Characterization of Asphaltene Precipitation: Bridging Flow Assurance and Formation Evaluation

Rohin Naveena-Chandran, Halliburton

June 30, 2022

Webinars

SPE International

## SPE Webinars are Sponsored by:

SPE

SPE Foundation

Webinars

SPE International

"An experiment is a question which science poses to Nature and a measurement is the recording of Nature's answer."

~ Max Planck

## Context

- Flow assurance issues are a costly challenge to mitigate
- Uncertainty exists in characterizing Asphaltene Onset Pressure (AOP)
- A need for a solution to augment lab analysis

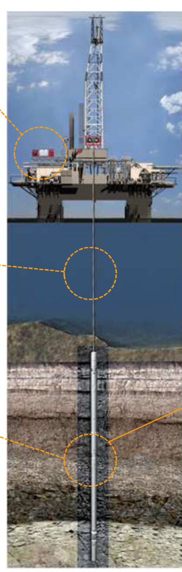
# Asphaltene Behavior

Webinars

| | |
|---|---|
| APE: | Asphaltene Precipitation Envelope |
| UAOP: | Upper Asphaltene Onset Pressure |
| ARFO: | Asphaltene-Resin Flocculation Onset |
| BP: | Bubble Point |
| LAOP: | Lower Asphaltene Onset Pressure |

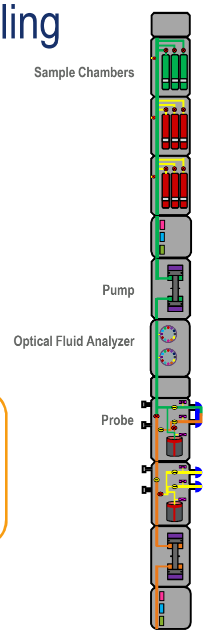
# Formation Evaluation: Downhole Sampling

Webinars



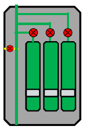

Formation Evaluation data acquired during the Drilling Phase includes

**Formation Pressures & Samples**

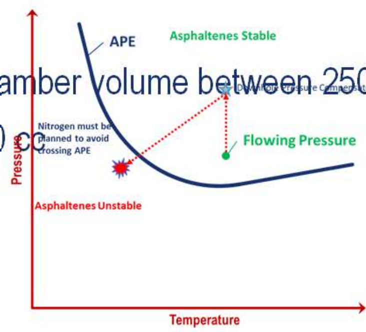



Wireline Formation Tester (WFT)

## Sample Chamber Module



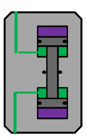
- Holds PVT Sample Chambers
- Nitrogen compensation *can* preserve samples above APE
- Chamber volume between 250cc to 750 cc





Wireline Formation Tester (WFT)

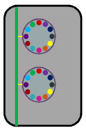
## Pump Module



- Cleans sample from mud filtrate to uncontaminated reservoir sample
- Configured according to hydrostatic overbalance

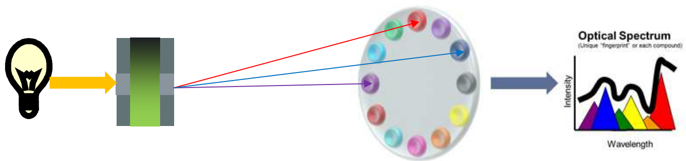

Wireline Formation Tester (WFT)

# Optical Fluid Analyzer Module



**Optical Fluid Analyzer Measurements**

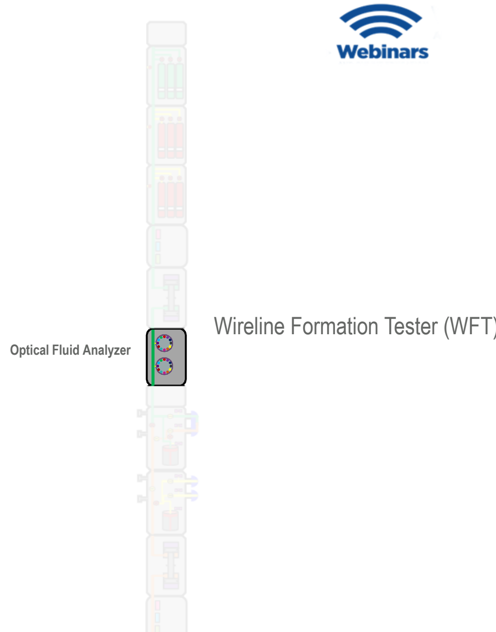
- Saturates %
- Aromatics %
- Resins %
- Asphaltenes %
- Gas Oil Ratio (GOR)
- Light Intensity
- Color
- C1:C5, C6+ %



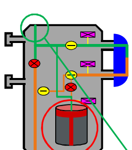

**Light Source** **Sample**

**Integrated Computational Element (ICE)**

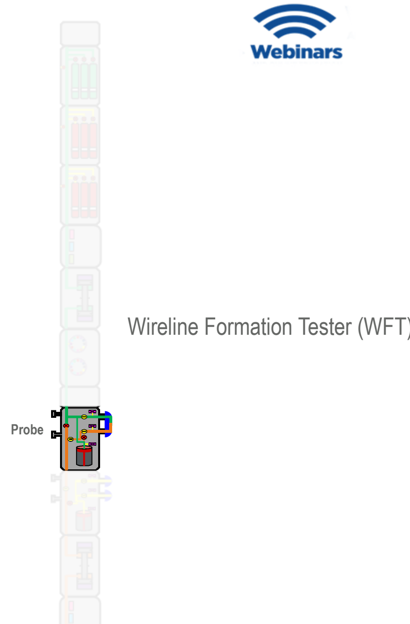
Optical Filter and Computation of fluid compositional properties




# Probe Module

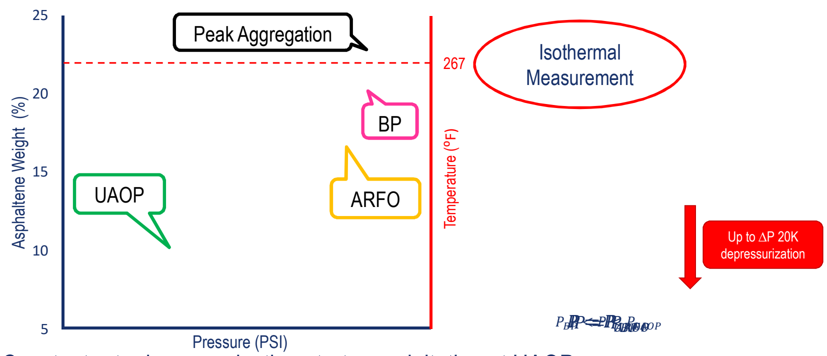


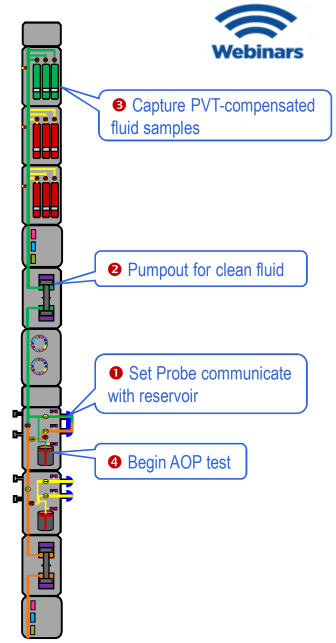
- Measures Formation Pressure with Pressure, Volume, Temperature Sensors
- Flowline connects reservoir fluid to Optical Fluid Analyzer
- Pretest piston and isolation valves able to deplete pressure within WFT



# AOP Test Sequence

Webinars



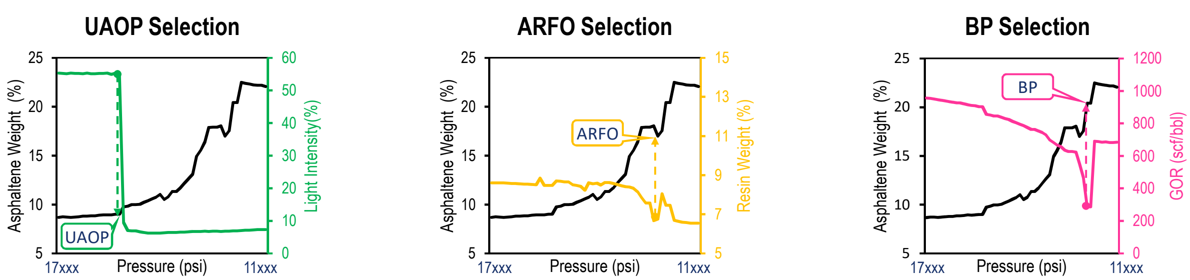




1. Constant rate depressurization starts precipitation at UAOP
2. Flocculation starts at ARFO
3. Increased aggregation of asphaltenes at BP
4. End Test: Gas charge increases Asphaltene Concentration

SPE International

# UAOP, ARFO, BP Selection

Webinars




- Light Intensity inflection signifies Upper Asphaltene Onset Pressure (UAOP)
- Resins increase signifies Asphaltene-Resins Flocculation Onset (ARFO)
- GOR inflection signifies Bubble Point (BP)-complemented with C1-C3 behavior

Gulf of Mexico example

SPE International

# Lab Comparisons

Webinars

- Downhole AOP values higher than lab indicative of optical sensor sensitivity downhole to detect the onset in-situ
- A value biased higher than the lab is also more risk representative

| Downhole AOP (PSI) | Lab (PSI) | Δ(PSI) |
|---|---|---|
| 13279 | 12600 | 679 |
| 12631 | 12300 | 331 |
| 9790 | 9000 | 790 |
| 10600 | 10400 | 200 |

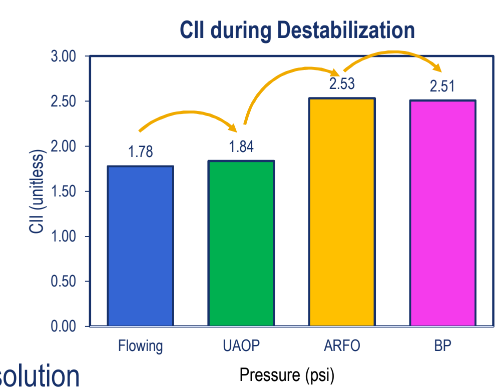
SPE International

# Modeling Method: Colloidal Instability Index

Webinars

$$CII = \frac{Saturates\% + Asphaltenes\%}{Aromatics\% + Resins\%}$$

| | |
|---|---|
| $CII \leq 0.7$ | Asphaltene Fraction stable |
| $0.7 \leq CII \leq 0.9$ | Asphaltene Fraction uncertain |
| $CII \geq 0.9$ | Asphaltene Fraction unstable |

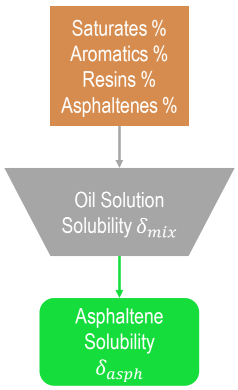


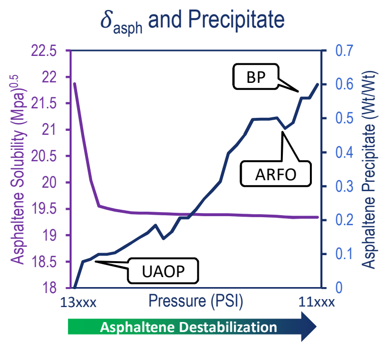

- CII @ 1.78 indicates higher tendency to precipitate out of solution
- CII values reflect instability as asphaltenes precipitate during destabilization

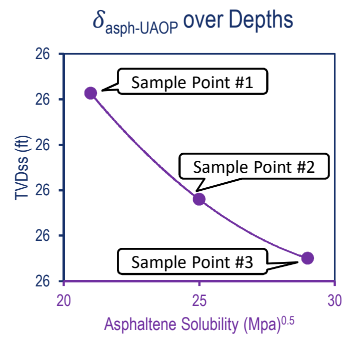
SPE International

# Modeling Method: Solubility

Webinars




Gulf of Mexico example

- Resolve reservoir connectivity with asphaltene solubility gradient

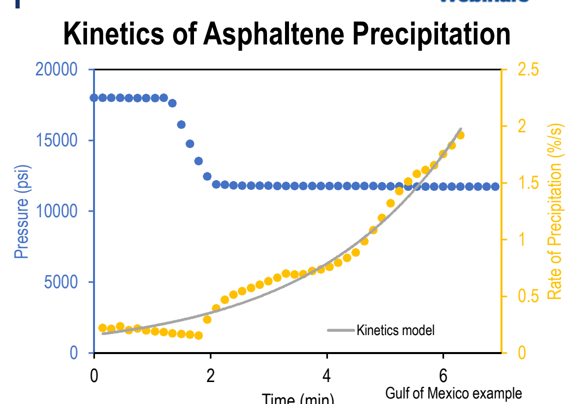
SPE International

# Kinetics of Asphaltene Precipitation

Webinars

$$\frac{dC}{dt} = k_p\left(C_0 - C_A^{eq}\right)e^{k_p \Delta t}$$

| | |
|---|---|
| $\frac{dC}{dt}$ | Rate of asphaltene precipitation |
| $k_p$ | Precipitation kinetic factor |
| $C_0$ | Asphaltene concentration in solution pre-precipitate |
| $C_A^{eq}$ | Asphaltene precipitated concentration |
| $\Delta t$ | Incremental time from UAOP |




Gulf of Mexico example

- Describe the rate of asphaltene precipitation and aggregation
- Data honors model

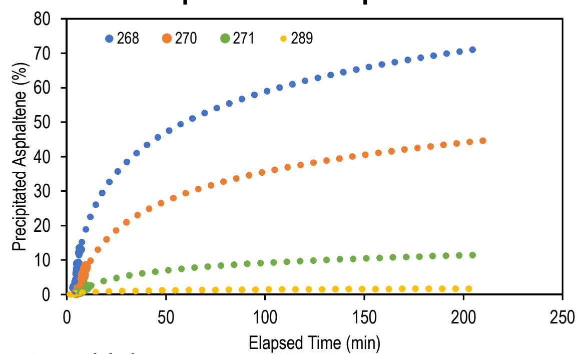
SPE International

# Precipitation Kinetic Factor

Webinars

| Station | Temp. (°F) | $k_p(s^{-1})$ |
|---|---|---|
| 1 | 268 | $6.2x10^{-3}$ |
| 2 | 270 | $5.9x10^{-3}$ |
| 3 | 271 | $2.3x10^{-3}$ |
| 4 | 289 | $2.1x10^{-3}$ |

**Asphaltene Precipitation**




Gulf of Mexico example

- Lower $k_p$ values support "slower" precipitation rate at higher temperatures
- Corroborates theory of greater stability (equilibrated) at increasing depths
- Validates asphaltene solubility behavior: increase at higher temperatures

SPE International

# Conclusion

Webinars

- Presented an efficient method to determine AOP downhole during Formation Evaluation
- Demonstrated a way to drastically reduce uncertainty with accurate AOP values
- Illustrated how data can be used to model asphaltene stability, solubility and the kinetics of precipitation

SPE International

# Acknowledgements


- Nikhil Joshi and the SPE Flow Assurance Technical Section

- Kosmos Energy


**Rohin.Naveena-Chandran@Halliburton.com**

One Petro: "Enhancing the Understanding of Asphaltene Precipitation: A Novel Approach Under In-Situ Conditions"