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Application Note (181017-1)

Assessment of Oil Mobility, Evaluation of Evaporative Loss and Correlation of Reservoir Compartments using HAWK Petroleum Assessment Method (HAWK-PAM)

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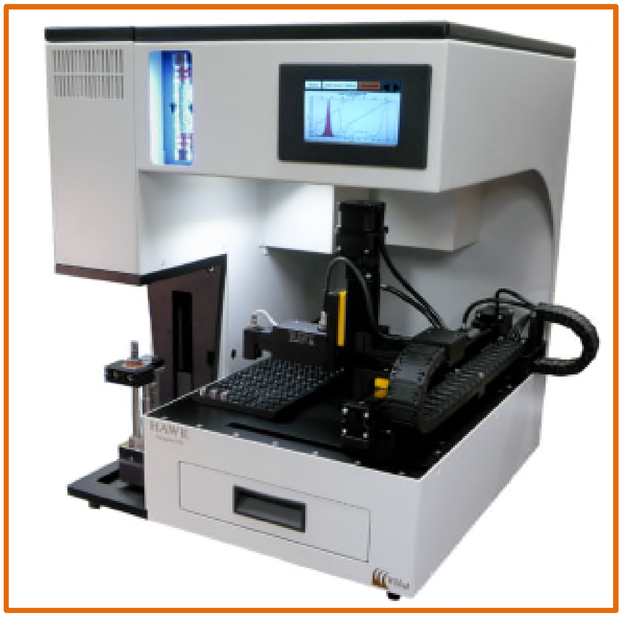
Pyrolysis and HAWK Petroleum Assessment Method (HAWK-PAM)

Pyrolysis has been used to characterize petroleum source rocks for over 40 years now (Barker, 1974; Espitalie et al., 1977). Up to the present date, pyrolysis instrumentation has been utilized to evaluate source rock formations (e.g., Jones, 1984; Peters, 1986; Peters and Caasa, 1994). Jarvie (2012) sought to directly address identification of sweet spots in unconventional reservoir intervals in his promulgation of the pyrolysis interpretation parameter referred to as "Oil Saturation Index" or Normalized Oil Content (Jarvie et al., 2001; Jarvie and Baker, 1985). However, such results do not provide any indication of oil quality or its mobility.

Wildcat Technologies has advanced the capabilities and utility of bulk thermal extraction/pyrolysis instrumentation with its advanced HAWK instrument that provides highly accurate and reliable measure of TOC, oil and kerogen yields as well as thermal maturity. Wildcat Technologies has advanced this technology further by announcing the launch of its recently developed multi-ramp/multi-zone pyrolysis method that is now operational on the HAWK Pyrolysis instrument. HAWK Petroleum Assessment Method (HAWK-PAM) is geared at petroleum assessment in both unconventional and conventional systems (Maende, 2016).



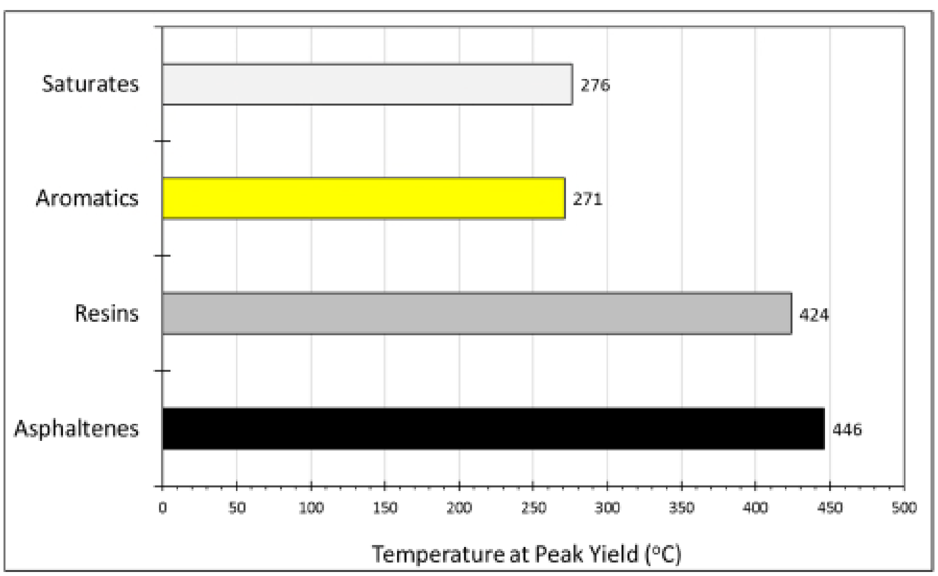
The HAWK Petroleum Assessment Method (HAWK-PAM) utilizes five zones using multiple ramp and isotherm routines assigned during a single sample analysis. A ramp rate of 25°C is utilized to generate five petroleum peaks – four on oil fractions and one on kerogen. Each isotherm has its own specific Tmax indicative of the maximum evolution temperatures. Because HAWK-PAM measurement is initiated at 50°C, it enables better quantification of volatile oil than was previously possible on pyrolysis instruments. In addition, this method enables measurement of API Gravity from drill cuttings, cores, outcrop samples and soil samples, in addition to oils and other fluids.

The peak names and associated temperature of occurrence are as shown in the table below:

Peak (zone) Name	Oil-1	Oil-2	Oil-3	Oil-4	K-1
Temperature Range (°C) within which Tmax is designated	~50 °C to ~100 °C, hold for 5 minutes	100 °C, hold for 5 minutes	Ramp 100 °C to 180 °C at 25 °C per minute. Hold for 5 minutes	Ramp 180°C to 350 °C at 25 °C per minute. Hold for 5 minutes	Ramp 350°C to 650 °C at 25 °C per minute. Hold for 5 minutes
Petroleum Fraction	C4-C5	C6-C10	C11-C19	C20-C36	Kerogen (plus any C37+)
SARA disposition	Saturates and Aromatics			Polars	n/a

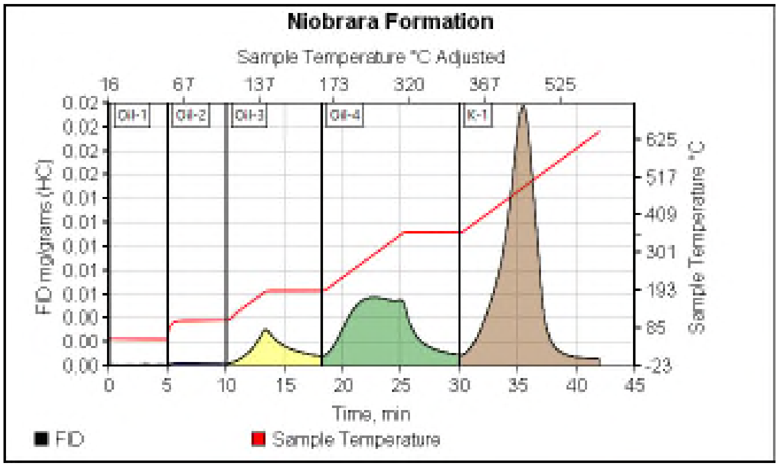
Approximation of carbon number ranges and SARA fraction disposition utilized in the multiple ramp and isotherm program used in the HAWK-PAM

Additional methodologies partially segregate the polars into resin and asphaltenes fractions based on their Tmax differences. This was shown by Jarvie et al. (2015) where the saturates and aromatics largely volatilize whereas the resins and asphaltenes decompose during pyrolysis at different temperature (Tmax) values. A high content of resins and asphaltenes will be detected in the Oil-4 fraction from HAWK-PAM along with higher molecular weight hydrocarbons.



Volatilization and Tmax temperatures for saturates and aromatics and resins and asphaltenes, respectively

A typical pyrogram generated using the HAWK Petroleum Assessment Method using five different ramp and isotherm times and temperatures appears as shown below:



Five ramp temperatures and isotherms using the HAWK-PAM program

HAWK-PAM Oil-1, Oil-2, Oil-3, Oil-4 and K-1 fractions (Maende *et. al*., 2017), can be expressed on the basis of petroleum refinery products (gasoline, kerosene, diesel, jet oil, lubricating oil and asphalt) as shown in the table below:

								Petroleum Fraction				
						API Gravity	Sum	C4 - C10	C11 - C19	C20 - C36	C37+	Total
Sample ID	**Oil-1 (mg HC/g rock)**	**Oil-2 (mg HC/g rock)**	**Oil-3 (mg HC/g rock)**	**Oil-4 (mg HC/g rock)**	**K-1 (mg HC/g rock)**	**API Gravity Prediction (°)**	**Sum (Oil-1, Oil-2, Oil-3, Oil-4, K-1) (mg HC/g rock)**	**Gasoline = Oil-1 + Oil-2 (wt. %)**	**Kerosene + Diesel = Kerosene + Jet Fuel = Oil-3 (wt. %)**	**Lubricating Oil = Oil-4 (wt. %)**	**Asphalt = K-1 (wt. %)**	**Per cent sum**
Permian Basin; Rock Extract	0.01	1.66	33.95	94.57	12.31	39	142.50	1.17	23.82	66.36	8.64	100
Eagle Ford Shale; Oil	14.13	53.13	94.98	134.91	29.65	43	326.80	20.58	29.06	41.28	9.07	100

Peak (Zone) Name	Oil-1	Oil-2	Oil-3	Oil-4	K-1
Temperature Range (°C) within which Tmax is designated	~50 °C to ~100 °C, hold for 5 minutes	100 °C, hold for 5 minutes	Ramp 100 °C to 180 °C at 25 °C per minute. Hold for 5 minutes	Ramp 180 °C to 350 °C at 25 °C per minute. Hold for 5 minutes	Ramp 350 °C to 650 °C at 25 °C per minute. Hold for 5 minutes
Petroleum fraction	C4-C5	C6-C10	C11-C19	C20-C36	Kerogen (plus any C37+)
SARA disposition	Saturates and Aromatics			Polars	n/a

HAWK-PAM Oil-1, Oil-2, Oil-3, Oil-4 and K-1 fractions expressed on the basis of petroleum refinery products

Assessment of Oil Mobility using HAWK Petroleum Assessment Method (HAWK-PAM)

With HAWK-PAM results of both the rock and extract of the same sample, oil mobility can be estimated using both the HAWK-PAM API gravity and the (Sum of Oil1, Oil2 and Oil3)/(Sum of Oil1, Oil2, Oil3 and Oil4). A check on the oil mobility may be achieved by looking at the difference of (Sum of Oil1, Oil2 and Oil3) – (Oil4) for the rock with a lower difference being indicative of higher mobility. An illustration of how to deduce oil mobility is depicted in the table below.

Sample ID	Sample Type	Oil3/Oil4	Sum of Oil1, Oil2 and Oil3 (mg HC/g rock)	Sum of Oil1, Oil2, Oil3 and Oil4 (mg HC/g rock)	Oil Mobility Ratio (Sum of Oil1, Oil2 and Oil3)/(Sum of Oil1, Oil2, Oil3 and Oil4)	Check on Oil Mobility (Sum of Oil1, Oil2 and Oil3) – (Oil4)	HAWK-PAM API gravity
8750 ft	Extract	0.2	102.67	601.1	0.17		42
8750 ft	Rock	0.66	3.03	7.39	0.41	-4.36	
8756 ft	Extract	0.21	85.02	471.35	0.18		39
8756 ft	Rock	0.67	2.8	6.69	0.42	-3.89	
8757 ft	Extract	0.19	83.44	500.24	0.17		40
8757 ft	Rock	0.74	2.97	6.68	0.44	-3.71	

An illustration of how to deduce oil mobility

Oil Mobility Ratio after correction for Evaporative Loss using HAWK Petroleum Assessment Method (HAWK-PAM)

Using the value obtained through multiplying the HAWK-PAM Oil3/Oil4 ratio by the (Oil3/Oil4 of Rock)/(Oil3/Oil4 of Extract), an Oil-3 value that is deemed to have some correction of evaporative loss can be obtained as illustrated in the table below. Oil mobility ratio after some correction for evaporative loss can then be obtained and used for mobility evaluation together with the HAWK-PAM API gravity that is obtained after some correction for evaporative loss.

Sample ID	Sample Type	Oil Mobility Ratio before some correction for evaporative loss	Oil3 before correction for evaporative loss	Oil3 /Oil4	(Oil3/Oil4 of Rock)/(Oil3/Oil4 of Extract)	Oil3 after some correction for evaporative loss = Oil3 before some correction for evaporative loss x (Oil3/Oil4 of rock)/(Oil3/Oil4 of Extract)	Oil Mobility Ratio (Sum of Oil1, Oil2 and Oil3)/(Sum of Oil1, Oil2, Oil3 and Oil4) after some correction for evaporative loss	HAWK-PAM API gravity after some correction for evaporative loss
8750 ft	Extract	0.17	99.68	0.2	3.28	326.95	0.55	47
8756 ft	Extract	0.18	82.64	0.21	3.14	259.22	0.56	44
8757 ft	Extract	0.17	80.43	0.19	3.83	307.83	0.62	46

An illustration of how to do some correction for evaporative loss and then deduce oil mobility

Evaporative loss correction is achieved by utilizing the change in the rock's oil3/oil4 ratio with that of the extract's oil3/oil4 ratio. This is because whereas the rock's oil-3 measured value is virtually an exact measure of the rock's oil-3 content, the extract's oil-3 measured value is lower than actual because of the evaporative loss of this component during the drying down process that allows the solvent that was used for extraction to evaporate off. The measured oil-4 value in both the rock and the extract is virtually an exact measure of the rock's and extract's oil-4 content because it does not undergo evaporative loss. After obtaining the evaporative loss value of the extract's oil-3, the corrected value is then used to recalculate both the mobility ratio of the extract and its HAWK-PAM API gravity value.

Seven parameters are computed as ratios of Rock to Extract (or oil) for reservoir compartments correlation using HAWK Petroleum Assessment Method (HAWK-PAM)

- Oil-3
- Oil-4
- K-1
- Sum(Oil1, Oil2 and Oil3)
- Sum(Oil1, Oil2 and Oil3) /Sum(Oil1, Oil2, Oil3 and Oil4)
- Sum(Oil1, Oil2 and Oil3) - (Oil4)
- HAWK-PAM API gravity

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