PS Development of Source Rock Kinetic Models for Fluid Property Prediction in Unconventional Shale Plays: A Case Study from the Permian and Neuquen Basins*

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Abstract

Hydrocarbon fluid properties are essential factors in the well performance of unconventional shale plays, together with the effective permeability and a favorable pore pressure regime. Fluid properties depend on the source rock type and maturity level; higher gas-oil-ratio, lower density, and lower viscosity fluids will provide the best production rate and ultimate recovery in liquid-rich shale plays (Wan et al., 2013).

Basin and petroleum system modeling can be used to predict in-situ hydrocarbon fluid properties when coupled with description of source rock characters and its generation kinetics. In this study, data from Vaca Muerta and Woodford shales are used to propose and test a series of kinetic models. Different datasets include lab-derived kinetics data on selected source rock samples, large set of regular RockEval data on shales, and field production data. A comparison of these custom kinetic models against default models for different organofacies source rocks is shown and a discussion of the importance of the different model input parameters is presented.

The resulting kinetic models are coupled with a regional basin and petroleum system model to predict in-situ fluid properties, such as gas-oil-ratio, API gravity, and viscosity. The expulsion model used in these calculations considers inorganic porosity and saturation, organic porosity, and initial oil sorption capacity. An important aspect of these predictions involves a good characterization of source rock facies and its lateral variations as the source rock properties (HI, TOC) also impact kerogen conversion and, in the end, fluid properties.

Instantaneous generation and expulsion over a narrow thermal stress range are thought to be more representative of the in-situ fluids in shale plays than cumulative products from expulsion and migration (Cander, 2012). A comparison of the instantaneous generation results against data from produced fluids is shown, and differences in results are discussed taking into account multiple factors such as capillarity, multi-phase flow dynamics, and in-situ versus migrated fluids.

References Cited

Abrams, M.A., 2014, Petroleum System Charge Analysis for Liquid Rich Unconventional Plays: Unconventional Resources Technology Conference, Denver, Colorado, 25- 27 August 2014, URTec 1922067, p. 1377-1386.

Cander, H., 2012, Sweet Spots in Shale Gas and Liquids Plays: Prediction of Fluid Composition and Reservoir Pressure: AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012, Search and Discovery Article #40936 (2012), Website accessed February 2017.

Pepper, A.S., and P.J. Corvi, 1995, Simple Kinetic Models of Petroleum Formation - Part I: Oil and Gas Generation from Kerogen: Marine and Petroleum Geology, v. 12/3, p.291-319.

Peters, K E., A.K. Burnham, and C.C. Walters, 2015, Petroleum Generation Kinetics: Single Versus Multiple Heating- Ramp Open- System Pyrolysis: American Association of Petroleum Geologists Bulletin, v. 99/4, p. 591- 616.

Wan, J., R.S. Barnum, D.C. DiGloria, A. Leahy- Dios, R. Missman, and J. Hemphill, 2013, Factors Controlling Recovery in Liquid Rich Unconventional Systems: International Petroleum Technology Conference Beijing China 26- 28, March 2013, ITPC 17103.

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Introduction

Organofacies as defined by Pepper and Corvi (1995) are a good proxy for kinetic models in exploration studies where no other data to constrain the model are available. In unconventional shale plays, in-situ fluid properties are key for productivity and a more accurate description of the kinetics is required. For that reason, a series of kinetic models were generated and tested for two shale plays, the Vaca Muerta shale play from Neuquen Basin, Argentina, and the Woodford shale in the Permian Basin, USA. These two formations show, in general, excellent source-rock characteristics, with very high-TOC and generative potential.

Methods

Geochemical characterization of the source rock potential of the Woodford and Vaca Muerta formations was first evaluated using internal databases for the Permian and Neuquen basins. These analyses provided information on organic richness, presence of producible hydrocarbons (S1, S1/TOC), and generative potential (S2, HI, TOC).

This screening study was also helpful when picking samples for the kinetic analyses. Samples in the immature or early maturity window located close to the areas of interest were selected. Sidewalls core samples from organic rich intervals in the Woodford Fm. and core samples from organic rich mudstones of the Vaca Muerta Fm. were analyzed for total organic content (Leco TOC), pyrolysis, vitrinite reflectance, and bulk programmed pyrolysis kinetic analysis (2,5,10,25 and 50° C/min) on whole rock. Discrete reactivity models and free frequency factors were used as suggested by Peters (2015).

Woodford Formation

Source rock characterization

- Very high TOC, generative potential (HI)
- Significant generated volumes
- Elevated free HC, but low S1/TOC suggests potential adsorption to organic matter

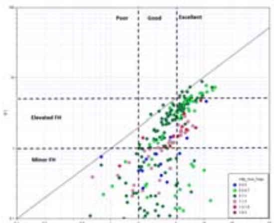

Fig.1) Plot of S1 vs. Leco TOC showing amount of free HC and potential producible oil.

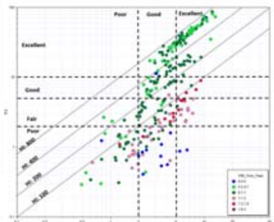

Fig.2) Plot of S2 vs. Leco TOC showing quality of organic matter.

Pyrolysis experiment simulating HC generation

Five heating rates bulk pyrolysis were used to simulate hydrocarbon generation on three Woodford samples with a vitrinite reflectance of around 0.6 %Ro and same facies type.

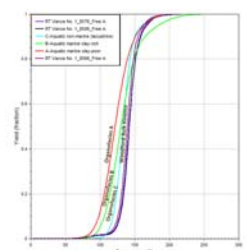

Fig.3) Comparison of Woodford bulk kinetic models against organofacies models as defined by Pepper and Corvi (1995)

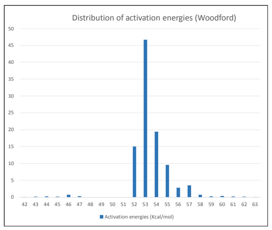

Fig.4) Distribution of activation energies from mix samples of Woodford Fm.

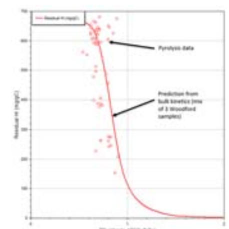

Fig.5) Residual HI vs. %Ro. Predicted curve based on kinetic data (solid line) and HI obtained from pyrolysis (dots)

The resulting kinetic model obtained from a mix of these three samples was used to derive a HI prediction against %Ro that could be compared with pyrolysis data (Fig. 5). In general, a good matching was found which gave more confidence in the model. In this way, both HI and bulk kinetics were used to constrain the kinetic model.
The comparison with default organofacies indicates that Woodford kinetics is similar to "Organofacies C" but generation seems to start later. This could be due to the fact that samples were obtained from early mature source rocks.

Vaca Muerta Formation

Source rock characterization

- High TOC, generative potential (HI)
- Significant generated volumes
- Elevated free HC and medium to high S1/TOC

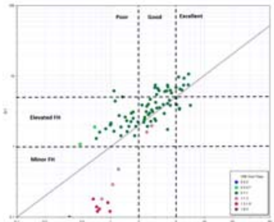

Fig.6) Plot of S1 vs. Leco TOC showing amount of free HC and potential producible oil.

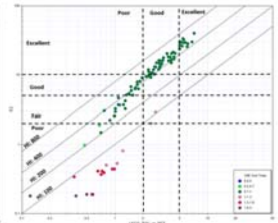

Fig.7) Plot of S2 vs. Leco TOC showing quality of organic matter.

Pyrolysis experiment simulating HC generation

Five heating rates bulk pyrolysis were used to simulate hydrocarbon generation on Vaca Muerta samples with a vitrinite reflectance of around 0.75 %Ro.

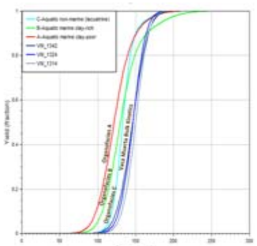

Fig.8) Comparison of Vaca Muerta bulk kinetic models against organofacies models as defined by Pepper and Corvi (1995)

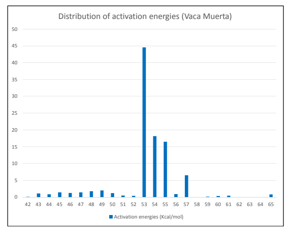

Fig.9) Distribution of activation energies from mix samples of Vaca Muerta Fm.

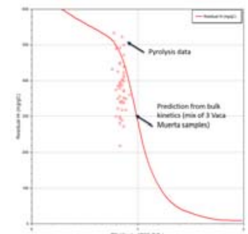

Fig.10) Residual HI vs. %Ro. Predicted curve based on kinetic data (solid line) and HI obtained from pyrolysis (dots)

Samples representative of the same facies were selected in the Vaca Muerta Fm. to derive a kinetic model. The model shown in Fig.10 results from the mix of these samples and is compared with data from pyrolysis. The comparison with default organofacies indicated that Vaca Muerta kinetics is also similar to "Organofacies C" with generation starting at a later temperature as was seen in the case of the Woodford. This late generation could also be apparent as the samples used to conduct the study are not in the immature window (0.75 %Ro).

Fluid property prediction

Unconventional development of liquid rich systems can improve overall economics but flow in a two-phase system can impact ultimate recovery. The performance of these systems is highly dependent on phase behavior, in-situ fluid composition, and initial reservoir conditions (Wan et al., 2013). In that context, prediction of fluid properties is key in the evaluation of resource plays.

In this study, different kinetic models were tested for Woodford and Vaca Muerta shales for specific regions of the Permian and Neuquen Basins, respectively. In the end, the model that best matched Rock Eval, kinetic data, and fluid properties measured in the lab was selected. In that way, custom organofacies models were derived for both shales.

The integration of a calibrated pseudo-3D model with the source rock geochemical properties, and kinetic model was used in the prediction of fluid properties. In Trinity software, these predictions are based on empirical relationships derived from fluid properties measured in oil samples obtained from different basins worldwide. This allows calculating properties such as API gravity, gas-oil-ratio, and viscosity. For these predictions, the ARCO expulsion model was applied to take into account the saturation of oil and gas in the organic porosity as well as the inter-granular porosity.

Woodford Formation

An instantaneous API gravity map was created for the Woodford by coupling the custom organofacies model with a Permian Basin BPSM (Fig. 11). The relationship built in Kinex for API gravity and maturity was modified to better match fluid data from the production (parameter b for API).

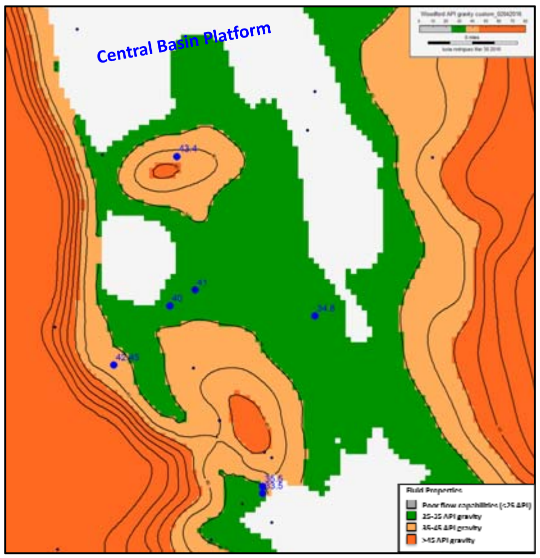

Fig.11) API gravity prediction for Woodford in an area located in the Central Basin Platform (Permian Basin, USA). Blue dots indicate the location of the calibration data.

API gravity data from in-house analysis together with data from IHS Enerdeq were used for calibration (blue dots on Fig.11). The calibrated model indicates where the best flow capabilities can be encountered.

Other maps such as viscosity and GOR maps were built but the calibration of these maps was more difficult due to lack of data or poor data quality. In the case of the GOR prediction, the values were too low when compared with production data from a public database (IHS Enerdeq).

An explanation for the difficulty in obtaining modelled GOR values comparable with production data is found in the multiple factors affecting this property. A good understanding of the source rock characteristics such as lateral HI variations, the selection of gas adsorption model, and migration effect (in-situ vs cumulative GOR prediction) is necessary in order to predict fluid flow and, consequently, GOR of the produced fluids.

Vaca Muerta Formation

A similar methodology to the one described for the Woodford was followed for the Vaca Muerta Fm. Instantaneous API gravity map was derived for the Vaca Muerta shale by coupling the custom kinetic model with a Neuquen Basin BPSM (Fig. 12).

API gravity data measured in wells with production from Vaca Muerta shale were used as part of the calibration (blue dots in Fig. 12). Most of the available data were located in the area situated to the north of the Dorsal of Huincul close to the location of the well where the kinetic studies were performed.

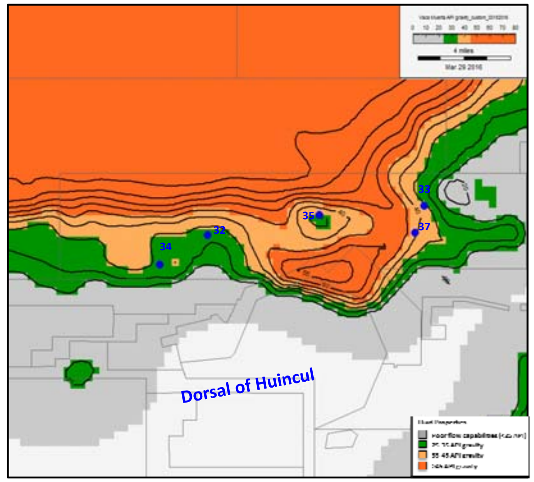

Fig.12) API gravity prediction for Vaca Muerta in the Dorsal of Huincul area (Neuquen Basin, Argentina).

Instantaneous viscosity was also computed and adjusted to match viscosity data from PVT (Fig.13). Viscosity impacts the flow capabilities and areas with less viscous fluids can help defining the play fairway.

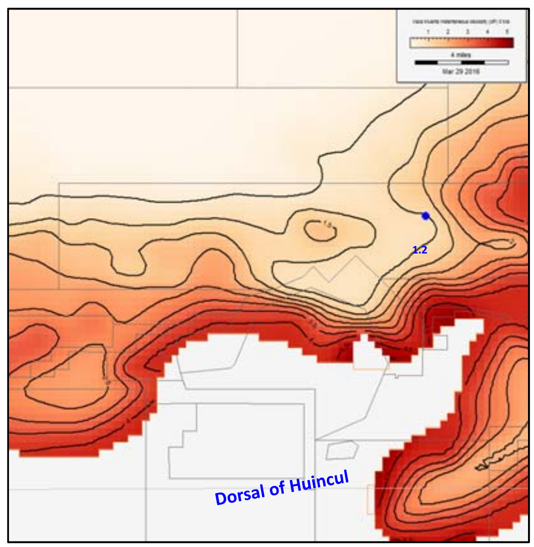

Fig.13) Viscosity prediction (cP) for Vaca Muerta in the Dorsal of Huincul area (Neuquen Basin, Argentina). The blue dot indicates the location of viscosity data.

Discussion

Kinetic models have a big impact on the prediction of generated volumes and fluid types. These models are hard to constrain and, even though a compositional kinetic analyses could be run, there will be still uncertainties in hydrocarbon generation and expulsion processes. That is why, the methodology proposed seems to be a good and inexpensive approach for deriving kinetic models.

Another uncertainty is related to the fact that kinetics will change as source rock facies changes. For that reason, the resulting fluid properties maps should be used with caution where differences in facies are observed or in areas where no calibration is available.

Other complications for fluid property prediction are not just linked to the kinetic model. In unconventional shale plays, the produced fluids should be similar to an instantaneous product but some fractionation is expected. Heterogeneity of storage and migration pathways will cause some fractionation in the hydrocarbon composition. This will impact the model prediction and should be taken into account when modeling fluid properties.

Conclusions

- Simple kinetic models can be derived from RockEval, bulk kinetic data, and fluid properties data (API gravity).
- Both shale plays show a later onset of generation and faster when compared with typical marine source rock (organofacies B). Kinetic models for Woodford and Vaca Muerta shales are more similar to organofacies C.
- These models can be used to derive fluid properties maps which are key in unconventional resource play evaluation. API gravity maps together with maturity maps can be integrated as part of the CRS map.
- Uncertainties in kinetic models need to be taken into account as well as uncertainties in the fractionation process that occurs after hydrocarbon generation.

References

- Abrams, M.A., 2014, Petroleum system charge analysis for liquid rich unconventional plays, URTeC 1922067, Unconventional Resources Technology Conference, 25-27 August 2014.
- Cander, H., 2012, Sweet Spots in Shale Gas and Liquids Plays: Prediction of Fluid Composition and Reservoir Pressure. Search and Discovery Article #40936 (2012).
- Pepper, A.S., and Corvi, P.J., 1995, Simple kinetic models of petroleum formation-Part I: oil and gas generation from kerogen, Marine and Petroleum Geology, 12, no.3, p.291–319.
- Peters, K. E., A. K. Burnham, and C. C. Walters, 2015, Petroleum generation kinetics: Single versus multiple heating-ramp open-system pyrolysis: AAPG Bulletin, v. 99, no. 4, p. 591-616.
- Wan, J., Barnum, R.S., DiGloria, D.C., Leahy-Dios, A., Missman. R., and Hemphill, J., 2013, Factors controlling recovery in liquid rich unconventional systems, ITPC 17103, International Petroleum Technology Conference Beijing China 26-28, March 2013.

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