Petroleum System Modelling

as uniquely applied to the MSGBC BASIN STUDIES
by First Exchange Corp

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This short release outlines the basin modeling methodology incorporated into FEC's MSGBC Basin studies as uniquely developed and practised by Dr. Andy Carr. It also explains the theoretical reasons why his procedures yield different results, for example as regards generation timing and hydrocarbon yields, compared to other models.

Successfully predicting risk in petroleum exploration must involve the complete integration of all the geochemical, geological and physical factors operating within a basin into a model that allows exploration geoscientists to fully understand the basin's dynamics and its oil and gas generation history. This requires:

1) the determination of subsidence, uplift and thermal histories though time, and
2) the determination whether or not there was HC generation, and if there were the commercial quantities and the phases of such generated hydrocarbons.

Hydrocarbon charge failures are considered by FEC to be the most common reason for unexpected well results. Outcomes vary from dry holes related to the lack of maturity, to trapping mechanisms post-dating migration as has been the recent case in northern Senegal and southern Mauritania, to the unexpected discovery of gas rather than the predicted oil. Consequently in our MSGBC Basin Studies, we have placed our greatest emphasis on applying basin modelling and incorporating oil and gas geochemistry as a means of crosschecking the basin models.

Dr. Andrew Carr has led our Petroleum Systems initiative since 1999. His methodology begins conventionally by determining subsidence and uplift histories though time. Preparatory investigation is taken to the base of the lithosphere using gravity and magnetics (these procedure developed for FEC by Andrew Long will form the subject of a future occasional short release). Reliable thermal histories are also required. Major events such as rifting are crucial to understand, but the post-rifting thermal history is equally important. These events are determined using local control and where required for age determinations from the regional geology. Conventional models predict rock temperatures during subsidence using models for post-rift subsidence and thermal history (e.g. McKenzie, 1978) combined with calibration of paleo-thermal indicators, e.g. vitrinite reflectance, and Rock-Eval Tmax. The problem with the thermal history models used by conventional modellers is that their thermal history solutions assume that thermal energy is conserved, whereas the laws of Physics tells us that energy is conserved (Carr and Carr, in press). Our supplemental modelling starts with the same heat flow into the basin derived from the top Moho temperature (1330° C), then accounts for additional thermal energy generated during subsidence due to the conversion of potential energy into thermal energy, i.e. heat. The amount of additional thermal energy generated by this method is ~10° C m^{-3} for each kilometre of subsidence.

Other modifications to the thermal history model involve the increased heat flow during uplift events. Normal petroleum system modellers do not sufficiently account for the increase in basement-basin interface heat flow during periods of uplift. Physics again tells us that this normal modelling methodology is incorrect, since during mechanical work (generation of the upward force responsible for the inversion) additional heating is produced due to the friction between moving surfaces, in the basement and the crust.

Having derived the thermal history from Physics, this thermal history is then calibrated using kinetic models for vitrinite reflectance, while other kinetics are used to determine the timing, phase and volume's of petroleum generation. The 'normal' kinetic models however contain a fundamental flaw in that *they do not conserve energy*. This arises from the absence of pressure in both the activation energy (Ea) and pre-exponential A factors in the models, although the A value is also thought to be temperature independent (thereby giving the constant A values contained in the models, whereas the A value is temperature-dependent, whilst the entropy change value is also *pressure dependent*. The effect of pressure on Ea comes from the pV (mechanical) work done by the reacting kerogen atom on its surrounds. The 'normal' kinetic models appear to contain 10 kJ $mol^{-1,}$ whereas in geological basins the amounts of pV activity to be accounted for in modelling can be more than >100 kJ mol^{-1} higher due to the much higher pressures in incompressible materials (e.g. rock, water) surrounding the kerogen. The effect of pressure retarding the amounts of petroleum generated can be seen in Figure 1. In this model, the volume's of petroleum generated using the current kinetic models is shown against those including effect of pressure. In the absence of pressure, predicted volumes of petroleum cannot be derived while ensuring that energy is conserved; put another way there is insufficient temperature in the rocks at the temperature and pressures in geological basins, as the current models predict petroleum generation while not supplying sufficient thermal energy The problem with the A values is illustrated in Figure 2. Using small entropy changes (ΔS) as occurs during petroleum generation (Stainforth, 2009), the physical derivation of A mostly predicts (lower) and therefore slower reaction rates (rate at which petroleum can be generated) than expected given the experimentally derived constant values as used in the kinetic models currently available for petroleum generation derived graphically largely from low-pressure experimentation. The pressure effect is to reduce the ΔS value due to pressure compressing the molecules, although this only becomes significant for gas generation. The result is, where overpressure is present, to slow down generation allowing, for example, the Oil Window to persist to depths that would be modelled by non-pressure influenced software to be in the Gas Window. FEC modeling found that overpressure influences are present in Northern Senegal and presumably across the border northwards into Mauritania.

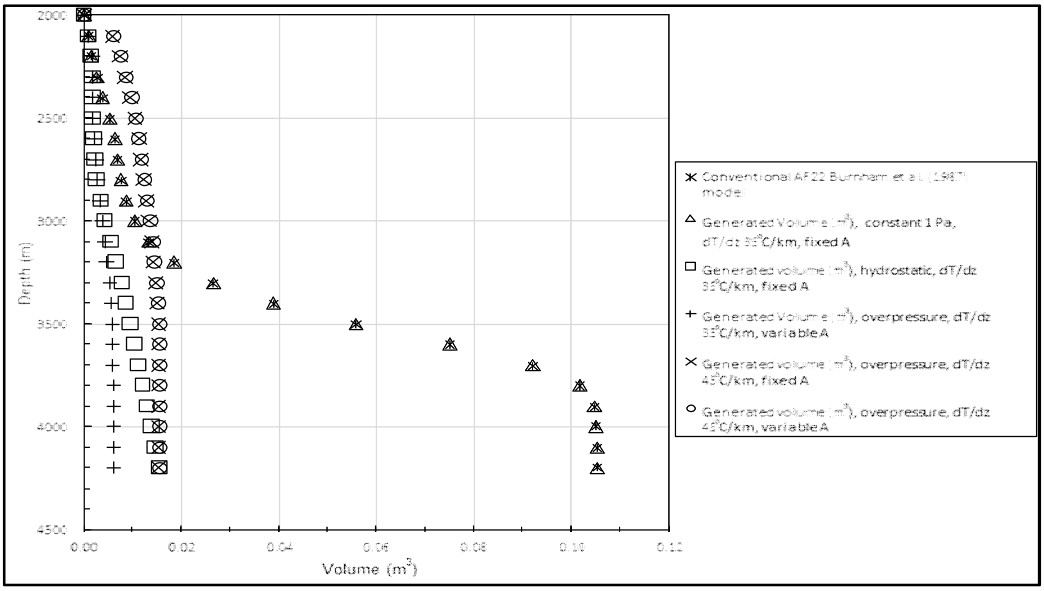

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Figure 1. Shown using open triangles is the conventional predicted hydrocarbon volume generated from a Type I kerogen with 5% TOC and a depth activation energy (Ea) that includes 1 Pa of pressure in the pV component (the star crosses). Introducing either hydrostatic pressure or overpressure significantly reduces the generated volumes, because the inclusion of pressure increases the Ea term again both with constant A and variable A values (as shown in Figure 2 below). The diagram also shows that increasing the temperature alone will not significantly increase the generated volumes.

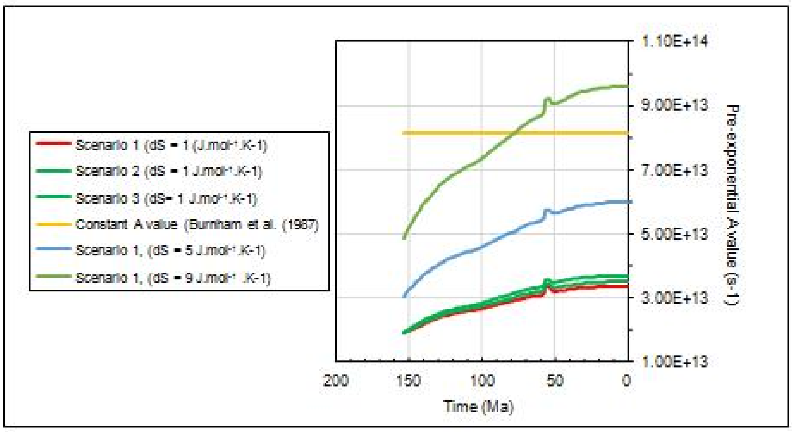

Figure 2. The graphical/computer method used in all current models for petroleum generation provides a constant A value that are invariant with regards to temperature. However, physics requires the A value to be dependent on both temperature and entropy change.. In this study the predicted A value are much lower than those given by Pepper and Corvi (1995), although as the entropy change increases, the A's become closer. The effect of this lower A values is to slow the reaction rate, i.e. the amount of petroleum generation. The scenarios refer to different radiogenic heating values in the heat flows used to model petroleum generation.

The introduction of thermodynamics into the thermal modelling means that temperatures can increase faster producing an earlier onset of oil and gas generation, that would / could with time totally exhaust any further petroleum generation potential in the source rocks. However, introducing pressure into the kinetics together with the use of variable A values controlled by temperature and pressure, results in understanding that a much slower rate of petroleum generation and expulsion from the source rocks could have occurred. Since the laws of thermodynamics must be obeyed in all natural systems, petroleum system modeling prediction not obeying relevant physical laws can never be correct, except by chance.

References

Carr A.D. and Carr N. P, in press. Implications of thermodynamics to thermal history and petroleum system modeling. AAPG Hedberg Conference, Santa Barbara, 2016.

McKenzie D., 1978. Some remarks on the development of sedimentary basins. Earth and Planetary Science Letters, 40, 25-32.

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, 3, 291-319.

Stainforth J. G., 2009. Practical kinetic modeling of petroleum generation and expulsion. Marine and Petroleum Geology, 26, 552-572.

Please contact FEC should further information be required, either on their basin modelling procedures or their reports on the MSGBC Basin.

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