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Using Dynamic Data to Estimate Fracture Permeability in a Carbonate Brownfield

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SUMMARY

This paper aims to present the fracture permeability aspect of an integrated workflow whose goal was to predict reservoir permeability in a carbonate brownfield using available dynamic data. The dynamic data was used to estimate a permeability height product (kh) which was tested in dynamic simulations, where both pressure match and production index match drove the selection of a suitable fracture permeability distribution. Well tests indicated reservoir permeability $\gg$ matrix in a significant number of tests. Fractures are assumed responsible for the excess permeability after a basic comparison of the Fracture Production Index (Reiss, 1980) where $kh_{welltest}/kh_{matrix}$ values indicated a fracture signature in some wells. Our analysis of the data led us to interpret that the production data could be reasonably matched with a model where 33% of the reservoir had an excess fracture permeability of 372 mD +/- a standard deviation of 626 mD.

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Multiple sensitivities of the permeability height function (kh) were calculated, and the differences in the sensitivities included: (1) fracture production index cut-off value (FPI), (2) height, (3) skin, (4) spatial distribution of the upscaled cells with fracture permeability. The basic workflow consisted of utilizing the semi (or pseudo) steady state solution of the radial diffusivity PDE for lightly compressible fluids and constant terminal rate (Dake, 1978). Solving for kPLT was done with two different height models – one is a flow unit model that is geologically based and one is an inflow zone model that is based on flow height from spinner data in an open hole. Heights for these two models varied from as low as 1 meter in the inflow zone, likely from a fracture or small fault system, to 147 meters in the flow unit zone, where the perforation was performed in a porous and permeable reservoir section. The sensitivities also included different skin values (-4.5, -2.5 and -1.5).

Based on the sensitivities, when kPLT was below 5-10 times the value of k_{matrix} , the wells were defined as showing a matrix signature. When kPLT was $> 5-10$ times the k_{matrix} , the tests were defined as showing a fracture signature. For the geologically constrained 'flow unit' height model with FPI and skin sensitivities, a fracture signature was seen in 16% – 33% of the tests (n=144). In the inflow zone, or spinner data, constrained height model, a fracture signature was seen in 33% – 57% of the tests (n=144). In the end, the FPI, height and skin values were used to determine the fracture permeability and standard deviation to be distributed into a static model. Simulations indicated the model that best matched production index of the wells was the model with fracture permeability distributed around fracture clusters, geologically akin to damage zones for small scale faults under seismic resolution.

While the methodology we have detailed here is still immature, the resulting fracture permeability distribution and its implementation into the static model have given us a first step toward quantifying the influence of fractures on reservoir permeability. No direct evidence of the fracture system in form of cores, or borehole image logs were made available for this study, however, a matrix model was developed and fell far short in terms of permeability distribution in the reservoir from production data. While models were discussed that included vuggy or karst zones in the reservoir, a fracture model is preferred owing to a combination of geologic knowledge and production data. Excess permeability calculated from dynamic data drives the assumption that fractures are present. At reservoir depths, the fracture sets are compatible with burial related fractures – stylolites and opening mode I fractures, also commonly known as tension gashes, as well as stratabound joints. Core descriptions contained notes referencing fractures, but were not specific on fracture type. Presence of a stratabound joint set is theorized to have grown due to remote tectonic stresses, and is assumed to match 'pre-folding' fractures from outcrop and analogue fields.

Tight time constraints and limited geologic data led to the development of this workflow, and have provided us with a method to interpret production log tests with a geological framework. While fractures are certainly present, excess permeability from the PLT analysis do not show systematic trends, and spatial heterogeneity in terms of stratigraphic layering (i.e. super-k matrix zones or highly fractured bed intervals) vs. vertical fracture corridors of small offset are uncertain and will likely have an important impact on reservoir flow and recoverability.

References

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