NFR22

Keynote Speaker - Fracture Characterization and Modeling Over the Last Few Decades, Current Progress and Future Outlook

M.B. Woldeamanuel* (Geology Specialist, Saudi Aramco)

SUMMARY

The first part of this talk focuses on a short review on the major efforts made in the past few decades to understand fractures and fractured formations both in the industry (oil and gas, hydrogeology, nuclear waste management) and academic community. The second part of the talk focuses on a discussion of typical workflow for detection, characterization, parameterization, prediction, modeling, validation and verification of fractures from limited direct subsurface data, and how static and dynamic data can be integrated to get a more complete picture of the reservoir. The final part of the talk points out some general future research directions.

1 ABSTRACT

The first part of this talk focuses on a short review on the major efforts made in the past few decades to understand fractures and fractured formations both in the industry (oil and gas, hydrogeology, nuclear waste management) and academic community. The second part of the talk focuses on a discussion of typical workflow for detection, characterization, parameterization, prediction, modeling, validation and verification of fractures from limited direct subsurface data, and how static and dynamic data can be integrated to get a more complete picture of the reservoir. The final part of the talk points out some general future research directions.

For the characterization and modeling of natural fractures, the first challenge is the availability of a direct dataset which is limited to core and borehole image logs. Therefore, over 99% of fracture characterization is based on limited direct data and prediction from seismic and dynamic data. The second challenge is well design (vertical, highly deviated and horizontal wells), each with its own limitations. The third challenge is that fractures occur on different length-scales: macro-, meso- and micro-scale. The dynamic impact of the three types of fractures is also different. Macro-scale fractures connect different mechanical units thereby controlling the dynamic behavior of the reservoir including water-cut, gas injection and/or oil production. Meso-scale fractures enhance the local porosity and permeability, and the micro-scale fractures are embedded within the matrix blocks and connect the pores and vugs.

A case study will be presented showing how limited data can be used efficiently to reduce uncertainty and to better understand fractured reservoirs by integrating geological, geophysical and reservoir engineering data. The studied field is situated in the NE of Saudi Arabia, comprising two main carbonate reservoirs that formed during Middle Mesozoic (Callovian and Oxfordian). The anticline is elongated in the NNE-SSW direction (020° strike) which formed in response to WNW-ESE directed compression (Oman ophiolite obduction) in the late Cretaceous and may later be affected by ENE-WSW directed Zagros deformation. The macro-scale features were deduced from curvature, 3D-seismic attribute and dynamic data conditioned to well data. The meso-scale fractures were determined mainly from formation micro-imager (FMI) results in approximately 90 wells and limited core data. Micro-scale fractures were qualitatively assessed. Our work mainly focused on evaluating the former two types. The majority of meso-scale fractures interpreted from borehole images were delimited by bed boundaries (bed-restricted) and their attributes such as orientation, spacing/density and aperture (from well test permeability and compared with apertures deduced from FMI) were deduced.

It was found that the occurrence of fractures was controlled by the mechanical stratigraphy which is a function of lithology (limestone, dolomite and anhydrite), structural position (crest, flank or nose) and petrophysical properties (porosity). The natural fractures described in this work are fold-related (axis-parallel and perpendicular in the hinge, and tensile and conjugate shear fractures on the flank). Fracture density, defined as the number of fractures per unit length or the length of fractures per unit area or fracture surface area per unit volume, is inversely related to the porosity with the highest density in the tight limestones ($\phi < 10\%$) and dolomites; average density for limestone with intermediate porosities $10 < \phi < 20\%$ and low density in porous limestones with $\phi > 20\%$. Once these factors have been established on FMI data from 90 wells, it was applied to more than 550 wells for better definition and control of the mechanical stratigraphy. This brings a major step in defining the mechanical stratigraphy for predicting the occurrence of fractures in undrilled parts of the reservoir volume and for planning future infill drilling.

As part of their curriculum, many universities are acquainting their graduates with fractured reservoirs. In addition, the emergence of high performance computing technology, the awareness of the earth science community and the application of sophisticated tools has made the acquisition, processing, analysis and interpretation of huge amount of data relatively easier for modeling fractures in the last couple of decades. International conferences and workshops have also helped by creating platforms for exchange of ideas and sharing experience between academic community and the

industry. Naturally fractured reservoirs makeup a large percentage of the world's remaining hydrocarbon reserves, occur in all rock types and throughout the stratigraphic column (*cf.* Aguilera 1995, Nelson 2001). In addition, the move towards developing unconventional reservoirs creates ample opportunities for researchers studying fractures and their impact in subsurface.

Keywords

Carbonate reservoirs, natural fractures, fracture attributes, borehole image logs

Acknowledgements

Saudi Aramco for permission to present the work and to my co-workers Murtada Al-Habib, Debasis Chaudhuri, Abdalla Laota and Khalid Hawas

References

- Aguilera, R. [1995] *Naturally Fractured Reservoirs*. 2nd edition, PennWell Books, Tulsa, 521.
- Nelson, R.A. [2001] *Geologic Analysis of Naturally Fractured Reservoirs*. 2nd Edition, Gulf Publishing, Boston, 332.