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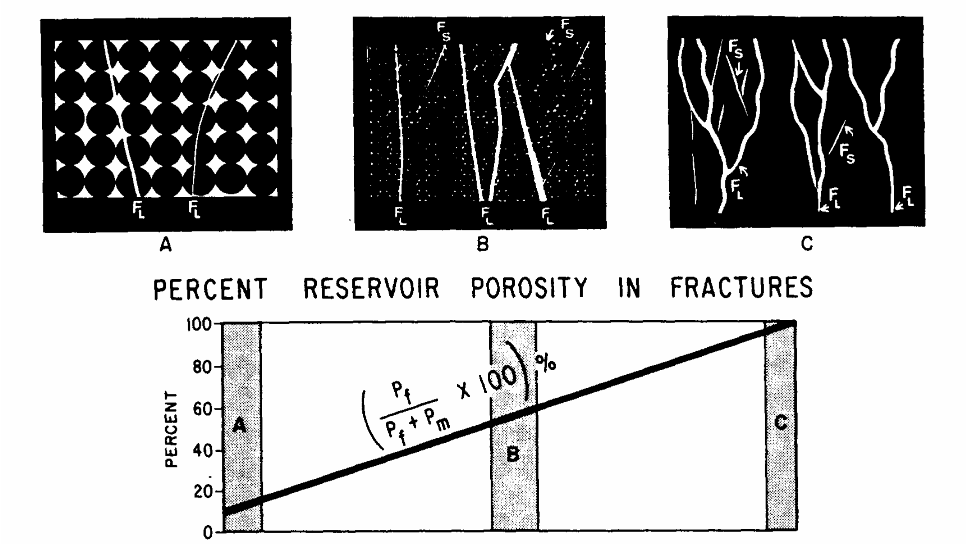
Quantifying matrix-to-fracture connectivity in fractured reservoirs

Dr. C. ALIMONTI, Dr. A. ALISCIONI (La Sapienza, Uni. di Roma),
Bob HARRISON (Enterprise Oil), Roberto GAMBINI (OMV)

Introduction

Accurate estimation of deterministic recoverable reserves is a formidable task for engineers and geo-scientists. It is even more challenging if the reservoir is naturally fractured and exhibits dual porosity behaviour. The major problem is estimating how much of the hydrocarbon, stored in the matrix porosity system, will be recovered via the fracture network. The interconnectivity between matrix and fracture, affectionately termed the *X factor,* is the important parameter in the exercise. Unfortunately, it is very difficult to constrain. New research into this topic has just begun at La Sapienza, Rome University, and its primary objective is to ascertain whether the deterministic *X factor* can be constrained sufficiently to be used with confidence when estimating reserves in dual porosity systems. The ultimate goal is to develop a robust deterministic volumetric model of dual porosity systems for use by engineers and geo-scientists involved in screening exploration prospects and commercial opportunities. However, to achieve this goal, the model must provide accurate estimates of original oil-in-place, both in the matrix as well as in the fracture system. The added knowledge of how the matrix and fracture system interact is fundamental in determining appropriate production strategies. Future research will attempt to link in bottom up approaches (numerical simulation of fracture networks) and top down approaches (regional strain intensity mapping) by employing the calibration field data sets currently being set up.

Dual Porosity Model



To meet this challenge, a dual porosity system approach to estimating reserves and matrix-to-fracture connectivity is proposed. From a storage capacity point of view, naturally fractured reservoirs can be classified into three groups as outlined by McNaughton & Garb, 1975, as shown below.

Reservoirs of type A have high storage capacity in the matrix system and low storage capacity in the fractured system, reservoirs of type B have about similar storage capacity in matrix and fractures, and in reservoirs of type C, the storage capacity is exclusively in the fracture network. For reservoirs of type A and type C, conventional single porosity models are applicable as their inherent assumptions hold. However, there is an important number of naturally fractured reservoirs in which fractures not only assist permeability in an already producible reservoir matrix, but also contribute with storage capacity. For these reservoirs of type B, a new approach was derived. Type B reservoirs are divided in two sub-types. Reservoirs of type B-I exhibit very good petrophysical characteristics for the matrix indicating movable oil, but type B-II reservoirs have poor characteristics that inhibit oil production from the matrix. The new dual porosity volumetric equation proposed by the authors uses the above model as a framework and their associated research will try to bracket and constrain the variables within the model.

X Factor Equation

An age-old problem with dual porosity systems is exactly how to estimate the reserves stored in them. One deterministic method is to assume that the fracture and matrix systems behave differently. Hence, the fracture system has its own parameters, which are independent of the matrix system. A new dual porosity deterministic volumetric equation is proposed which is very simple and is shown below:

$$Reserves_{mtx} = STOIIP_{mtx} \cdot [\mathbf{X} \cdot RF_{frac} + (1-\mathbf{X}) \cdot RF_{mtx}] \qquad [1]$$

$$Reserves_{frac} = STOIIP_{frac} \cdot RF_{frac} \qquad [2]$$

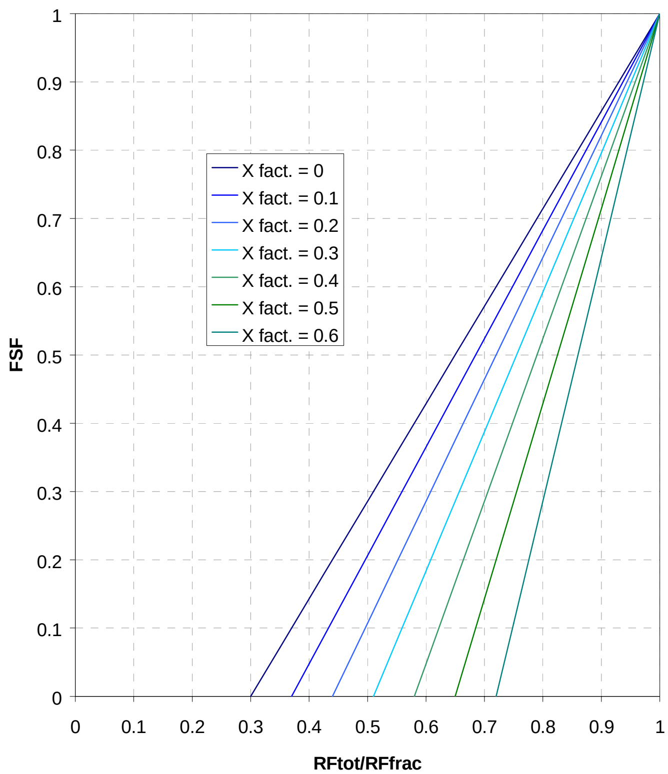
$$Reserves = Reserves_{mtx} + Reserves_{frac} \qquad [3]$$

The Fracture STOIIP Fraction (FSF) represents the ratio of fracture STOIIP to the total STOIIP. Hence, if we substitute FSF into equation [1] above, the total reserves will be defined as,

$$Reserves = STOIIP \cdot [\ (1 - FSF) \cdot [\ \mathbf{X} \cdot RF_{frac} + (1-\mathbf{X}) \cdot RF_{mtx}] + FSF \cdot RF_{frac}\ ] \qquad [4]$$

Equation [4] above can be rewritten to provide an *X factor* equation in its general form,

$$\mathbf{X} = [(RF_{tot} - RF_{mtx})/(RF_{frac} - RF_{mtx}) - FSF] / (1 - FSF) \qquad [5]$$



All the parameters above are standard, except the *X factor*, which implicitly includes the matrix-to-fracture connectivity and controls the amount of recovery into the fracture system from the matrix system. The *X factor* represents the matrix-to-fracture connectivity and ranges between 0 (no connectivity, matrix reserves will be only produced by the well directly from the matrix) and 1 (all matrix reserves are produced via the fracture network).

The input parameters for equation [5] are the estimated reserves, the total STOIIP, the RF for fractures and matrix and the FSF. The relationship is linear and the *X factor* can be determined easily. The *X factor* relationship is shown opposite for the case where RF_{mtx} /RF_{frac} = 0.3.

Depleted, mature reservoirs represent a good source of data with which to constrain many of the unknowns in dual porosity volumetrics. For example, the produced oil is a good estimate of reserves, STOIIP can be determined from material balance, the fracture RF can be assumed close to 1, and finally, an estimate of FSF can be obtained from petrophysical studies.

Sensitivity Study

When attempting to determine the *X factor*, it is fundamental to understand the impact of each parameter in the dual porosity system volumetric equation. A sensitivity analysis has been conducted on the volumetric equation containing the *X factor* where a variation of ±10% in each of the parameters was considered. The parameters FSF and RF_{mtx} have less impact on the results, as was expected from inspection of the structure of the new volumetric equation. These two parameters appear in both the numerator and the denominator, so the effect of any variation in them is reduced. In contrast, the parameters RF_{frac} and RF_{tot}, have much more influence over the result. Hence, these latter two parameters are those that the research has been designed to target and constrain. It follows that if the research is successful, then the X factor will also be sufficiently constrained.

Research Programme

The research at La Sapienza aims to constrain the *X factor* by targeting the problem in three phases:

1. Deterministic STOOIP and Reserves models will be matched with material balance using input from the production case histories of several mature fields in Italy. Examples include

Vega (Sicily), *Rospo Mare* and *Sarago Mare* (Adriatic). This will provide an initial "feel" for the important parameters in the model.

2. Where the field data allows, Discrete Fracture Network (DFN) simulations will be performed and matched to the case histories. Integration of the results from the initial deterministic modelling and those from DFN simulation should provide an improvement in the uncertainty envelope of the RF_{mtx} parameter before and after DFN simulation. Thus, a "bottom up" approach to fractured reservoir modelling may be achievable.

3. Attempts will be made to integrate the results of past regional stress/strain intensity work, and calibrating these results to the field case histories. This "top down" approach may help pinpoint zones of intense fracturing prior to drilling. It would be interesting to see whether the calibrated "bottom up" approach agrees with the calibrated "top down" approach.

Other benefits from this research programme will be a family of matched fractured reservoir models that can be run to investigate the variation in recovery due key influences such as presence and strength of an aquifer, hydrocarbon type and composition, reservoir architecture and well location. Each of the matched models will also provide a database of cumulative probability distributions for any of the key parameters used as input into volumetric calculations.

The paper will address the shortcomings of the current approach to dual porosity volumetrics and look at the sensitivity to the various volumetric parameters. The preliminary results from the current research work will be discussed. Finally, the future progress and direction of the integrated research programme will be presented.