Upscaling procedure applied to the Benchmark model UNISIM-II

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Abstract

The carbonate reservoirs are characterized by multi-scale heterogeneities, from the pore scale to the reservoir scale. The flow simulation of refined models with such heterogeneities, can lead to simulation larger CPU time consumption and computational limitations, due to the high number of blocks. The upscaling allows the properties of a fine grid to be adapted to a coarser grid. The objective of this study is to evaluate the best upscaling method to be applied to the Benchmark case UNISIM-II, associated with a naturally fractured carbonated reservoir, in a reasonable CPU time consumption,. The methodology is divided into three stages: (1) division of reservoir into characteristic flow units (CFU); (2) upscaling by heterogeneities scale for each CFU; (3) extrapolation of appropriate upscaling methods of each CFU for the full simulation model. The methodology allowed the definition of a reference solution and to get control of static properties and pseudo-functions (relative permeability) along the upscaling procedure. The approach allowed to obtain the best upscaling method and illustrates how the prior characterization, based on the upscaling by characteristics flow units, can assist in the best region for well completion.

Keywords: Upscaling, Fractured Carbonate Reservoirs, Dual Porosity, Reservoir Simulation.

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1. Introduction

The carbonate reservoirs hold more than an half of the world´s oil proven reserves, leading to a great economic opportunity. The study of carbonate reservoirs is complex as carbonate rocks have multi-scale heterogeneities due to depositional environment, genesis and fracturing. A great number of these reservoirs are naturally fractured and post depositional phenomena can induce the generation of vugs and fractures. In order to reproduce such geological characteristics and the interaction between the porous medium and flow simulation, the choice of appropriate upscaling methods is an essential challenge (Ahr, 2008; Mashio *et al*., 2002).

The upscaling is an adaptation of petrophysical properties from a refined grid for the same properties in a coarser grid. The application of this process is due to computational limitationsand CPU time consumption. One of the main upscaling purposes is to preserve information relating to the fine grid behavior. For a given method, two aspects must be taken into account: (1) the conformity between the results obtained for the coarse grid compared to the results obtained for the fine grid and (2) the upscaling time. Considering the assumption of a proper upscaling approach, if the numerical simulation of the fine grid was possible, the results obtained from numerical simulation at the coarse grid should be similar to those obtained for the fine grid (Ligero *et al*., 2001; Maschio e Schiozer, 2003).

The flow simulators are very useful in many practical applications, including the validation of upscaling techniques (Christie, 2001). In flow simulation of fractured reservoirs the dual porosity and dual permeability proposed by Warren and Root (1963) are the main flow models to represents the matrix fracture transfer fluid.

The Pre-salt carbonate reservoirs of Santos Basin, Brazil, have unique characteristics such as the presence of geological features with high permeability which induce in high flow rates. It is uncertain if they are fractures or very thin layers. Despite the presence or absence of fractures, these reservoirs are associated with carbonate reservoirs with heterogeneous flow characteristics (Correia *et al*., 2015).

This work focuses on the Benchmark UNISIM-II, which represents a carbonated reservoir naturally fractured with subsalt features. The objective of this work is to evaluate what is the best upscaling method to be applied to UNISIM-II, associated with a naturally fractured carbonated reservoir. The simulation model behavior should be similar to the geological model, within an acceptable simulation time.

2. Methodology

This section shows a resume of each step to achieve the purpose for this work. The methodology was adapted from Correia *et al*. (2016).

2.1. Step 1 - Division of reservoir in CFU

To evaluate the most appropriate and efficient upscaling procedure the reservoir is, firstly, separated according to the scale of heterogeneities and dynamic behavior in regions with similar petrophysical and close dynamic characteristics called CFU (characteristic flow units). The use of a reference grid is not viable for the entire reservoir due to the high computational simulation time and, sometimes, the same upscaling method isn’t the most suitable for different CFU. By dividing the reservoir according to the different units flow characteristics it is possible to define a reference solution (fine grid) and get control of the static properties and pseudo functions (relative permeability curve) to obtain a numerical relationship between the fine mesh and the coarse mesh along the upscaling procedure.

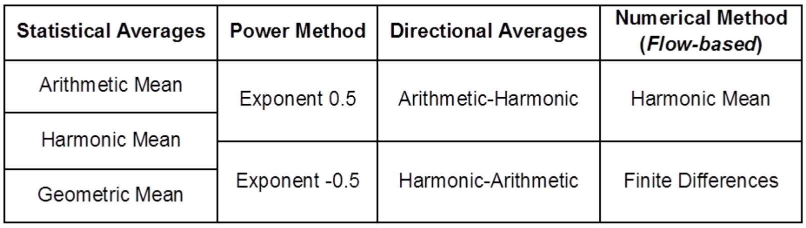
2.2. Step 2 – Upscaling

A region between wells is defined for each CFU in order to enable the use of a reference solution (fine mesh). Following the concept of CFU it’s expected that the characterized region between wells will reproduce the dynamic and static behavior of the CFU, for the entire reservoir. Therefore, the upscaling is performed for a region between wells for each CFU to enable the use of a reference solution. For the upscaling, is used the Petrel software, from Schlumberger.

2.2.1.Step 2.1 – Matrix Upscaling

In this section the upscaling of static properties (porosity, permeability and net to gross) of the matrix is performed. The compared methods are specified in Table 2.1.

Table 2.1: Upscaling methods.



Statistical Averages	Power Method	Directional Averages	Numerical Method (*Flow-based*)
Arithmetic Mean	Exponent 0.5	Arithmetic-Harmonic	Harmonic Mean
Harmonic Mean			
Geometric Mean	Exponent -0.5	Harmonic-Arithmetic	Finite Differences

For flow simulation we use the commercial black-oil simulator IMEX, of CMG. The resulting parameters from the simulation, that are used for comparison between fine and coarse grid are the water cut, medium reservoir pressure, oil recovery factor and oil flow. The validation is performed by comparing the simulation results obtained for the coarse and fine grid, used as reference.

2.2.2.Step 2.2 – Fracture Upscaling

This section describes the fracture upscaling procedure, which consists in two methods: Oda and Oda Corrected.

The validation and comparison between the upscaling methods, like in the previous step, are performed through histograms and numerical simulation.

After selecting the most appropriate upscaling method, the adjust can require a match procedure based on the use of pseudo functions (pseudo-curved of capillary pressure or relative permeability). The adjustment through relative permeability pseudo-curves is accomplished by varying the Corey exponents. The Corey exponent delimits the mobility of the water and oil phases. In relation to the capillary pressure, the restriction of capillary effects limits the water soaking into the matrix causing a rapid advance of water in the fracture. (Correia, 2014)

2.3. Step 3 – Simulation Model

This step consists in the upscaling for the entire reservoir but applying the appropriate upscaling techniques and pseudo-functions for each CFU, previously defined.

The validation consists in the evaluation of a numerical consistency of the simulation model based on the presence of errors or inconsistencies in the numerical simulation. An initial production strategy is applied based on four sets of five spots, comprising in total, four injection wells and sixteen producing wells to illustrate the influence of different CFU in the flow and production, over ten years.

For validation, the influence of different CFU in the flow and oil production is verified, taking into consideration a sensitivity study in the completion of wells according to the flow units. Six different completion strategies are adopted : (1) full completion for the entire thickness of the reservoir (2) completion only in blocks with Super-k intersection (3) completion in blocks without Super-k, (4) completion in blocks with Super-k excluding the fracture, (5) completion in blocks without Super-k and without fracture and (6) completion only in blocks with intersecting fractures.

3. Application

The case study used in this work is the Benchmark UNISIM-II, based on a combination of characteristics of the fields of the Brazilian pre-salt and the Ghawar field, developed by Correia *et al*. (2015).

The geological model (fine grid) has a block size of 50x50 meters horizontally and, about 1 meter vertically. The simulation model (coarse grid) as a block size of 100x100 meters horizontally and approximately 8 meters in the vertical.

The field is characterized by four facies, derived from different geological environments: high energy represented by grainstones, average energy represented by packstones, low energy environment represented by a non-reservoir facie and the Super-K unit. According to Correia *et al*. (2015) “the term Super-k features was first introduced to Ghawar field and is related to very thin layers with high permeability and porosity.”

The reservoir is divided by two characteristic flow units, one CFU (grainstone, packstone and non-reservoir) is characterized only by the background facies, the other is characterized by the background facies (grainstone, packstone and non-reservoir) and Super-k features. For each characteristic flow unit, we cut one representative region in order to enable the use of a reference model (refined grid) for the upscaling matching procedures. The region dimension is representative of an inter-well region. The first has a dimension of 1200m*1200m*300m and the second has a dimension of 800m*600m*60m. Two wells, one injector and one producer, are added to the model to perform the dynamic validation of upscaling.

4. Results and Discussion

The methodology step 1 does not contain practical results, so it is included in the previous application section.

4.1. Step 2 - Upscaling

4.1.1. Matrix Upscaling

Figure 4.1 and Figure 4.2 show the porosity and net to gross distribution obtained for the arithmetic mean and the fine grid, for CFU with Super-k and without Super-k. The porosity and the net to gross properties are additive what means that the application of the arithmetic mean in performing upscaling is enough to give good results.

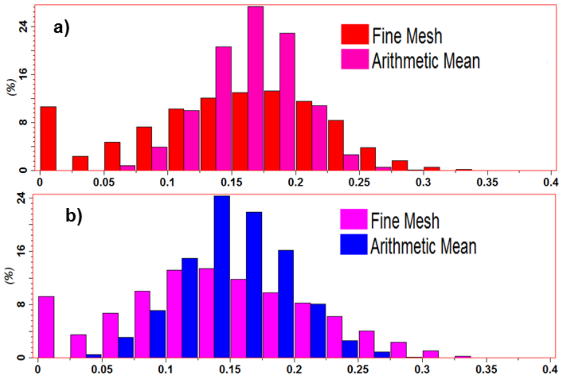


Figure 4.1: Histogram of the porosities obtained by arithmetic mean and fine mesh. a) CFU with Super-k, b) CFU without Super-k.

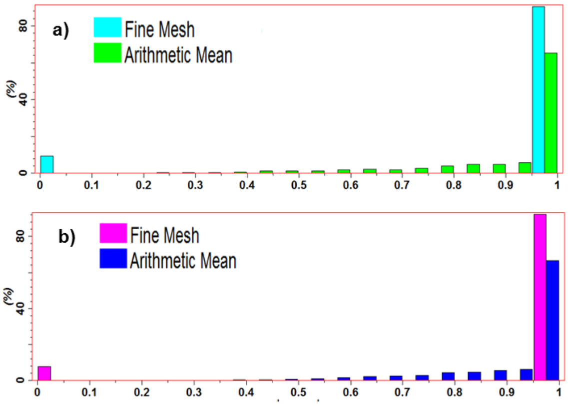


Figure 4.2: Histogram of net to gross obtained by arithmetic mean and fine mesh. a) CFU with Super-k, b) CFU without Super-k

For the CFU with Super-k features, the combined harmonic-arithmetic mean and flow-based method based on finite differences (closed flow) gives the best match between the coarser and fine grid (Figure 4.3).

To these methods is applied one cutoff on the rock type above 400 mD of permeability. So, for permeabilities above 400 mD, the simulation model considers the Super-k rock/fluid data. Otherwise, the rock/fluid representative for background facies is considered. The relative permeability curve for Super-k features is similar to the fracture system. The relative permeability curve is assumed as two straight-lines function with endpoints at zero and 100% saturation. The capillary pressure for fracture system is zero. This assumption is carried out due the presence of Super-k unit which has distinct characteristics influencing the flow dynamics, with the aim of seek a better fit compared to the reference mesh.

The combined harmonic-arithmetic mean presents as the best method as it requires smaller upscaling time consumption compared to the numerical method (Figure 4.3).

For the CFU without Super-k features the combined harmonic-arithmetic mean and the flow-based method based on finite differences (closed flow) provided the best fit between the coarser and fine grid

(Figure 4.4). Although both of these methods present a good fit in relation to the reference solution, the combined harmonic-arithmetic mean implies less upscaling time consumption.

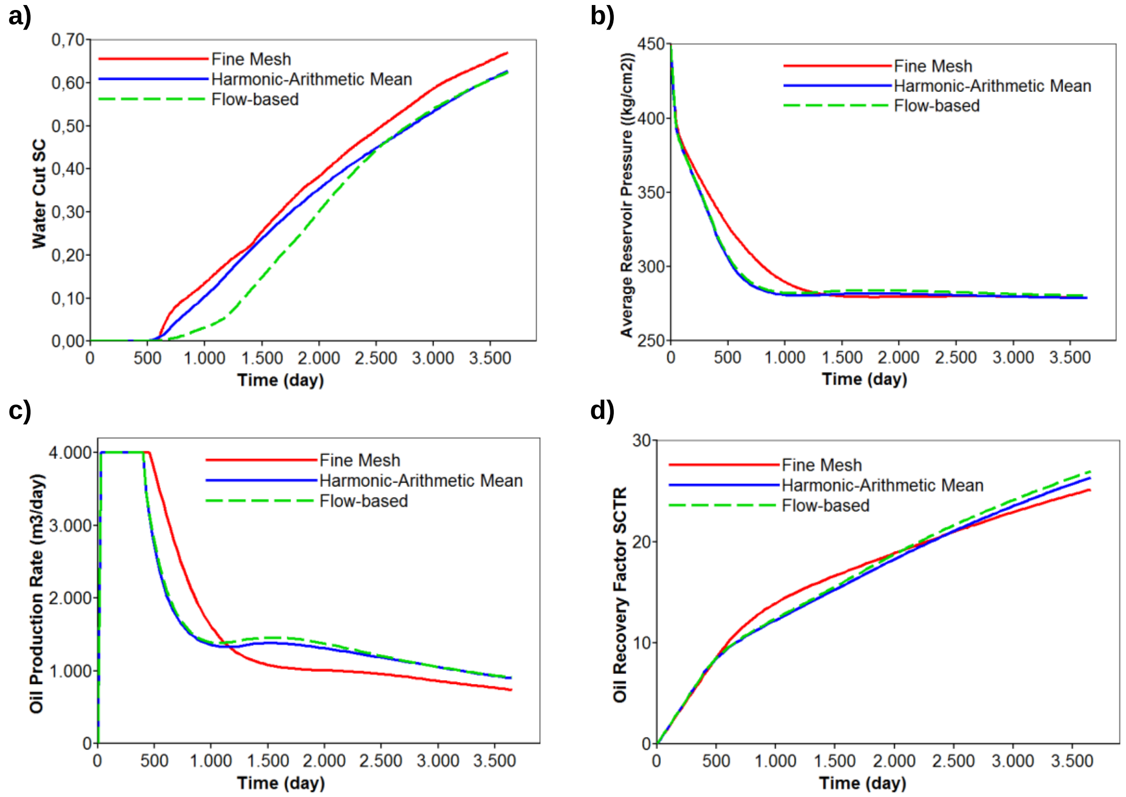


Figure 4.3: CFU with Super-k - Comparison of production parameters for fine mesh, harmonic-arithmetic mean and numerical method. a) Water cut; b) Average reservoir pressure; c) Oil production rate, and d) Oil recovery factor.

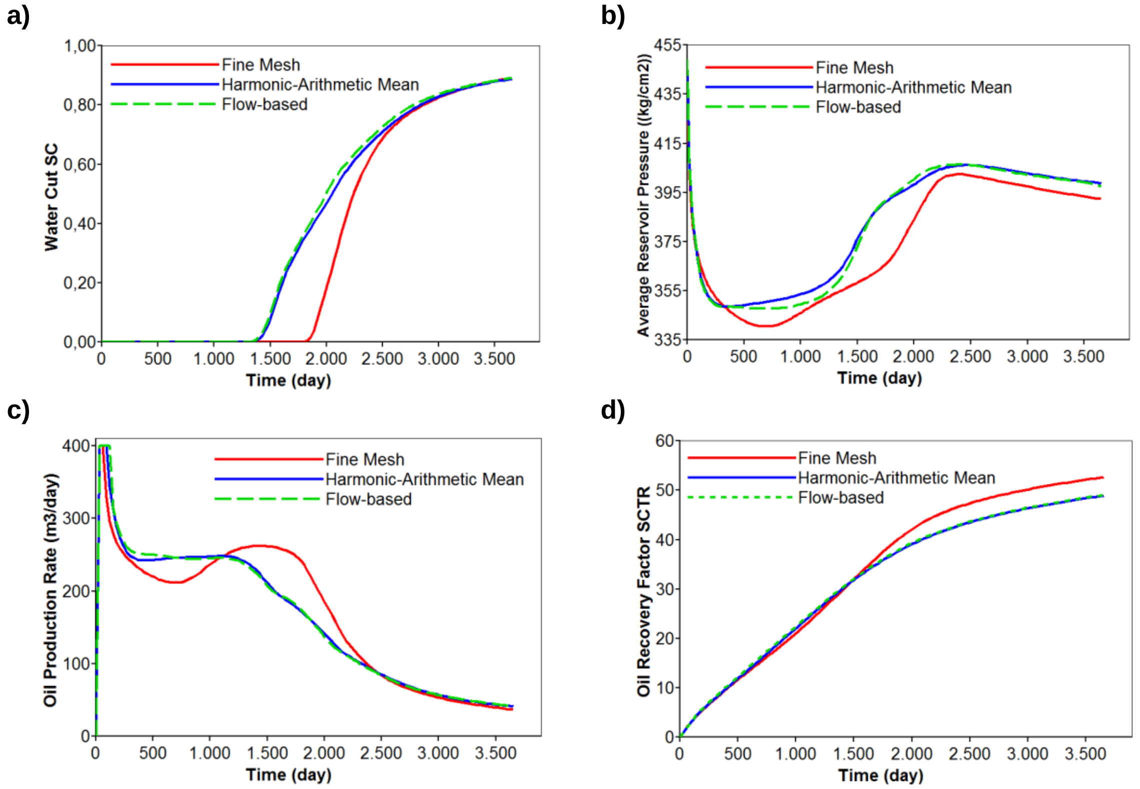


Figure 4.4: CFU without Super-k - Comparison of production parameters for fine mesh, harmonic-arithmetic mean and numerical method. a) Water cut; b) Average reservoir pressure; c) Oil production rate, and d) Oil recovery factor.

4.1.2. Fracture Upscaling

For the CFU with Super-K features the results show that the method that gives the best fit in relation to the fine mesh and less upscaling time consumption is the Oda Corrected method. Although it presents a good fit relatively to the fine mesh, it's possible to improve the fit by applying a pseudo-curve of relative permeability. The Figure 4.5 illustrates the initial relative permeability curve and pseudo-relative curve applied for the matching procedure. The adjustment is performed through varying the Corey exponents for Kro and Krw. A change in the Corey exponent relative to Krw curve it is implemented in order to restrict water from soaking into the matrix and induce rapid advance of water in the fracture which allows the adjustment of Oda Corrected method in water cut.

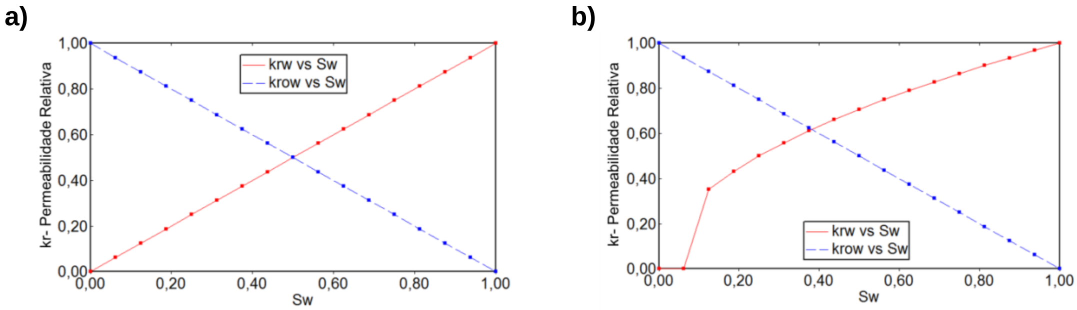


Figure 4.5: Permeability transition. a) Relative Permeability base and b) Pseudo-curve of relative permeability.

The Figure 4.6 illustrates a comparison between the Oda Corrected method approach before and after the adjustment. It can be observed that the curve of Oda Corrected method is closer to the curve of fine mesh after the application of pseudo-curve of relative permeability.

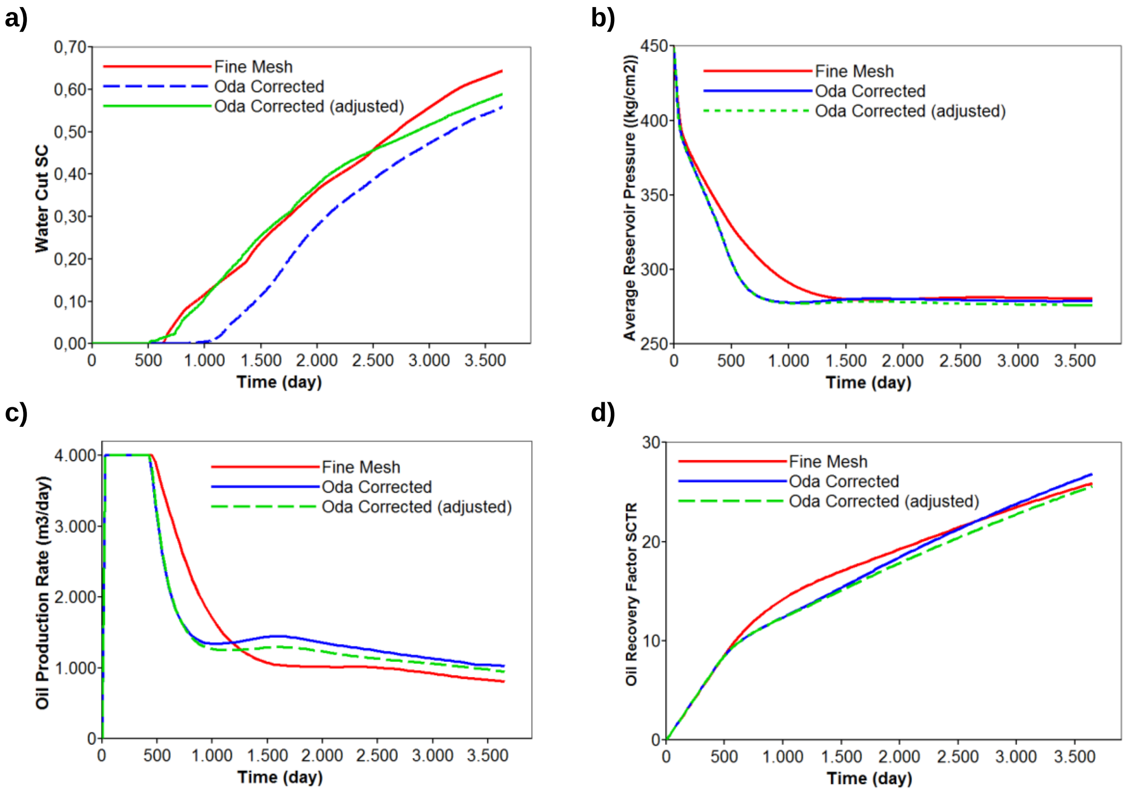


Figure 4.6: CFU with Super-k - Comparison of production parameters for fine mesh, harmonic-arithmetic mean and numerical method. a) Water cut; b) Average reservoir pressure; c) Oil production rate, and d) Oil recovery factor.

For the CFU without Super-k features, after analysis of all parameters (Figure 4.7), it is possible to verify that the Oda Corrected method allows a closer match with the fine mesh. The Oda Corrected method compared with the Oda method involves less upscaling time consumption and allows the obtainment of better results.

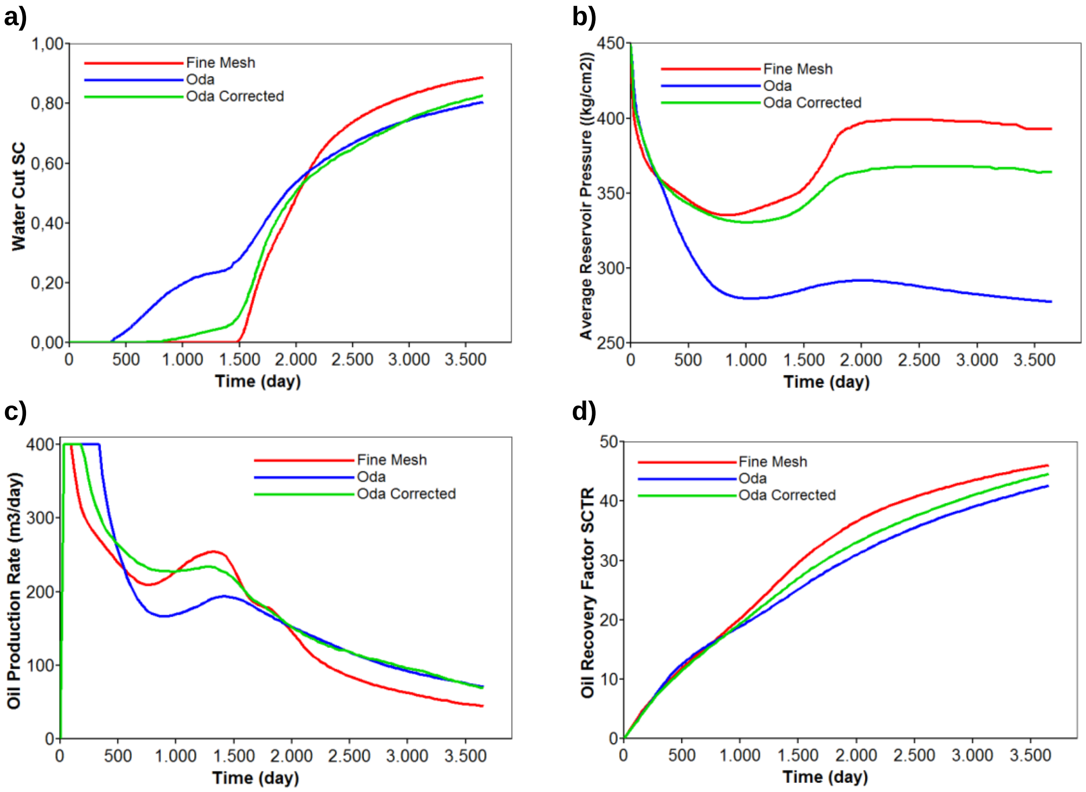


Figure 4.7: CFU without Super-k - Comparison of production parameters for fine mesh, harmonic-arithmetic mean and numerical method. a) Water cut; b) Average reservoir pressure; c) Oil production rate, and d) Oil recovery factor.

4.2. Step 3 – Simulation Model

The numerical validation of the simulation model consists of applying an initial production strategy (16 production wells and 4 injection wells of water), in order to evaluate the numerical consistency of the model and illustrate the influence of each characterized flow unit in the flow and oil production.

To illustrate the influence of the different units in the flow and production it is necessary to perform a sensitivity study in well completions in function of the present unit. The comparison is made between wells 2, 4, 8, 10, 15 and 20 by calculating the average water and oil flow corresponding to each strategy for 365, 1095, 2191 and 3652 days (Figure 4.8). It can be observed that the flow rates for water and oil are higher when applied the strategies: (1) full completion and (2) completion in blocks with Super-k excluding the fracture.

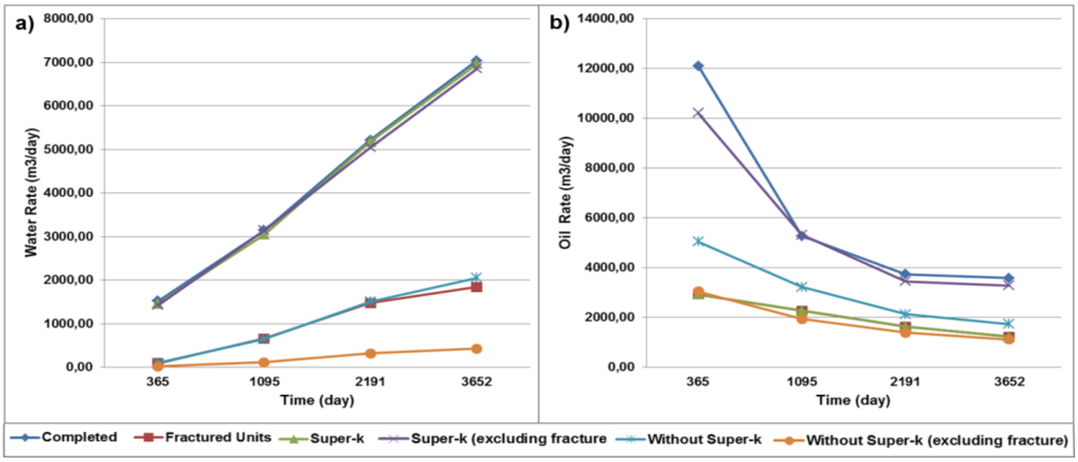


Figure 4.8: Averages of flow of water and oil corresponding to each strategy

The Figure 4.9 shows the comparison, based on water cut and oil recovery factor, between the initial strategy and other strategies applied to the entire field. It can be observed that the low values of water cut and greater values of oil recovery factor are obtained in completion strategies without Super-K, with and without fracture. It is possible to verify the reverse, high water cuts and low oil recovery factor values when applied the completion strategies with Super-k, with and without fracture. This fact is due to the small pore volume and high permeability of Super-k units. The oil is trapped in the matrix, since there is no enough time for its imbibition, and the water has a faster advance in Super-k system.

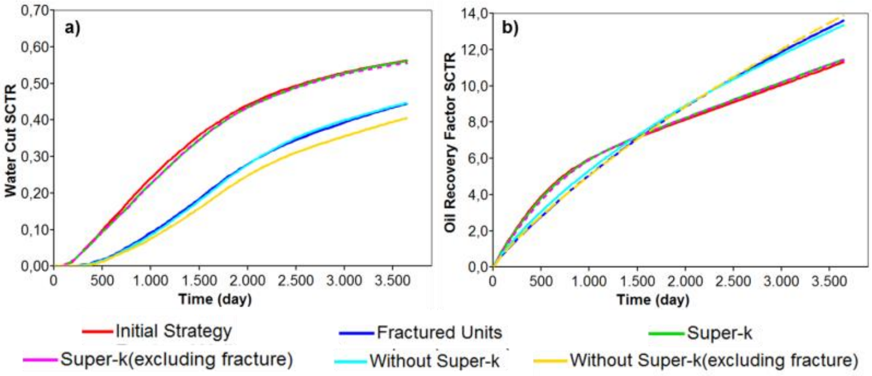


Figure 4.9: Comparison between strategies. a) Water cut and b) Oil recovery factor.

5. Conclusion

The main goals of this study were achieved, by reaching the best upscaling procedure and methods to be applied to the model Benchmark UNISIM-II.

- The porosity and net to gross are volumetric properties (additive variable), so the arithmetic mean is efficient in the representation of these properties.
- In the matrix upscaling the method applied to the permeability that allows the closest match to the reference solution is the combined harmonic- arithmetic mean. This method shows similar results to numerical upscaling methods. However, the combined mean showed less time of upscaling since it is a combination of analytical methods.

- The use of Oda Corrected method yields results closer to the results obtained for the reference solution and less upscaling time consumption compared with the Oda method.
- As the case study is partially fractured, the difficulty to represent fractures in reservoir simulation is increased as both methods available in commercial software (Oda and Oda Corrected) are only valid for high connected discrete fracture networks. The numerical method has a high computational time and it’s unreliable to apply large scale models. Therefore, it is expected the loss of information through the upscaling methods available in the software.
- The previous characterization based on a hierarchical upscaling procedure through characteristic flow units and heterogeneities scale can contribute in the best region to implement the completion of the well.
- The completions in blocks without the presence of Super-k (with and without fracture) rock-type results in a lower production of water and high oil recovery factor compared to the total completion and the remaining approaches.

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