DEVELOPMENT OPTIMIZATION OF A MARGINAL OIL FIELD

Ana Sofia Canelhas Castanho

ASTRACT

This thesis intends to demonstrate the development of a Marginal Field in onshore Brazil, by maximizing the use of available techniques for data integration in order to achieve the best reservoir characterization and an increase in oil reserves.

The term “Marginal Field” refers to an oil field that may not produce enough net income to compensate development. However, in a favorable economic scenario it may be commercial. It is generally associated with the presence of low hydrocarbons reserves, low productivity reservoirs and a high degree of uncertainty.

The reduction of costs in both well drilling and surface facilities construction resulted so far on the project positive net return. Future challenges will be to sustain the current oil production and increase oil recovery via optimization of the field development plan, that may require the use of a water injection scheme to improve recovery.

With the above in mind and using Mass Balance Equation (MBE), the first tasks were to confirm the initial volume of oil in the reservoir (Original Oil in Place- OOIP) and verify that the production mechanism was through an active aquifer.

Then to test the advantages of a secondary recovery scheme by means of water injection, simulation of flow lines (streamlines) was performed. This allowed to evaluate and compare the increase in oil recovery resulting from injecting water versus the natural depletion scheme.

INTRODUCTION

The Field under analysis is located onshore of the Potiguar Basin, in the northeast Brazil (Figure1). The Potiguar Basin is a mature and one of the most prolific basins of the Brazilian onshore.

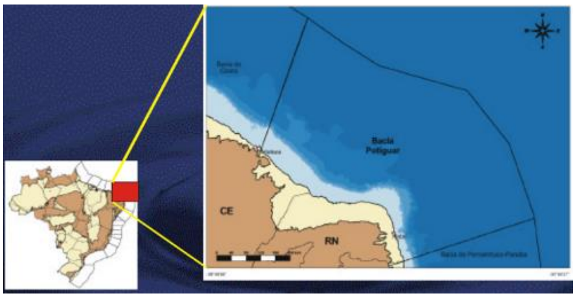

Figure 1 – Field Location, Potiguar Basin, NE Brazil

This basin evolved since early stages of Pangeia breakup (early Cretaceous). Basin infill is strongly related and controlled by different phases of tectonic evolution, resulting in the with Pendência Formation (lacustrine environment) related with rift phase, Alagamar Formation related with transitional phase and all the others related with a drift phase.

The geological targets at this shallow position of the basin (Figure 2) are the siliciclastic reservoirs from Açu Formation at depths ranging from 300m to 500m. This transgressive formation comprises fluvial environments (braided to meandering) with transition to estuarine system.

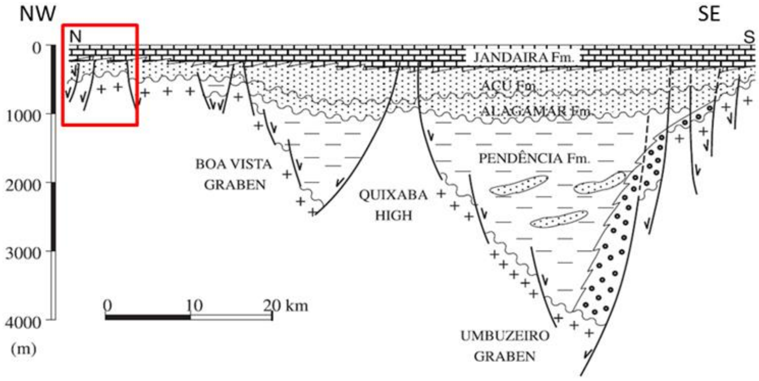

Figure 2 – Schematic NW-NE section through Potiguar Basin with red box indicating approximately the position of Partex Blocks (adapted from Anjos et al., 2000)

The studied oil field comprises two different structures, the West and the East (Figure 3). The oil production started in 2007 and from the 28 wells already drilled, 25 therefrom are producing in average a total five hundred barrels of oil a day (500 bbl/d).

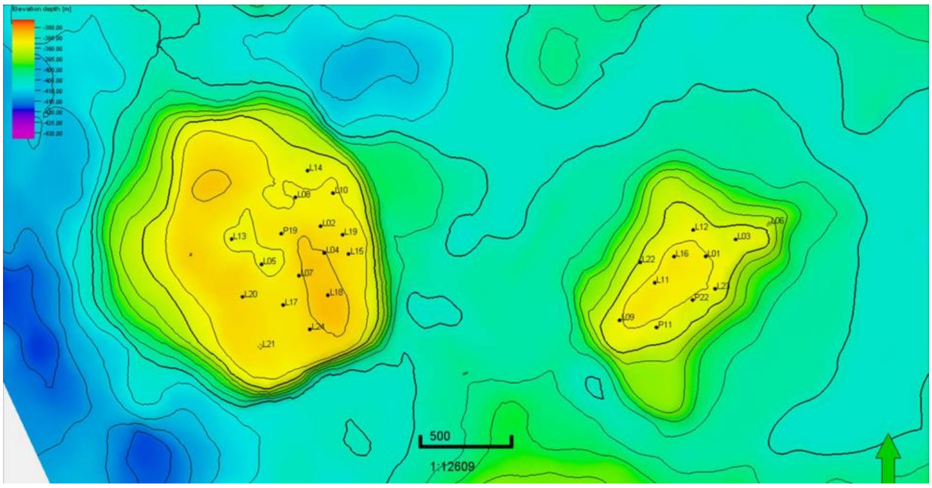

Figure 3 – West and East Field Structures

The productive reservoirs are composed by shallow interbedded sandstone channels and fine shale laminations with complex geometry. The oil is considered paraffinic with low pour point, which easily create conditions for high deposition of paraffins.

All these factors induce very low productivities with high water cuts. Additionally, extremely low salinity formation water (less than 3500 ppm NaCl) has a negative impact on the accuracy of HC saturation estimation from open hole logs and later, reservoir modelling.

The uncertainties found during the geophysical and geological characterization of the reservoirs are then reflected in the 3D geological and dynamic models. The integration of multidisciplinary areas is one of the most challenging tasks and requires a great effort to continuously minimize reservoir uncertainties.

The term “Marginal Field” refers to an oil field that may not produce enough net income to make it worth developing. However, in a favorable economic scenario it may be commercial. It is generally associated with the presence of low hydrocarbons reserves, low productivity reservoirs and a high degree of uncertainty. It’s successful economic development implies a continuous optimization of development strategies, to make the project more solid, minimizing the investment risks.

In addition to the aspects related to the reservoir, other elements such as the environmental impacts, field access, political stability and oil price, can heavily influence the development of these kind of fields, being thus the risk management and an effective control of the mitigation measures thereof critical issues.

METHODOLOGY

- **Material Balance**

The Material Balance Equation (MBE) has been used by reservoir engineers for a long time as the basic tool for interpreting and predicting reservoir performance.

The general form of the material balance equation was presented for the first time by R.J. Schilthuis in 1936. The equation formulates a balance of volumes in which the observed cumulative production, expressed as the underground recovery, is considered equal to the expansion of the fluids still remaining in the reservoir (including the water from an aquifer in contact with the hydrocarbon zone), caused by the finite pressure decline induced by production itself.

Material balance analysis is an interpretation method used to determine the original oil and gas in place and to predict petroleum reservoir performance based on production and static pressure data analysis, also to evaluate the remaining reserves by applying the principle of material balance to rate-time decline analysis. Proper understanding of reservoir behavior and future performance prediction is necessary to have a good knowledge of the driving mechanism that controls the fluids movement in the reservoir.

Accurately estimating hydrocarbon reserves is important, because it affects every phase of the oil and gas business. Quantifying the uncertainties in original hydrocarbon in place (OOIP) estimates can support development and investment decisions for individual reservoirs. Thus, uncertainty quantification is an extremely important step.

- **Streamlines Simulation**

Streamlines simulation is a powerful complementary tool to more traditional simulation techniques, and the simulated flux lines are expected to play an important role in field production optimization and reservoir management.

Streamlines are lines representing fluid flow that are tangent to the instantaneous velocity field under steady state flow between sources and sinks (Figure 4).

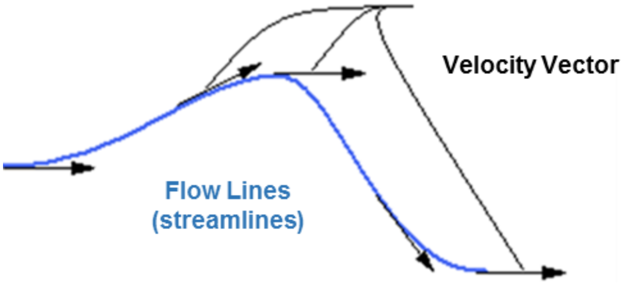

Figure 4 – Streamlines Definition

Streamlines represent a snapshot of the instantaneous flow field and thereby produce data such as drainage/irrigation regions associated with producing/injecting wells and flow rate allocation between injector/producer pairs that are not easily determined by other simulation techniques (Figure 5).

The computational speed and novel solution data available have made streamlines an important, complementary approach to traditional simulation approaches to perform sensitivity runs.

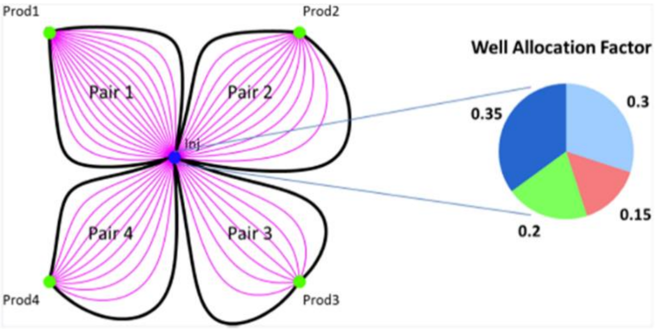

Figure 5 – Well pairs and well allocation factors *(Khan & Al Zaabi, 2014)*

Specifically, streamlines can be used to:

- Efficiently perform parametric studies
- Visualize fluids flow
- Balance patterns
- Determine efficiency of injectors and producers
- Optimize and manage field injection/production.
- Aid in history matching
- Enable ranking of production scenarios/geological models

Streamlines are typically used when heterogeneity is the predominant factor governing the fluid flow behavior, providing a “quick” visualization of reservoir fluid flow main directions, being an unique way to conceptualize and quantify injector-producer well connectivity. The optimization process starts by generating streamlines and associated Well Allocation Factors (WAF) at a current time using the numerical simulation model.

CASE STUDY

- **Material Balance Equation**

Concerning uncertainty reduction, the first task was, as said, to validate the oil in place (STOOIP). The comparison between STOOIP values obtained from numerical simulation with those calculated through the Material Balance Equation (MBE) showed very similar figures with an average of 3.4 MMSTB and 6.17 MMSTB, for the East and Western Structures, respectively.

The use of EBM allowed also the identification of the reservoir production mechanism by drive indexes calculation, such as:

- DDI (Depletion Drive Index)
- SDI (Segregation Drive Index)
- WDI (Water Drive Index)

- CDI (Formation and Connate Water Compressibility Index)

These indexes indicate the relative magnitude of the various energy sources acting in the reservoir. If the drive indexes do not sum to unity (or very close to 1), the correct solution to the material balance has not been obtained.

The Figure 6 shows that the index with the highest weight is the WDI (Water Drive Index) and the sum of all indexes is equals 1. According the results, one can conclude that the production mechanism of this reservoir is by aquifer expansion.

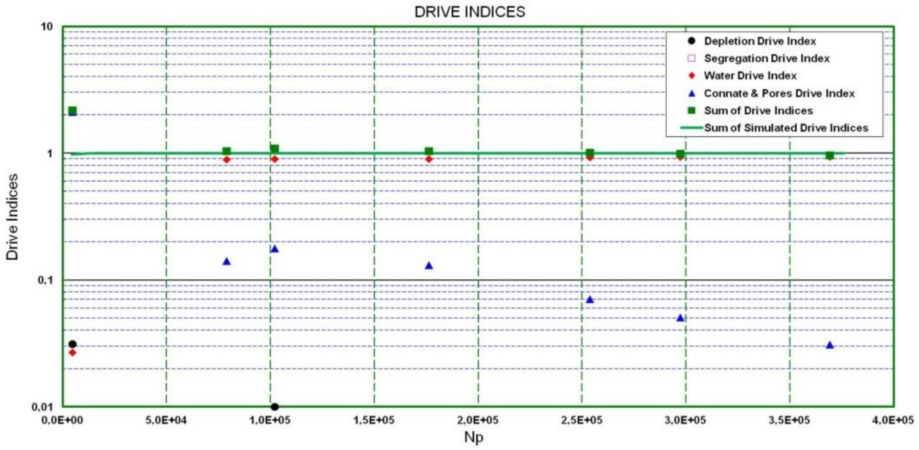

Figure 6 – *Drive Indexes* for East Structure – *Water Drive*

In order to detect aquifers as well as to characterize them, Campbell plot, is the most useful diagnostic tool to identify the relative strength of aquifers.

The Figure 7 below shows that the pressure values (red dots) are above the green line (STOOIP), which indicates the presence of an additional power factor and may be an aquifer. In this case, the plot also confirmed the presence of a very strong aquifer.

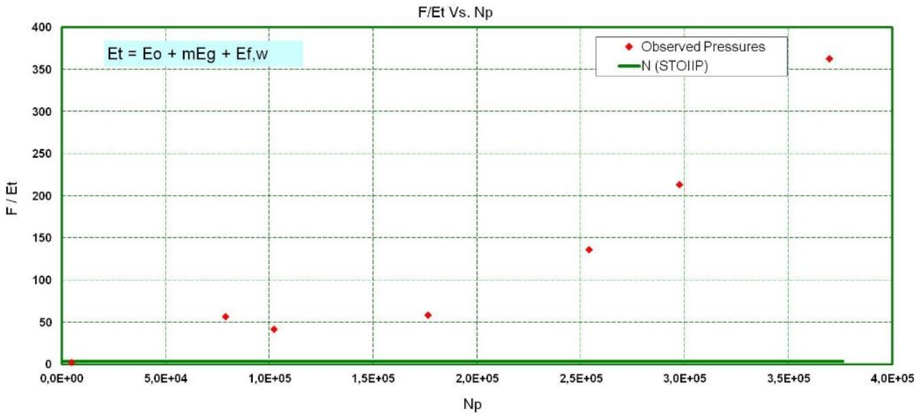

Figure 7 – Campbell Plot for East Structure

The reservoir is in communication with a surrounding active aquifer. This allows influx of water into the reservoir and provide the pressure support needed to compensate the fluids production.

- **Static Pressures and Reservoir Characteristics**

According the EMB conclusions (presence of an active aquifer), a detailed study of the petrophysical properties of the reservoir and its integration with the analysis of wells static pressures allowed a better characterization of the reservoir.

In the East Structure, there are ten (10) wells in production since 2007 until 2015. The Figure 8 shows the location and the static pressure distribution for all wells.

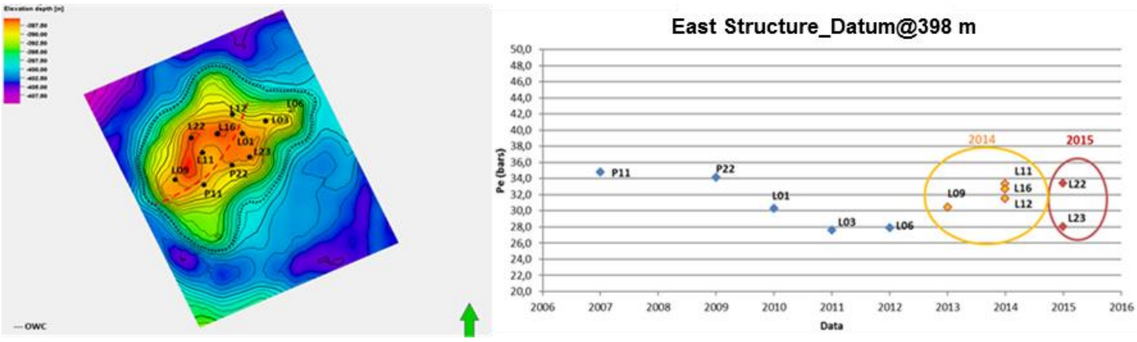

Figure 8 – a) Structural Map b) Static Pressures Distribution for the East Structure

- In the Southeastern part of the reservoir there is a natural depletion and that includes the P11 wells, P22, L01, L03 and L06;
- The Static pressures for the wells drilled in the last two campaigns 2014 and 2015 (L09, L11, L12, L16, L22 and L23) have higher pressure values and very close to the initial pressure recorded in the discovery well (P11), except for well L23;
- Well L23 has a pressure of around 28 bar, 5 bar less than the well L22, both drilled in 2015 campaign.

Considering the reservoir geometry (characterized by sand bodies with moderate lateral continuity and vertical low connectivity) is important integrate the geological component in this evaluation through the porosity and permeability analysis.

Analyzing the Figure 9, the new wells (L09, L11, L12, L16 and L22) seems to be in a different channel with high permeability and better connectivity in a preferred direction and also connected to the aquifer.

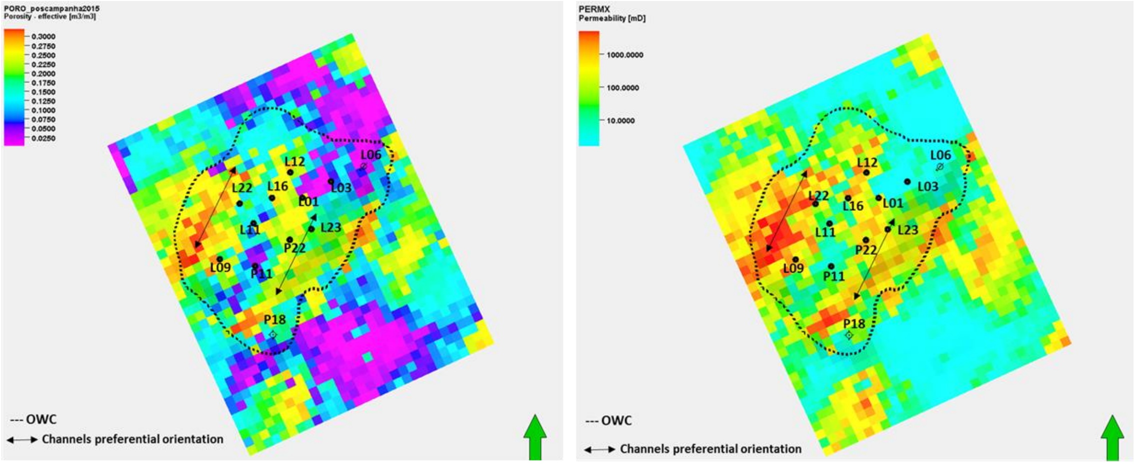

Figure 9 – Porosity and Permeability distribution for the East Structure, respectively

This analysis identified the geological heterogeneity as being the main factor to control fluid flow in the reservoir.

Through the analysis of static pressures, it is possible to infer the connectivity of sand bodies and existence of baffles to flow or even, possible compartmentalization of areas of the reservoir because of geological heterogeneity.

- **Streamlines Simulation**

To infer the possibility of a secondary recovery scheme by injecting water, numerous scenarios were tested by converting producers to injectors. The scenario that presented the best recovery factor (RF=27%) was the one which considered the conversion of well L03.

Consequently, this was the case that served as basis for the simulation of flow lines (streamlines) to evaluate the additional oil recovery by water injection versus the natural depletion.

The Figure 10 shows the flow lines at the beginning of the injection for the well L03.

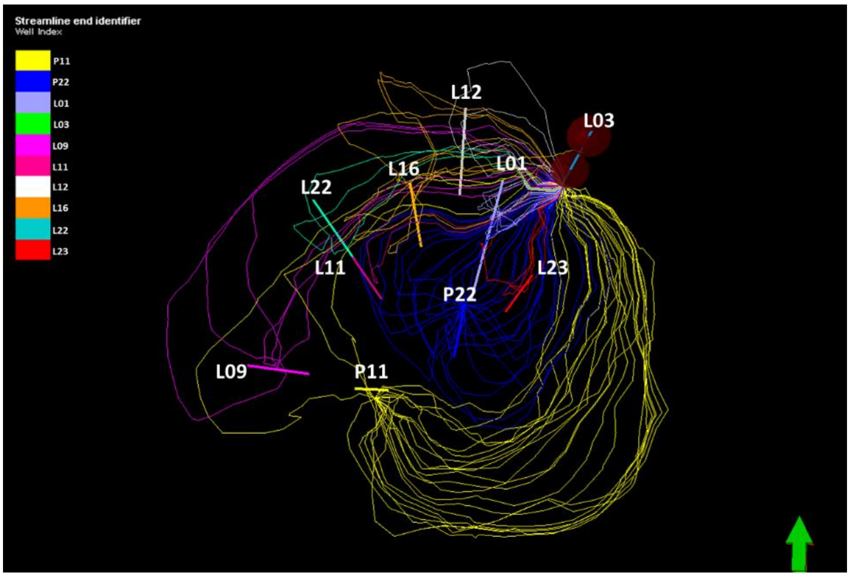

Figure 10 – Streamlines at the beginning of water injection

The main aspect to emphasize is the good connectivity in the reservoir. The flow lines showed that water injected into the L03 can reach all producing wells.

Despite all wells being affected by the injection, the contribution for each is relatively low and in some cases, nonexistent (Figure 11).

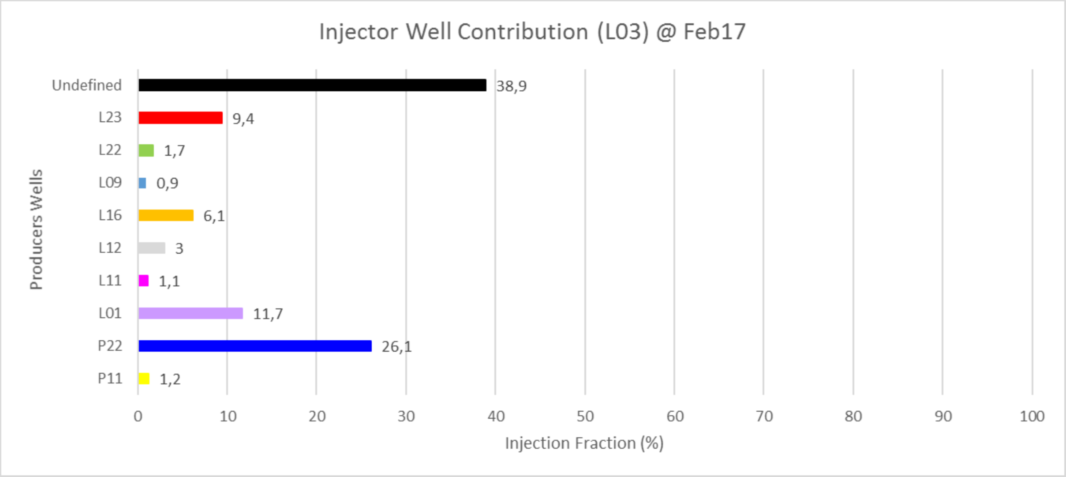

Figure 11 – Water injection contribution for producer wells

The well P22 has the major gain followed by L01 and L23 with 26%, 12% and 9%, respectively. Moreover, at the start of injection, 39% of injected water is lost as it flows to the aquifer. For this reason, the injection efficiency is very low and it has confirmed the impact of channels´ connectivity in the field ultimate oil recovery.

CONCLUSIONS

In this study, the material balance equation has proven to be a very useful tool to validate the Oil in Place and identify the driving mechanism that controls the fluids movement in the reservoir.

A detailed study of the petrophysical properties of the reservoir and its integration with the analysis of wells´ static pressures allowed a better characterization of the reservoir. This analysis identified the geological heterogeneity as the main factor to control fluid flow in the reservoir.

Another conclusion is that the injection of water as a secondary recovery method tends to be inefficient. Considering the low oil recovery factor, it is advisable to continued use of streamlines applied to new injection wells in order to confirm this and infer the areas where the water injection would increase the oil recovery factor.

The seamless integration of all available information together with the use of specific technologies allows for a proper reservoir management and development plan optimization by means of reserves maximization.

REFERENCES

- ALCOBIA, V., (2014), ”Material Balance Calculations”, Master Manuals

- DATTA-GUPTA, A., (2000), “Streamlines Simulation: A Technology Update”, SPE-65604

- GUERREIRO, L. *et al*.(2013), “The Challenge of Developing Complex Maginal Fields, example of NE Brazil”, SPE 162332-PP

- HAVLENA. D. & ODEH. A, (1964), “The Material Balance as an Equation of a Straight Line,S.”

- ROSA, A. J., (2011), “Engenharia de Reservatórios de Petróleo”, Editora Interciência