RESERVOIR NUMERICAL SIMULATION WITH LOCAL REFINEMENT

Valmir F. Risso
DEP – FEM – UNICAMP, Caixa Postal 6052, Campinas – SP, 13083-970
valmir@dep.fem.unicamp.br

Denis J. Schiozer
DEP – FEM – UNICAMP, Caixa Postal 6052, Campinas – SP, 13083-970
denis@dep.fem.unicamp.br

Edson Wendland
SHS – EESC – USP, Caixa Postal 359, São Carlos – SP, 13560-970
ew@sc.usp.br

Abstract. *This work analyses a methodology for reduction of the computational effort, maintaining the level of precision of more detailed simulations, when the interest is just in a certain area of the field, for example, in the forecast of mature fields. This methodology is a tool for support in the choice of the best strategy of oil recovery. In large fields this choice is difficult, because the simulations are very slow and many simulations are necessary in order to define the best strategy. There are several techniques that facilitate the accomplishment of fast simulations for this type of problem. In this work, local refinement was studied. For the evaluation of local refinement technique, several different meshes for the same region of interest were tested and compared. The results indicate that the method of local refinement is viable, leading to satisfactory agreement with more detailed models. Using local refinement, it was possible to reduce the time of simulation in more than 80 percent compared with the conventional method, maintaining an adequate precision. This work showed that it is possible to investigate specific regions of interest in reservoirs of great dimensions and to get satisfactory results, with reduction of the computational effort.*

Keywords. *Numerical simulation, local refinement, oil fields, porous media.*

1. Introduction

The numerical simulation is an instrument of extreme importance in the evaluation, project and development of oil fields. Using computer models, it is possible to foresee the behavior of the reservoir and to optimize the production process. Usually, the simulation is hindered by the size of the field, the number of wells, the complexity of the geological model, and the amount of data necessary to guarantee the reliability of the model. The size of the model is frequently limited by the memory and speed of the processors. This fact is observed frequently in applications such as history matching.

Sometimes, the use of local refinement can represent a good option to reduce the computer effort. Nacul *et alli* studied the technique of static refinement, with a Cartesian grid, showing that it is possible to apply the local refinement only in selected areas of the reservoir, where a better resolution is necessary. The main advantage is that using the local refinement results comparable with a complete fine grid can be obtained.

Gourley and Ertekin studied techniques of static refinement and tested its efficiency in models with impermeable barriers to flow. Excellent agreement between the results of the locally refined grid and the fine grid for the production of oil, water and gas could be achieved. With the refined grid the execution was 12% faster than with the fine grid.

Heinemann *et alli* applied the dynamic local refinement in simulations of reservoirs and they concluded that the dynamic refinement facilitates a larger accuracy in the characterization of the pressure and of the saturation.

Wasserman applied the static local refinement in three-dimensional reservoirs and concluded that the results were good, especially when compared with values of non refined meshes and that the vertical local refinement is important.

Al-Towailib and Liu studied the application of local refinement as an alternative for models of great dimensions of reservoirs of petroleum and concluded that the time and the human effort reduced. Furthermore, the credibility of the adjustment production and of the forecast of the behavior of the reservoir increases with the elimination of possible inconsistencies in the characterization of reservoirs.

This work analyses a methodology for reduction of the computational effort, maintaining the level of precision of more detailed simulations, when the interest is just in a certain area of the field, for example, in the forecast of mature fields. There are several techniques that facilitate the accomplishment of fast simulations for this type of problem. In this work the local refinement was studied.

2. Methodology

In large fields, the choice of the best strategy for oil recovery is difficult because the simulations are very slow and many simulations are necessary in order to define the best strategy. The methodology discussed in this section can be a good tool for support in this choice.

In order to measure the performance of the different refinement strategies, the solutions were compared with the results of a base model simulated with a fine grid. A Black-Oil commercial simulator was used to simulate all cases presented here.

2.1. Base Model

The base model (Figure 1) has a grid of 68x36x6, with block dimensions of 112.5 by 112.5 m (14688 blocks – 10086 active blocks). The density of the oil was 887 kg/m^3 (28 ^{0}API) and the bubble point pressure was 211 kgf/cm^2. The reference pressure was 322 kgf/cm^2 in a depth of 3041 m. In the adjustment process, 45 wells were used: 32 producers and 13 injectors. The reservoir was adjusted for a period of ten years, with five years of water injection.

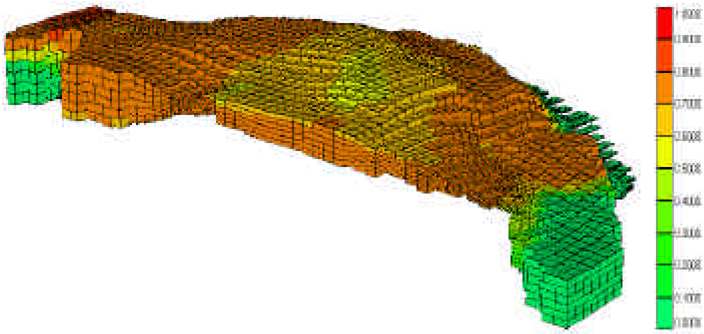


Figure 1: Simulation model of the reservoir. The legend indicates the oil saturation.

2.2. Region of Interest

The region of interest was chosen based on the oil volume available in the reservoir after 10 years of operation. This distribution is shown in the map of oil volume per unit of area (Figure 2). The region of interest is indicated by the white square (10% of the total area of the reservoir), where a great oil volume is concentrated (33% of the total volume of the reservoir). The region of interest is described by 6 layers, 16 lines and 16 columns (1536 blocks).

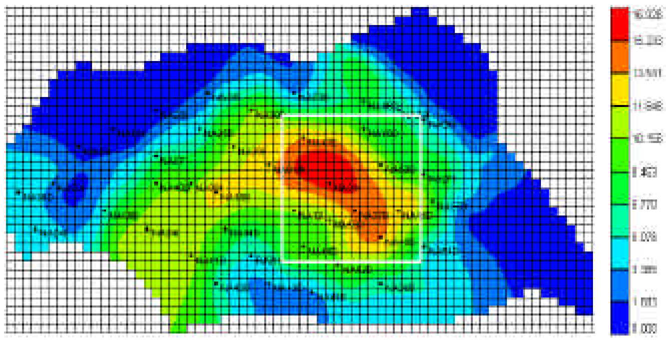


Figure 2: The region of interest is indicated by the white square. The legend indicates the oil volume per unit of area.

2.3. Local Refinement Method

The analysis was executed sequentially, focusing the following stages:

1. Transition from coarse to fine grid. Some models were tested, involving refinement with gradual and brusque variation in the size of the blocks.
2. Definition of the extension of local refinement. Different models were tested, involving refinement restricted to and refinement exceeding the region of interest.
3. This stage involved a variation between the size of the blocks of the refined models and the size of the blocks of the base model. The variations were: 1:2, 1:4 and 1:8. For each one of these variations, two situations were analyzed: with and without refinement in the region of interest.

2.4. Results Analysis Method

The quality of the results obtained is analyzed in comparison with the solution of the base model. Considering surface conditions, the error in the results of the simulations, after 10 years of forecast in the region of interest were computed. The errors in the cumulative oil production (Np), water (Wp) and gas (Gp) of the producer wells were calculated by:

$$Ep_i(\%)=\frac{\sum_{1}^{n}\left|\frac{R_{bj}-R_{ij}}{R_b}\right|}{n}\times 100 \qquad (1)$$

Where,

Ep_i = average well error between model "i" and base model
R_{bj} = resulted for the well "j" of the base model
R_{ij} = resulted for the well "j" of the model "i"
R_b = result for the base model (considering all wells inside the interest region)
n = number of producer wells

The error in the cumulative oil production (Np), water (Wp) and gas (Gp), in the region of interest, were calculated by:

$$Er_i(\%) = \left| \frac{R_b - R_i}{R_b} \right| \times 100 \tag{2}$$

Where,

Er_i = cumulative error between model "i" and base model
R_b = result for the base model (considering all wells inside the interest region)
R_i = result for the model "i" (considering all wells inside the interest region)

The reduction in simulation time for each model in comparison with the base model, was calculated by:

$$Ts_i(\%) = \frac{T_i}{T_b} \times 100 \tag{3}$$

Where,

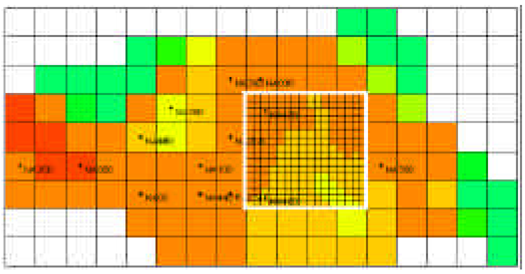
T_b = simulation time of base model
T_i = simulation time of the model "i"
Ts_i = relation between T_i and T_b

3. Numerical Results

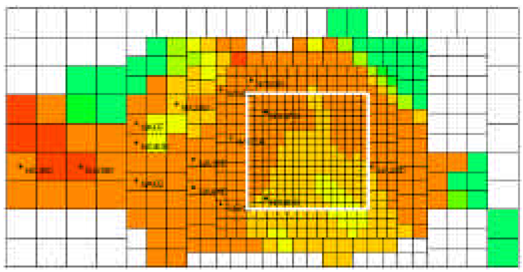
The Local Refinement Method consists in the variation in the size of the blocks, with a fine grid, in regions where more detail is necessary, for example, near wells.

3.1. Type and Localization of the Refinement

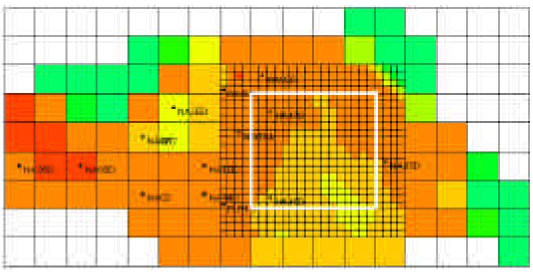
To define the type of refinement, two configurations were tested. A brusque variation of block size is shown in Figure 3-a, whereas a gradual variation is shown in Figure 3-b. To define the enlargement of the refinement two configurations were tested. The refinement exceeding the region of interest with a brusque variation (Figure 3-c) and the refinement exceeding the region of interest with a gradual variation (Figure 3-d).



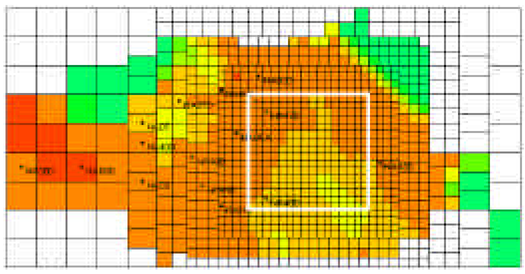
(a) Refinement Restricted to the Interest Region.



(b) Intercalated Restricted to the Interest Region.



(c) Refinement Exceeds Interest Region.



(d) Intercalated Exceeds Interest Region.

Figure 3: Type and Localization of the Refinement.

Figure 4 shows the numerical simulation results obtained for the type and localization of the refinement.

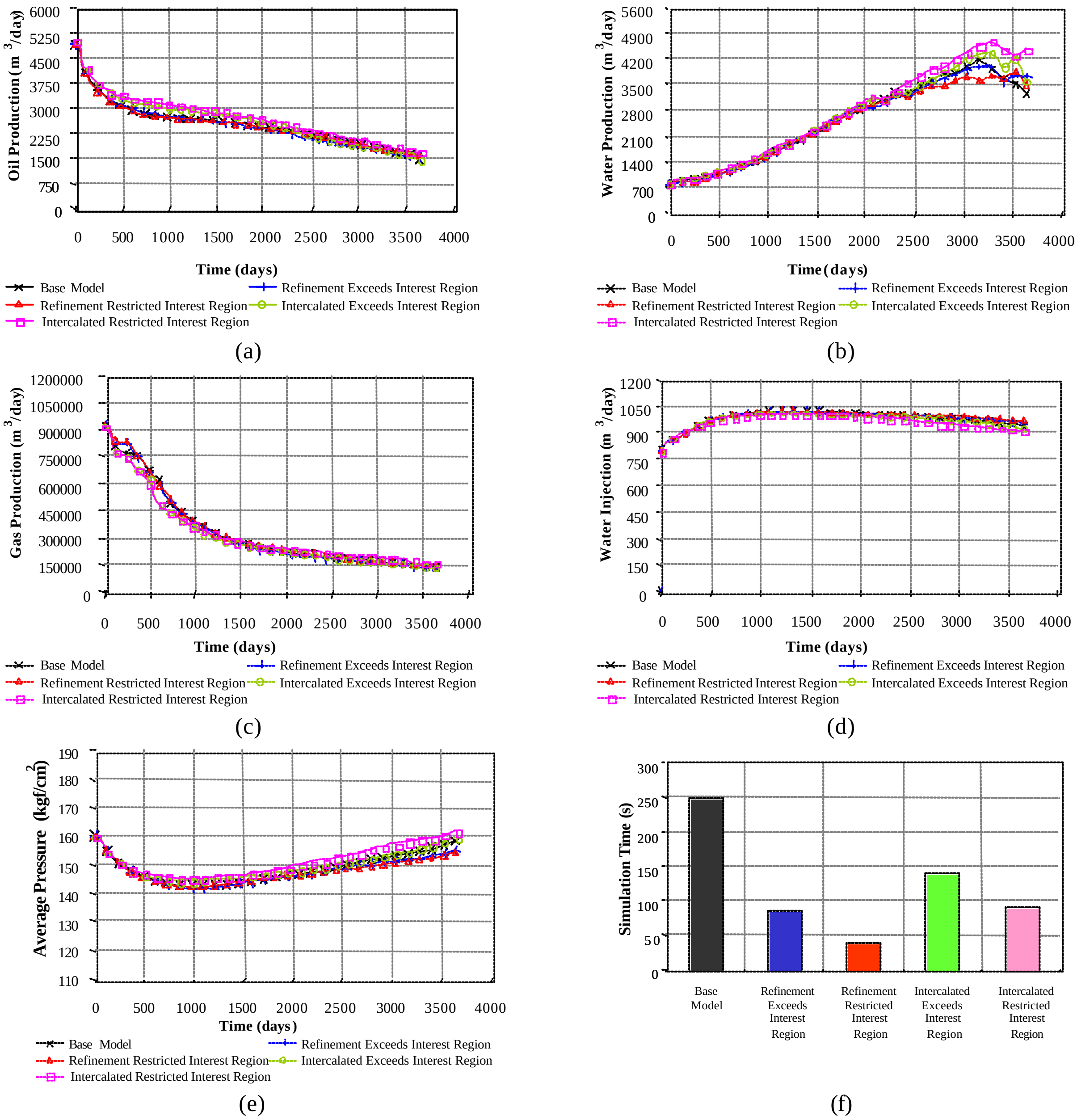


Figure 4: Oil Production (a), Water Production (b), Gas Production (c), Water Injection (d), Average Pressure (e) and Simulation Time (f) after ten years of forecast, for different type and localization of the refinement.

The table 1 shows the variations in accumulated productions, accumulated injection, pressure and simulation time.

Table 1: Variations between the tested models and the base model, for the type and localization of the refinement.

Type and Localization of the Refinement	**Er** (Eq. 2)					**Ts** (Eq. 3)
	Accumulated Production			**Injection**	**Pressure**	**Simulation**
	Np (%)	**Gp (%)**	**Wp (%)**	**Wi (%)**	**(%)**	**Time (%)**
Refinement Exceeds Interest Region	1.34	1.20	0.42	0.23	1.90	34.36
Refinement Restricted Interest Region	**0.28**	**1.74**	**2.02**	**0.50**	**2.37**	**15.61**
Intercalated Exceeds Interest Region	3.94	5.53	3.82	0.95	0.80	56.23
Intercalated Restricted Interest Region	8.32	2.00	8.78	2.07	2.29	35.64

It is possible to observe in Figure 5, that the errors of the results in the region of interest and the producer wells presented the same behavior. It is possible to conclude that for this case the best model was refinement restricted to the region of interest, with a brusque variation in the size of the blocks between the region of interest and the rest of the reservoir. The errors for this model were small and the reduction in the simulation time was 84%.

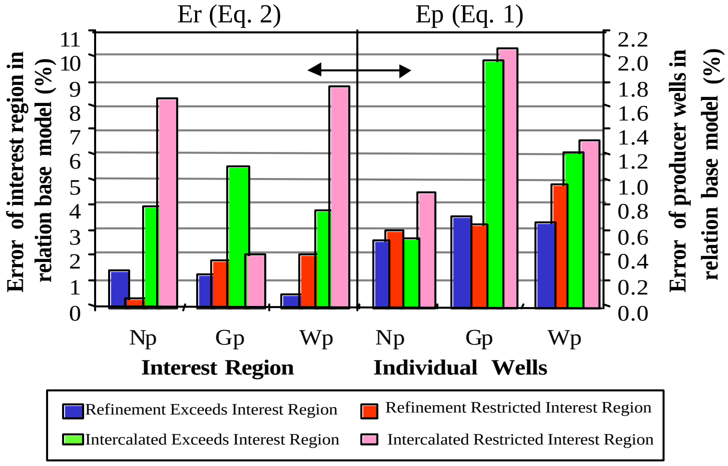
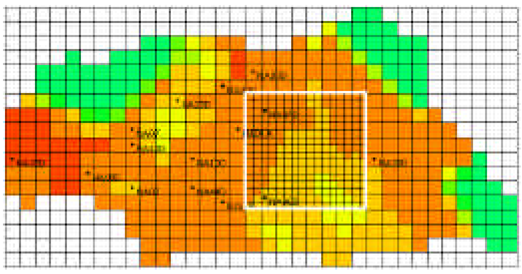


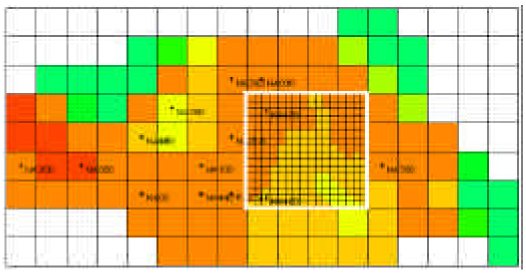
Figure 5: Errors in the cumulative productions in comparison with the base model, for each type of refinement.

3.2. Effect of Refinement

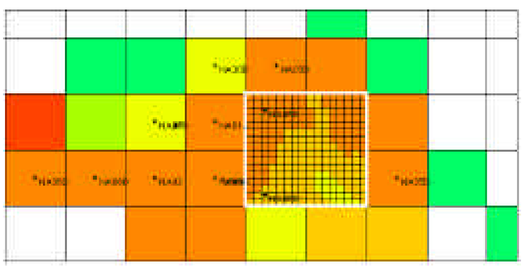
After definition of the type of refinement, some variations among blocks of the base model and blocks situated outside de region of interest were tested. Two situations were analyzed for each ratio between the size of the blocks: with refinement (for the region of interest the grid of the base model was kept) in the ratio 1:2 (Figure 6-a), 1:4 (Figure 6-b) and 1:8 (Figure 6-c), and without refinement in the ratio 1:2 (Figure 6-d), 1:4 (Figure 6-e) and 1:8 (Figure 6-f). The results of each one of these cases were compared with the solution of the base model.



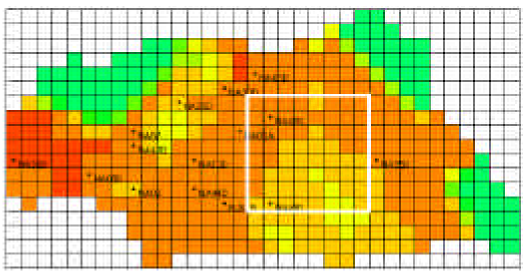
(a) Model with refinement - ratio 1:2.



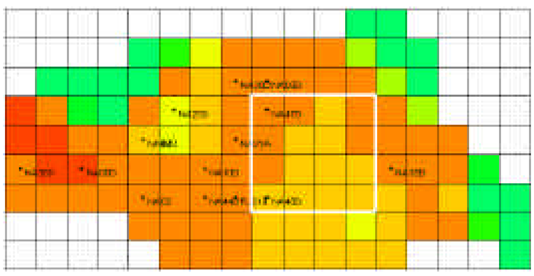
(b) Model with refinement - ratio 1:4.



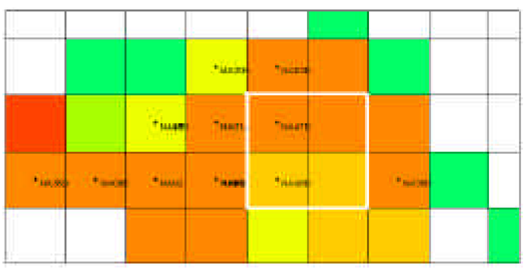
(c) Model with refinement - ratio 1:8.



(d) Model without refinement - ratio 1:2.



(e) Model without refinement - ratio 1:4.



(f) Model without refinement - ratio 1:8.

Figure 6: Different meshes for the evaluation of the effect of refinement.

Figure 7 shows the results obtained for the evaluation of the effect of refinement.

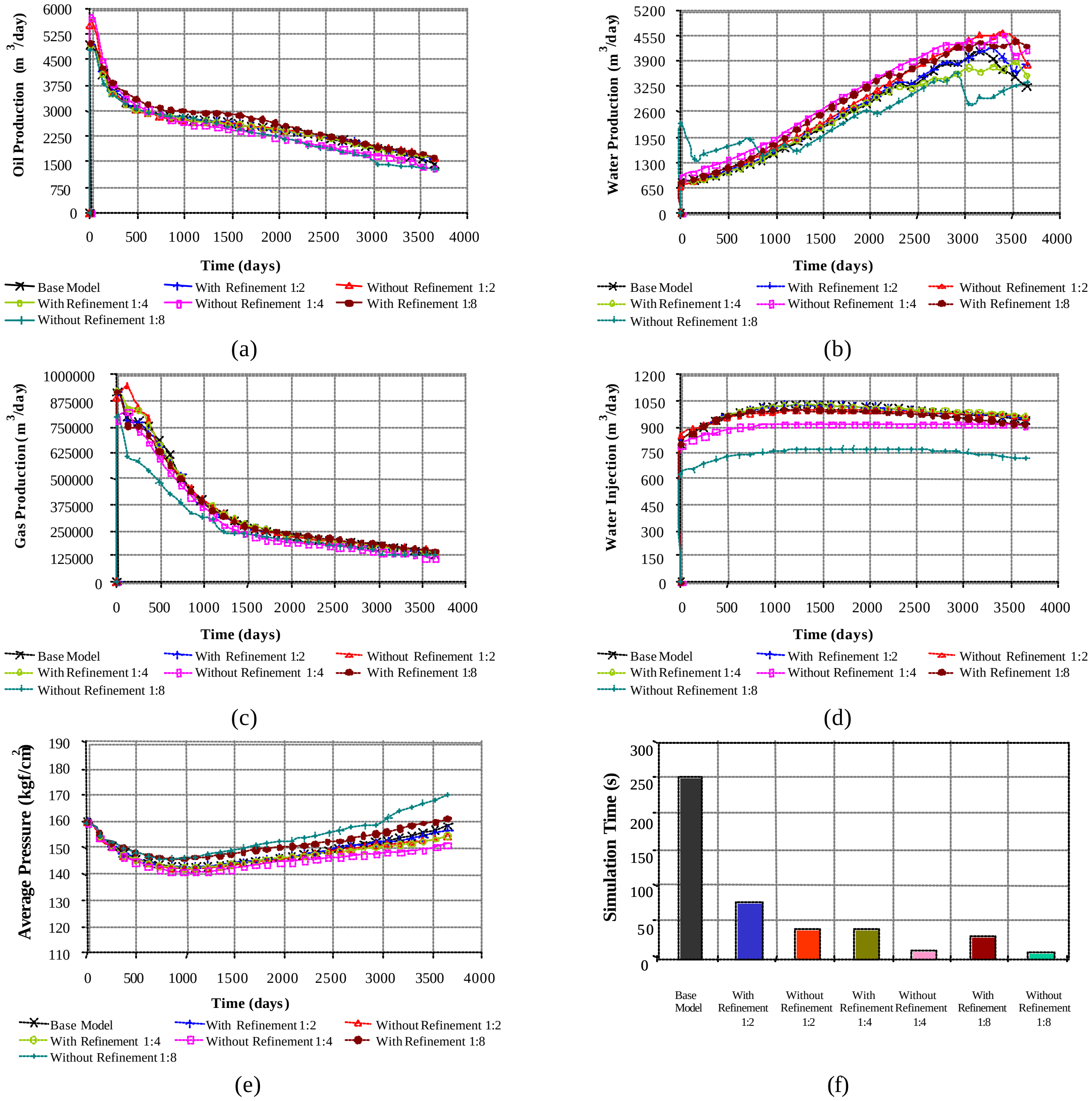


Figure 7: Oil Production (a), Water Production (b), Gas Production (c), Water Injection (d), Average Pressure (e) and Simulation Time (f) after ten years of forecast, for evaluation of the effect of refinement.

The table 2 shows the variations in accumulated productions, accumulated injection, pressure and simulation time.

Table 2: Variations between the tested models and the base model, for the effect of refinement.

Effect of Refinement	**Er** (Eq. 2)					**Ts** (Eq. 3)
	Accumulated Production			**Injection**	**Pressure**	**Simulation**
	Np (%)	**Gp (%)**	**Wp (%)**	**Wi (%)**	**(%)**	**Time (%)**
Model With Refinement – 1:2	0.65	0.63	2.32	0.01	0.78	31.70
Model With Refinement – 1:4	**0.28**	**1.74**	**2.02**	**0.50**	**2.37**	**15.61**
Model With Refinement – 1:8	6.38	0.82	12.17	2.22	1.95	12.11
Model Without Refinement – 1:2	0.84	3.18	9.90	0.81	2.17	15.70
Model Without Refinement – 1:4	4.60	9.54	16.97	7.89	3.99	3.80
Model Without Refinement – 1:8	7.49	19.18	6.22	23.94	7.49	1.70

It is possible to observe in Figure 8 that the models without refinement yield worse results in the production and the best results in relation to the simulation time. Since the errors were significant, it is possible to conclude that refinement is important in such case.

In the investigated case, the best ratio was 1:4 (intermediate refinement). In the ratio 1:8, some numerical errors occur due to the proximity of wells. The errors, for refinement 1:4 were small and simulation time was reduced in 84%.

In large oil fields, it is necessary to use a coarser grid to reduce the simulation time significantly. However if the number of wells is great and the distance between wells is small, the use of this technique can be limited.

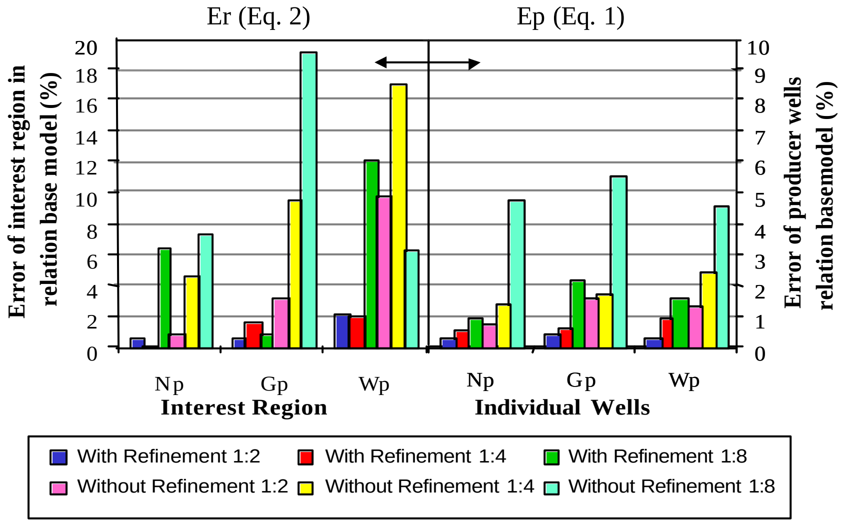


Figure 8: Errors in the cumulative productions for models with and without refinement in relation to the base model.

4. Conclusions

This work describes a methodology based on local refinement for the reduction of the simulation time, when the objective is to test strategies of oil recovery in specific regions of oil reservoirs, for example, in forecast of the behavior of mature reservoirs.

It could be shown that it is possible to speedup the simulation process up to 84% with the Local Refinement maintaining an adequate precision.

In the example tested here, the best strategy was to refine only the region of interest using an intermediate refinement, with ratio 1:4 (related to the hole reservoir). The results show that the local refinement method is viable, but if the proximity of wells increases, it can lead to improper solutions.

5. Acknowledgements

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6. References

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