ABSOLUTE PERMEABILITY UPSCALING NEAR WELLS IN FINE GRIDS REPRESENTING PETROLEUM RESERVOIRS

Eliana Luci Ligero
Departamento de Engenharia de Petróleo -Faculdade de Engenharia Mecânica – UNICAMP
Caixa Postal 6122 – Cep 13081-970
Campinas – SP – Brasil
eligero@dep.fem.unicamp.br

Bernabé Alfredo Sanjombi
Departamento de Engenharia de Petróleo -Faculdade de Engenharia Mecânica – UNICAMP
Caixa Postal 6122 – Cep 13081-970
Campinas – SP – Brasil
sanjombi@dep.fem.unicamp.br

Denis José Schiozer
Departamento de Engenharia de Petróleo -Faculdade de Engenharia Mecânica – UNICAMP
Caixa Postal 6122 – Cep 13081-970
Campinas – SP – Brasil
denis@cepetro.unicamp.br

Abstract. *Upscaling techniques are commonly used to adapt the fine grid properties to coarser grids with an adequate number of cells in order to be used in reservoir simulation. The property usually submitted to upscaling is absolute permeability. Although various upscaling techniques are available for absolute permeability, in practice, it is difficult to select the most adequate for each type of reservoir heterogeneity. In fact, there is no general rule that is applicable to all types of petroleum reservoirs. An important aspect to be considered in upscaling is the fine grid cells that contain wells. The usual techniques used to calculate equivalent permeability are appropriated only for cells far from the wells. The well grid cells require a special treatment during upscaling or reservoir simulation in order to take into account the radial flow pattern near wells. In this work, some fine grids with different heterogeneities are submitted to upscaling. These fine grids and their respective coarse grids are simulated and the results obtained by both grids are compared. The influence of special treatmens applied to well blocks in coarse grids is evaluated. It is possible to observe the great importance of the well block in Cumulative Oil and Water Production for producer wells, being very difficult to define a general rule that is suitable to all reservoir wells.*

Keywords*. Upscaling, Absolute Permeability, Near Well Upscaling, Well Treatment, Petroleum Reservoir Simulation*

1. Introduction

Advances in geostatistical techniques allow reservoir properties, such as absolute permeability, to be described by more and more fine models. However, these detailed reservoir models cannot be used directly for numerical simulation because they would require high amount of time and computational effort and also an elevate memory storage capacity. As consequence, it is necessary to coarsen detailed reservoir properties to a scale which is more appropriate for reservoir simulation. Since permeability is not an additive property, arithmetic mean is not the only possible way to calculate the equivalent permeability. In fact, there are other simple algebraic formulas, which can be used to obtain the equivalent permeability, such as harmonic, geometric and power law means. Another manner to calculate the equivalent permeability is through numerical methods, which require numerical simulation of partial differential equations.

A review of techniques to calculate the equivalent permeability is presented by Cruz (1991), Renard and Marsaly (1997) and Romeu *et al*. (1997). Although methods to upscale absolute permeability are well established, the changes of scale are inevitably associated to loss of information. It is practically impossible to obtain a complete equivalence between a real heterogeneous medium and the corresponding upscaled one. Galli *et al*. (1996), who studied quick upscaling techniques, observed that there are no universal rules that are valid for all types of petroleum reservoirs, being necessary to adapt the averaging rules to the configuration of the medium under study.

An important aspect to be considered in upscaling is the fine grid cells that contain wells. According to Ding (1995), these grid cells require special treatment during upscaling in order to take into account the flow pattern near wells. Two flow types should be considered in a petroleum reservoir, linear flow pattern in regions with low pressure gradient and radial flow near the wells with high pressure gradient. Therefore, the usual techniques used to calculate equivalent permeability are applicable only for the cells far from the wells. Near the wells, the equivalent permeability calculation requires special methods that consider the radial flow pattern. One of the objectives of this paper is to present a review about available near well upscaling techniques.

Previous studies carried out by Ligero *et al*. (2001), Ligero *et al*. (2002) and Ligero and Schiozer (2003) have shown the importance of absolute permeability in well blocks and the necessity of special treatments to coarse blocks containing well in the reservoir simulation. Unlikely previous works, in this paper only one permeability upscaling technique is used to obtain the equivalent permeability for coarse grids. The main goals are to study the permeability upscaling near wells and to propose modifications in simulation models of coarse grids in order to approximate as much as possible the fine and coarse reservoir simulation results.

2. Literature review

2.1. Upscaling near well

Upscaling techniques that have been developed for entire reservoir may be not adequate when used in the vicinity of well blocks. These techniques may fail because they assume uniform pressure gradients near wells, however pressure gradients near wells are not uniform.

A manner to calculate equivalent permeability in blocks with wells is to consider radial flow in series through the layers that wells are completed. The equation to calculate this permeability considering two zones in series is presented by Craft and Hawkins (1959). However, this equation may be extended to include three or more layers in series.

The necessity for a special upscaling technique in the proximity of wells where radial flow pattern should be taken into account was considered by Ding (1995), which proposed a new upscaling procedure. The proposed method determines the transmissibilities in the vicinity of wells and the numerical productivity index simultaneously by introducing a radial flow conditional. Ding (1996) shows the importance of representing three-dimensional pressure distribution of the flow in the vicinity of wells. This pressure distribution was used to propose a general three-dimensional well model, which calculates the numerical productivity index at the well block and also the equivalent transmissibility near the well. The off-diagonal elements in the permeability tensor were not considered by Ding (1996). However, Ding e Urgelli (1997) implemented the previous Ding's work and generalized the approach for a full permeability tensor.

An inconvenience of Ding's approach is the necessity to calculate the equivalent permeability based on the results of fine grid numerical simulation. Nevertheless, repeated numerical simulations for all coarse grid blocks may require high computational time. Soeriawinata *et al*. (1996), in order to avoid lengthy numerical simulations, developed an analytical technique that considers radial flow geometry near the well to upscale well block effective permeability. The method is based on the concept of incomplete-layers using serial and parallel averaging procedures modified for radial flow.

Durlofsky *et al*. (2000) proposed a general method to calculate coarse scale well block transmissibilities and well indexes for vertical wells in two and three dimensions. The approach represents an extension of the technique developed by Ding (1995). Unlikely Ding's method, where a fine grid problem is solved, this methodology is based on the identification and solution of specific local problems that are possible to capture the characteristics of the flow field. Numerical results for various bi and three-dimensional problems have shown to provide accurate coarse grid results.

2.2. Well treatments

It is a well-known fact that there is no equivalence between the well block and bottom hole pressure, because in most cases the grid block dimensions are greater than wellbore radius. The flow rate in a well is proportional to the difference between block and well pressure (Peaceman, 1978; 1983).

Some nomenclatures used in well treatments are well defined by Palagi (1992): (1) the proportionality coefficient is the well productivity or injectivity according to the type of well; (2) the well index is the part of the proportionality coefficient that takes into account the geometry factor of the well and (3) a well model is known as the model used to determine the well index.

The well model proposed by Peaceman (1983), which is applicable to wells in non-square grid blocks and anisotropic permeability has become, according to Wolfstainer *et al*. (2001), the default procedure in virtually all commercial simulators. Consequently, the well index or productivity parameters can be treated to approximate the coarse grid simulation results to those obtained for the fine grid.

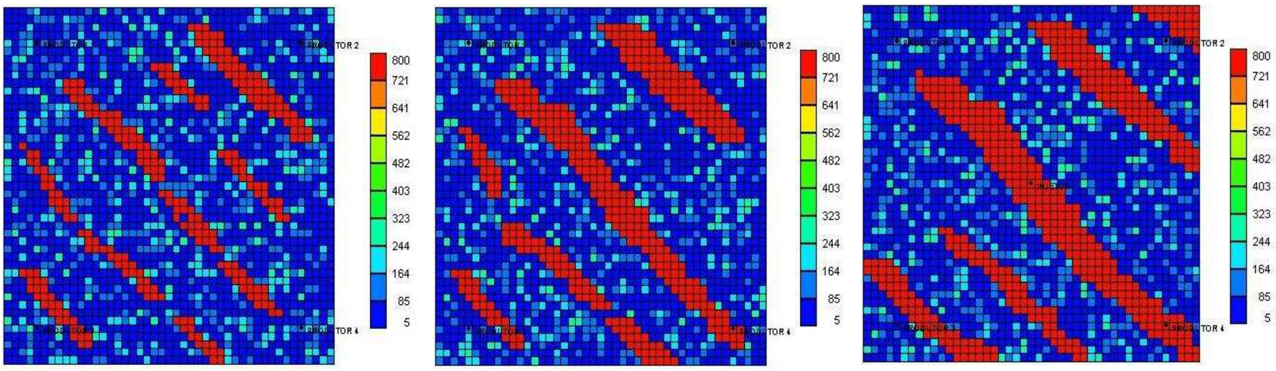
Considering the aim of representing a well in a correct way, it is relevant to consider complex trajectories, near-well gridding and upscalling, coupling with wellbore effects. Although well productivity may be significantly influenced by wellbore hydraulics, well performance is often dominated by near well heterogeneities (Ding, 1995; Wolfsteiner *et al*, 2000). Therefore, it has arisen the problem of upscaling near well, which is one of the objectives of this paper.

3. Application

In this work, fine grids with 45x45x3 cells are submitted to upscaling in order to generate coarse grids with 5x5x3 cells. Three different absolute permeability distributions of fine grids are considered: (1) Homogenous permeability in each layer (permeability values are equal to 100 mD, 200 mD and 300 mD in layers 1 to 3 respectively), (2) Presence of channels that facilitate the fluid flow in reservoir, Figure 1 and (3) Presence of barriers which make difficult the fluid flow in reservoir, Figure 2. In all fine grids, permeability in x and y directions are considered equal, and in z direction the absolute permeability is admitted as 30% of permeability values in x and y directions.

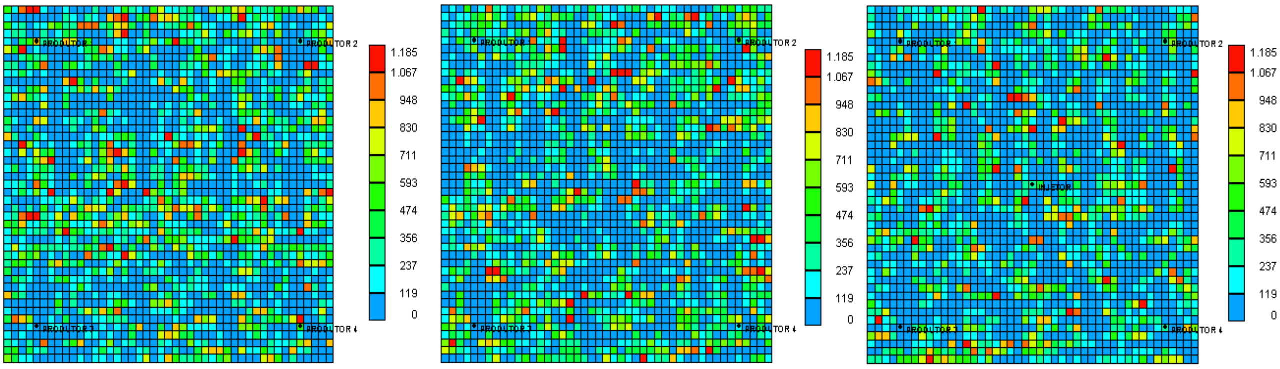
3.1. Upscaling techniques

Unlikely previous studies carried out in bi and three-dimensional fine grids (Ligero *et al*., 2001; Ligero *et al*., 2002 and Ligero and Schiozer, 2003), where various upscaling techniques were used to obtain the coarse grids, in this work only an unique upscaling technique is employed to generate the coarse grids. The used upscaling technique is a numerical method. According Renard e Marshaly (1997), in upscaling problems it is preferable to use a numerical method whenever possible. An important reason to use a fixed upscaling technique is to emphasize the study of the influence of well treatments in production parameters. Another difference related to previous works is the consideration of radial flux near well. The equivalent permeability of a block with well is calculated considering zones in series as presented by Craft and Hawkins (1959).



(a) (b) (c)

Figure 1. Fine grid with channels - Permeability distribution in x direction for: (a) Layer 1, (b) Layer 2 and (c) Layer 3.



(a) (b) (c)

Figure 2. Fine grid with barriers - Permeability distribution in x direction for: (a) Layer 1, (b) Layer 2 and (c) Layer 3.

3.2. Reservoir simulation and well treatments

The well treatment is intimately related to the numerical reservoir simulation. In this work, the reservoir simulations are executed through a *Black-Oil* commercial simulator. The production strategy adopted for the three fine permeability grids are the same: one injector well, operating at constant water rate injection, located on the center of the grid and four production wells operating at constant pressure and located on the corners of the grid, Figures (1) and (2). The production parameters used to compare a fine grid simulation results to those obtained from coarse grids are Cumulative Oil and Cumulative Water Production.

In addition to the simulation of the coarse grid without special treatment to the wells (Coarse Grid) and the equivalent permeability calculated considering radial flux near well (Coarse Grid – Rad), five well treatments are considered: (1) Use of coarse grid substituting equivalent permeability of well block for the permeability of well block in the fine grid (Coarse Grid – Kf), (2) Use of the coarse grid with refining of coarse blocks where wells are located (Coarse Grid – Ref), (3) Well indexes in coarse grid are equal to well indexes in fine grid (Coarse Grid – WI), (4) Equality of well indexes combined to permeabilities of well coarse blocks substituted by the values of permeabilities of well fine blocks (Coarse Grid – Kf – WI) and (5) Near well equivalent permeability obtained considering radial flux combined with equality of well indexes (Coarse Grid – Rad – WI).

4. Results

4.1. Homogenous permeability

Figure 3 shows the reservoir cumulative oil and water production. It is possible to observe that the cumulative water production of the coarse grid is practically coincident to the curve obtained for the fine grid. However, for the cumulative oil production there is a difference between the fine and coarse curves almost during all the time of simulation. This fact illustrates that simple procedure of upscaling, maintaining the values of equivalent permeability equal to those of the fine grid, is responsible for a discrepancy between the cumulative oil production for the fine and coarse grids. The cumulative oil and water production for producer wells present similar behavior to that ones obtained for the reservoir as indicated in Figure 3.

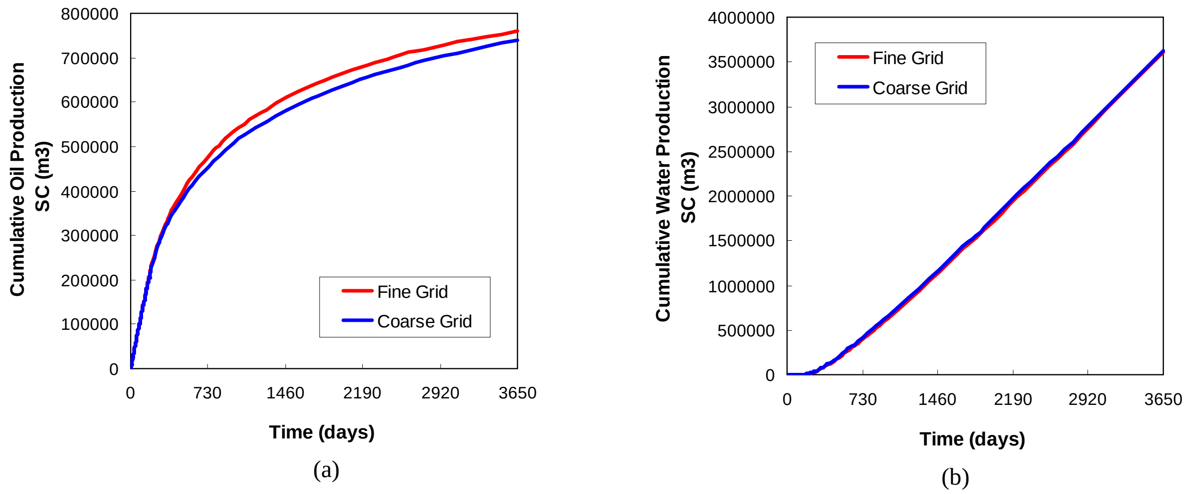


Figure 3. Homogenous permeability – (a) Reservoir cumulative oil production
(b) Reservoir cumulative water production.

4.2. Presence of channels

For the reservoir with preferential channels to flow, cumulative oil and water production are shown in Figure 4. It is possible to observe that the curves obtained with coarse grids are practically coincident, independently of the well treatment adopted. This behavior induces to one conclude that it is not necessary a well treatment to approximate the coarse grid curves to that obtained with a fine grid. However, considering cumulative oil and water curves for producer wells, Figure 5, it is possible to observe that the coarse curves obtained through upscaling considering radial flow and with well treatments are not coincident and have different positions related to fine curve. This fact illustrates the importance of special treatment of well blocks in upscaling problems.

Figure 5 shows that for each producer well, there is not a common treatment that is adequate for all producers contained in coarse reservoir models. The well treatment softens the difference between oil and water cumulative production for both reservoir and producer wells, but it is not sufficient to reduce the discrepancy between such curves. The most adequate well treatment for a particular producer well is associated to the fluid flow path between injector and producer wells. The influence of the path can also be observed for all producer wells in simulation results of the coarse grid without well treatment (Coarse Grid), which is the most distant curve from the fine grid curve.

Therefore, Figures 4 and 5 evidence the importance of well blocks in simulation results when a coarse grid is used and the difficulty of obtaining a general rule to define the well treatment to be employed.

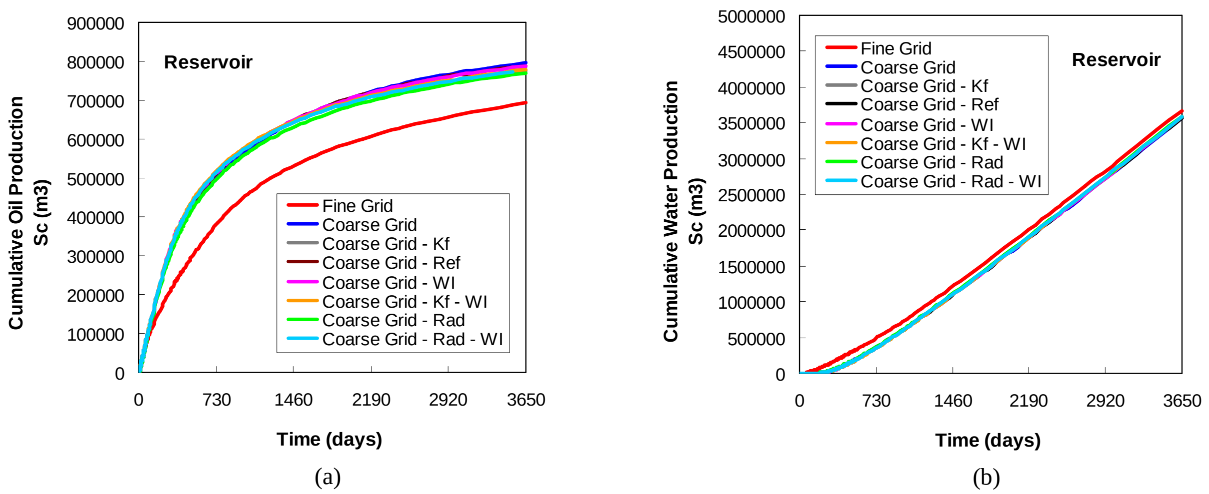


Figure 4. Presence of channels – (a) Reservoir cumulative oil production
(b) Reservoir cumulative water production.

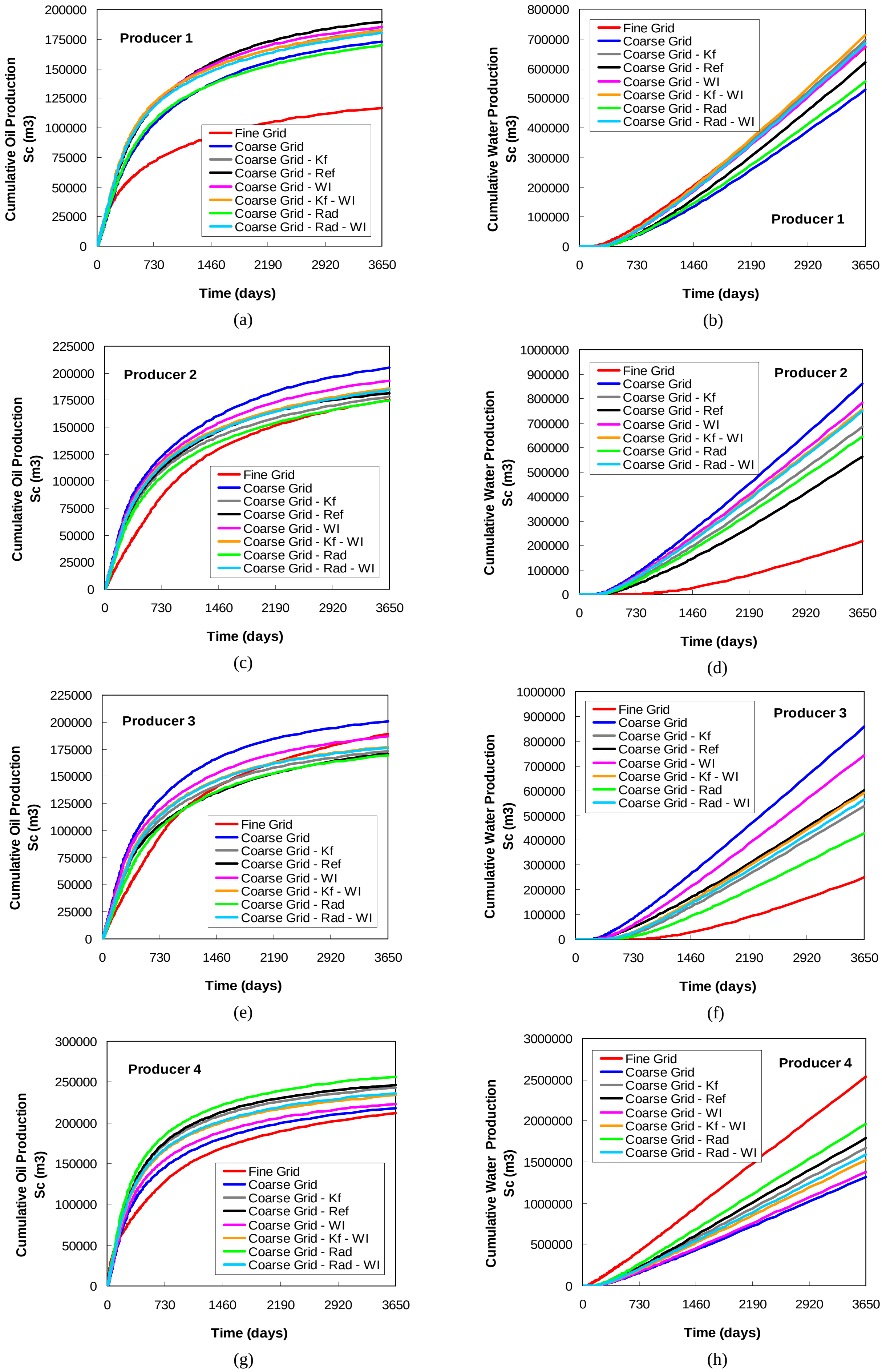
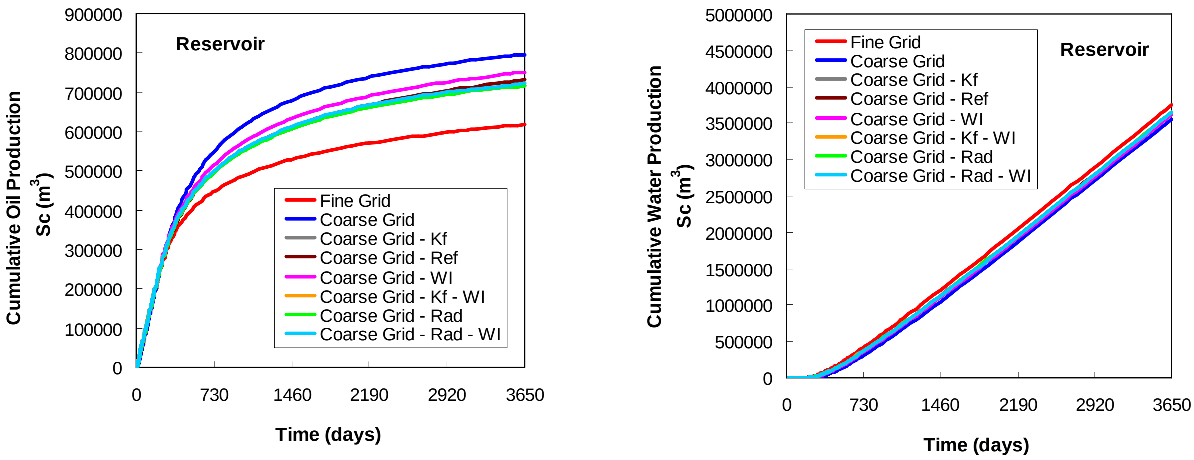


Figure 5. Presence of channels – Producer wells - Cumulative oil and Cumulative water production.

4.3. Presence of barriers

For the reservoir with barriers, cumulative oil and water production are shown in Figure 6. The coarse curves for oil production are almost coincident, the only exception is the curve for coarse grid without well treatment, which represents the worst behavior compared to the fine grid. The fine and coarse curves for water production are practically coincident. Just as observed in the case with channels, the analysis of reservoir production by itself should conduce to a wrong conclusion that the well treatment is not important in upscaled grids submitted to flow simulation.

Figure 7 shows cumulative oil and water production for producer wells in the reservoir. Also, it is possible to observe that there is not a general rule to choose the best well treatment that can adequate for all producer wells in a reservoir. Special attention must be given to Producer 3 since this well is the only one that is located in a low permeability region in all layers. The curves of cumulative oil and water production are shown in Figure 3(e) and (f), respectively. For both graphics the results obtained for the coarse grid without well treatment (Coarse Grid) are not able to represent properly the fine grid curves. For water production the equality of well index (Coarse Grid – WI) is not also an adequate well treatment for the coarse grid.



(a) (b)

Figure 6. Presence of barriers – (a) Reservoir cumulative oil production
(b) Reservoir cumulative water production

5. Conclusions

In this work, the importance of well blocks of coarse grids in reservoir simulation results was studied. Either the equivalent permeability of well blocks in a coarse grid should be calculated considering radial flow near well or the coarse blocks with wells should receive special treatment in the simulation model. Some well treatments to coarse well blocks were proposed in order to approximate as much as possible the coarse and fine curves for oil and water cumulative production.

It was observed through comparison between fine and coarse grid simulations that results based only in reservoir production parameters could lead one to mistakenly conclude that special treatments are not necessary to obtain a good agreement of such grids. However, the oil and water cumulative production of producer wells clearly show the importance of well treatment in the simulation of a coarse grid obtained through upscaling.

It was possible to conclude that the most adequate well treatment for a particular producer well is associated to the way the fluids flow between injector and producer wells. Furthermore, it is possible to observe that there is not a general rule to choose a treatment that can be adequate for all producer wells in a reservoir.

6. Acknowledgements

The authors wish to thank Petrobras and FINEP (CTPETRO) for financial support.

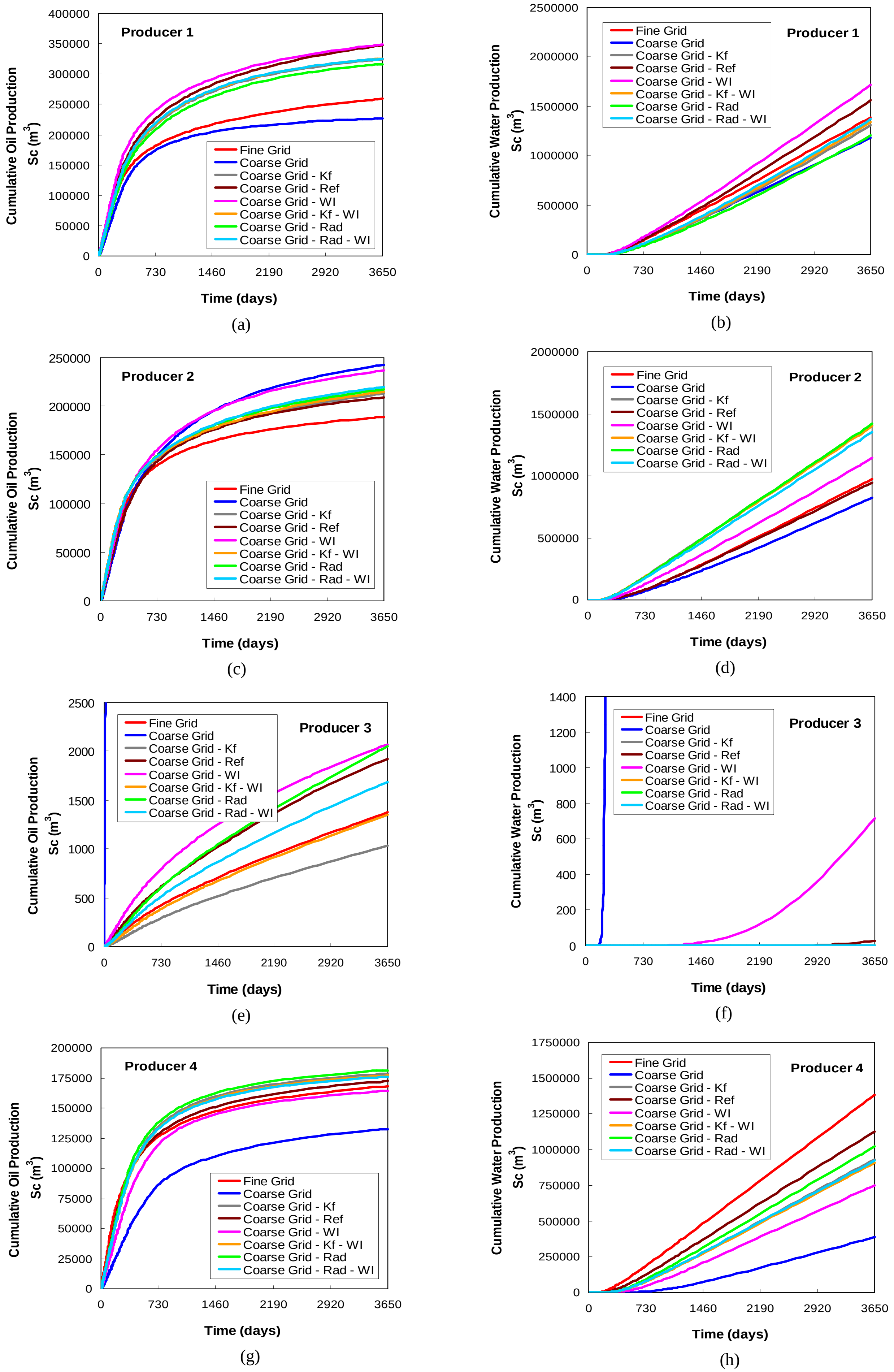


Figure 7. Presence of barriers – Producer wells - Cumulative oil and Cumulative water production.

5. References

Craft, B.C., Hawkins, M.F., 1959, “Applied Petroleum Reservoir Engineering”, Prentice-Hall Inc., England Cliffs, New Jersey, pp. 293-295.

Cruz, P.S., 1991, “Análise Crítica dos Métodos de Mudança de Escala Associados à Simulação Numérica de Reservatórios", Master Thesis, Unicamp, Campinas.

Ding, Y., Urgelli, D., 1997, “Upscaling of Transmissibility for Field Scale Flow Simulation in Heterogeneous Media”, SPE 38016, 14th SPE Symposion on Reservoir Simulation, June, Dallas, Texas, USA, pp. 311-312.

Ding, Y., 1996, “A Generalized 3D Well Model for Reservoirt Simulation”, SPE 30724, SPE Journal, December, pp. 437-450.

Ding, Y., 1995, “Scaling-up in the Vinicity of Wells in Heterogeneous Field”, SPE 29137, 13th SPE Symposiun on Reservoir Simulation, February, San Antonio, Texas, USA, pp. 441-451.

Duslofsky, L.J., Milliken, W.J. and Bernath, A., 2000, “Scaleup in the Near-Well Region”, SPE Journal, Vol.5, No. 1, March.

Galli, A., Globet, P., Griffin, D., Ledoux, E., Le Loc’h, G., Mackay, R. and Renard, P., 1996, “Quick Upscaling of Flow and Transport Related Parameters”, May, Technical Report.

Ligero, E.L., D.J. Schiozer, 2003, “Efecto de la Transferencia de Escala de la Permeabilidad Absoluta en la Simulación Numérica de Yacimentos”, Informatión Tecnológica, Vol. 14, No. 2, March-April.

Ligero, E.L., Maschio, C. and Schiozer, D.J., 2002, "Transferência de Escala Associada à Simulação de Fluxo: Tratamento Especial dos Poços em Malhas Bi e Tridimensionais", 9th Brazilian Congress of Thermal Engineering and Sciences, October, Caxambú, Minas Gerais, Brazil.

Ligero, E.L., Schiozer, D.J. and Romeu, R.K., 2001, "Aplicação da Transferência de Escala na Caracterização de Reservatórios - Influência da Permeabilidade Absoluta Equivalente na Simulação Numérica de Escoamento", 16th Brazilian Congress of Mechanical Engineering, November, Uberlândia, Minas Gerais, Brazil.

Palagi, C.L., 1992, “Generation and Application of Voronoi Grid to Model Flow in Heterogeneous Reservoirs”, Ph.D. Thesis, Stanford University, California.

Peaceman, D.W., 1983, “Interpretation of Well-block Pressures in Numerical Reservoir Simulation with Nonsquare Grid Blocks and Anisotropic Permeability”, SPE Journal, June, pp 531-543.

Peaceman, D.W., 1978, “Interpretation of Well-block Pressures in Numerical Reservoir Simulation”, SPE Journal, June, pp. 183-194.

Renard, Ph., Marsily, G., 1997, “Calculating Equivalent Permeability: A Review”, Advances in Water Resource,Vol.20, Nos 5-6, 253-278.

Romeu, R.K *et al*., 1997, “Cálculo de Propriedades Equivalentes para Transferência de Escala (Programa UPA)”, Technical Report, Petrobras, Rio de Janeiro, Brazil.

Soeriawinata, J., Kasap, E. and Kelkar, M., 1996, “Permeability Upscaling for Near-Wellbore Heterogeneities”, SPE 36516, SPE Annual Technical Conference and Exhibition, October, Denver, Colorado, USA, pp. 283-294.

Wolfsteiner, C., Aziz, K. and Durlofsky, L.J., 2001, “Modeling Conventional and Non-Conventional Wells”, Sixth International Forum on Reservoir Simulation, September, Hof/Salzburg, Austria.

Wolfsteiner, C., Durlofsky, L.J., and Aziz, K., 2000, “Approximate Model for Productivity of Nonconventional Wells in Heterogeneous Reservoirs”, SPE Journal, Vol. 5, No. 2, June, pp. 218-226.