COMPARISON OF DISCRETIZATION METHODS FOR MODELLING NEAR-WELL PHENOMENA IN THERMAL PROCESSES

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HEAVY OIL

Comparison of discretization methods for modelling near-well phenomena in thermal processes

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ABSTRACT

The treatment of near-wellbore flow phenomena has a strong influence on reservoir simulation results for thermal processes. Using large well gridblocks can result in high predicted injection pressures, and inaccurate predictions of override and coning behaviours.

Several new discretization methods have been proposed to efficiently provide more accurate modelling of the near-wellbore region. These methods, Cartesian hybrid grids, control-volume finite-element (CVFE) grids, and CVFE hybrid grids, have been implemented in a general purpose thermal reservoir simulator. In this paper, they are compared for the modelling of three thermal processes: single well cyclic steam stimulation, multi-well cyclic steam stimulation, and steam drive.

Results show that Cartesian hybrid grids and CVFE hybrid grids provide an efficient means of accurately modelling near-well phenomena. In multi-well cyclic steam stimulation processes, the hybrid grids allow the use of cylindrical grids to accurately and efficiently model the near-wellbore region, while including the influence of adjacent wells with offset steaming. For steam drive processes, the hybrid grids predict earlier steam override and breakthrough times than a standard Cartesian or CVFE grid. The CVFE hybrid grid has the advantages of providing more geometric flexibility and a more consistent discretization at the boundary between the CVFE and cylindrical grid than the Cartesian hybrid grid.

Introduction

The treatment of near-wellbore flow phenomena has a strong influence on reservoir simulation results. In the current practice for field-scale simulation with communicating wells, a coarse Cartesian grid system is used to represent the reservoir, and wells are represented as sources or sinks within the coarse gridblock. This representation of wells is usually not adequate, especially in thermal processes. For example, the ability to inject steam depends on the viscosity reduction of oil or bitumen by heat conduction and convection in the vicinity of the wellbore. Thus, because the well is located within a coarse gridblock, an artificially high well injectivity has to be used to allow steam injection. Similarly, for producers, the coning behaviour is not properly handled in coarse gridblocks and empirical pseudo-functions, which are not always accurate, are normally used. For horizontal wells, the near-well phenomena have even a stronger effect on the simulation results because of the longer completion lengths.

Accurate simulation of a field-scale thermal project with a Cartesian grid would be extremely costly due to the large number of gridblocks required to accurately model the phenomena occurring in the field. Small gridblocks are required near the well to model the rapidly changing properties (temperature, pressure, viscosity, saturation, etc.) in this region. To reduce the over-all cost of the simulation, gridblocks with larger volumes may be used away from the wells where changes occur less rapidly and have less impact on simulation results. Typical methods used to vary the volumes of Cartesian gridblocks result in large aspect ratios for many gridblocks, which can lead to further discretization errors.

For an accurate simulation of near-well phenomena, the best grid system is the cylindrical grid system because it follows the potential and stream lines near the well. This grid system has been extensively used in single-well coning studies and single-well cyclic steam stimulation. However, it does not allow the simulation of a field with more than one well. To incorporate accurate modelling of near-well phenomena in field-scale simulation, Pedrosa and Aziz[1] suggested the use of cylindrical grids within Cartesian grids. In their approach, coarse Cartesian gridblocks that contain wells are refined using cylindrical grids. The system of coarse Cartesian grids with fine cylindrical grids is called a hybrid grid system. Pedrosa and Aziz applied their techniques to black-oil systems only.

The hybrid grid system described in Pedrosa and Aziz requires the well to be at the centre of the coarse Cartesian gridblock, which is quite a severe limitation for field-scale simulation. Although Pedrosa[2] reported in his Ph.D. thesis how his techniques may be modified to handle off-centred wells, no results nor validations were given. The complexity of the discretization in a hybrid grid system occurs at the interface between the coarse and fine grids. At the interface the flow is linear in the coarse Cartesian grid and radial in the fine cylindrical grid. The discretization proposed by Pedrosa yields large errors when the well is displaced from the centre of the gridblock. A control-volume finite-element (CVFE) hybrid grid is proposed in this work as a method of overcoming the problems with the Cartesian hybrid grid.

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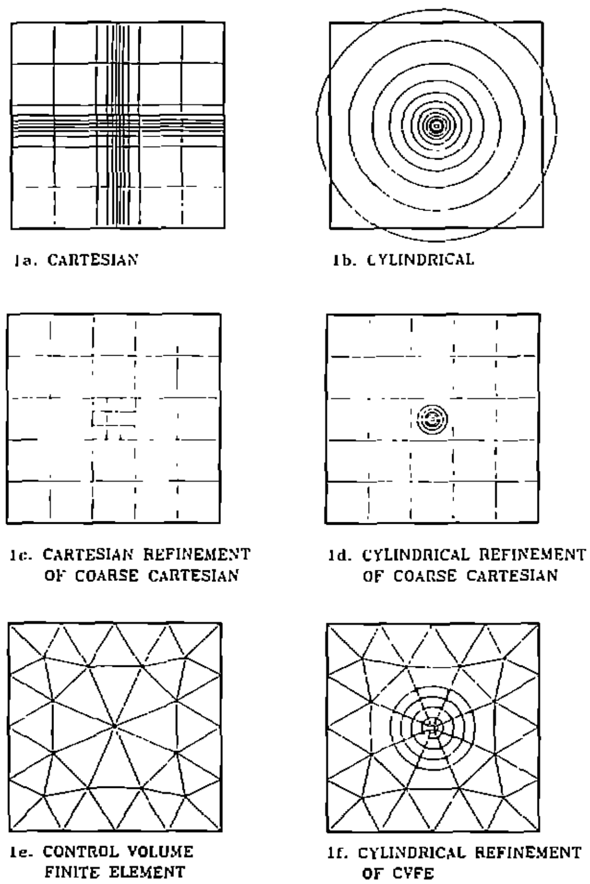

FIGURE 1. Schematic of different grids used for Case 1.

Near-well Grid Refinement

Figure 1 shows a schematic drawing of each of the discretization methods described in this section. Cylindrical grids have been in common use for many years. They are normally used for modelling a single well with a large drainage radius, and can also be adapted for use in the modelling of symmetry areas in various types of pattern floods. Cylindrical grids have small gridblock volumes near the well and large gridblock volumes away from the well. The usual practice is to increase the outer radius of the successive radial gridblocks by a constant ratio. This is known as a constant geometric or logarithmic increase.

If a single well is being studied and the flow pattern is radially symmetric, a cylindrical grid can accurately model the near-well phenomena with a minimum number of gridblocks. Thus, cylindrical grids are normally used in the study of radially symmetric problems, including many single-well cyclic steam stimulations. However, a cylindrical grid is not appropriate for modelling a multi-well field once wells start to influence each other, or if there are no circular or square areas of symmetry. Thus, while a cylindrical grid accurately models the near-well radial flow, it cannot be used for the modelling of most field-scale multi-well thermal projects.

The use of a coarse Cartesian grid with Cartesian refinement near wells has been suggested as a means of obtaining small gridblocks near the wells and larger gridblocks away from the wells. In this method, a coarse Cartesian grid is first defined. Each coarse block containing a well is then further refined with a Cartesian grid[3]. This Cartesian refined grid has two disadvantages. First, the standard finite difference discretization on a Cartesian grid will not be particularly accurate for radial flow which occurs near the well. Secondly, in the absence of a pressure interpolation scheme at the boundaries between the coarse and fine grids, large errors can occur in estimating the flow across these boundaries. Cartesian refinement was not further investigated in this work.

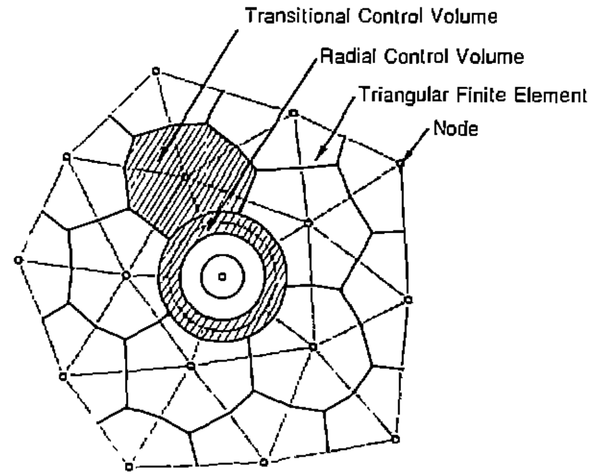

FIGURE 2. Control-volume finite-element hybrid grid.

Cylindrical Refinement of Cartesian Grid

An alternative method of refining a coarse Cartesian grid is to use a cylindrical refined grid near the well. This method, called the Cartesian hybrid grid method, can accurately model a radial flow pattern near the well while allowing large Cartesian gridblocks away from the well. This type of refinement has been previously applied to black-oil simulation[1,4], but to date no application to thermal simulation has been reported.

Control-Volume Finite-Element Method (CVFE)

The grids described above use finite-difference discretization techniques. Control-volume finite-element (CVFE) discretization, which allows more flexibility in the location of gridnodes and the sizes of block volumes, is an alternative to finite-difference discretization. Gridnodes can be concentrated near the wells, resulting in gridblock volumes being smaller in this region. Arranging a large number of gridnodes around the wells allows a more accurate modelling of the radial flow occurring in this region than the finite-difference method on a square grid would allow. A properly constructed CVFE grid will minimize grid orientation at less computational cost than a nine-point finite-difference discretization method[5].

Cylindrical Refinement of CVFE

A method of coupling a CVFE grid with a cylindrical grid around the well has been developed as part of this project. The approach offers a high degree of geometric flexibility. Large cylindrical regions can be prescribed arbitrarily without being constrained by the dimensions of the Cartesian grid. The remainder of the reservoir is filled with finite elements as shown in Figure 2. Because of the geometric flexibility of CVFE, it can accommodate arbitrary well locations in a reservoir. The cylindrical grid refinement of Cartesian grids requires the well to be at the centre of the gridblock which is not always possible.

This method of grid refinement has also better accuracy than the cylindrical refinement of Cartesian grid. By placing CVFE nodes around the well as shown in Figure 2, the transition between flow in the fine grid (which is radial) and flow in the coarse grid is smooth. The CVFE node locations in Figure 2 show that the radial flow aspect is also modelled in the coarse CVFE grid. This is not the case for Cartesian grid where the radial flow aspect is distorted. One manifestation of this distortion is the grid orientation effect exhibited by Cartesian grids[6]. CVFE also allows the placement of as many nodes as necessary around the fine cylindrical grid to obtain the desired accuracy. The grid is referred to as the CVFE hybrid grid.

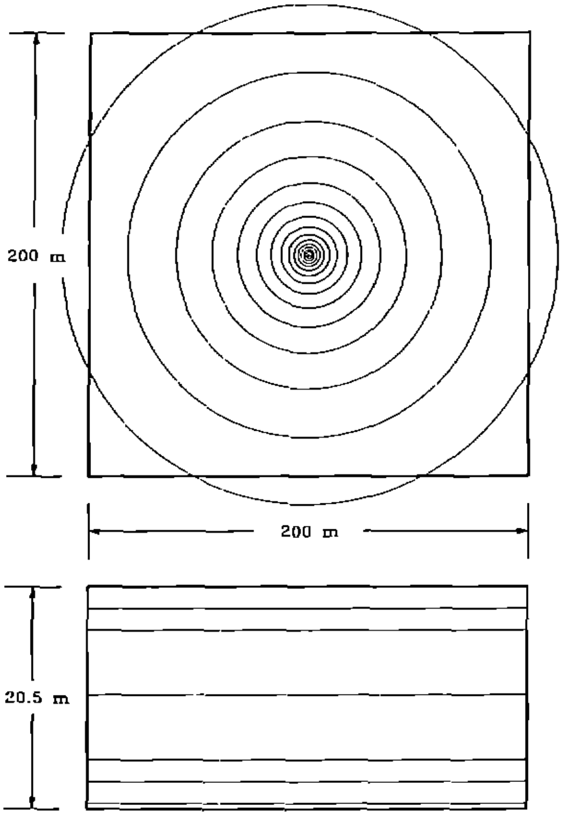

FIGURE 3. Geometry and cylindrical grid for Case 1. A single well on a 4 ha spacing. The bottom layer (0.5 m) is initially water.

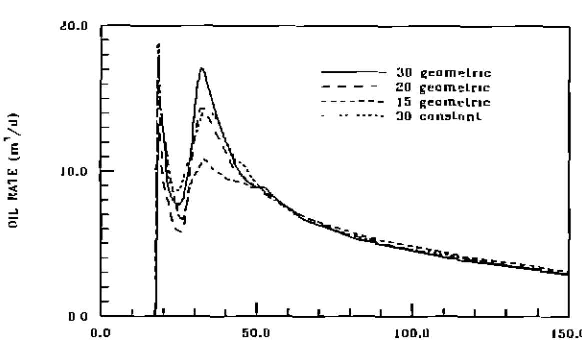

FIGURE 4. Case 1 — comparison of oil rate for four cylindrical grids.

Case 1 — Cyclic Steam Stimulation of a Single Well

Process Description

Case 1 corresponds to the simulation of a single cyclic steam stimulation well. While a single well does not constitute a "field-scale" process, Case 1 will help to establish an understanding of how the various grid types can be used to accurately model near-well phenomena. In large cyclic steam stimulation projects, wells can have a large influence on each other due to offset steaming and production[7]. In modelling such a project, the discretization method chosen must both be able to accurately model the near-well phenomena as well as the pressure influence and the flow between wells. This first case looks at discretization methods suitable for modelling near-well phenomena.

The geometry chosen for Case 1 is that of a single well on 4 ha (10-acre) spacing (Fig. 3). The simulated area is areally a square with 200 m (656 feet) on a side. The reservoir consists of a 20 m (65 feet) oil zone over a 0.5 m (1.5 feet) bottom water zone. The oil viscosity and the relative permeability curves are similar to those of the Aberfeldy heavy oil field[6]. The reservoir has a uniform horizontal permeability of 2 Darcys and a vertical permeability of 1 Darcy.

The steam injection phase consists of 1000 m^3 (6290 bbl) cold water equivalent of steam injected at a constant rate of 100 m^3/d (629 bbl/d) with a maximum bottom hole pressure of 5171 kPa (750 psia) for 10 days. The injection phase is followed by a seven-day soak period. The production period lasts for 133 days, during which the well is operated on a maximum rate constraint of 79.5 m^3/d (500 bbl/d) and a minimum bottom hole pressure constraint of 117 kPa (17 psia). The well, used for both injection and production, is perforated in the oil zone but not in the water zone.

Grid Sensitivity Study Using a Cylindrical Grid

A cylindrical grid was used to perform a grid sensitivity study for Case 1. The square areal outer no-flow boundary was modelled as a circle of equal area. Runs were done using 3, 5, 6, and 10 layers to model the oil zone plus an additional layer to model the bottom water zone. While the results of the runs with 6 and 10 layers were similar, runs with fewer than 6 layers had considerably different oil rates. From this study it was determined that six layers were required to accurately model the oil zone, with layer thicknesses of 2 m, 2 m, 6 m, 6 m, 2 m and 2 m proceeding from top to bottom. The bottom water zone was modelled with a single layer of 0.5 m. All of the following runs were done using this seven-layer model.

A second sensitivity study was performed to determine the number and size of gridblocks in the radial direction required for an accurate simulation. From this study it was determined that a fairly large number of small blocks were needed near the well to accurately model the oil rate. One of the geometries used, that of twenty radial blocks with the outer block radii increasing geometrically, is shown in Figure 3. A comparison of the oil rates versus time for four of the cylindrical grids is shown in Figure 4. The "geometric" runs correspond to cases where the outer gridblock radii satisfy $r_{i+1}/r_i = \text{constant}$. The "constant" run has $r_{i+1} - r_i = \text{constant}$ for the first 20 inner gridblocks following by larger outer gridblocks. On the basis of cost and accuracy, the run using a cylindrical grid with 20 geometrically increasing radial gridblocks and seven vertical layers was chosen as the base case with which to compare runs using other discretization methods.

Fine-grid Runs

For a radially symmetric problem, such as Case 1, a cylindrical grid is required for the minimum number of gridblocks. However, for a multi-well problem with offset injection and production and inter-well communication, a cylindrical grid cannot be used to model the entire field. Thus, it is of interest to see if the other discretization methods can reproduce the results of the cylindrical fine-grid simulation.

Several different Cartesian grids were used in attempting to reproduce the results of the cylindrical fine-grid simulation. By using a large number of small gridblocks, the Cartesian grid could adequately reproduce the cylindrical fine-grid results (Figs. 5 and 6), although the predicted oil production for the first cycle was 13% below that predicted by the cylindrical-grid simulation. The fine Cartesian grid was constructed by first dividing each of the two horizontal directions into five gridblocks. The middle row and column are then subdivided into 23 rows and columns (Fig. 1a). A total of 729 gridblocks per layer were required. Thus, the Cartesian grid clearly requires too many gridblocks to be of use in the accurate modelling of near-well phenomena in a field-scale simulation.

Similarly, a CVFE grid with enough gridblocks was able to give a good match of the cylindrical grid predictions. However, the num-

TABLE 1. Cumulative injection and production for the various grids used in Case 1

Grids	Injection	Production		Blocks per
	Water (m^3)	Oil (m^3)	Water (m^3)	Layer
Cylindrical				
30 Radial (geometric)	997.8	789.3	2849.0	30
30 Radial (constant)	998.4	804.9	2913.2	30
20 Radial (geometric)	999.4	764.7	2801.4	20
15 Radial	999.8	777.3	2740.4	15
Fine Grid				
20 Radial (geometric)	999.4	764.7	2801.4	20
Cartesian	999.7	665.2	2866.8	729
Cartesian hybrid	998.9	671.1	2702.9	38
CVFE	998.7	820.1	2945.6	666
CVFE hybrid	999.4	809.4	2990.6	45

ber of gridblocks required (666 per layer) was again too large for this grid to be used for multi-well field-scale runs.

A Cartesian hybrid grid was constructed by taking a 5 by 5 Cartesian grid and placing a 14 radial division cylindrical grid in the middle gridblock (Fig. 1d). A CVFE hybrid grid was also constructed with 28 CVFE nodes and a local cylindrical grid with 17 subdivisions (Fig. 1f). Both the Cartesian hybrid grid and the CVFE hybrid grid were able to give results similar to the cylindrical fine-grid simulation (Figs. 5 and 6).

A comparison of the number of gridblocks used by each type of grid, and the predicted cumulative oil and water production after 150 days for each of the grids is given in Table 1. It can be seen that for similar predicted production rates, the number of gridblocks required when using the Cartesian grid or the CVFE grid was an order of magnitude higher than the number required by the Cartesian hybrid grid or the CVFE hybrid grid. This results in large CPU time and memory savings when using the hybrid grids.

Coarse-grid Runs

Runs were also performed with the 5 by 5 coarse Cartesian grid for comparison. Figure 7 shows the results obtained with the coarse Cartesian grid. Also shown are the results from the fine cylindrical grid run and the Cartesian hybrid grid run. In the coarse Cartesian run, the maximum bottom hole pressure constraint of 5171 kPa was reached rapidly, due to slower temperature increase and consequent low oil mobility in the large well gridblock. Holding to the maximum bottom hole pressure constraint results in a reduced steam injection rate of 16 m^3/d (100 bbl/d) of cold water equivalent instead of the desired rate of 100 m^3/d (629 bbl/d) which was maintained in the fine-grid runs. With the lower injection rate, less energy is injected into a reservoir and a smaller volume of oil is mobilized, which results in a low predicted oil production as shown in Figure 7. An additional run was performed with the coarse grid by forcing a constant injection rate of 100 m^3/d (629 bbl/D) irrespective of the required bottom hole pressure. The results of the constant injection rate run, which are also included in Figure 7, show a more reasonable oil rate. However, the values are higher than the rates predicted by the fine cylindrical runs. The bottom hole pressure required to inject 100 m^3/d (629 bbl/d) in the coarse grid was 32.5 MPa (4720 psia), which is unrealistically high.

The above coarse-grid runs indicate the necessity of near-well local grid refinement to obtain meaningful results. The fine-grid runs show that cylindrical grid refinement is the most efficient way to achieve high resolution of near-well phenomena for both the Cartesian and CVFE grids.

Observation

For all fine-grid runs, a double peak was observed in the oil rate. This double peak can be interpreted as follows.

As production begins, the pressure in the near-well region dropped rapidly to near the bottom-hole pressure of the well. The temperature near the well also dropped, but less rapidly due to the heat capacity of the rock. As this occurs, heat became available to evaporate the water near the well, and together with the drop in pressure, led to an increase in the gas saturation. Examination of

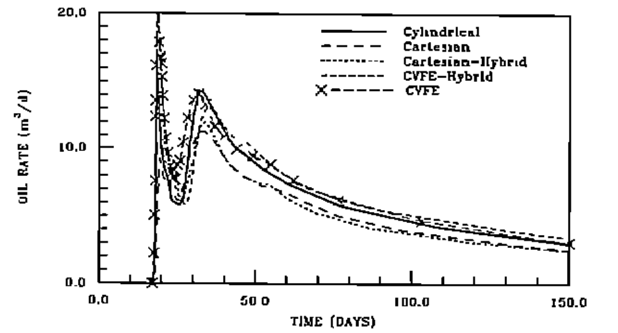

FIGURE 5. Case 1 — comparison of oil rates for different fine grids.

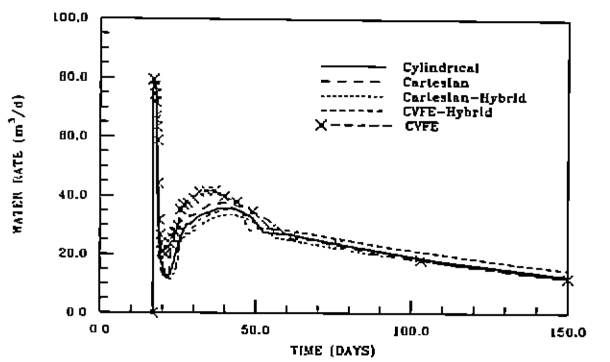

FIGURE 6. Case 1 — comparison of water rate for different fine grids.

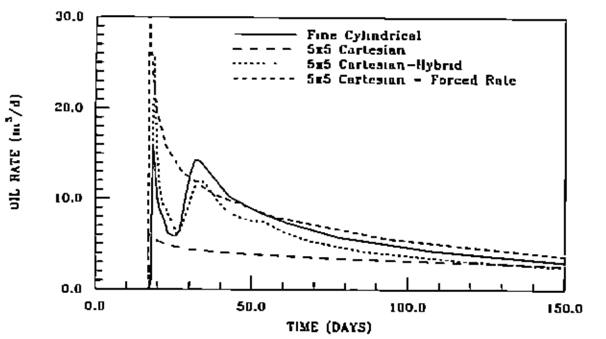

FIGURE 7. Case 1 — comparison of oil rates between coarse, fine and hybrid grids.

the three-phase relative permeabilities reveals that the relative permeability to oil decreases with increasing gas saturation, even when the oil saturation remains constant. This decreasing oil relative permeability resulted in a decline in oil rate. After some time, most of the steam was produced, leading to a decrease in gas saturation and an increase in oil relative permeability. This results in the second peak in the oil rate.

Additional runs were performed using different relative permeability curves. These runs also exhibited this double peak behaviour, though to a lesser degree than in Case 1.

Case 2 — Multi-well Cyclic Steam Stimulation

Process Description

Case 2 corresponds to a multi-well cyclic steam stimulation with offset steaming. A symmetry pattern of two wells in a staggered

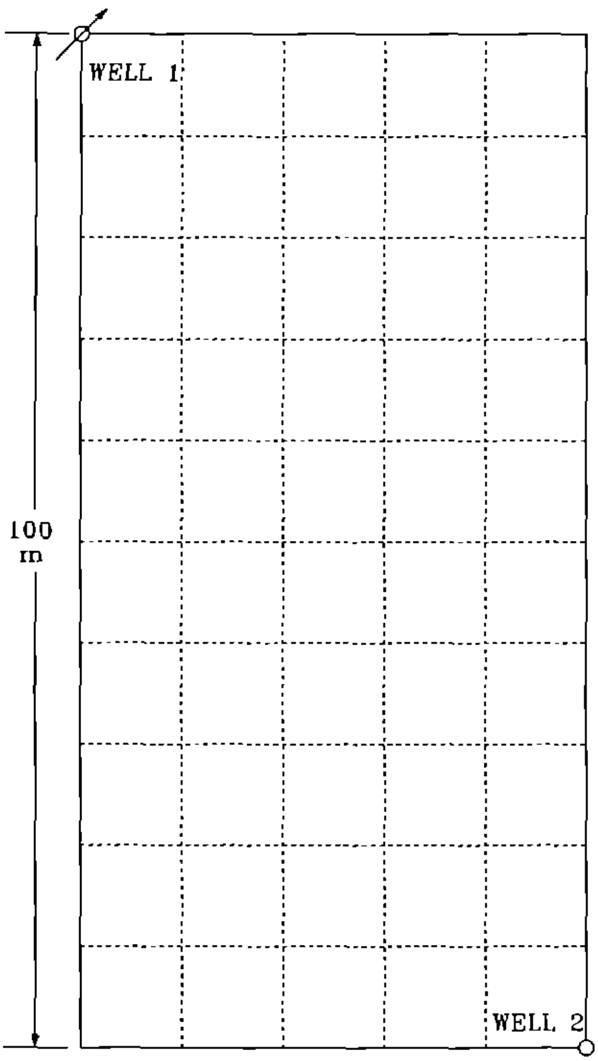

FIGURE 8. Geometry and coarse Cartesian grid used for Case 2 and Case 3.

line pattern was simulated. The wells were located on a 2 ha spacing (half of that used in Case 1). The same oil and water zone thicknesses as Case 1 were used, as well as the same fluid, rock-fluid, and rock properties. The geometry and coarse Cartesian grid are shown in Figure 8. Due to symmetry, only one quarter of each well needs to be simulated. However, all the reported injection/production rates and cumulatives have been scaled up to full well rates and volumes.

The simulated period was 210 days and involved three injection and production cycles for each well. Each cycle consisted of a ten-day period of steam injection at a rate of 100 m^3/d (629 bbl/d), followed by a seven-day soak period and fifty-three days of production. This cycle was repeated three full times for Well 1. Well 2 started by producing for seventeen days, then began following the same cycle as Well 1. Thus, the cycles of Wells 1 and 2 were offset by seventeen days. Well 1 began its first production cycle just as Well 2 began steam injection. As the simulation was ended at 210 days, the final production period for Well 2 was only 36 days.

Simulation Grids

Case 2 was run with six different grids. For all grids, the same seven layers as in Case 1 were used. The grids were as follows:

- *Coarse Cartesian Grid* — Each layer was divided into a 5 by 10 = 50 gridblocks of equal size per layer (Fig. 8). Each gridblock was 10 m by 10 m in size. Due to the large well block sizes, unrealistically high injection pressures were required at the beginning of steam injection to force the specified steam injection rate.
- *Fine Cartesian Grid* — Starting with the above coarse Cartesian grid, the boundary blocks were refined into four irregularly spaced blocks (Fig. 9a). The well blocks were only 1 m by 1 m in size. A total of 176 gridblocks was used in each layer.
- *Cartesian Hybrid Grid* — Starting with the above coarse Cartesian grid, the well blocks were refined with seven cylindrical blocks (Fig. 9c). The radius of the well block was 1 m. A total of 62 gridblocks per layer was used.
- *Coarse CVFE Grid* — A CVFE grid with 49 gridblocks per layer was used (Fig. 9d).
- *Fine CVFE Grid* — A CVFE grid with 144 gridblocks per layer was used (Fig. 9e).
- *CVFE Hybrid Grid* — The well blocks of the coarse CVFE grid were refined into 7 cylindrical grids (Fig. 9f). Note that the innermost radii are too small to be seen on the figure. The radius of the well blocks were 1 m. A total of 61 gridblocks per layer was used.

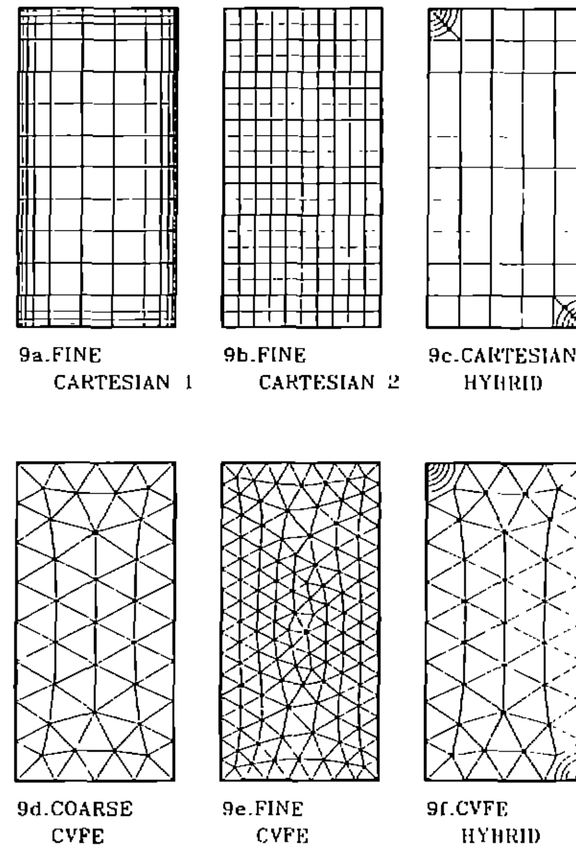

FIGURE 9. Grids used for Case 2 and Case 3. For CVFE the finite-elements are shown.

Case 2 simulation was run with the above grids. The predicted oil production rates for Well 1 and Well 2 are shown in Figures 10 and 11, respectively. The cumulative oil production from both wells predicted by each of the grids is shown in Figure 12 and is reported in Table 2.

Discussion of Results

As shown in Figure 12, the predicted oil production using the Cartesian hybrid grid and the CVFE hybrid grid are in good agreement, while the predicted productions using the other grids were significantly higher. The fine Cartesian grid, which was designed with approximately the same size well block as the Cartesian hybrid grid,

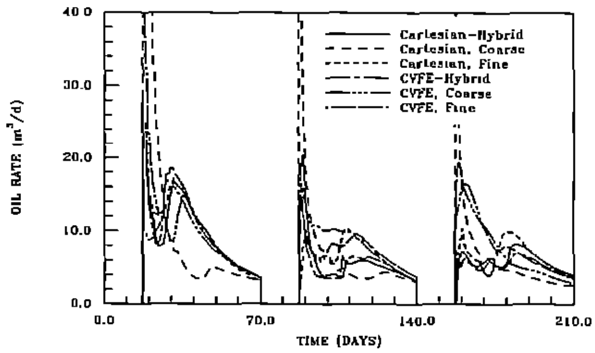

FIGURE 10. Case 2 — comparison of oil rates for Well 2.

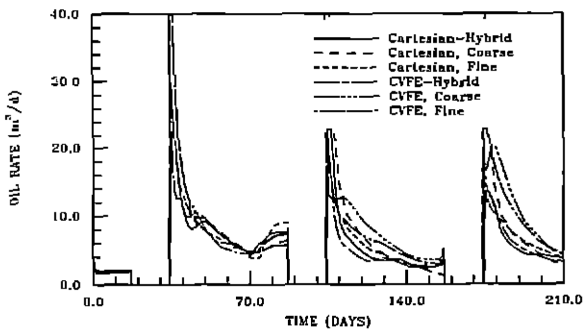

FIGURE 11. Case 2 — comparison of oil rates for Well 2.

TABLE 2. Cumulative injection and production for the various grids used in Case 2

Grids	Total Water Inj. (m^3)	Oil Production (m^3) Well 1 (m^3)	Well 2 (m^3)	Total (m^3)	Blocks per Layer
Cartesian hybrid	6000.	1091.2	929.6	2020.8	62
Coarse Cartesian	6000.*	1181.6	1151.2	2332.8	50
Fine Cartesian	6000.	1206.4	973.6	2180.0	176
CVFE hybrid	6000.	1090.8	886.4	1977.2	61
Coarse CVFE	5804.	1272.0	1138.4	2410.4	49
Fine CVFE	5960.	1319.6	1149.2	2468.8	144

*For the coarse Cartesian grid, there was no maximum bottom hole pressure constraint for injection wells.

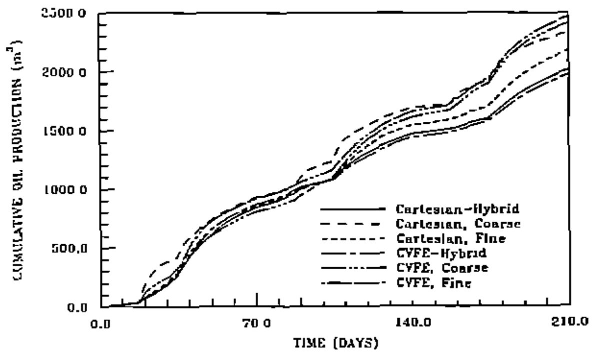

FIGURE 12. Case 2 — cumulative oil production from both wells.

TABLE 3. Cumulative injection and production for the various grids used in Case 3

Grids	Injection Water (m^3)	Production Oil (m^3)	Water (m^3)	Blocks per Layer
Cartesian hybrid	157671	86438	161328	62
Coarse Cartesian	153868	84181	157630	50
Fine Cartesian	140519	75964	145613	200
CVFE hybrid	159350	87201	163000	61
Coarse CVFE	153715	84244	157035	49
Fine CVFE	143324	78559	148462	144

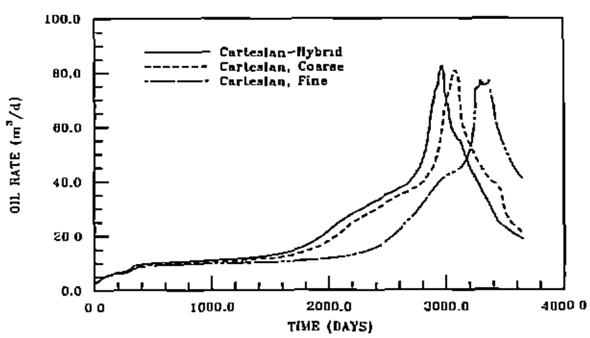

FIGURE 13. Case 3 — comparison of oil rates for Cartesian grids.

is in closest agreement with the hybrid grids. If more blocks had been used in the fine Cartesian grid, better agreements with the hybrid grids would have been obtained. However, the fine Cartesian grid had over 2.5 times as many gridblocks as the hybrid grid cases, with a proportionally greater CPU time and computer memory requirement.

The higher cumulative oil production predictions of the non-hybrid grids are due to the larger sizes of the well blocks and near-well blocks. These larger block sizes force the injected steam to remain at the bottom of the injection zone further into the formation, thus reducing steam override. The large gridblock sizes also increase the time (or amount of injected steam) required to completely saturate the near-well blocks with water and steam. This results in higher oil saturations in the near-well gridblocks, and a higher initial oil production rate. This effect is particularly noticeable in later cycles. Thus, an optimization of slug size, injection rate, soak period, and production period, based on a grid with large well gridblocks will give less accurate results than one based on a Cartesian hybrid grid or a CVFE hybrid grid with small well gridblocks.

Case 3 — Steam Drive

Process Description

Case 3 corresponds to the simulation of a steam-drive process, based on the same geometry as in Case 2. Steam was continuously injected into one well in the symmetry pattern. Fluids were produced from the other well. The geometry, layers, fluid, and rock-fluid properties were identical to those used in Case 2. Steam was injected into Well 1 at a rate of 50 m^3/d for 3650 days (ten years). Well 2 was allowed to produce with a bottom hole pressure of 117 kPa (17 psia).

Simulation Grids

Five of the simulation grids were the same as those used in Case 2 (Fig. 8 and Figs. 9c, 9d, 9e, and 9f). The only different grid was the fine Cartesian grid, which was modified to 200 identically sized gridblocks per layer (Fig. 9b).

Discussion of Results

The oil production rates for all Cartesian grids are shown in Figure 13. The cumulative oil production at the end of the simulation period predicted by each grid is shown in Table 3. The oil production rates for the CVFE grids and the fine Cartesian grid are shown in Figure 14.

The Cartesian hybrid grid and CVFE hybrid grid allow a more effective modelling of near-well steam override. This steam over-

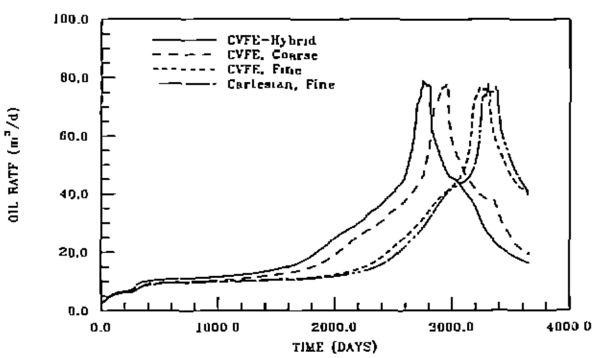

FIGURE 14. Case 3 — comparison of oil rates for CVFE grids.

ride causes an earlier steam breakthrough and a lower sweep efficiency. These give rise to an earlier peak oil rate for the hybrid grids compared to the coarse grids in Figures 13 and 14. In Figure 13, the Cartesian hybrid grid predicts the peak oil rate at about 150 days earlier than in the coarse Cartesian grid run. In Figure 14, the peak oil rate for the CVFE hybrid grid occurs at about 170 days prior to the peak predicted by the coarse CVFE grid.

A coarser grid in the middle of the simulated region resulted in a noticeable amount of numerical dispersion, with a consequent earlier steam breakthrough time. As depicted in Figure 13, the time of the peak oil rate for the fine Cartesian grid run is about 320 days after the peak for the coarse Cartesian grid run. Similarly, in Figure 14, the peak for the fine CVFE grid run is also about 320 days after the peak for the coarse CVFE grid run.

For the coarse grid, the above two sources of error work in opposite directions. The low grid resolution near the well results in less override and delayed steam breakthrough while the poor grid resolution in the middle of the region results in numerical dispersion and earlier steam breakthrough. Because these two sources of error partially cancel each other, it would appear that the coarse grids provide a better prediction of oil recovery than the hybrid grids. Indeed, in Figures 13 and 14, the coarse grid results are closer than the hybrid results to the fine grid results.

Conclusions

Hybrid grids, combining cylindrical grids near wells with Cartesian or CVFE grids between wells, can effectively model thermal processes with fewer grid blocks than ordinary Cartesian or CVFE grids. Hybrid grids are particularly useful for modelling multi-well cyclic steam stimulation processes where well production is affected by offset steaming in adjacent wells. Indeed, hybrid grids use cylindrical grids to accurately model the near-well region and Cartesian or CVFE grids to link together these regions. While the near-well region is less important in steam-drive processes, hybrid grids can more accurately model steam override near the well than ordinary Cartesian grids.

CVFE hybrid grids have two advantages over Cartesian hybrid grids[9]. Firstly, the interface between the cylindrical and the CVFE grids is handled more accurately and more easily than the interface between cylindrical and Cartesian grids. Secondly, the CVFE hybrid grid can accommodate irregular well spacings and reservoir boundaries.

In modelling steam drive processes, hybrid grids do not remove the need for reasonably small gridblocks in the interwell region to reduce numerical dispersion.

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