A New Simulator for Dynamic Local Grid Refinement for Reservoir Simulation

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Abstract

The ability to predict the performance of a petroleum reservoir is of immense importance for the petroleum industry. Numerical simulation is the most powerful tool that can be used for reservoir performance prediction. In the current study a new simulator has been designed for two phase compressible oil water flow through compressible porous media. The new simulator is able to treat the frontal advancement and the high rate of change region by static and dynamic local grid refinement. A new approach is proposed in this study to trace the frontal advancement. The proposed simulator has been applied to several field reservoir cases and show good performance.

الخلاصة

ان القدرة علي التنبؤ بادائية المكامن النفطية تعد من الأمور المهمة في الصناعة النفطية . تعتبر المحاكاة العددية الأداة الأكثر قوة التي يمكن استخدامها للتنبؤ بادائية المكمن. في الدراسة الحالية تم تصميم نموذج محاكاة جديد للجريان المنضغط بطورين النفط و الماء خلال الأوساط المسامية مع اخذ انضغاطية الصخور بنظر الأعتبار. النموذج الجديد قادر على معالجة التقدم الجبهوي و معدلات التغير العالية في المناطق الحساسة و المهمة بواسطة استخدام ما يسمى بالتنعيم الشبكي المحدد المستقر او الحركي. تم استخدام طريقة جديدة اقترحت في هذه الدراسة لمتابعة التقدم الجبهوي. النموذج الجديد في الدراسة الحالية طبق على عدد من الحالات المكمنية الحقلية و اظهر ادائية جيدة.

Introduction

Numerical reservoir simulation has gained wide acceptance as an important decision making tool. Its models are routinely used for approximate solution describing flow and transport in oil, gas or geothermal reservoir.

Numerical simulation is an instrument of extreme important 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. Simulation is affected by the size of the field, the number of wells, the complexity of the geological model, and the amount of details necessary to guarantee the reliability of the model.

The conditions of the reservoir fluids, such as pressure, temperature, phase compositions, and concentrations of dissolved solids or liquids and non condensable gases, may show strong spatial variability in the vicinity of production and injection wells. Large spatial variations also can occur near reservoir heterogeneities, such as fault and lithologic contacts.

In numerical simulation, fine gridding is required to accurately represent steep changes in fluid conditions. This can necessitate prohibitively large numbers of grid blocks in conventional simulators.

Grid type and Discretization Errors

The numerical errors of a solution of a set of differentiated equations on a grid are caused by the truncation errors due to the discrimination (Soleng and Holden 1998).[1] The tradeoff between space discretization accuracy and computational work can be improved by increasing grid resolution.

Using coarse grid can be led to significant error in saturation fronts of numerical simulation (Garcia and Pruess 2000).[2]

Three types of errors are associated with any numerical solution of partial differential equations (Mansell et. al. 2002)[3]:

- i- Round of error which is occurred as a consequence of finite precision arithmetic in numerical calculations.
- ii- Truncation or discretization error which occur due to truncation of the specific expansion used.
- iii- Inherited errors represent accumulation of total errors from round and truncation errors.

Truncation error can be reduced by means of finer grid spacing.[2] The most fine grid the smaller the truncation errors. From the other hand, reducing discretization errors through grid refinement increase the number of grid blocks and increases computational work. Pruess and Garcia [4] introduced a procedure to estimate the relation between the grid spacing and number of grid blocks with computational effort. If N is the number of blocks. V is a given reservoir volume, h is grid spacing. D is the dimensionality of the flow problem. Then the number N of grid blocks in a given reservoir volume V increases with decreasing grid spacing h proportional to $1/h^D$. Computational work for a reservoir simulation increases with number of grid blocks proportional to N^w with $w=1.4 - 1.6$ for iterative solvers, and w approximately equal 3 for direct solvers.

The local grid refinement can represent a good option to reduce computer effort (Valmir F. et. al. 2003).[5]

But from other side, the non uniform grid produces additional terms in truncation error. The numerical error and its propagation depend on the differential equations and the discretization method. In elliptic dominated equations like the pressure equation, the local numerical error is closely related to the local truncation error. This is not the case in hyperbolic and parabolic problems, like the saturation equations.[1]

Local grid refinement

Generally, grid refinement contains many aspects and can be classified as follows:

1- Refinement type:
   - a- Static grid refinement by using fixed refined grid without any change with time.
   - b- Dynamic grid refinement by using changeable grid during the simulation period depending upon certain conditions.

2- Region of refinement :
   - a- Conventional or global grid refinement in which the lines of refinement reach the outer boundaries of the simulated area. An example is shown in Fig.(1.b).
   - b- Unconventional or local grid refinement focused in some region in simulated area an example is shown in Fig.(1.c).

3- System of refinement :
   - a- Linear or Cartesian or normal grid refinement in which the coordinates of refined region are similar to the coarse or base

grid. An example shown in Fig.(2.a).

b- Hybrid grid refinement in which the coordinates of the refined region are different from those of base grid. An example is shown in Fig.(2.b).

4- Ordering schemes:

Most ordering schemes can be used with grids having local refinement. The ordering schemes type that can be used depending on the way of base and local grid treatment. Figs.(3) and (4) illustrate two different ordering schemes.

5- solution approach:

Actually, the result of grid refinement is two different grid systems, the first is the base or coarse grid, and the second is the sub or refined grid. Several approaches can be used to treat these two different grids, and can be illustrated briefly as follows:

a- Single matrix or unified solution by which the whole system is solved as one matrix which include the refined region. This approach led to non banding matrix and thus the method of solution must take into account this important aspect.

b- Separate matrices by which the whole system divided into two sub systems, the coarse or base grid with an averaging values for refined region and the second is the refined region with boundary conditions interactive with base grid. In this state, the two sub systems matrices are still banded.

6- Treatment of boundaries (the interactivity) between the two adjacent coarse and refined grid blocks. Fig(5) shows adjacent blocks with different sizes and their ordering scheme. There are several ways to handle this aspect[6]:

a- two point finite difference approximation method:

$$\Phi_x = \frac{2\left(\Phi_{2,2} - \Phi_{2,1(1,1)}\right)}{\Delta x_{2,2} + \Delta x_{2,1(1,1)}} + o(h^0) \quad ....(1)$$

b- three point finite difference approximation method

$$\Phi = \left[12\Delta y_{1,2}(\Phi_{1,2} - \Phi_{2,1(1,1)}) + 4\Delta y_{2,2}(2\Phi_{1,2} + \Phi_{2,2} - \Phi_{2,1(1,1)})\right] / \left(6(\Delta y_{1,2})(\Delta x_{1,2})\right) + o(h^1) \quad ......(2)$$

c- five point finite difference approximation method

$$\Phi_x = \frac{C\Phi_{2,2} - D\Phi_{1,2}}{\Delta x_{2,1}(C+D)} - \frac{CD(A\Phi_{2,1(1,1)} - B\Phi_{1,1(2,1)} - (A+B)\Phi_{2,1(1,1)})}{AB(A+B)}$$

$$A = \frac{\Delta y_{1,1(2,1)} + \Delta y_{2,1(1,1)}}{2}$$

$$B = \frac{\Delta y_{1,1(2,1)} + \Delta y_{2,1(2,1)}}{2}$$

$$C = \frac{\Delta y_{1,2}}{2} + \frac{\Delta y_{2,2}}{6}$$

$$D = \frac{\Delta y_{2,2}}{3}$$

..................................(3)

Literature reviews

An illustrative solution technique on locally refined grids was presented by Price and Coats 1974.[2] They describe the ordering schemes and discretization methods. They used solution techniques that solve both fine and coarse grid equations in the same system of linear equations.

Quandlle 1993[8] used two different types of flexible grid, control volume grids and locally refined grids. The two types were applied by using ready simulators known as ECLIPSE 100 and ECLIPSE 200.

Liyan Zhao 1994[6] introduces an extended study on dynamic locally refined grid with solution method called domain decomposition. Domain decomposition approach divides the whole region into two regions and tries to solve each one separately with interactive boundary conditions.

Slong and Holden[1] concentrate their work on heterogeneity and up scaling and how to solve this problem by local grid refinement. They introduced what is known as elastic gridding. Elastic grid shown in Fig.(6) is a variant of variational grid optimization based functional with a non Euclidean metric tensor. They present the difference between two types of grids for the same problem when the geological model is concerned.

Pruess and Garcia[4] introduced a local grid refinement in geothermal reservoir. They implement a scheme for local grid refinement to production and injection into fractured two phase reservoir. After two years, the simulation results show excellent agreement between the fine and locally refined grids simulations with geologically refined simulator. Also, the coarse grid simulators show larger discretization errors.

Garcia and Pruess[2] develop a general scheme for local refinement of 2D Cartesian grid compatible with simulator known as TOUGH2.

Mansel et. al. [3] investigates the flow of water and chemical flow in soil with adaptive grid refinement. Local refined grid was designed depending on the lithology and geological view of simulated area as shown in Fig.(7).

Valmir F. Risso et. al.[5] analyze a methodology for reduction of computational effort, maintaining the level of the precession of more detailed simulations. They made several comparisons to achieve the following effects:

1-The effect of local grid refinement.
2-The optimum ratio of the refined blocks size to that of the coarse grid.

Their final results can be summarized in Tables (1) and (2).

Depending on Table (1), they conclude that local grid refinement shows good results for tested cases. From Table (2), also, it can be concluded that refinement restricted to the region of interest give best results. From table (2), the model with out refinement yields worst results in the production and the best results in relation to the simulation time. The best refinement ratio was 1:4 (intermediate refinement).

Yannick C. et. al. 2004[9] propose the use of local grid refinement techniques to efficiently mix different grid blocks scales in fully coupled basin simulation. Basin simulation is the simulation represents the sediment deposition during long time period.

New Simulator

In the present work, the new simulator Tiger 2008 is designed for multi phase compressible oil water flow through porous media. The compressibility of rock has been considered. Equations (4) illustrate the general diffusivity equation for multi phase compressible oil and water flow through compressible porous media.

$$\frac{\partial}{\partial x}\left[\lambda_{WX}\left(\frac{\partial P_W}{\partial x}-\gamma_W\frac{\partial h}{\partial x}\right)\right]+\frac{\partial}{\partial y}\left[\lambda_{Wy}\left(\frac{\partial P_W}{\partial y}-\gamma_W\frac{\partial h}{\partial y}\right)\right]+\bar{q}_W=\frac{\partial}{\partial t}[\phi S_W.b_W] \quad \text{.........(4.1)}$$

$$\frac{\partial}{\partial x}\left[\lambda_{OX}\left(\frac{\partial P_O}{\partial x}-\gamma_O\frac{\partial h}{\partial x}\right)\right]+\frac{\partial}{\partial y}\left[\lambda_{Oy}\left(\frac{\partial P_O}{\partial y}-\gamma_O\frac{\partial h}{\partial y}\right)\right]+\tilde{q}_O=\frac{\partial}{\partial t}[\phi S_O.b_O] \quad \text{.........(4.2)}$$

where:

$$\lambda_{WX}=\frac{K_X.K_{rw}.b_W}{\mu_W} \quad \text{.......... (4.3)}$$

$$\lambda_{OX}=\frac{K_X.K_{ro}.b_O}{\mu_O} \quad \text{......... (4.4)}$$

$$\lambda_{WY}=\frac{K_Y.K_{rw}.b_W}{\mu_W} \quad \text{.......... (4.5)}$$

$$\lambda_{OY}=\frac{K_Y.K_{ro}.b_O}{\mu_O} \quad \text{......... (4.6)}$$

More information about the conventional reservoir simulation procedures and techniques can be found in Al-Subeeh [10] and Al-Rubayee.[11]

This simulator is designed to be able to handle the several types of grids:

1- conventional grid by assigning fixed uniform dimension block size.
2- Global refinement grid by assigning variable block sizes in the same grid through interested regions either statically (fixed sizes through all simulation period), or dynamically (with moving variable block sizes positions) during the simulation period depending on the certain fluid properties (such as saturation).

A flowchart describing the general processes in this simulator can be found in appendix (A).

New approach to trace the frontal advancement with dynamic local grid refinement

In the present work a new approach to trace the frontal advancement in a reservoir is introduced. This new approach can trace the change in any one or more fluid variables such as pressure or saturation. The new approach stand on the change in the interested selected variables through all simulated region at each time step. The investigated changes are found by comparing the old and new values of interested variables and calculate the rate of change during each time step by which the initiation of changing front are trying to predicted. The calculated values of rates of change are compared and detect the position and blocks through which the front takes place. The detected positions transformed automatically to subroutine called REFINER which performs the dynamic grid refinement.

During the grid refinement, a certain interpolation method is used which produces the interpolated values through refined regions. If there are no available new or modified input data for these regions, the interpolation method must be elected carefully to insure distributions of the interpolated variables compatible with the original or last calculated values. Appendix (B) shows a flowchart describing the general processes in proposed dynamic local grid refinement

Tested Cases

The new simulator in the current study was applied to several reservoir cases. Some of them are illustrated in Fig.(8) to Fig.(16).

A reservoir sector with a good aquifer along one of its flanks (along one of J-direction). The simulated reservoir is under pressure maintenance with no oil production below bubble point pressure and no water influx at pressure more than 5500 psi. Fig.(8) illustrates the network and input/output data for case(3.1). A fixed grid has been used for this case with dimension of (L=20) blocks in I-direction and (m=5) in J- direction. The producing well is situated at (I=L, J=M). The same reservoir case is resimulated but with coarse grid dimension (5) in I-direction and (5) in J-direction which is illustrated in Fig.(9).

The case (3.3) is shown in Fig.(10), in this case, the dynamic local grid refinement is applied. The initial grid dimension in I-direction and in J-direction are (5) blocks. The refinement is applied locally through all blocks of (I=2). The final grid dimension are (8) blocks in I-direction and (5) blocks in J-direction. The results are shown in Fig.(10). The same case is resimulated but with more active water aquifer. This led to more water invasion and thus relatively rapid change in water saturation. Fig.(11) shows the fixed network and with no grid refinement, while Fig.(12) shows the same case but with grid refinement.

There are several cases illustrated in Fig.(13) through Fig.(16) deal with different reservoir conditions and show the effect of grid refinement.

Conclusions

1- It can be concluded that the using local grid refinement led to a less calculation effort and thus less time of processing especially in reservoir cases containing different regions where the ratio of elapsed time of processing as percentage is about 7.8.

2- The local grid refinement is more important in narrow flow regions such as regions around the well and in heterogeneous reservoirs.

3- In some cases the local grid refinement produces best results especially when the network of simulated region and block shapes are designed depending on the geological and lithological aspects or when there are rapid changes in fluid and rock properties.

Nomenclature

- b_l 1/Bl   Shrinkage factor of phase l, cu.ft./SCF.
- I   Number of grid block in the x-direction.
- J   Number of grid block in the y-direction.
- Kr_l Relative permeability of phase l.
- Kx   Horizontal absolute permeability in the x- direction, md.
- Ky   Horizontal absolute permeability in the y- direction, md
- P_l Pressure of phase l , Psi.
- q_l Flow rate of phase l, SCF/D/ cu.ft. of grid bulk volume.
- S_l Saturation of phase l. fraction .
- x,y   Directions in the Cartesian co-ordinate system.

Greek symbols

- Δ Difference operator .
- Δ_s Grid spacing of co-ordinate s (X,Y), ft.
- Δ_x Horizontal difference operator in the x- direction.
- Δ_y Horizontal difference operator in the y- direction.
- γ_l Density of phase l in terms of gradient, Psi. /ft.
- λ_l Mobility of phase l, md/ c.p.
- μ_l Viscosity of phase l, c.p.
- ϕ Porosity, fraction.
- Φ_l Potential of phase l, Psi.

Subscript Symbols

i Grid block index in the x-direction.
j Grid block index in the y-direction.
l Phase , l = o, w
o Oil.
r Rock.
w Water.

Superscript Symbols

n Time level.
/ Derivative.

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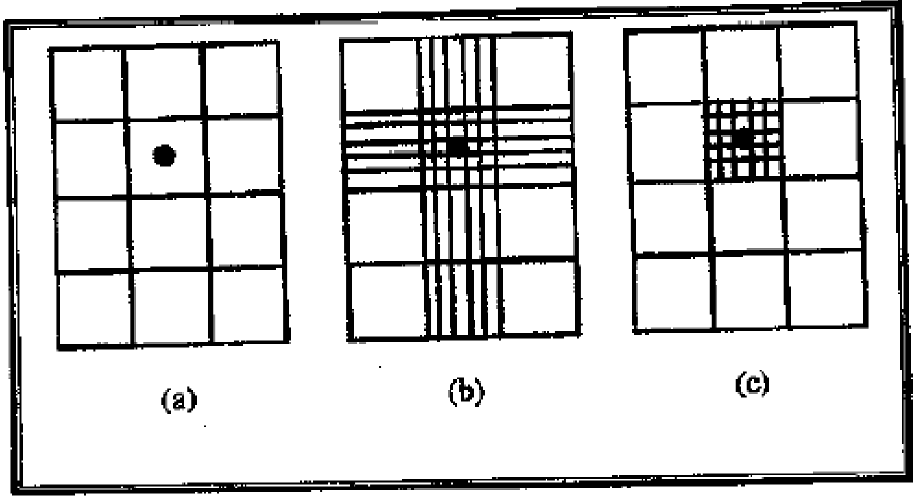
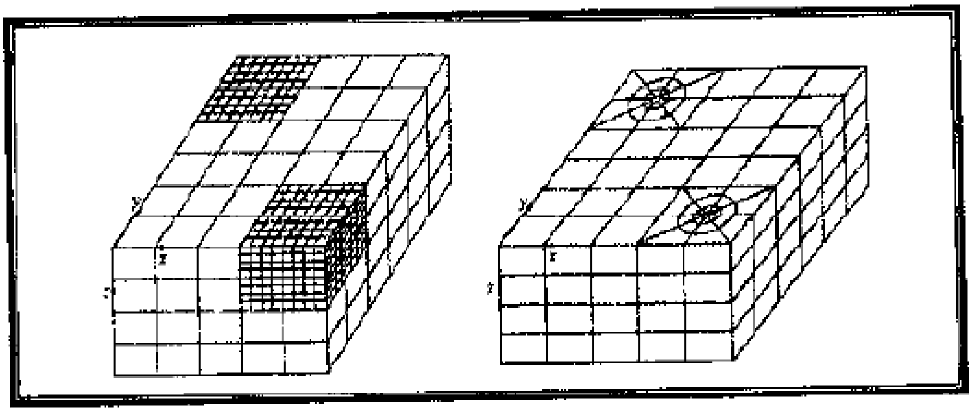
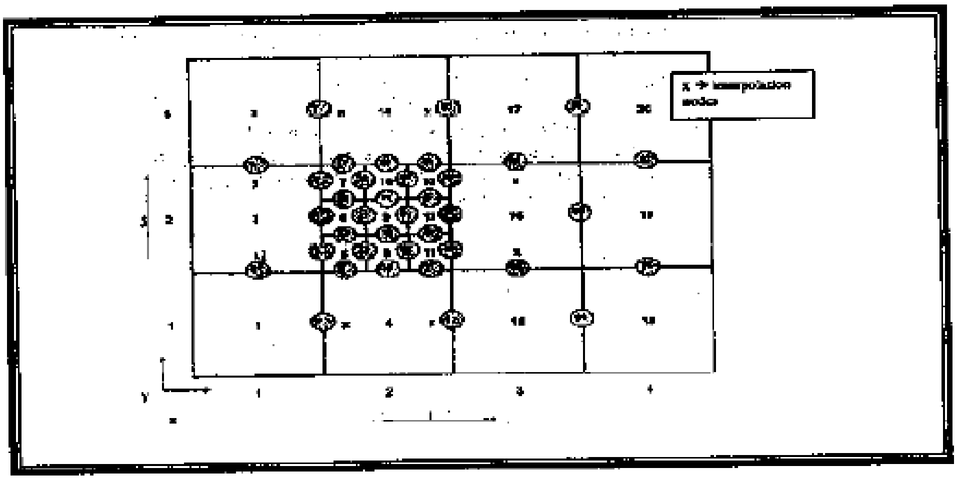


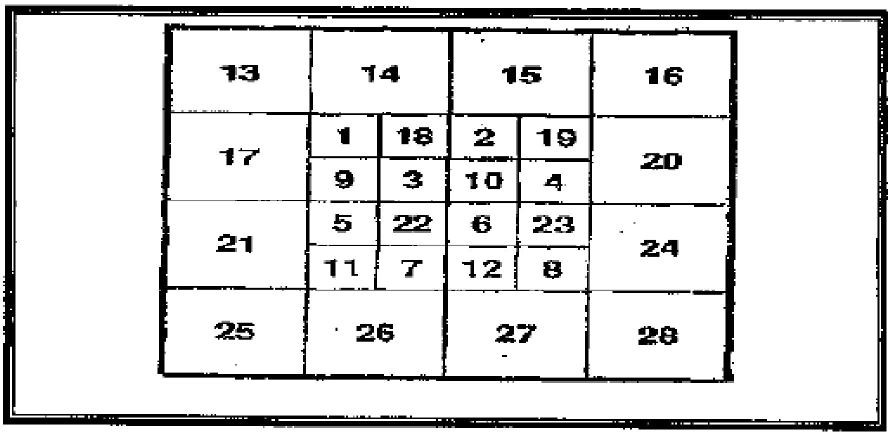
Figure(1) Global and local grid refinement.[4]



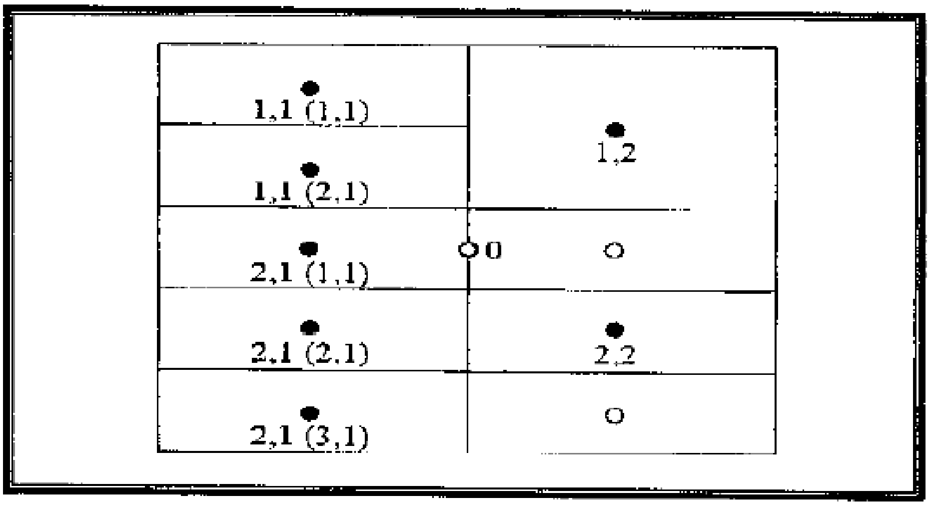
Figure(2) Normal and hybrid grid refinement (after Lian Zhao 1994)[6]



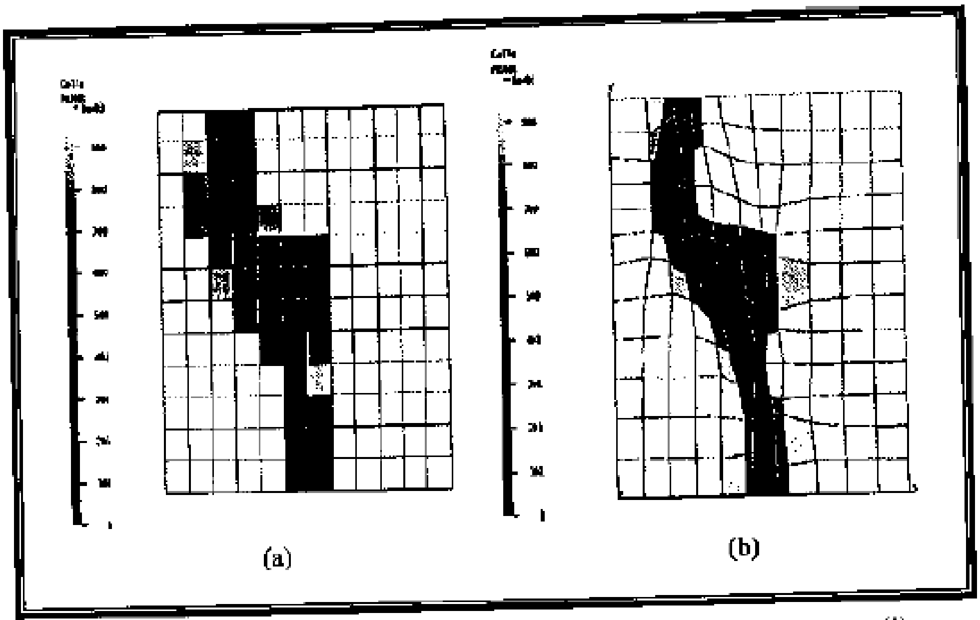
Figure(3) An ordering scheme used with local grid refinement[2]



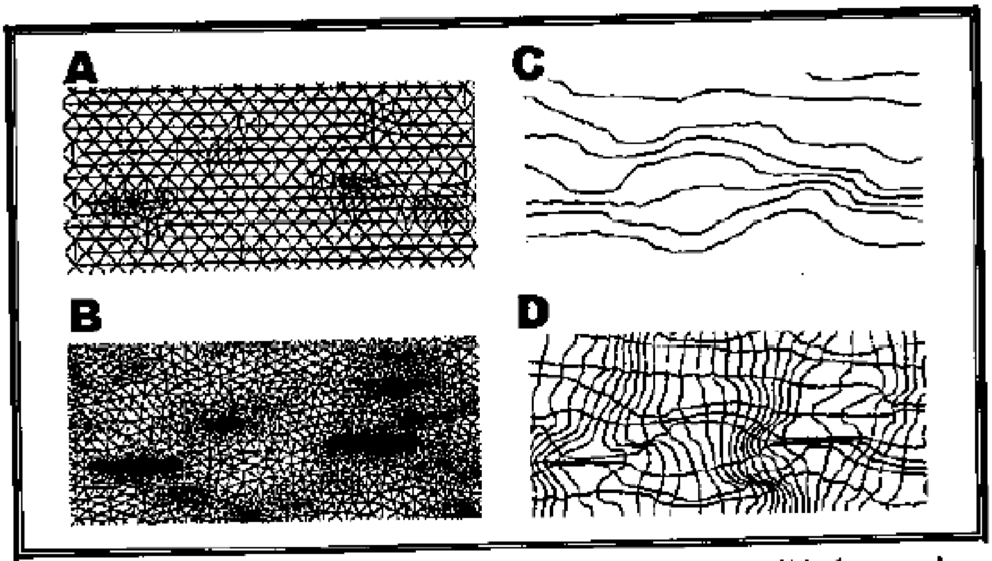
Figure(4) An ordering scheme called a two step RRB on a locally refined grid (after Brand and Holneman 1990)(7)



Figure(5) Treatment the boundaries between adjacent coarse and fine blocks.(6)



Figure(6) Grid construction depending on geological model.[1]



Figure(7) A grid constructed and modified depending on lithology and geological aspects.[3]

Table(1) Refinement region extension.[5]

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	56.22
Intercalated Restricted Interest Region	8.32	2.00	8.78	2.07	2.29	35.64

Table(2) Coarse grid to refined block sizes ratio.[5]

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	5.38	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	9.34	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

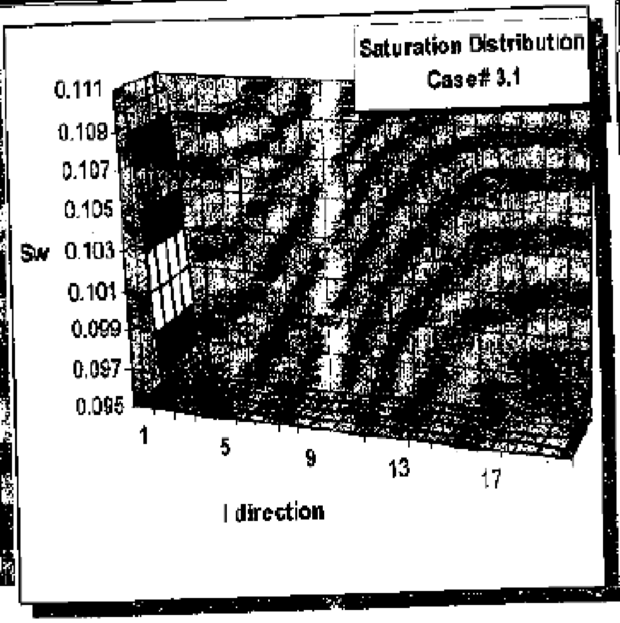
Case # 3.1

ΔX = 175 m
ΔY = 700 m
ΔZ = 700 m

Total Length = 3500 m
Total Wide = 3500 m
Net Thickness = 700 m

Fixed Grid :
Block No. I direction = 20
Block No. J direction = 5

** No LGR

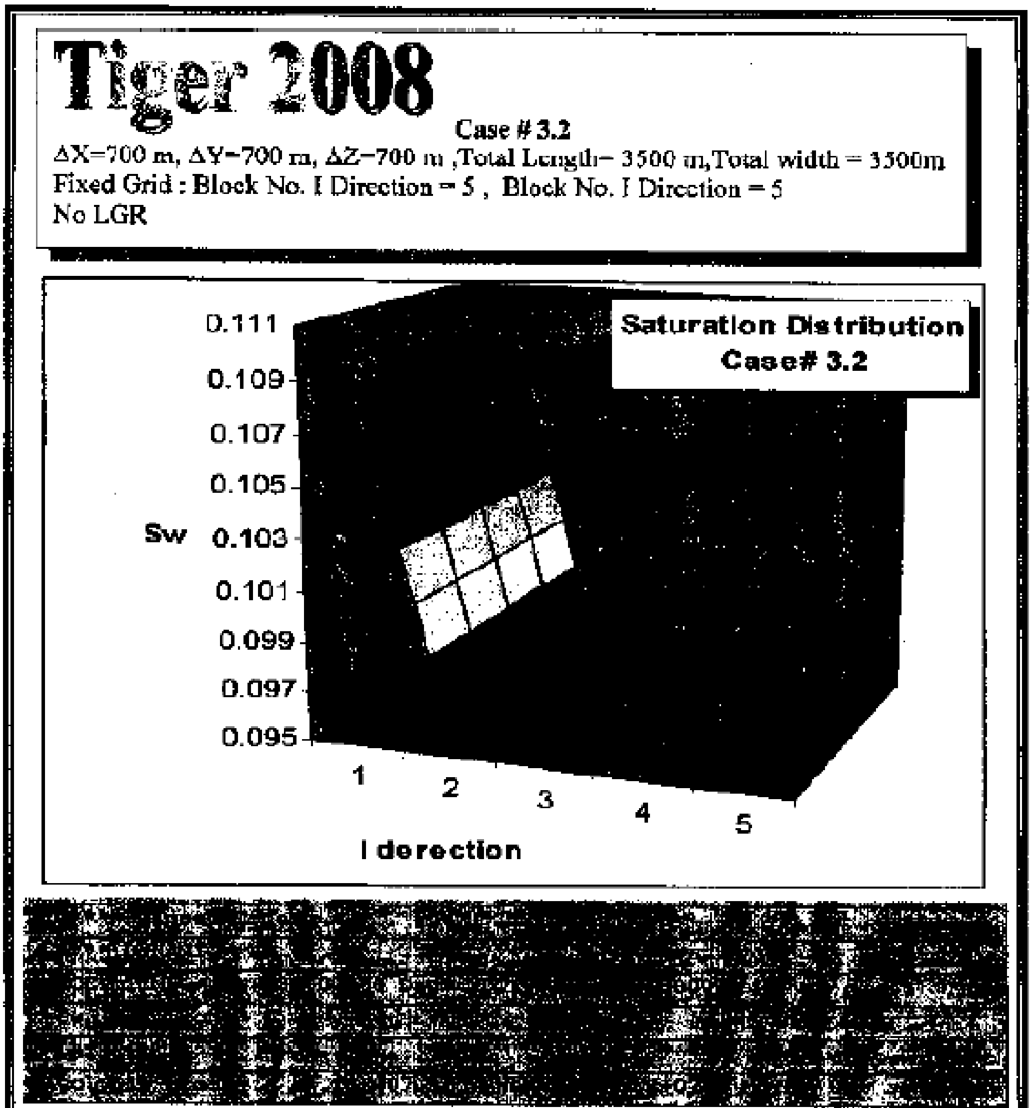



```
*** Elapsed Time = .19E+04 SEC.
*** DYNAMIC
ACC. TIME = 3000.000 Day. DT = .100000
Sw (fraction)
LAYER 1
Acc. Oil Prod.= .30E+07 Acc. Wo= .30E+07 STB
```

J \ I	1	2	3	4	5	6	7	8	9	10
1	0.1102	0.0964	0.095	0.096	0.095	0.095	0.095	0.095	0.095	0.095
2	0.1102	0.0964	0.096	0.095	0.095	0.095	0.095	0.095	0.095	0.095
3	0.1102	0.0964	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
4	0.1102	0.0964	0.096	0.095	0.095	0.095	0.096	0.096	0.095	0.095
5	0.1102	0.0964	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095

11	12	13	14	15	16	17	18	19	20
0.095	0.096	0.095	0.095	0.095	0.095	0.096	0.095	0.095	0.095
0.095	0.095	0.095	0.095	0.095	0.096	0.096	0.095	0.095	0.095
0.096	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
0.095	0.096	0.095	0.095	0.096	0.096	0.095	0.095	0.095	0.095
0.095	0.095	0.095	0.095	0.096	0.095	0.095	0.095	0.095	0.095

Figure (8) Final results for case No. 3.1.



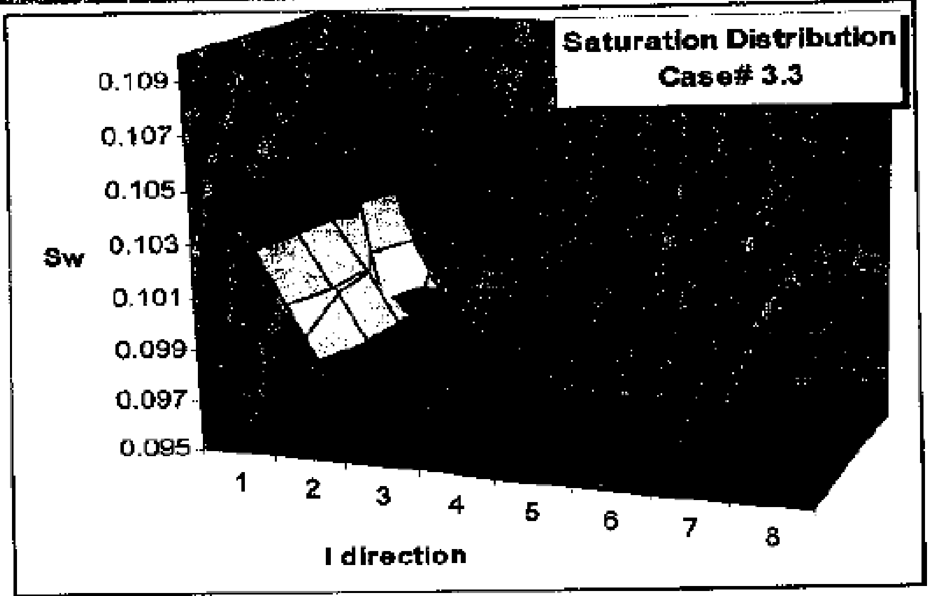
J I	[illegible]	2	[illegible]	[illegible]	[illegible]
[illegible]	0.1102	0.0964	0.096	0.095	0.095
[illegible]	0.1102	0.0964	0.096	0.095	0.096
[illegible]	0.1102	0.0964	0.096	0.095	0.096
[illegible]	0.1102	0.0964	0.095	0.095	0.095
[illegible]	0.1102	0.0964	0.096	0.095	0.095

Figure (9) Final results for case No. 3.2.

Tiger 2008

Case # 3.3

ΔX=700 m, ΔY=700 m, ΔZ=700 m ,Total Length= 3500 m,Total width = 3500m
Initial Grid : Block No. I Direction = 5 , Block No. I Direction = 5
Final Grid : Block No. I Direction = 8 , Block No. I Direction = 5



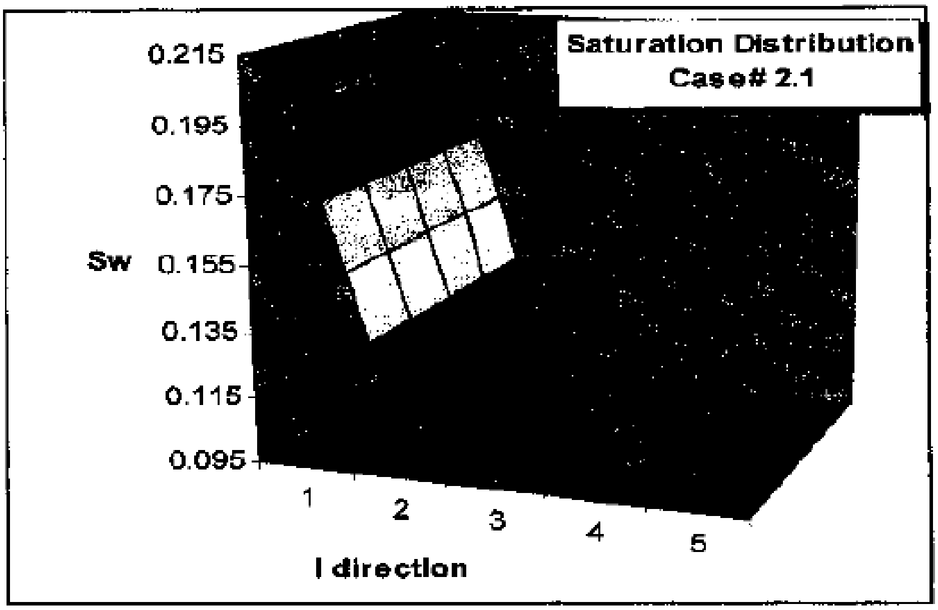
J I	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.1048	0.0998	0.0954	0.095	0.095	0.095	0.095	0.095
[illegible]	0.1049	0.1008	0.0962	0.095	0.095	0.095	0.095	0.095
[illegible]	0.105	0.1009	0.0962	0.095	0.095	0.095	0.095	0.095
[illegible]	0.1101	0.0821	0.096	0.095	0.095	0.095	0.095	0.095
[illegible]	0.1054	0.0995	0.0965	0.095	0.095	0.095	0.095	0.095

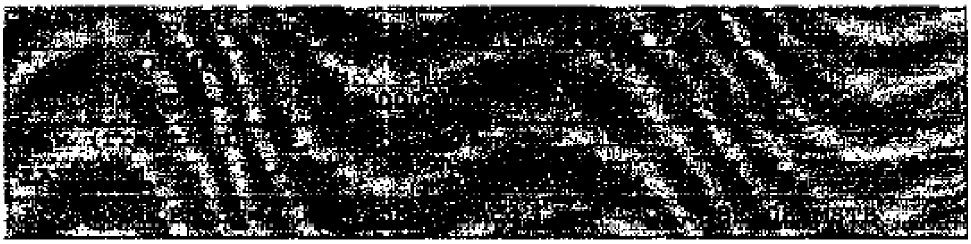
Figure (10) Final results for case No. 3.3.

Tiger 2008

Case # 2.1

ΔX=700 m, ΔY=700 m, ΔZ=700 m ,Total Length= 3500 m,Total width = 3500m
Fixed Grid : Block No. I Direction = 5 , Block No. I Direction = 5
No LGR



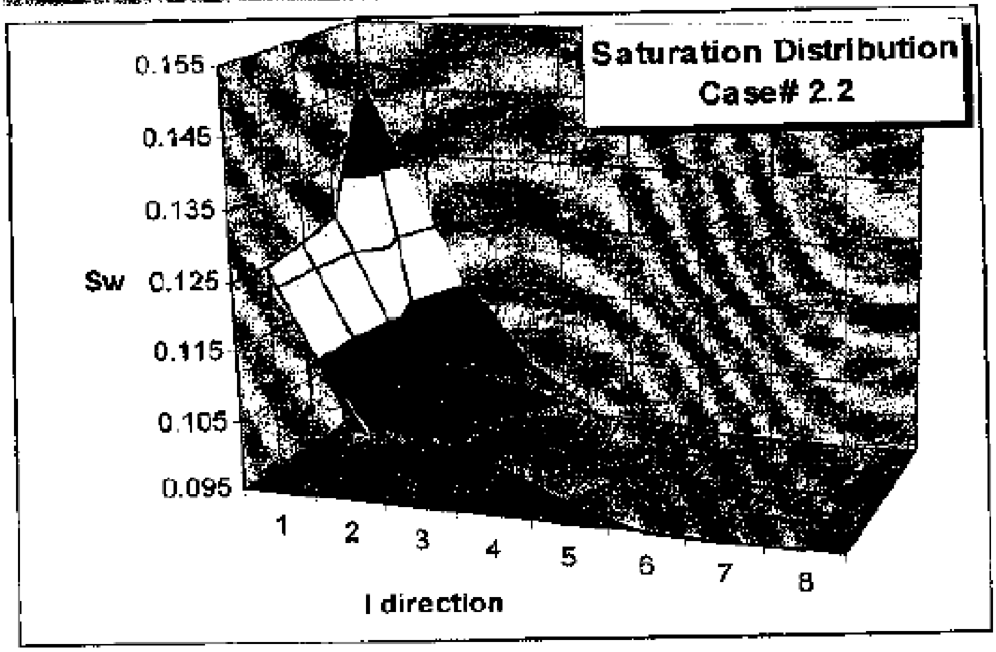


[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.2013	0.1087	0.0964	0.095	0.095
[illegible]	0.2012	0.1086	0.0963	0.095	0.095
[illegible]	0.2012	0.1086	0.0963	0.095	0.095
[illegible]	0.2013	0.1087	0.0964	0.095	0.095
[illegible]	0.2014	0.1089	0.0966	0.095	0.095

Figure (11) Final results for case No. 2.1.

Case # 2.2

ΔX=700 m, ΔY=700 m, ΔZ=700 m ,Total Length= 3500 m,Total width = 3500m
Initial Grid : Block No. I Direction = 5 , Block No. I Direction = 5
Final Grid : Block No. I Direction = 8 , Block No. I Direction = 5




```
*** Elapsed Time = 10E+03 SEC
  ***DYNAMIC
ACC. TIME =      5000.000 DAYS  DT =      2.812500
 Sw (fraction)
LAYER  1
Acc. Oil Prod.=      .13E+08 Acc. We=      .13E+08  MSTB
```

	1	2	3	4	5	6	7	8
1	0.1275	0.1077	0.1052	0.1024	0.0979	0.095	0.095	0.095
2	0.1284	0.1082	0.1059	0.1034	0.1002	0.095	0.095	0.095
3	0.1299	0.1099	0.1081	0.1057	0.103	0.0952	0.095	0.095
4	0.1483	0.0617	0.0961	0.0935	0.0948	0.095	0.095	0.095
5	0.1299	0.116	0.1034	0.0966	0.096	0.095	0.095	0.095

Figure (12) Final results for case No. 2.2.

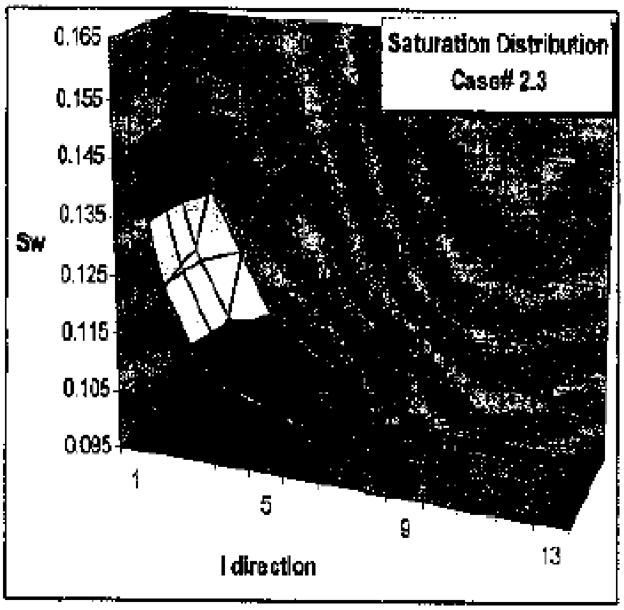
Tiger 2358

Case # 2.3

ΔX = 350 m
ΔY = 700 m
ΔZ = 700 m

Total Length = 3500 m
Total Wide = 3500 m
Net Thickness = 700 m

Initial Grid :
Block No. I direction = 10
Block No. J direction = 5
Final Grid (DLGR) :
Block No. I direction = 13
Block No. J direction = 5



*** [illegible]
Sw (fraction) [illegible]
LAYER [illegible]
Oil Prod [illegible]

J I	[illegible]	2	3	[illegible]	5	6	7
1	0.1467	0.1242	0.1124	0.1089	0.1073	0.1031	0.0958
2	0.1481	0.1261	0.1146	0.1092	0.1076	0.1035	0.096
3	0.1486	0.1268	0.1153	0.1093	0.1078	0.1037	0.0961
4	0.1559	0.1358	0.125	0.1139	0.1093	0.1058	0.0973
5	0.1556	0.116	0.1042	0.0953	0.0947	0.0935	0.095

[illegible]	[illegible]	10	[illegible]	12	13
0.096	0.095	0.096	0.095	0.095	0.095
0.095	0.095	0.095	0.095	0.095	0.096
0.095	0.096	0.095	0.095	0.095	0.095
0.095	0.095	0.095	0.095	0.095	0.096
0.095	0.095	0.095	0.095	0.095	0.095

Figure (13) Final results for case No. 2.3.

[illegible]

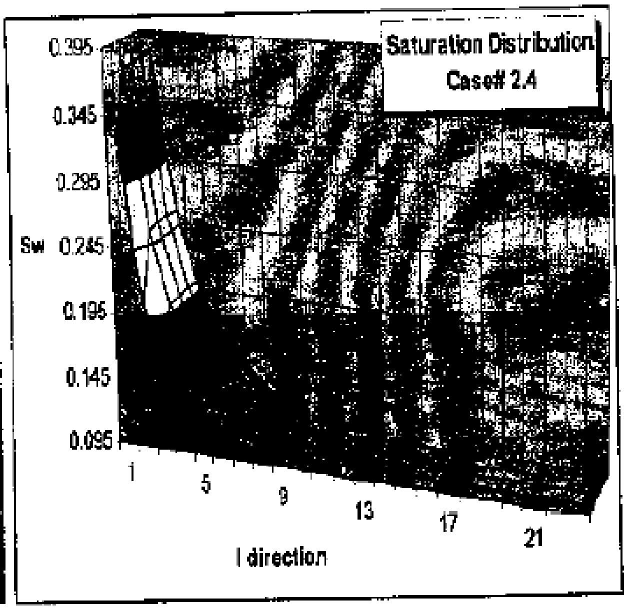
Case # 2.4

$\Delta X = 175$ m
$\Delta Y = 700$ m
$\Delta Z = 700$ m

Total Length = 3500 m
Total Wide = 3500 m
Net Thickness = 700 m

Fixed Grid :
Block No. I direction = 20
Block No. J direction = 5

** No LGR



Elapsed [illegible]
DYNAMIC [illegible]
Sw [illegible]
Acc [illegible] Acc. We [illegible]

	1	2	[illegible]	[illegible]	5	6	[illegible]	[illegible]	9	10
[illegible]	0.3342	0.2042	0.169	0.1558	0.144	0.115	0.1072	0.1032	0.0969	0.095
[illegible]	0.3769	0.2543	0.2001	0.1687	0.1664	0.1282	0.1092	0.1059	0.1023	0.0964
[illegible]	0.3781	0.256	0.2014	0.17	0.167	0.1292	0.1094	0.1062	0.1027	0.0969
[illegible]	0.3782	0.2563	0.2017	0.1704	0.1573	0.1299	0.1098	0.1071	0.1036	0.0982
5	0.3776	0.256	0.2009	0.1701	0.1577	0.1324	0.1193	0.1455	0.0423	0.095

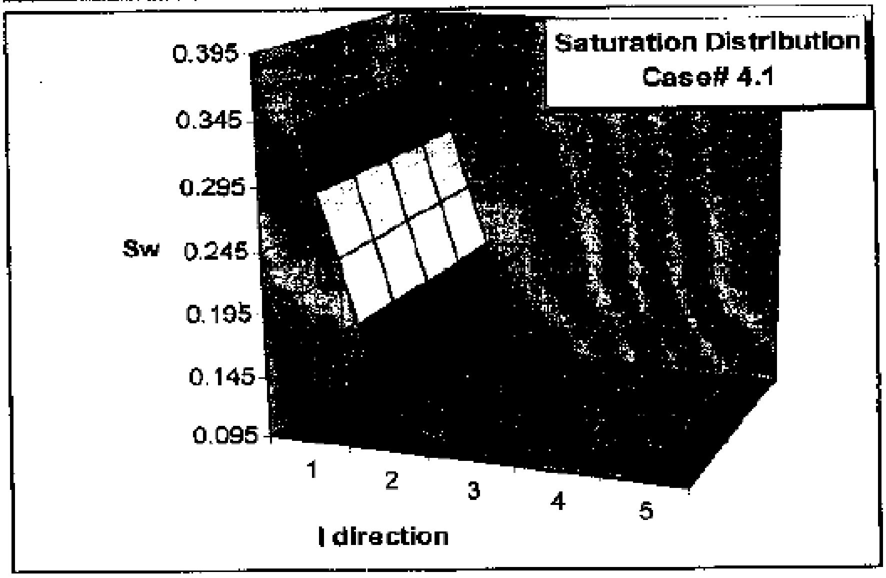
[illegible]	12	[illegible]	14	15	16	[illegible]	18	19	20	21	[illegible]	23
0.095	0.095	0.095	0.095	0.095	0.095	0.096	0.095	0.095	0.095	0.095	0.095	0.096
0.095	0.095	0.095	0.095	0.095	0.095	0.096	0.095	0.095	0.095	0.095	0.096	0.095
0.095	0.095	0.096	0.095	0.095	0.095	0.095	0.095	0.096	0.096	0.095	0.095	0.095
0.096	0.095	0.095	0.095	0.096	0.096	0.095	0.095	0.095	0.095	0.096	0.095	0.095
0.095	0.095	0.095	0.095	0.096	0.095	0.095	0.095	0.096	0.095	0.095	0.095	0.095

Figure (14) Final results for case No. 2.4.

Tiger 2008

Case # 4.1

ΔX=700 m, ΔY=700 m, ΔZ=700 m ,Total Length= 3500 m,Total width = 3500m
Fixed Grid : Block No. I Direction = 5 , Block No. I Direction = 5
No LGR



*** Elapsed Time [illegible] SEC [illegible]
[illegible] DYNAMIC [illegible]
[illegible] TIME [illegible] Day [illegible]
[illegible] fraction) [illegible] LAYER 1 [illegible]
[illegible] Oil Prod [illegible] E+09 [illegible]

	1	2	[illegible]	4	5
1	0.3456	0.1187	0.0999	0.095	0.095
2	0.3453	0.1179	0.0996	0.095	0.095
3	0.3452	0.1179	0.0996	0.095	0.095
4	0.3454	0.1185	0.1001	0.095	0.095
5	0.3456	0.1193	0.1008	0.095	0.095

Figure (15) Final results for case No. 4.1.

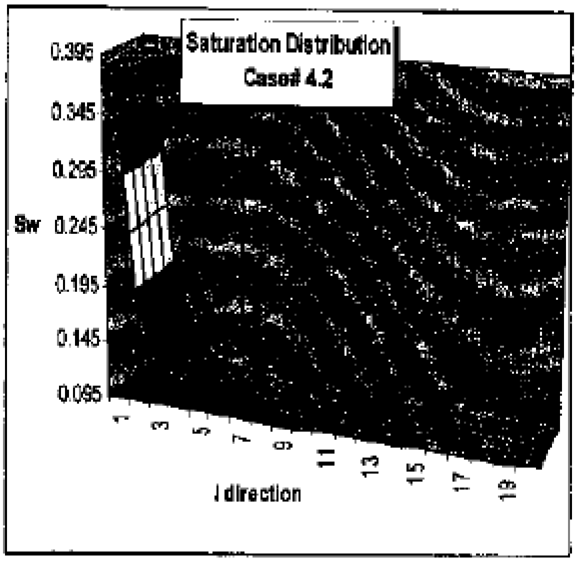
Case # 4.2

ΔX = 700 m
ΔY = 700 m
ΔZ = 700 m

Total Length = 3500 m
Total Wide = 3500 m
Net Thickness = 700 m

Initial Grid :
Block No. I direction = 20
Block No. J direction = 5

** No LGR



[illegible] E+05 Sec
DYNAMIC [illegible]
ACC. TIME = 5000.000 day [illegible]
[illegible]
Acc. Oil Prod. = [illegible] E+05 Acc. [illegible] MSTB

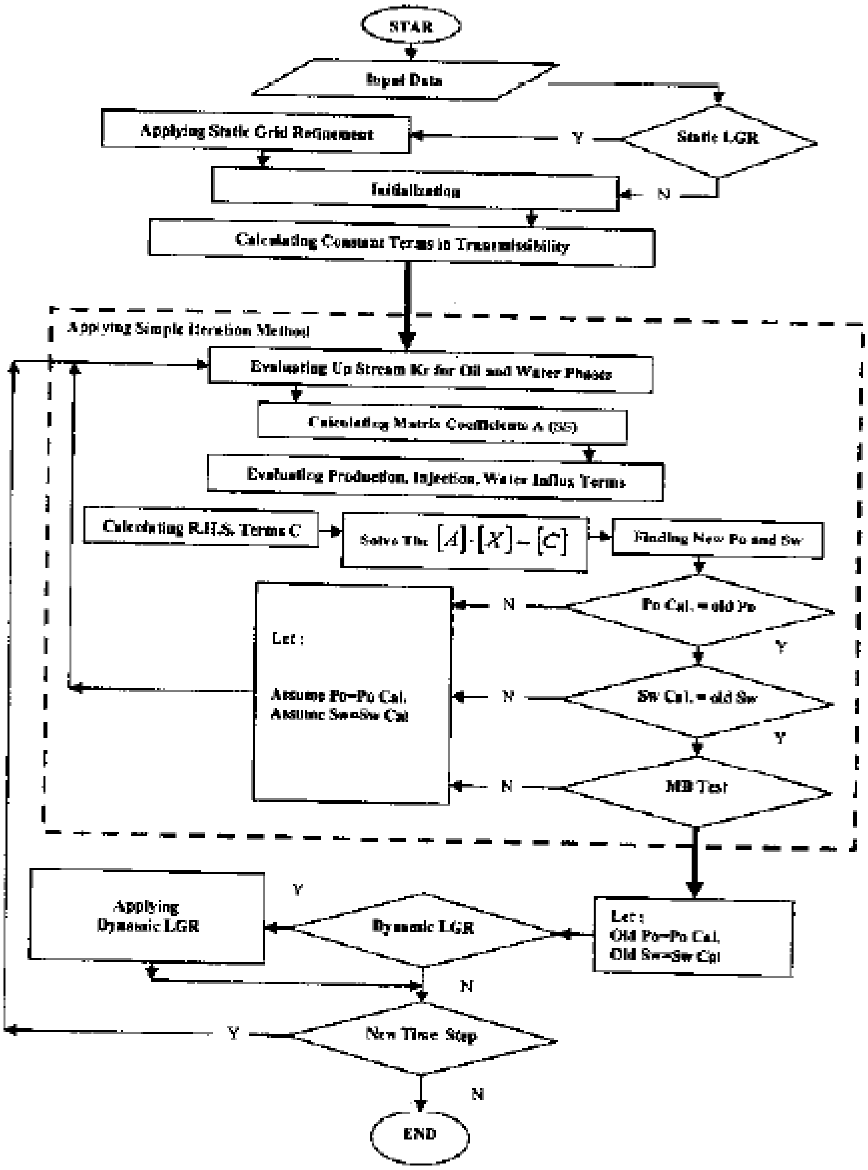
	1	2	3	4	5	6	7	8	9	10
1	0.3764	0.1822	0.1356	0.11	0.1065	0.1028	0.0969	0.095	0.096	0.095
2	0.3765	0.1823	0.1357	0.11	0.1065	0.1026	0.0969	0.095	0.095	0.095
3	0.3766	0.1824	0.1359	0.11	0.1066	0.1029	0.097	0.095	0.095	0.096
4	0.3767	0.1827	0.1362	0.1101	0.1067	0.103	0.0973	0.095	0.095	0.096
5	0.3769	0.1829	0.1364	0.1102	0.1068	0.1032	0.0975	0.096	0.095	0.095

11	12	13	14	15	16	17	18	19	20
0.095	0.095	0.095	0.096	0.095	0.095	0.096	0.095	0.096	0.095
0.096	0.095	0.096	0.095	0.096	0.096	0.095	0.096	0.096	0.095
0.095	0.096	0.095	0.095	0.096	0.096	0.095	0.096	0.096	0.095
0.095	0.096	0.095	0.095	0.095	0.096	0.095	0.096	0.095	0.096
0.096	0.096	0.095	0.095	0.096	0.096	0.095	0.096	0.095	0.096

Figure (16) Final results for case No. 4.2.

Appendix (A)

Flowchart exhibiting the general processes in the simulator.



Appendix (B)

Flowchart demonstrates the general process in dynamic LGR