IMPERIAL COLLEGE LONDON

Department of Earth Science and Engineering

Centre for Petroleum Studies

Upscaling of Relative Permeability to Minimise Numerical Dispersion

By

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A report submitted in partial fulfillment of the requirements for the MSc and/or the DIC.

September 2011

DECLARATION OF OWN WORK

I declare that this thesis *upscaling of relative permeability to minimize numerical dispersion* is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced, and/ or with appropriate acknowledgement given.

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Abstract

Upscaling in numerical reservoir simulation is required when the computer time requirements to run a fine grid simulation of length scale 10-100m becomes too large. In waterflooding and other multiphase flow situations, it may then be necessary to upscale relative permeabilities. Relative permeability curves obtained from laboratory core analysis (core scale, in cm)) are converted to pseudo-relative permeability to reduce numerical dispersion and describe the effects of reservoir heterogenity on flow in simulation models.

Numerical dispersion in reservoir modelling can be caused by the effects of discretizing continous flow properties in discrete gridblocks by commercial simulators using finite difference methods. This phenomenom is seen in the difference between the production rate, recovery and field pressures simulation results of the fine grid model and resulting coarse grid model. Normally pseudos are generated from fine grid simulations. This is in itself a time-consuming process. It would be much quicker if it were possible to derive these pseudos analytically. In addition dynamic pseudo-relative permeability methods tend to predict different pseudos for every grid block in a coarse grid simulation which may result in a very large and unwieldy input data set.

Here we examined an analytic method for deriving pseudofunctions to compensate for numerical dispersion. Three pairs of pseudo-relative permeabilities are required to compensate for numerical dispersion in 1D, 2D homogeneous and heterogeneous systems. One pair for the injector wellblock, one pair for the intermediate wellblock between the wells and one pair for the producer wellblock. The pseudofunctions are well-behaved and maintain the endpoint values of the parent rock curves. The performance of the analytical pseudo-functions does not depend on the gridblock size or nunber of gridblocks present.

In heterogeneous systems, we propose first homogenisation of the model to develop of effective relative permeability and effective absolute permeability. The effective relative permeability can then be converted analytically to pseudo-relative permeability that compensate for numerical dispersion.

The performance of the new upscaling method shows that in production scenarios, pressure changes, water breakthrough and two phase production profile after breakthrough can be predicted by running only the coarse grid simulation for the 1Dimensional model. Moreover, the watercut development profile can adequately be predicted using the performance of the pseudo-functions in the two phase flow regime.

Although, the results we have obtained are accurate for 1D and approximate for 2D systems further investigation is required to extend the approach to 2D and 3D homogeneous and heterogeneous systems and real field applications with many producers and injectors.

Acknowledgements

I utilize this opportunity to express my utmost high gratitude to my college supervisor, Dr. Ann Muggeridge, for her support guidance and direction throughout the duration of the project.

Also, I wish to profoundly thank my family for their support and love during the course of my Msc Program, and finally thank my fellow Msc, Petroleum Engineering students whose encouragement had helped to see me through this course.

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Here we examined an analytic method for deriving pseudofunctions to compensate for numerical dispersion. Three pairs of pseudo-relative permeabilities are required to compensate for numerical dispersion in 1D, 2D homogeneous and heterogeneous systems. One pair for the injector wellblock, one pair for the intermediate wellblock between the wells and one pair for the producer wellblock. The pseudofunctions are well-behaved and maintain the endpoint values of the parent rock curves. The performance of the analytical pseudo-functions does not depend on the gridblock size or nunber of gridblocks present.

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Introduction

Numerical reservoir simulation is an important tool used in the petroleum industry for reservoir fluid flow description and performance prediction. In recent studies, Batycky et al (1997), Vega et al (2004) and Safian and Ramirez (2008) the fine grid geological models used are of the order 10^5 -10^6 gridblocks. This poses a challenge to meet computational requirements for extremely fine grid geological models. These fine grid models are often coarsened for flow simulation, in which single phase upscaling is required to give suitable average values of absolute permeability and also, input of rock relative permeability to generate flow functions for the coarse gridblocks.

In two phase systems, reservoir fluid flow behaviour cannot be fully characterized by absolute permeability especially when the heterogeneity 'correlation length' is close in size to the gridblock to be scaled up e.g. a high permeability channel in a lower permeability system and as an extensive narrow shale barrier in a high permeability system following the analysis of Muggeridge (1991), Christie (1996) and Barker and Thibeau (1997). The use of rock relative permeability curves in simulation models may produce numerical dispersion in results such as the smearing seen in the saturation – dimensionless distance profile. Numerical dispersion phenomena can be attributed to the discretization of continous flow variables in gridblocks combined with the use of coarse grid models. The size of the gridblocks and time steps taken can affect the quantity and level of numerical dispersion in coarse grid models, with larger gridblock sizes having higher levels of dispersion (Lantz, 1971). Pseudo-relative permeability functions can be formulated from laboratory relative permeability curves to scale up multiphase fluid flow property in coarse grid models and reduce numerical dispersion in simulation results. These pseudo-functions can be formulated analytically (Hewitt et al, 1998), and numerically (Barker and Dupouy, 1996).

Numerically formulated or dynamic pseudo-functions are obtained from the results of the simulation of a fine grid model. These dynamic pseudofunctions are generated to reduce numerical dispersion in coarse grid reservoir models. Barker and Thibeau (1997) summarized six dynamic pseudoisation methods. The Kyte and Berry (1975), pore volume weighted and total mobility methods reproduce fine grid results to an extent, however they produce non-single value, negative, and infinite pseudo-relative permeabilities and make severe asssumptions about boundaries. These make them difficult to use. Stone's, weighted relative permeability (Eclipse Simulator Pseudo) and quasi-steady state dynamic methods give poor results due to assumptions on total mobility, restrictive conditions such as neglect of coarse grid gravity term, and neglect of time derivative of saturation respectively which make the methods ineffective when these vary or become significant. The main limitations of most dynamic relative permeability upscaling methods are that a different set of pseudofunctions are needed in every grid cell and flow axis, that the pseudo-relative permeabilities are a function of well position and flowrates and the problem of running the fine grid simulation initially which we are trying to avoid (Barker and Thibeau,1997), (Christie, 1996). These create computational challenges and can present huge and unwieldy input datasets in 3D field simulations.

As a result, there is a significant work investigating the grouping of pseudo-relative permeabilities to reduce the number required. Hewitt et al (1998) analytically investigated this using an approach based on the method of characteristics to define flow variables for grid representations in a waterflood. Their results showed that the changes required to account for discretization effects on a coarse grid depend only on the ratio of the distances from the injection block boundary to the inlet and outlet faces of a particular gridblock i.e. they explained why different pseudo-relative permeabilities are needed in each grid block. They also showed that the required changes on relative permeability are independent of gridblock size and the total number of gridblocks used. However, the method produced increases in oil pseudo relative peameabilities above its endpoint. Christie (1996) used a semi-analytic renormalization technique to deduce effective relative permeability and also suggested in his work that pseudofunctions can be ordered based on flow variables such as minimum of total mobility curve and slope of fractional flow at the shock front height. Barker and Thibeau (1997) suggested that the grouping of pseudo-relative permeability can be based on the different rock types in the coarse grid model. They added that instead of running a full fine grid simulation; a sector model or dual scale simulation models can be used. In the upscaling of heterogeneous fine grid models, Muggeridge (1991) investigated these using multistage simulation methods to show that using pseudo-relative permeability data in homogeneous coarse grid model can illustrate mean properties of flow of the fine grid heterogeneous model.

This study will show, in contrast to the results of Hewitt et al (1998), that only three sets of pseudos are needed to upscale two phase flow in a homogeneous line drive; one pair for the injection well-block , one set for the production well block and another set for other intermediate gridblocks. We will use pseudo relative permeability analytically derived from Buckley Leverett theory to control numerical dispersion for a range of waterfloods. The generated pseudos are tested in a range of homogeneous and heterogeneous, 1D and 2D models. For heterogeneous reservoirs, the pseudoisation method involves two main steps, homogenisation and compensation of numerical dispersion following a method proposed by Muggeridge (1991). The resulting pseudos were input into 1D homogeneous coarse grid models and simulation results of the fine grid and coarse grid models, with and without two phase upscaling were compared. The method was also applied to the control of numerical dispersion in a homogeneous 2D quarter five-spot model. In this case the upscaling was less successful because upscaling needs to include radial flow effects.

Definitions and Concepts of Study

Let us consider an ideal condition of one dimensional continous water injection into a coarse grid reservoir model in which the water displaces the oil in the pore volume of the model gridblocks.The waterflooding is carried out at high flowrates and the inter-block flow occurs in the horizontal direction (x-direction) in a simplified reservoir model with constant connate water saturation S_{wc}, so we can neglect the effects of capillary pressure and gravity. The continous flow of oil and water in the reservoir during displacement are described by Darcy's two phase flow equation for water and oil

$$q_w = -\frac{KK_{rw}(S_w)A}{\mu_w}\frac{\partial P}{\partial x} \quad (1)$$

$$q_o = -\frac{KK_{ro}(S_w)A}{\mu_o}\frac{\partial P}{\partial x} \quad (2)$$

where total flow is given by

$$q_T = q_o + q_w \quad (3)$$

where q_t is the total flowrate in the reservoir.

Assuming immiscible incompressible displacement of oil by water, the fractional flow of water developed by Leverett (1941) can be given as a fraction of the total flow.

$$f_w = \frac{q_w}{q_w + q_o} \quad (4)$$

where q_o and q_w are oil and water phase interblock flowrates respectively. We also express fractional flow as a function of relative permeability and viscosity ratio of oil and water. (Leverett, 1941)

$$f_w = \frac{1}{1+\frac{K_{ro}(S_w)\mu_o}{K_{rw}(S_w)\mu_w}} \quad (5)$$

The mobility of oil and water in the displacement is represented by the ratio of the relative permeability to fluid viscosities of oil and water and are given by

$$\lambda_w = \frac{K_{rw}(S_w)}{\mu_w} \quad (6)$$

$$\lambda_o = \frac{K_{ro}(S_w)}{\mu_o} \quad (7)$$

Therefore the mobility of oil and water at a point can be said to be a function of the water saturation at that point in any gridblock. For the displacement of oil by water in one dimension, the total mobility is

$$\lambda_T = \lambda_W + \lambda_O \quad (8)$$

The displacement of oil by water can be described analytically by Buckley & Leverett (1942) Frontal Advance Theory for one dimensional displacement. The Frontal Advance Equation showing the relationship between change in distance, saturation and fractional flow (Buckley & Leverett, 1942)

$$\frac{\partial x}{\partial t} = \frac{q_t}{A\phi}\frac{\partial f_w}{\partial S_w} \quad (9)$$

This gives rise to a characteristic, dimensionless velocity which is equivalent to the slope of the fractional flow curve at a particular saturation (Welge 1952).

$$v = \frac{df_w}{dS_w} = \frac{\Delta f_w}{\Delta S_w} \quad (10)$$

This shows that each saturation moves through the reservoir with a velocity equivalent to the slope of the fractional flow curve at that saturation. Given a table of relative permeability and water saturation using equation 5, the shock front saturation can be obtained using Welge construction method (Welge, 1952). Inspection of equations 4 and 5, we observe that the fractional flow curve is affected by fluid viscosity ratio for a constant rate horizontal displacement.

Formulation of Pseudo-Relative Permeability Curves

Here we will summarize the analysis of pseudo-relative permeabilities to compensate for numerical diffusion that was originally derived by Muggeridge (private communicaton). The rock relative permeability is calculated and tabulated. (refer to Appendix B1 for correlations).

Figure 1 shows the non-uniform saturation of the last gridblock and the smearing it caused at its outlet face due to the discretization of continous flow varaible. Numerical diffusion occurs because finite difference reservoir simulators calculate an average saturation and assumes this saturation is uniform within the gridblock and evaluates the flow downstream the gridblock in the next timestep based on this average saturation characterized by a saturation front and its relative permeability. But in reality, the saturation within the gridblock may not be uniform as shown in Figure 1 and may be less than the average saturation. A flowrate which is evaluated based on the average saturation will not be representative and may cause numerical diffusion or smearing seen in a saturation distance profile. The fewer the number of gridblocks between well locations then the higher the numerical diffusion levels (Lantz, 1971).

The Buckley Leverett shock front describes the sudden increase in saturation from immobile connate water saturation to mobile water saturation, therefore the velocity of the shock front should determine the water breakthrough time in a homogeneous reservoir model. The increase in watercut in the produced fluid will depend on the shock front saturation level and the rise behind it to the $1 - S_{or}$ water saturation level (rarefaction) (Buckley & Leverett, 1942).

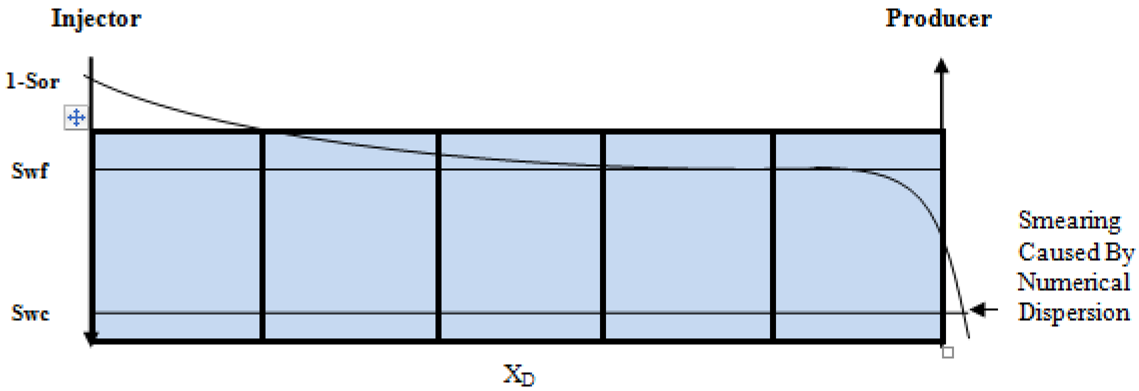


Figure 1 Saturation distance profile showing inter-gridblock saturation distribution and smearing of the last gridblock caused by numerical dispersion.

The accurate prediction of the breakthrough time and watercut profile in field reservoir studies and their effect on production rate, recovery and reservoir pressure depends on the accurate depiction of this saturation distance profile. Moreover, reservoir engineers can predict reservoir decline curve much better, improve field life and economics and surface facilities management. Consequently, this accurate prediction depends on our ability to reduce numerical dispersion observed to as low as possible in our flow simulation models.

We will formulate two pairs of pseudo-relative permeabilities using Buckley Leverett analytical solution (Buckley & Leverett, 1942) and the concept of change in fractional flow with change in saturation (Leverett 1941, Buckley & Leverett 1942). A pair of laboratory rock curves will be input into the inlet gridblock to the injection wellblock and also into the production wellblock. One pair of formulated pseudo-relative permeabilities will be input into the injector wellblock and the second pair of pseudo-relative permeabilities input into intermediate non-well blocks between the injector wellblock and producer wellblock. These pseudos will be tested in homogeneous one dimensional and two dimensional models undergoing linear waterflooding. The pseudo-relative permeabilities will also be tested in three two dimensional heterogeneous models to understand the effect of sub-grid scale heterogeneity on flow and recovery (Muggeridge, 1991) and reduce numerical dispersion.

Injector Wellblock

When the shock front reaches the outlet face of the injector wellblock i, the average saturation in the gridblock is calculated analytically by

$$\overline{S_w} = \frac{1}{\Delta x}\int_{x_{i-\frac{1}{2}}}^{x_{i+\frac{1}{2}}} S_w(x)\,dx \qquad (11)$$

$S_w(x)$ can be obtained from Buckley & Leverett saturation versus distance plot at any distance and Δx is the size of any gridblock. Relative permeability values for saturations less than this average saturation in the rock curve table is equated to zero to depict the Buckly Leverett continuos solution. (Buckley & Leverett, 1942). We call this new value water pseudo-relative permeability which is recorded in the pseudo-rock table as K_{rwp} . This instructs the simulator to equate to zero flowrates and relative permeabilities for water saturations lower than the gridblock average and numerical dispersion can be reduced

$$K_{rwp} = 0 \qquad S_{wj} < \overline{S_{wf}} \qquad (12)$$

For a rock curve and water saturation table, the discretized solutions to our derived analytic equations (refer to Appendix B for the analytic derivations and equations) to upscale our coarse grid models will be done using 1D finite difference approximation in line with most commercial simulators. Most commercial simulators make use of single point upstream weighting finite difference approximation. Now, consider the shock front saturation moving at a velocity obtained from equation 13, the dimensionless time it requires to reach the outlet face of the gridblock is

$$\tau = \frac{S_{wf} - S_{wc}}{f_{wJ}} \qquad (13)$$

where f_{wJ} and S_{wf} are the fractional flow and water saturation of the shock front in the rock curve table. In addition, individual water saturations higher than the shock front in the rock curve table will move a distance given by when the shock front reaches the gridblock outlet face

$$x_j = \frac{f_{wj} - f_{w(j+1)}}{S_{wj} - S_{w(j+1)}} \times \frac{S_{wf} - S_{wc}}{f_{wJ}} \tag{14}$$

We to obtain pseudo-total mobility $\Psi_T(S_{wJ})$ required by the shock front water saturation to reach the gridblock outlet face

$$\frac{1}{\Psi_T(S_{wJ})} = \frac{S_{wf} - S_{wc}}{f_{wJ}} \sum_{j=J}^{j=n} \left[\frac{f_{wj} - f_{w(j+1)}}{S_{wj} - S_{w(j+1)}} - \frac{f_{w(j+1)} - f_{w(j+2)}}{S_{w(j+1)} - S_{w(j+2)}}\right] \frac{1}{\lambda_{T_J}} \tag{15}$$

In the saturation distance profile in Figure 1, due to the discontinuity of the shock front, the average saturation over a distance is calculated with saturations higher than the shock front using the analytical Buckley & Leverett solution. (Buckley & Leverett, 1942). For water saturations in this range and higher than the shock front saturation we can compute their velocities and distance. This velocity is a function of the water pseudo-total mobility $\Psi_T(S_{wj})$ obtained by

$$\frac{1}{\Psi_T(S_{wj})} = \left(\frac{S_{wj} - S_{w(j+1)}}{f_{wj} - f_{w(j+1)}}\right) \sum_{j=j}^{j=n} \left[\frac{f_{wj} - f_{w(j+1)}}{S_{wj} - S_{w(j+1)}} - \frac{f_{w(j+1)} - f_{w(j+2)}}{S_{w(j+1)} - S_{w(j+2)}}\right] \frac{1}{\lambda_{T_j}} \tag{16}$$

where S_{wf} and S_{wj} are shock front saturation and rock table water saturation.

The pseudo-water mobility is obtained by

$$\frac{\lambda_w}{\lambda_T} = \frac{\Psi_w(S_{wj})}{\Psi_T(S_{wj})} \tag{17}$$

where λ_w and λ_T are the rock water and rock total mobilities and $\Psi_T(S_{wj})$ and $\Psi_w(S_{wj})$ are the total and water pseudo-mobility. We calculate water and oil pseudo-relative permeability from the water and total pseudo-mobility by

$$K_{rwp}(S_{wj}) = \Psi_w(S_{wj}) \times \mu_w \qquad S_{wj} \geq \overline{S_{wf}} \tag{18}$$

$$K_{rop}(S_{wj}) = \left(\Psi_T(S_{wj}) - \Psi_w(S_{wj})\right) \times \mu_o \qquad S_{wj} \geq \overline{S_{wf}} \tag{19}$$

Water saturations lower than the shock front saturation remains the same on the pseudo-relative permeability table. The oil pseudo-relative permeability is obtained from

$$\frac{1}{\Psi_{oj}} = \left(\frac{S_{wj} - S_{wc}}{S_{wf} - S_{wc}}\right) \frac{1}{\Psi_{Tj}} + \left[1 - \left(\frac{S_{wj} - S_{wc}}{S_{wf} - S_{wc}}\right)\right] \frac{1}{\lambda_o(S_{wc})} \tag{20}$$

Now, we can calculate the oil pseudo-relative permeability K_{rop} by

$$K_{rop}(S_{wj}) = \Psi_O(S_{wj}) \times \mu_o \qquad S_{wj} < \overline{S_{wf}} \tag{21}$$

Using Welge (1952) formulation for average saturation behind the shock front, we replace the rock table water saturations with average saturations for the saturation range $S_{wj} \geq S_{wf}$ using

$$\overline{S_{wJ}} = S_{wj} + \frac{(1 - f_{wj})(S_{wj} - S_{(j+1)})}{(f_{wj} - f_{w(j+1)})} \tag{22}$$

where S_{wj} is the water saturation obtained from the rock relative permeability table.

Non-Injector Gridblock

Immediately after the injector wellblock, the non-injector wellblock flow properties were also modified. For water saturations lower than the shock front saturation, the relative permeability is equated to zero for the same reason as the injector wellblock.

$$K_{rwp} = 0 \qquad S_{wj} < S_{wf} \tag{23}$$

We calculate the pseudo oil mobility for water saturations less than the shock front saturation with

$$\frac{1}{\Psi_{oj}} = \frac{1}{\lambda_T(S_{wf})}\left(\frac{S_{wj}-S_{wc}}{S_{wf}-S_{wc}}\right) + \left[1-\left(\frac{S_{wj}-S_{wc}}{S_{wf}-S_{wc}}\right)\right]\frac{1}{\lambda_o(S_{wc})} \qquad S_{wj} < S_{wf} \tag{24}$$

$\lambda_o(S_{wc})$ and $\lambda_T(S_{wf})$ are rock oil mobility at the connate water saturation and rock total mobility at the shock front saturation respectively. The oil pseudo-relative permeability K_{rop} is obtained by

$$K_{rop}(S_{wj}) = \Psi_o(S_{wj}) \times \mu_o \qquad S_{wj} < \overline{S_{wf}} \tag{25}$$

For saturations greater than the shock front saturation we use the same saturation and relative permeabilities in the rock table as in the pseudo-relative permeability table. We assume that the saturation in the gridblock is alike at the inlet and outlet and there is no need changing them with average saturations (refer to Appendix B for the explanation).

Methodology

Simulation Study

For the 1D, 2D homogeneous areal models and the 2D heterogeneous cross-sectional models, the steps outlined below were followed to investigate whether the upscaling of relative permeability using our pseudo-relative permeability curve does reduce numerical dispersion in the simulation of waterfloods through homogeneous and heterogeneous reservoirs:

1. Perform 1D and 2D homogeneous and heterogeneous fine grid simulations
2. Development of coarse grid models from fine grid models
3. Upscaling of absolute permeabilities in the resulting coarse grid models using conventional analytical methods (Christie 1996) for homogeneous and heterogeneous systems..
4. Formulation of Pseudo-relative permeabilities using Spreadsheet.
5. Input of rock and pseudo relative permeability curves obtained from a spreadsheet into coarse grid models.
6. Carry out 1D and 2D homogeneous and heterogeneous coarse grid simulations for:
    A. Models with upscaled relative permeability data
    B. Models with non-upscaled relative permeability data

A commercial black oil reservoir simulation program [reference] was used in this study.

1D Homogeneous Model

The pseudo-relative permeability functions were tested on 1D Cartesian coarse grid models which were a result of the coarsening process of a fine grid model currently undergoing waterflooding. The 1 Dimensional fine grid model was a 202 × 1 × 1 (x, y, z directions) Cartesian grid undergoing a linear water-drive. The model has one injector well at location (1 1 1) and producer well at gridblock (202 1 1). The initial reservoir pressure was 4000psia and the bubble point is very low compared to reservoir pressure to typify a simple black oil reservoir model. The fluid components of the reservoir are incompressible oil and water. There is no aquifer effect on the reservoir model. The fine grid is homogeneous in permeability in the *x*, *y* and *z* directions and have a net to gross of 1. The fluid viscosity ratio is 4 and the rock relative permeability input is the same as that used in the pseudoisation. The water is injected at a constant rate of 6500bbl/day at a pressure of 8000psia and oil is produced at the same rate, ensuring pore volume injected is equal to pore volume produced. The reservoir is produced such that the pressure remains above the bubble point pressure and gas is not evolved. The waterflooding is carried out for 6000days. The bottom-hole pressure for the producer is set at very low limit and the system is designed for rate control. The fine model was uniformly coarsened (except the injector inlet gridblock) by a factor of 40 and 20 reducing into 5 ×1 and 10 × 1 coarse grid models.

We avoided the need for modification of transmissibilities and scale-up of the wellblock during the coarsening process by maintaining the same dimensions for the inlet gridblock to the injector wellblock in the coarse grid models as in the fine grid model. (Ding & Renard 1994, Muggeridge et al 2002). We had two coarse grid models of 7gridblocks and 12gridblocks. In the heterogeneous models the absolute permeability is scaled-up or averaged using the pressure solver steady state technique (Christie, 1996).

Since the fine model is homogeneous, the coarse grid models are also homogeneous in absolute permeability for transmissibilities calculation as the fine grid models. Simulation results of recovery, flowrates and field pressures for fine grid, coarse grid and upscaled coarse grid were compared. The parameters of the model are shown in Table 1.

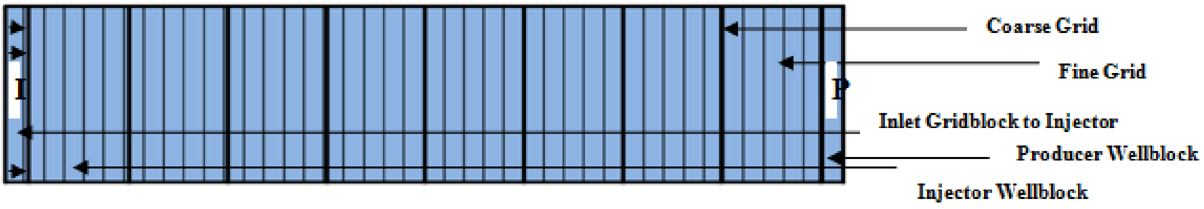


Figure 2. Fine grid and coarse grid showing the injector inlet gridblock.

Table 1 1D Fine Grid Model Paramenters;

Porosity	0.2
Oil Formation Volume Factor	1.0rb/stb
Water Formation Volume Factor	1.0rb/stb
Water Viscosity (cP)	0.5
Oil Viscosity (cP)	2.0
Water Compressibilty	3.03E-6/psia
Rock Compressibility	0.30E-05/psi
Uniform Permeability in Homogeneous Model	200md
Water Relative Permeability Endpoint	0.3
Oil Relative Permeability Endpoint	0.9
Residual Oil Saturation	0.1
Connate Water Saturation	0.2
Initial Reservoir Pressure	4000psi
Reservoir Dimension (ft)	3000×2000
Reservoir Thickness (ft)	100
Injector Well Location:	(1 1 1)
Producer Well Location	(202 1 1)

2D Homogeneous Model

The pseudofunctions were also tested on 2D synthetic rectangular areal models undergoing waterflooding. The model is a Cartesian 26 × 26 ×1 (x, y, z) fine grid model equivalent to a quarter-five spot field pattern.The injector wellblock and producer wellblocks occupy extreme opposite corners of the model as shown in Figure 3. The injector wellblock location is 26 × 1× 1while the producer wellblock location is 1×26×1.It has the same reservoir fluid model and rock and fluid properties as the 1D model. Waterflooding was carried out at a constant rate of 7500bbl/day and oil rate maintained at the same constant rate before and at water breakthrough. The secondary recovery was carried out for a period of 4000days. The model is homogeneous in permeability and net to gross is 1. The fine grid was coarsened to three coarse grid models of 6 × 6 ×1, 8 × 5 × 1, and 5 × 5 ×1. The main model parameters are shown in Table 2. The fine grid multiphase flow is represented by rock relative permeability curves used in the pseudoisation.

Two models of each coarse grid were generated and the multiphase flow property of one was upscaled. The 3pairs of rock relative permeability were input into the coarse grids and simulation results compared for compensation of numerical dispersion just as in the case of 1D model.

Table 2 2D Homogeneous Model Parameters

Porosity	0.2
Oil Formation Volume Factor	1.000rb/stb
Water Formation Volume Factor	1.000rb/stb
Water Viscosity (cP)	0.5
Oil Viscosity (cP)	2.0
Water Compressibilty	3.03E-6/psi
Rock Compressibility	0.30E-05/psi
Uniform Permeability in Homogeneous Model	400md
Water Relative Permeability Endpoint	0.3
Oil Relative Permeability Endpoint	0.9
Residual Oil Saturation	0.1
Connate Water Saturation	0.2
Initial Reservoir Pressure	4000psi
Reservoir Dimension (ft)	3000 ×1000
Reservoir Thickness (ft) .	100
Injector Well Location:	(26 1 1)
Producer Well Location	(1 26 1)

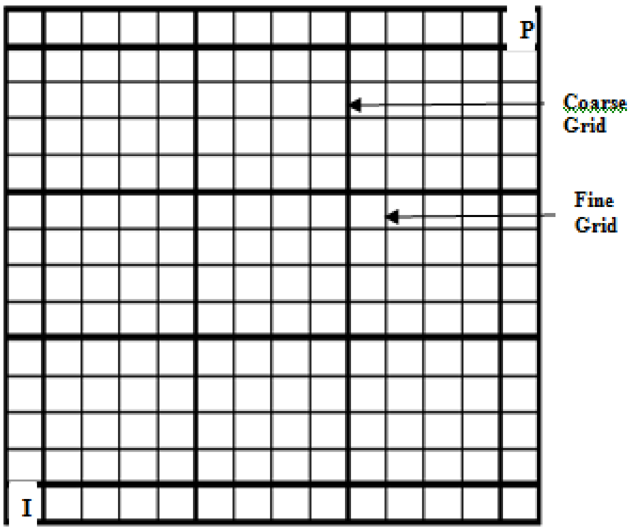


Figure 3 2D Homogeneous Fine Grid and Coarse Grid

Table 3 2D Heterogeneous Model Parameter

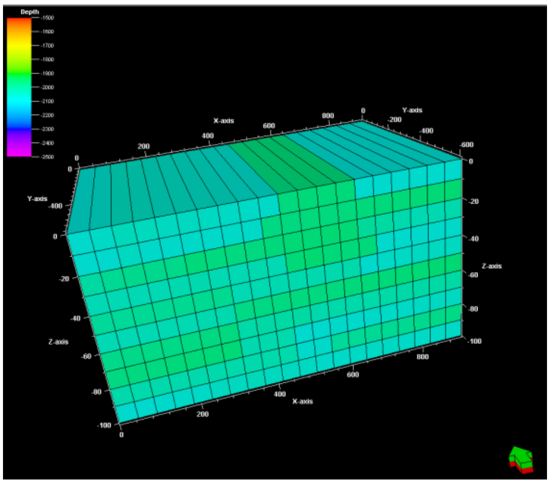
Porosity	0.2
Oil Formation Volume Factor	1.000rb/stb
Water Formation Volume Factor	1.000rb/stb
Water Viscosity (cP)	0.5
Oil Viscosity (cP)	2.0
Water Compressibilty	3.03E-6/psi
Rock Compressibility	0.3E-05/psi
Range of Permeability in Heterogeneous Layer Model	500-50md
Standard Deviation for Random Correlated System	20
Mean Permeability for Random Correlated System	100md
High Permeability Channel Range	49-150md
Water Relative Permeability Endpoint	0.3
Oil Relative Permeability Endpoint	0.9
Residual Oil Saturation	0.1
Connate Water Saturation	0.2
Initial Reservoir Pressure	4000psia
Reservoir Dimension (ft)	3000 ×1000
Reservoir Thickness (ft)	100
Injector Well Location:	(20 1 10)
Producer Well Location	(1 20 10)

2D Heterogeneous Model

We also tested the pseudo-relative permeabilities in three simple heterogeneous vertical cross-section models. The fine grid models were a Cartesian grid of 20×1×10 (x, y, z directions) dimensions. They had absolute permeabilities ranging between 50-150md which were randomly correlated, high-permeability channels in a low permeability system and a layered reservoir system respectively. The fluid model of the 1D and 2D homogeneous and 2D heterogeneous systems were the same.The general parameters of the models are shown in Table 3. In the random-correlated model, the water was injected at constant rate of 2500bbls/d and pressure and the producer had the same oil flowrate till water breakthrough.The permeabilities were generated using a random number generator with normal distribution and standard deviation of 20 and mean of 100md. The secondary recovery was carried out in 6000days.

The layered model had an increasing absolute permeability from the top to the bottom layer. The water injection flowrate was 9800bbl/d and oil rate was equal to the water injection rate before and at water breakthrough. Waterflooding and oil production were carried out in 4000days. In the channel reservoir, the water injection rate and oil production rate before breakthrough was 1450bbl/day. The water injection was carried out at pressure of 8000psia. Waterflooding and production of the reservoir was carried out in 6000days.

The calculated oil and water relative permeabilities were input in each of the models with a viscosity ratio of 4 between the oil and water. Each fine grid model was coarsened by undergoing two steps – homogenization of the heterogeneous fine grid into a 1D 4×1×1 (x,y,z) coarse grid models following an approach used by Muggeridge (1991) and calculation of relative permeability for the coarse grid models from simulation results of the fine grid model using the Johnson, Bossler and Naumman (1957) and the Jones and Roszelle methods (1978). The relative permeabilities calculated are input into one copy of the coarse grid models. The pseudoisation method of section two was carried out on the deduced oil and water relative permeabilities using the JBN method (Jones and Roszelle, 1978). One pair of rock relative permeabilities and two pairs of pseudo-relative permeabilities were input into the second copy of the coarse grid models just as the 1D and 2D homogeneous models and simulation results were compared for effects of heterogeneity representation in the coarse grid and compensation of numerical dispersion.



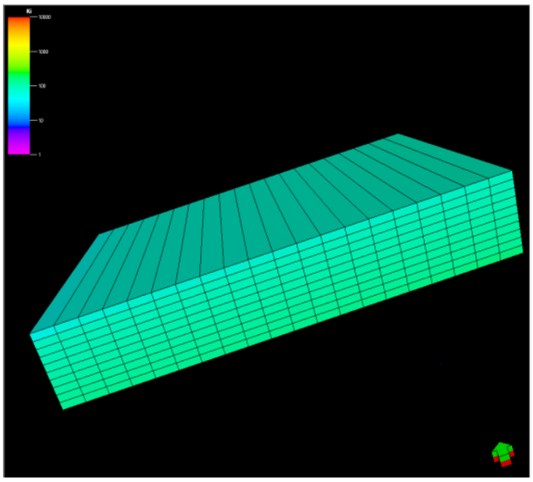
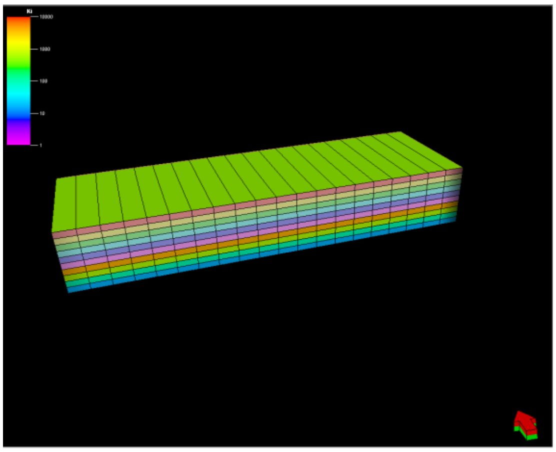


Figure 4(a) 2D Heterogeneous Channel Model; Figure 4(b) 2D Heterogeneous Random Permeability Model

Figure 4(c) 2D Heterogeneous Layered Model



Pseudoisation Results

1Dimensional Pseudo-Relative Permeability Formulation

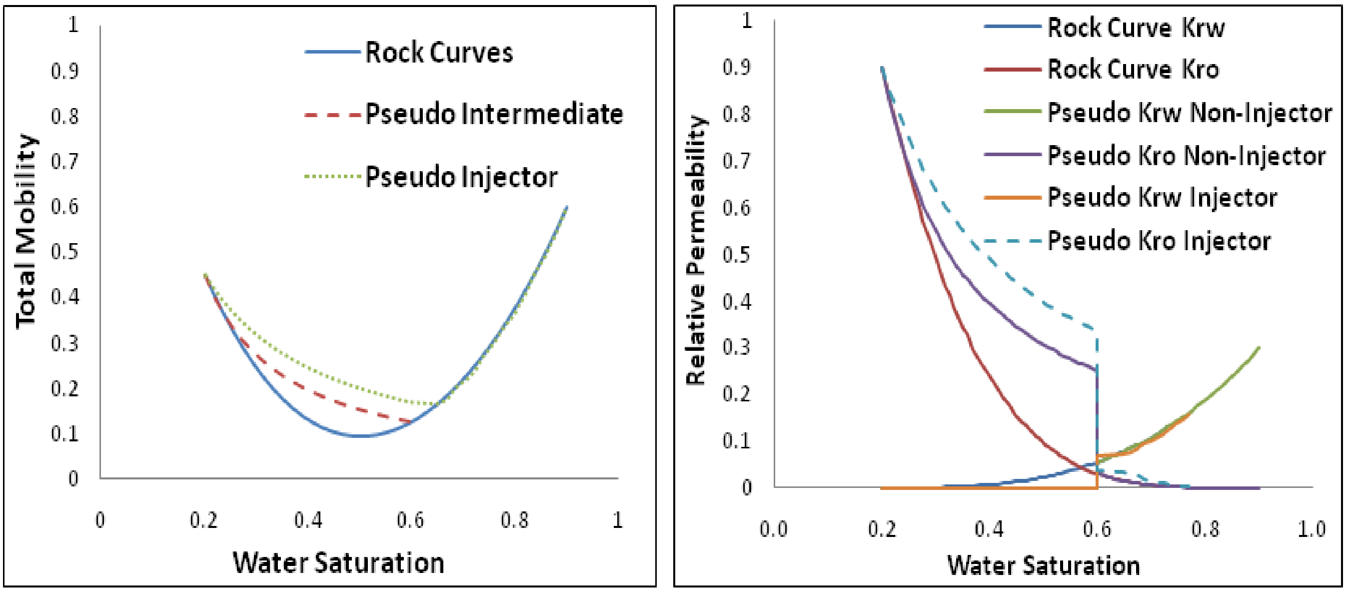


Figure 5(a) Total Mobility Plot for 1D and 2D Homogeneous; (b) Pseudo-relative permeability and relative permeability curve for the 1D derived Pseudos for 1D and 2D Homogeneous.

Figure 5(b) shows the pseudo-relative permeabilities generated from the rock curves for the 1D and 2D homogeneous case.The oil pseudo-relative permeability curves obtained moved to the right of the rock curves. This shows the classical shape of pseudofunctions required to reduce numerical dispersion as was also seen in the work of Barker and Dupuoy (1999). The two oil pseudos start at $1-S_{or}$ and had similar values as the rock oil relative permeabilities curve then suddenly rise above the rock curves at water saturations equal to 0.75, then increased further at the shock front of 0.598 rising to the same rock oil curve endpoint of 0.9. This is a difference to the outcome of Hewitt et al (1998) analysis in which their oil relative permeability rose above 1.0. The water pseudo obtained are very similar to the water rock curves from the shock front saturation of 0.598 to $1-S_{or}$ of 0.9. At lower water saturations to the S_{wc} the water pseudos remain at zero.

Figure 5(a) shows the rock curve and pseudo total mobilities calculated in equation 32, 33 and 36 in which at S_{wc} the rock total mobility was 0.45 which reduces to the shock front saturation and then increase to 0.6 at S_w equal to 0.9. The oil mobility for the intermediate gridblock decreased as the water saturation increases. The total mobility for the injector wellblock decrased from S_{wc} and reached a minimum at the average water saturation and then increased to 0.6. Pseudo-relative permeability and total mobility plots (please refer to Appendix B3) for the heterogeneous channel and layered system showed similar classical shape of pseudos that reduce numerical dispersion.

Simulation Study Results

1D Homogeneous Model Results

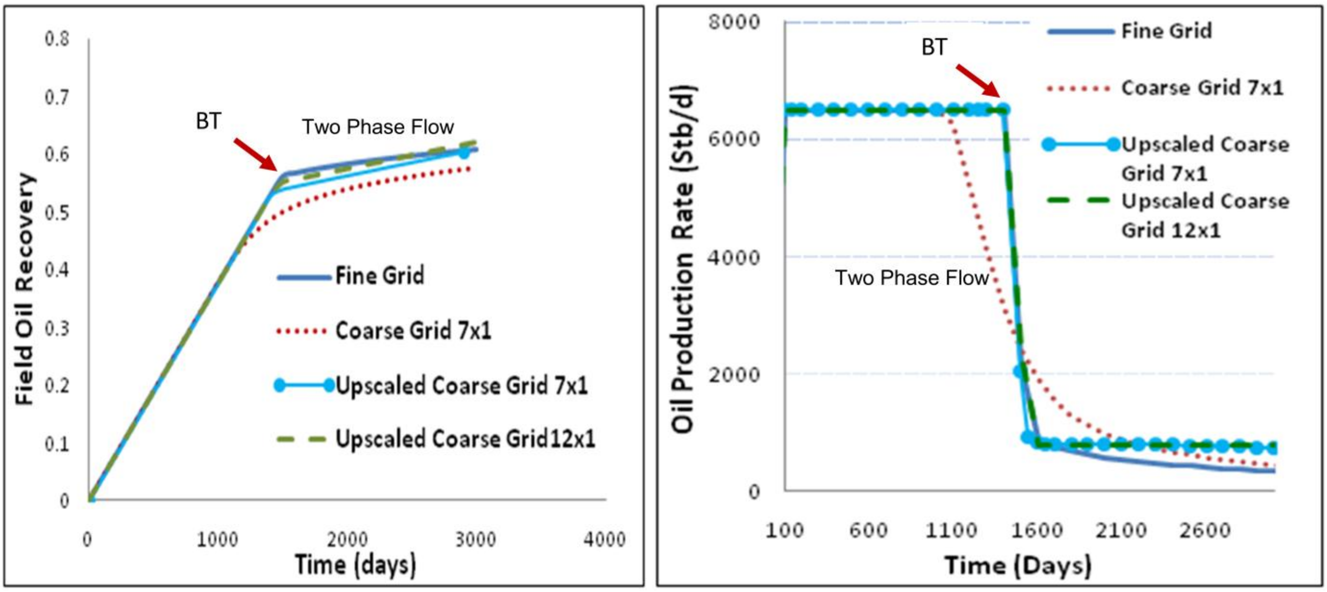


Figure 6(a) Production Rates of 1D Homogeneous Fine Grid and Coarse Grids; 6(b) Field Recoveries of 1D Homogeneous Fine and Coarse Grids

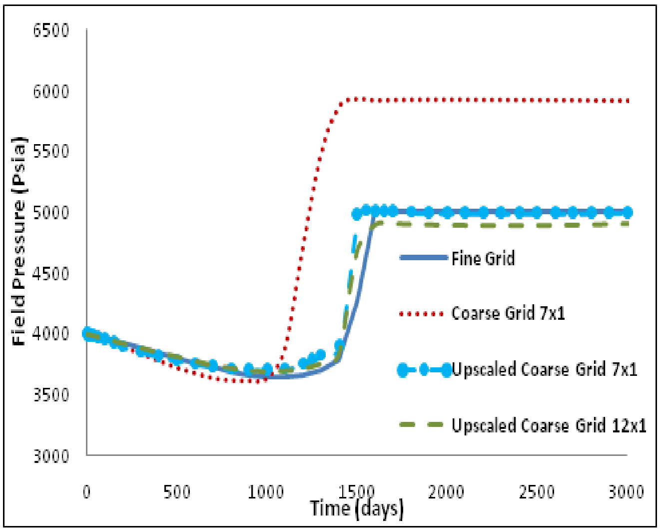


Figure 6(c) Comparison of Field Pressures for the 1D Homogeneous fine grid, upscaled coarse grid and standard coarse grids
The first case study is the 1D homogeneous model with permeability of 200md. The analytically derived pseudo-relative permeabilies was tested in a 1D model. The effect of numerical dispersion was observed in the oil production rates, field recovery and field pressures. The ability of the two upscaled coarse grid models to reproduce the results of the fine grid model was also evaluated. Figure 6(a) shows the comparison of oil production rate for the fine grid, 7×1 coarse grid and upscaled 7×1 and 12×1 coarse grids using the new pseudos. The standard coarse grid produced oil at the rate of 6500bbls/d and had its breakthrough earlier than the fine grid, upscaled coarse grids predicted breakthrough at exactly the same time as the fine grid model. After breakthrough, the fine grid had a similar two phase flow gradient with the upscaled 12×1 coarse grid and 7×1 coarse grid. The upscaled grids have been able to reduce numerical dispersion by 300days at breakthrough and predict similar water cut profile for 12×1 coarse grid and 7×1 coarse grid with the fine grid. Figure 6(b) shows a comparison of the field oil recovery for the fine grid, standard coarse grid and pseudo-upscaled coarse grids. The 12×1 and 7×1 upscaled coarse grids predicted water breakthrough time closer to the breakthrough time of the fine grid model with the 12×1 upscaled coarse grid the closest. The standard coarse grid predicted breakthrough time much earlier than the fine grid, producing the most incorrect prediction. In figure 6(c) the pressures of the fine grid, coarse grid and upscaled coarse grids were compared. The fine grid and upscaled coarse grids had closer pressure profiles during the course of production. The conventional coarse grid had a pressure profile with the lowest pressure coming earlier and then rising and stabilizing higher than the fine grid model. Production rate, recovery and pressures are a function of flow which is average saturation within the gridblock. The effect of numerical dispersion on saturation has caused the disparity between the fine grid results and coarse grid results. The pseudoisation have reduced the effects of numerical dispersion and improved the results of the upscaled coarse grid. Therefore, with the pseudoisation method, we have been able to a very large extent reproduce the results of the fine grid model.

2D Homogeneous Model Results – Quarter-Five Spot Pattern

The pseudos were also tested on three 2Dimensional coarse grid models. The field production rates, oil recoveries and field pressures results were compared on the fine grid, coarse grid and upscaled coarse grid.
Figure 7(a) shows the water breakthrough time of the 2D fine grid model, standard coarse grid and upscaled coarse grids. The upscaled 8×5 coarse grid, upscaled 6×6 coarse grid and upscaled coarse 5×5 grid had their breakthrough times closer to that of the fine grid model. The upscaled 8×5 coarse grid had the closest breakthrough time prediction to that of the fine grid and the upscaled 5×5 had the farthest. This could be attributed to the fact that the assumption of constant saturation may be less valid in one coarse grid than another. The standard coarse grid had the earliest breakthrough time. The use of the pseudo-relative permeabilities have reduced numerical dispersion in breakthrough time for upscaled coarse grids oil rate results. Figure 7(b) shows a similar water breakthrough time of the oil recoveries of the fine grid, and upscaled 8×5, 6×6 and 5×5 coarse grids. The standard coarse grid had an earlier breakthrough time when compared to that of the fine grid. The pseudoisation method has reduced the errors and reproduced similar breakthrough time for the fine and upscaled coarse grid recovery results.

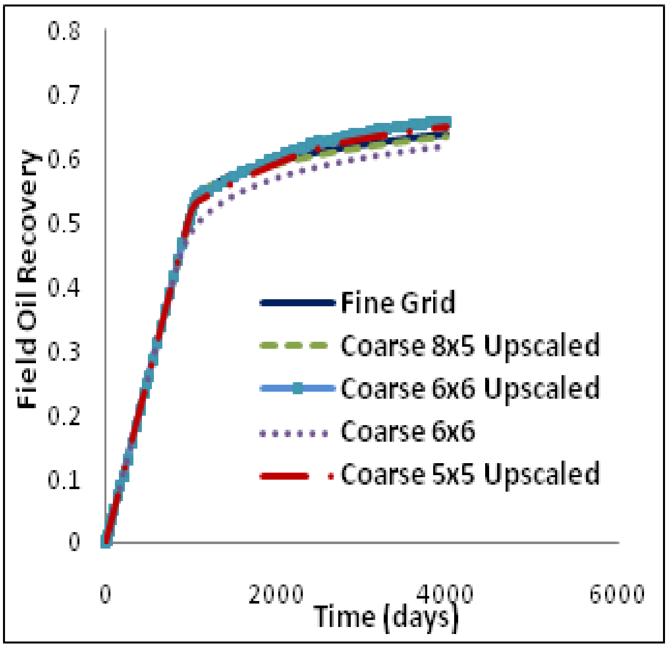


Figure 7 (a) Oil Recovery Comparison for the 2D Homogeneous Models

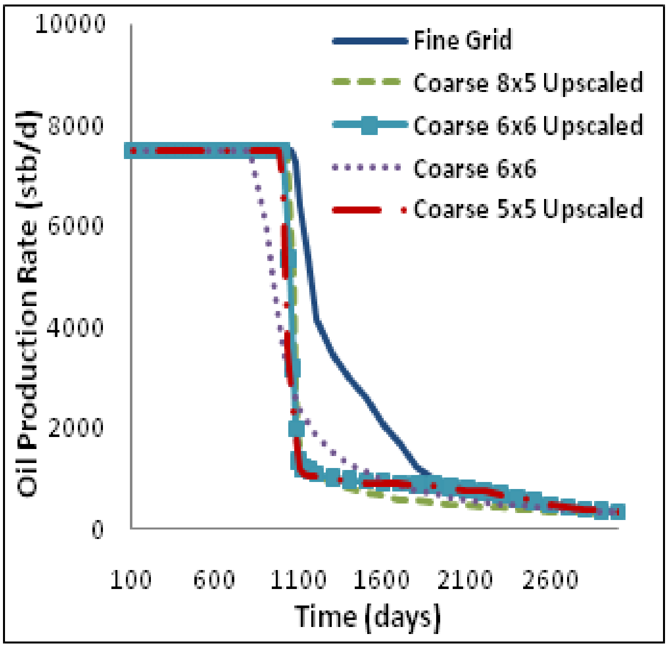


Figure 7(b) Comparison of Oil Production Rate in 2D Homogeneous Models

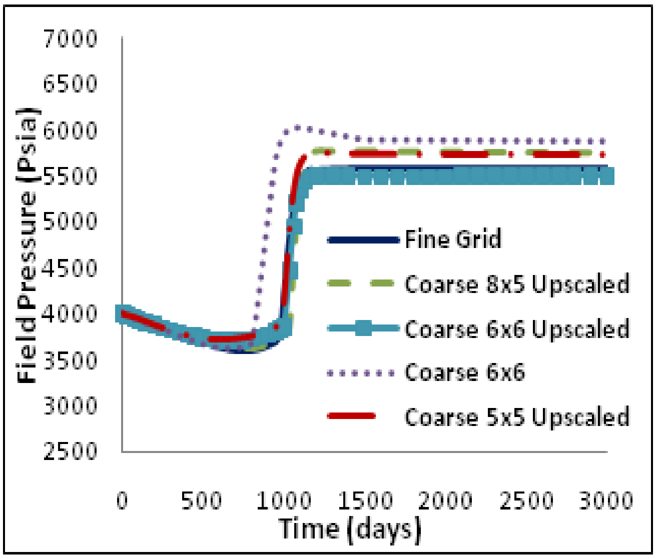


Figure 7(c) Comparison of Pressure Profile in 2D Homogeneous Models

Figure 7(c) showed pressure profiles for the fine grid, upscaled coarse grids and the standard coarse grid. The profiles of the upscaled were closer to the fine grid model with the 8×5 coarse grid having the closest pressure profile. The 5×5 upscaled coarse grid was the furthest of the three. The standard coarse grids predicted earlier pressure decline and rise than the fine grid due to numerical dispersion. The pseudoisation method have given better coarse grid results compared to the fine grid model with the 8×5 model, with largest number of gridblocks between the wellblocks giving the best performance and the 5×5 model with the smallest number of gridblocks giving the worst performance.

2D Heterogeneous Model Results

The pseudos were lastly tested on the two 2D heterogeneous models, a high permeability channel in a low density system and a layered system with increasing permeability. The topmost layer has the lowest permeability. Production rate, recovery and field pressures of the fine grid, homogenized fine grid, homogenized coarse grid and upscaled homogenized coarse grid were compared. In Figure 8(a) and 8(b) the upscaled coarse grid had its breakthrough time closer to the homogenized fine grid and standard fine grid. Also, the production rate showed upscaled coarse grid having closer breakthrough time and profile to the two fin grids compared to the standard coarse grid. Figure 9(b) showed similar trend as error between the two fine grid and upscaled coarse grids were reduced compared with the recoverys and production rates of the standard coarse grid, after the upscaling with the new pseudos that compensate for numerical dispersion. Similar results were obtained for the field pressures. The plot of saturation versus fractional flow curve for the random permeability using its JBN curves gave a characteristic no shock shape (refer to Appendix B4 for the plot).

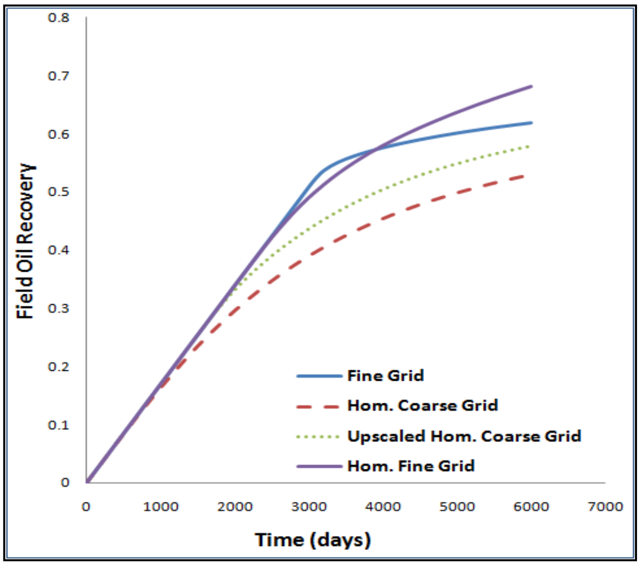


Figure 8(a) Comparison of Recoveries for Channel Model

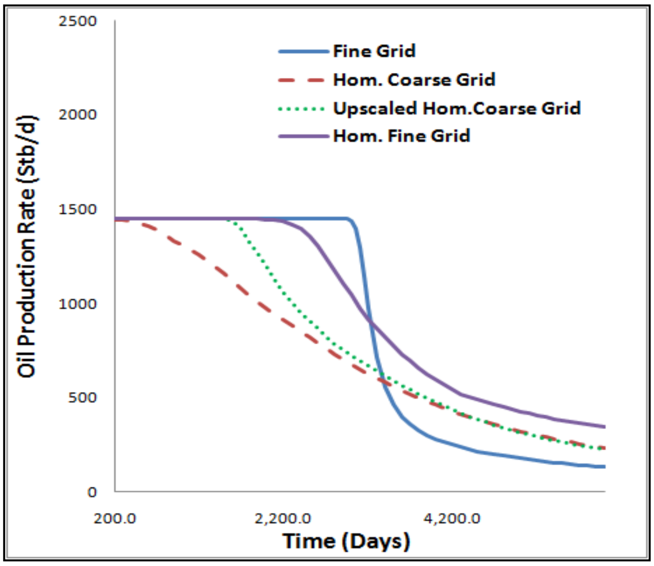


Figure 8(b) Comparison of Production Rate for Channel Model

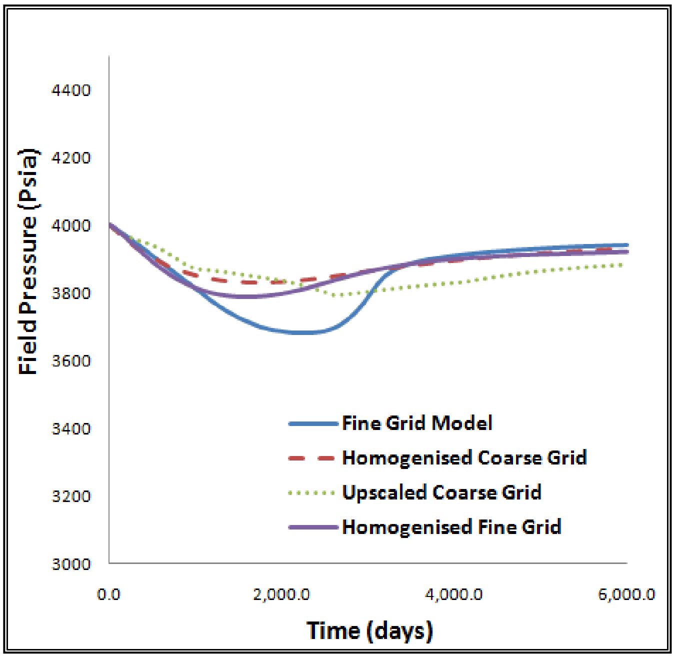


Figure 8(c) Comparison of Pressures of Channel Model

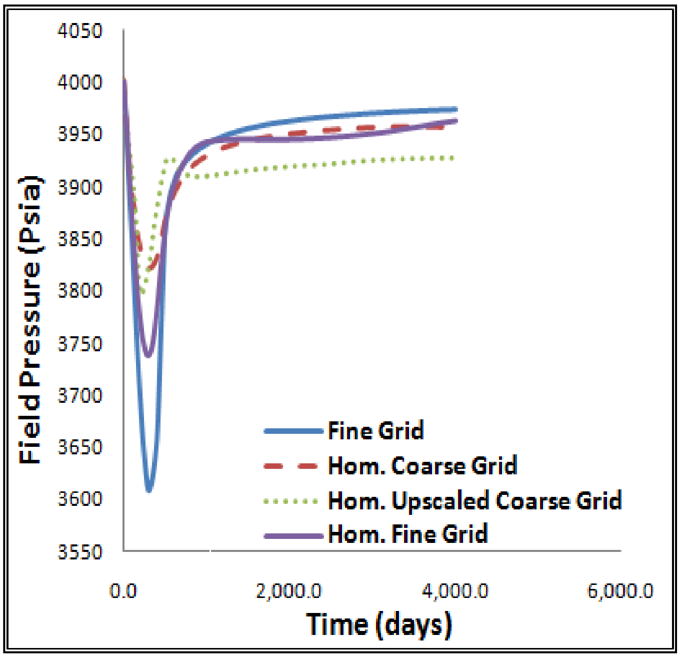


Figure 9(a) Comparison of Pressures for Layered Model

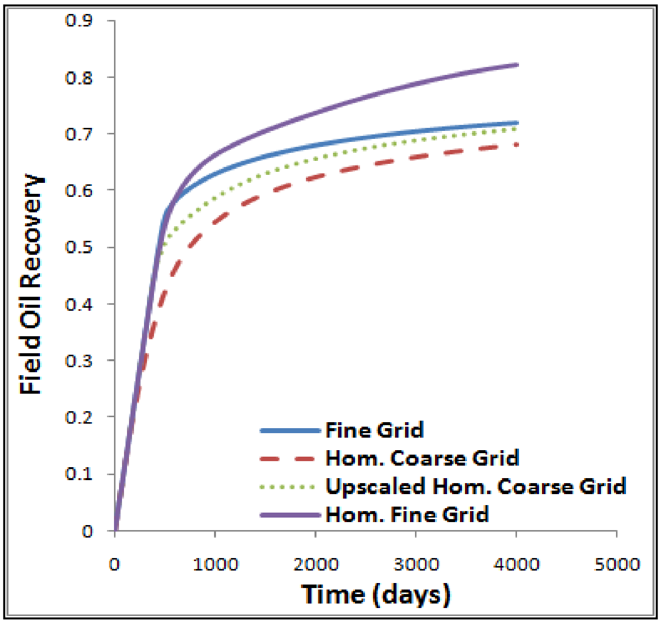


Figure 9(b) Comparison of Recovery for the Layered Model.

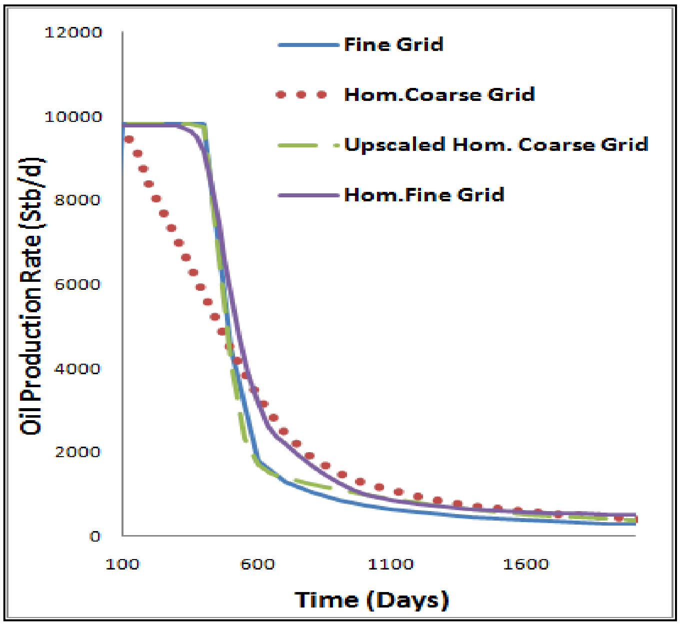


Figure 9(c) Comparison of Production Rate for the Layered Model

Discussion

A new relative permeability upscaling method was introduced and tested in different 1D, 2D homogeneous and 2D heterogeneous models undergoing waterflooding in this project. Unlike in earlier works, the 1D analytically derived pseudo-relative permeability was tested in not just in 1D but in 2D areal and heterogeneous line drive models. The 1D and 2D models tests with the use of the new upscaling technique showed improved results of the coarse grids when compared to the fine grid results. However, we observed reduced performance in 2D homogeneous and 2D heterogeneous models.

The 1D pseudo-relative permeability showed the classic shape for compensating numerical dispersion for the laboratory rock curves and JBN (1957) rock curves. This is a similar result obtained for earlier methods of pseudoisation. But in this study the curves were derived analytically using Buckley Leverett (1942) and Welge (1952) theories of 1Dimensional displacement. They also modified the oil relative permeability for saturations less than the shock front saturation and thus gave a much better prediction of reservoir pressure compared to the traditional methods of truncating of relative permeability curves. The pseudorelative permeabilities formulated worked for smaller and larger coarse gridblocks and for 7 and

12gridblocks. Moreover, it maintained the parent rock curve endpoint value and the mobilities calculated are between 0 and 1. Therefore any laboratory relative permeability can be easily and quickly converted to pseudos that compensate for numerical dispersion and input into coarse grid models to reproduce fine grid results.

In the 1D test case, the fine grid, coarse grid and upscaled coarse grids predicted the same oil production rate until water breakthrough. Here, the upscaled coarse grid reproduced exactly the fine grid water breakthrough time. The upscaled models also reproduced an improved two phase fine grid profile after breakthrough.The conventional coarse grid had errors in predicting the breakthrough profile. Also with increasing gridblock between the injector and producer wells we are able to have improved prediction of the two phase flow profile of the fine grid after breakthrough. Therefore, the results have shown that for a homogeneous 1D system, we may not need to run the fine grid simulation to obtain accurate results for our waterflooding scheme. That using two pairs of pseudo-relative permeabilities for upscaling can give satisfactory reproduction of fine grid results in 1D. This is in contrasts to conventional methods of using one pair pseudo-function for every gridblock. Also, that the performance of the pseudo-functions is independent of the gridblock size in the two phase flow region.

For the 2D homogeneous test case, the single phase flow profile for the the fine grid was reproduced by the standard coarse grid and upscaled coarse grid models. However, the breakthrough time was approximated only by the upscaled coarse grid models in the oil production rate and field recovery. With increasing number of gridblocks in between producer and injector a better match of breakthrough time can be predicted as can be seen by the 8×5 2D model result. But the two phase flow after breakthrough was not accurately predicted by both the upscaled and standard coarse grid models. This discrepancy can be attributed to radial flow effects which is very dominant near well in the producer and the injector and also strong in 2D areal models as the flow spreads from the injector to the producer. The producer wellblock was treated as an intermediate gridblock in this work. For improved flow description around the producer wellblock, pseudo-relative permeability may have to be developed for the wellblock. In addition, the formulation may have to be modified to incorporate radial flow effects for the producer and the injector wellblocks. Furthermore, we deduce that to fully compensate for numerical dispersion in coarse grid models three pairs of pseudo-relative permeabilities are needed to be input into the coarse grid models, one pair for the injector wellblock, one for the producer and one for the intermediate wellblocks.

The use of the JBN method (1957) to derive effective relative permeabilities used to convert a 2D heterogeneous fine grid models to a 2D homogenized fine grid model having constant effective absolute permeability and the conversion of the effective relative permeabilities to analytically derived pseudofunctions that compensate for numerical dispersion in homogenized coarse grid models was successful as seen in the channel model of figure 8(a), (b) and (c);and layered model of figure 9(a), 9(b) and 9(c). The homogenized fine grid gave a close and approximate match to the heterogeneous fine grid models for the oil rates, pressure and recovery plots. In practice it would be faster to homogenize two phase flow using steady state upscaling methods and then apply the analytic method described here to compensate for numerical diffusion. This should be investigated in future work.

The main conclusion of this work is that you do not need to develop pseudofunctions for every gridblock to compensate for numerical dispersion. We have seen that the analytically derived pseudofunctions provide good match to oil production rate, recovery and pressure unlike the traditional methods that simply truncate the rock relative permeabilities at the shock front saturation and setting them to be zero below the shock front.

Conclusions

In our study, we reduced numerical dispersion in coarse grid model results using pseudo-relative permeabilities analytically derived from Buckley & Leverett (1942). This involved creating pseudofunctions for the injector and non-injector gridblocks and inputing these into coarse grid models. From our analysis, the following conclusions can be drawn:

1. We only need three sets of pseudo-relative permeability to compensate for numerical dispersion seen in coarse grid models. These are one for the injector wellblock, one for the intermediate gridblocks between the wells and one for the producer wellblock. The producer wellblock pseudofuntions will serve to account for radial flow effects. The effect of radial flow was seen in the discrepancies of the 2D homogeneous l models. However, the nature of the producer wellblock pseudos was not treated by this work and needs further investigation.
2. We will need only one set of pseudo-relative permeabilities in the intermediate gridblocks between the producer wellblock and the injector wellblock. This was seen in the results of the 1D and 2D homogeneous areal model. Important implications of this is that you will only need different pseudo-relative permeabilities for different gridblocks in a heterogeneous model when you want to represent the impact of heterogeneities to flow in individual gridblocks and that grouping of pseudo-relative permeability for heterogeneous systems modeling should be based on similarity in heterogeniety. This is in contrast to the results by Hewitt et al. (1998) that the changes to pseudofunctions depend on the distance between inlet and outlet of gridblock to the injector wellblock.
3. We propose that heterogeneous systems can be homogenized using published JBN method (1957) and then the analytical method described in this work can be used to convert the relative permeability data to pseudofunctions that will compensate for numerical dispersion.
4. The pseudofunctions are easy to precalculate before a simulation which makes them less difficult to use than traditional truncated curves. They also provide better match for pressures than the truncated curves. Moreover, the method provides an easier way of upscaling than the dynamic pseudo-relative permeability methods as we do not need full scale fine grid simulation before computing the pseudos.

Recommendations And Further Work

From the conclusion of the study, recommendations for further work are:

1. Derivation of pseudo-relative permeabilities that will compensate for numerical dispersion for the producer wellblock.
2. Modification of already derived pseudo-relative permeability for the effects of radial flow in wellblocks in 2D and 3D systems
3. Modification of the analytically derived pseudofunctions for the effects of gravity for 2D cross-sectional and 3D systems and capillary pressure in low flowrate systems.
4. Investigate combinng the method with the use of steady state pseudo relative permeabilities for homogenization

Nomenclature

i = notation denoting gridblock position
j = notation denoting saturation position in the rock curve table.
J = notation denoting shock front saturation position in the rock curve table.
$K_{rw}(S_w)$ = laboratory or rock relative permeability of water phase
$K_{ro}(S_o)$ = laboratory or rock relative permeability for oil phase
$K_{rwp}(S_w)$ = Pseudo-relative permeability of water phase
$K_{rop}(S_o)$ = Pseudo-relative permeability for oil phase
S_w = saturation of the water phase
S_{w_f} = shock saturation of the water phase
$\overline{S_{w_f}}$ = Average saturation of the water phase behind the shock front
S_{w_c} = Connate Water Saturation
q_o = oil phase flow
q_w = water phase flow
q_t = total flowrate in the reservoir model
f_w = fractional flow of water phase
μ_w = viscosity of the water phase
μ_o = viscosity of the oil phase
λ_o = rock mobility of the oil phase
λ_w = rock mobility of the water phase
λ_T = Total mobility of the water phase
$\Psi_T(S_{wj})$ = Pseudo-total mobility
$\Psi_O(S_{wj})$ = Pseudo-oil mobility
$\Psi_w(S_{wj})$ =Pseudo-water mobility
Δx = gridblock size
P_{j+1} = Pressure in the gridblock $j+1$
ϕ = Porosity of the reservoir model
A = cross section of flow within a gridblock
t = time duration of flow
ζ = dimensionless time constant
K = Absolute Permeability
v = Dimensionless Velocity

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APPENDICES

APPENDIX A

CRITICAL LITERATURE REVIEW

UPSCALING OF RELATIVE PERMEABILITY TO REDUCE NUMERICAL DISPERSION

SPE Paper n°	Year	Title	Authors	Contribution
SPEJ	1998	"Analytical Calculation of Coarse-Grid Corrections for use in Pseudofunctions "	T. A. Hewitt, K. Suzuki, M.A. Christie	Due to discretization of flow properties on a coarse grid, corrections are required for pseudofunctions. This paper presented an approach to calculate corrections to pseudofunctions.
EAGE	1999	'An Analysis of Dynamic Pseudo-Relative Permeability Methods for Oil-Water Flows'	J.W. Barker, Philippe Dupouy	Provided the analysis of the properties of six widely used dynamic pseudo-relative permeability methods for incompressible, immiscible, two phase flow
35491	1997	A Critical Review of the Use of Pseudo-Relative Permeabilities for Upscaling	Barker J.W., Thibeau S.	Provides a summary of the practical difficulties encountered in the use of dynamic pseudo-relative permeabilities and highlights need for analytic alternatives.
EAGE	2009	"Vorticity as a measure of heterogeneity for improving coarse grid generation "	H. Mahani, Ann H. Muggeridge and M. A. Ashjari	1. This paper described sub-grid heterogeneity as a function of vorticity. 2. Provided knowledge on coarse grid generation, numerical dispersion reduction and homogenisation
37324	1996	" Upscaling for Reservoir Simulation"	M.A. Christie	This paper reviews and summarizes both single and two phase upscaling techniques
SPE R.E.	1994	"A New Representation of Wells in Numerical Reservoir Simulation"	Yu Ding, G. Renard	The paper presents a new analytical solution for near-well pressuire is presented for uniform and non-uniform grid-blocks
EAGE	2002	"Scale-up of Well Performance for Reservoir Flow Simulation"	A.H. Muggeridge, M. Cuppers, C. Bacquet and J.W. Barker	1. An example of a method of scale-up of near-well region.
74139	1971	"Quantitative Evaluation of Numerical Diffusion (Truncation Error)"	R.B. Lantz	1. The Paper presents quantification of numerical diffusion caused by finite approximation of flow properties. 2. It shows the interrelationship of gridblock number, size and time to numerical diffusion.
1023-G	1957	Calculation of Relative Permeability from Dispalcements Experiments	Johnson E.F., Bossler D.P., Naumann V.O.	Provides an analytic method for generating oil and water relative permeabilities from fine grid 2D heterogeneous model for a homogenized coarse grid model.
Reservoir Characterization II 1991	1991	Generation of Effective Relative Permeabilities from Detailed Simulattion of Flow in Heterogeneous Porous Media	Ann H. Muggeridge	The paper provided the methodology used in homogenizing the fine grid heterogeneous model and generating pseudo-relative permeabilities.

SPE 51269 (1998)

Analytical Calcultion of Coarse-Grid Corrections for Use in Pseudofunctions

Author: Hewitt T.A., Suzuki K., Christie M.A.

Contribution to upscaling of relative permeability for reduction of numerical dispersion:
1. Contributed with his technique of discretizing of saturation, relative permeability curves, fractional flow curves and mobility.
2. Provided the technique used for the determination of average saturation and relative permeability for non-injector well gridblocks.

Objective of the Paper:
1. To show a new method for calculating the corrections for fluid flow variables required to account for discretization of the continous Buckley Leverett solution on a coarse grid.

Methodology Used:
1. The new approach used a method of characteristic based on the material balance equation describing the displacement of oil by water to yield an expression for gridblock average saturation as a function of outlet face saturation.
2. The method of characteristics was used to develop the right changes to water saturation and flow properties relationships such as relative permeability required for discretization on a coarse grid.
3. Defined water saturations for the discrete representation of the Buckley Leverett continuos solution by averaging them over a volume on the discrete grid.

Conclusions Reached:
1. The differences between discretized relations and local relations used in contructing continous solution are the result of the different averaging volumes used in their definitions.
2. Interblock fractional flows are associated with upstream gridblock and average total mobility is measured between gridblock centers.
3. The modifications required to account for coarse gridblock effects depend only on the ratio of the distances from the injection boundary to the inlet and outlet faces of a discrete gridblock
4. The changes required for relative permeability for the discrete representation are not dependent of gridblock size and number of gridblocks, but depend on the number of gridblocks only for a uniform discretization, with the first gridblock immediately after the injector outlet face.

Comment
The new approach provides good information for the calculation of discretized water saturation, fractional flow and total mobility in a gridblock. However, the rise of oil pseudo relative permeability above endpoint and presence of non-monotonic relative permeability values is an issue.

EAGE/ Geological Society/ Petroleum Geoscience, Vol 5 (1999) PP 385-394

An Analysis of Dynamic Pseudo-Relative Permeability Methods for Oil-Water Flows

Author: Barker J.W., Dupouy P.

Contribution to Upscaling of Relative Permeability to Reduce Numerical Dispersion
Provided knowledge on the of the six main dynamic pseudo-relative permeability methods. Dynamic methods are one approach of creating pseudo-relative permeabilities that reduce numerical dispersion.

Objective of Paper
To analyze the properties of six widely used dynamic pseudo-relative permeability methods for incompressible, immiscible two phase flow.

Methodology Used:
1. Pseudorelative permeabilities from the six dynamic methods are generated from the results of the fine grid simulation on a coarse grid
2. The paper uses simplified Stones example of a dipping vertical cross-section consisting of two non-communicating layers of different permeability undergoing incompressible and immiscible displacement of oil by water in which the oil displacement
3. Analytically derived solution of the simplified Stone's example was obtained using the six methods equations and each were analysed for their properties and limitations.
4. Stones example with Buckley Leverett type of solution in each layer was solved numerically and analytically with the six methods and plots of relative permeability, pressure and water cut were compared for the two approaches using a 50X2 gridblock
5. In the Kyte and Berry method, average pressures from each coarse gridblock and total flowrates of each phase between adjacent coarse gridblocks from fine grid results calculation are input into Coarse grid Darcy flow equation to generate the pseudos.
6. The pore volume method used a similar technique as the Kyte and Berry, but pore volume weighted average pressure over gridblock is used to generate in the coarse grid Darcy flow equation.
7. Stone's and total mobility method uses the concept of total mobility to generate pseudos thereby avoiding problems associated in estimating the coarse grid average pressures.
8. Quasi- steady state method uses upscaled (by solution of Laplace Equation) permeability of each phase divided by the upscaled absolute permeability to calculate oil and water pseudos.
9. Weighted relative permeability calculates pseudos by as an average of the transmissibility weighted fine grid relative permeabilities on the outlet face of the coarse grid block.

Conclusions Reached:
1. Pore volume and Kyte and Berry methods reproduce fine grid results but with problems of infinite and negative pseudo-relative permeabilities, position dependent pseudo-capillary pressure makes them difficult to use.
2. Total mobility, Quasi-steady state, Stone and Weighted Relative permeability (Eclipse Pseudo) methods do not guarantee reproduction of the fine grid results.
3. Numerical dispersion compensation can be seen in the plots of relative permeability and water saturation, field pressure and water cut.

Comments
Kyte and Berry and Pore volume methods are stiil not very ideal practically as the former is dependent on pseudo-capillary pressure location while the latter produces negative and infinite pseudo-relative permeability values, so there could be a need for investigating alternative semi-analytic and analytic pseudoisation methods. The shape of the pseudo-relative permeabilitie is seen to move towards the right for all the methods are consistent with pseudoisation methods encountered.

SPE 35491 (1996)

A Critical Review of the Use of Pseudorelative Permeabilities Upscaling

Author: Barker J.W., Thibeau S.

Contribution to Upscaling of Relative Permeability to Reduce Numerical Dispersion

1. Provided knowledge on grouping pseudo-relative permeabilities in coarse grid

Objective of Paper

1. The paper describes the practicality and limitations of different dynamic pseudo-relative permeability methods.
2. To describe the suitabilitiy and reliability of various pseudo-relative permeability methods for use in scaling up from fine grid geological model to coarse grid fluid flow model.

Methodology Used

1. He summarized the individual capabilities and problems of each of the above mentioned six dynamic pseudo-relative permeability methods and came up with generalized practical difficulties with the use of any of the methods.
2. The Pseudorelative permeabilities are obtained using a saturation distribution based on the average saturation of each gridblock.
3. In viscous forces dominated case, the saturation distribution required is obtained from fine grid or dual-scale grid simulation and dynamic pseudo-relative permeabilities are calculated using any of the six main methods.

Conclusions Reached:

1. The limitations of dynamic pseudo relative permeability methods are computing a different set of pseudos for every coarse gridblock or classifying the gridblocks into different rock types, the choice and number of Fine grid models to be used and pseudos dependence on well locations and rates.
2. An alternative method to generating dynamic pseudo-relative permeability is to scale-up relative permeability analytically such as the large scale averaging method.
3. In the geological model, the effects on fluid flow of the correlated heterogenieites can be captured only qualitatively unless assumption of capillary or gravity equilibruim

Comments

The paper highlights the limitations of the six dynamic pseudo-relative permeability models used to reduce numerical dispersion. The problems of infinite and negative pseudo-rel perms, directional and non-zero pseudo capillary pressures and restrictive boundary conditions and assumptions of zero gravity and constant average total mibilty limits their practical use. These limitations provide opportunities for analytic and semi-analytic methods of pseudoisation to be investigated. Moreover, we are trying to solve the problem of running the fine grid simulation. The dynamic method requires the fine grid simulation to be run, making them less practical.

EAGE (8) 2002

Scale Up of Well Performance for Reservoir Flow Simulation

Author: Muggeridge A. H., M. Cuypers., C. Bacquet., J.W. Barker

Contribution to Upscaling of Relative Permeability to Reduce Numerical Dispersion
The project did not use the technique but it's an example of near-well scale-up methodology.

Objective of Paper

1. To investigate the use of the method of Ding in the scale –up of the near well region in 2D, 3D and partially penetrating problems.

Methodology Used

1. The permeability of the coarse grid can be scaled-up by superimposing the coarse grid on a fine grid heterogeneous model.
2. The method of Alabert & Corre (1991) was used to calculate each flow direction in the coarse grid.
3. Two implementations of Ding method was done, the first is a single flow fine grid simulation for each well and the output pressure and fluxes are read by a post processing program.
4. The second involves solution of pressure equation for single phase flow for each well on a limited region of the fine grid model (reduced computational domain).

Conclusions Reached:
The Ding method gave better results over conventional scale-up methods of well performance and gridblock transmissibility in heterogeneous models.

Comments
This method provides Ding's method of scale-up of well performance in the near well region where the radial flow regime is assumed predominant. The project assumes linear flow in the wellblock and non-wellblocks. The use of small well blocks for the injector wellblock provided sufficiently good results and did not pose convergence problems as informed by the paper. This new method avoids issues arising from scale-up of flow properties in the near-well region and any local grid refinement

SPE 2811 (1971)

Quantitative Evaluation of Numerical Diffusion (Truncation Error)

Author: R.B. Lantz

Contributions to Upscaling of Relative Permeability to Reduce Numerical Dispersion
The paper provided technique in selecting number and size of gridblocks and timesteps to be used in developing coarse grid models.

Objective of Paper

1. To show that numerical diffusion over a wide range of block size and time-step in numerical simulations is quantitative and not just qualitative.
2. To provide guidelines for selecting gridblock sizes and timesteps in order to keep numerical diffusion as small as possible.

Methodology Used:

1. The paper used a backward finte difference approximation for the convective-diffusive equation to represent numerical and physical diffusivity seen in miscible and immiscible displacements.
2. He compared backward difference numerical calculation with Welge analytical solution for a relative mobility curve taken at time of frontal saturation and a quarter of frontal saturation.

Conclusions Reached:

1. Little or no smearing was observed at time steps taken at Welge frontal saturation compared to significant diffusion at lower time steps
2. Most important numerical diffusion error is assumed to arise from the differential equations that include first-order derivatives
3. With increase in gridblock size, second order numerical diffusivity error could become substantial.
4. Quantitative value of numerical diffusity in displacements can be affected by a wide range of gridblock size and number and timesteps.
5.

Comments
Numerical diffusivity encounterd in reservoir simulation of immiscible systems such as the displacement during a waterflood exercise can now be quantified and modeled using this method.
The size and number of cells in a model can determine the level of numerical dispersion seen in the results of a coarse grid model. The input of pseudo-relative permeability reduces levels of numerical dispersion caused by the coarse gridding

Reservoir Characterization II (1991) Academy Press

Generation of Effective Relative Permeabilities from Detailed Simulattion of Flow in Heterogeneous Porous Media

Author: Muggeridge A.H.

Contribution to Upscaling of Relative Permeability to Reduce Numerical Dispersion
The paper provided the methodology used in homogenizing the fine grid heterogeneous model and generating pseudo-relative permeabilities.

Objective of Paper
To show how well effective relative permeabilities dynamically derived from heterogeneous fine grid model represents the average properties of fluid flow through heterogeneous porous media

Methodology Used
1. Detailed Simulation methods by Christie (1989) were used to derive the effective relative permeabilities from the fine grid heterogeneous models.
2. The oil recovery and effective relative permeability curves obtained for three different heterogeneous media were examined for their behavior and variability.
3. Effective absolute permeabilities were computed on a first stage with the method described by Begg, Carter and Dransfield (1987)
4. Effective relative permeabilities were computed using Jones and Roszelle Method (1978) in the second stage.
5. The absolute permeability and effective permeability were used to represent flow in 1D homogeneous equivalent.
6. Kyte and Berry method (1975) was used to develop pseudo-relative permeability that will compensate for numerical dispersion and incorporate effects of permeability variations.

Conclusions Reached:
1. Average properties of flow in a heterogeneous fine grid model can be represented by replacing the relative permeability data with pseudo-relative permeability.
2. Each reprensentative volume of the fine grid model used to develop effective relative permeability must contain a representative section of the permeability distribution.
3. Pseudofunctions can perform roles of representing effects of heterogeneity and compensating for numerical dispersion in coarse grid models.

Comments:
The paper combines several established numerical methods suggested by others to develop pseudofunctions and reduced dimensionalty of the model from 2Dimensional to 1Dimensional by successive scale-up. The use of the Kyte and Berry method to reduce numerical dispersion in the coarse grid model creates issues of negative non-single value and infinite pseudo-relative permeability. These can create difficulty in their use.

EAGE (15) 2009 PP 91-102

Vorticity as a measure of heterogeneity for Improving Coarse Grid Generation

Author: Mahani, H., Muggeridge A.H., and Ashjari M.A.,

Contribution to Upscaling of Relative Permeability to Reduce Numerical Dispersion
It provided technique to carry out effective gridding from fine grid to coarse grid to capture large scale heterogeneity effects on fluid flow.

Objective of Paper
To show how to generate flow simulation coarse grids from fine grid heterogeneous models with the aim of preserving large scale heterogeneities to flow.

Methodology Used
1. The grid coarsening technique involves fine grid construction, single phase flow simulation, vorticity map generation with finite difference method.
2. The fine grid is homogenized using the method of Li (1995) and lastly compensate for numerical dispersion in the coarse grid using the method of Muggeridge (1991).

Conclusions Reached:
1. Homogenised fine grid using vorticity maps gave a better match to the fine grid oil recovery and oil cut results from waterflooding simulation compared to uniformly homogenized coarse grid
2. Vorticity gives a measure of heterogeneity effects on large scale flow and permeability variation within the fine grid model
3. It can serve as a guide to coarse grid generation from fine grid heterogeneous models.

Comments
To retain some heterogeneity from the fine grid to the coarse grid, an effective gridding technique is required such that with the input of pseudo-relative permeability numerical dispersion would be reduced to a minimal value. The new gridding technique contributes to description of fine grid heterogeneity in coarse grid model

SPE 37324 (1996)

Upscaling for Reservoir Simulation

Author: M.A. Christie

Contribution to Upscaling of Relative Permeability to Reduce Numerical Dispersion

1. Provided technique and basis for use of Buckley & Leverret (1942) shock height for grouping pseudo-relative permeability data used for upscaling.
2. Contributed technique on use of pressure solver method and arithmetic harmonic analytical methods for absolute permeability upscaling in the homogenisation of heterogeneous fine grid model.

Objective of Paper

The paper reviews single phase upscaling and introduces multiphase upscaling as a further step to better obtain reservoir heterogeneity description.

Methodology Used

1. He used pressure solver method to show single phase upscaling of absolute permeability, with no flow boundary on the horizontal walls of the model.
2. For two phase upscaling, he used a semi-analytic renormalization technique King (1989), extended by Christie et al (1995) to obtain pseudo-relative permeabilities from.
3. He studied the rate dependency of pseudo-effective permeability by developing a velocity field based on known well locations and rates and pseudos are obtained using the knowledge of expected flowrates.

Conclusions Reached:

1. In two phase upscaling, two limitations are observed, pseudo-relative permeabilities can be rate dependent and may also need some form of grouping to order large number of effective permeabilities into a manageable quantity.
2. A plot of pore volume produced against time showed the pseudos predicted better recovery rates and gave a better match than using the rock curves.
3. For any upscaling algorithm used, other checks should be performed to validate results.

Comments

1. Two phase upscaling can show the effects of reservoir heterogeneity more effectively than single phase upscaling.
2. Single phase upscaling could be insufficient when the correlation size of the permeability system is close in size as upscaled gridblock.
3. Grouping of relative permeability data provides a means reducing computing requirements and difficulties as well as averaging other flow properties in two phase upscaling.
4. Dynamic pseudoisation technique provides pseudo-relative permeability that are rate and well location dependent, limiting its usage and creating computational difficulties.

SPE 1023-G (1957)

Calculation of Relative Permeability from Displacements Experiments

Author: Johnson E.F., Bossler D.P., Naumann V.O.

Contribution to Upscaling of Relative Permeability to Reduce Numerical Dispersion
The paper provides an analytic method for generating oil and water relative permeabilities from fine grid 2D heterogeneous model for a homogenized coarse grid model.

Objective of Paper
To show a new method for generating water and oil relative permeabilities from data obtained during a waterflood experiment performed on a linear porous body.

Methodology Used:

1. Very high injection rates was used in the waterflooding experiment to obtain stabilized displacement and constant flow velocity in all cross sections of the porous core sample of about 2-3in in length.
2. High flowrate and high pressure gradient developed across core was used to make the capillary pressure negligible during pressure drops.
3. Used differential equations developed from Welge correlations and Rapoport relative injectivity concept to calculate individual relative permeabilities from data generated from the displacement test.

Conclusions Reached:
1. Method tested and found to yield reliable results which are in agreement with methods using direct measurements of relative permeability in the laboratory.

Comments:
This method is fast and reliable, in agreement with welge fractional flow curve. However use of differential equations could lead to errors and practical difficulty when using tabulated data obtained from the field.

SPE 6045 (1978)

Graphical Techniques for Determining Relative Permeability from Displacement Experiments

Author: Jones S.C., Roszelle W.O.

Contribution to Upscaling of Relative Permeability to Reduce Numerical Dispersion
The paper provided a graphical form of the Johnson Bossler method which can be applied to field tabular rate, water cut and pressure data.

Objective of Paper
To simplify the calculation of relative permeability from displacement data by using graphical constructions.

Methodology Used
1. Carried out unsteady state displacement with successive oil-flooding and water-flooding on a water saturated linear core to irreducible water saturation to determine water injection rates, pressure drop and effluent water.
2. Fractional flow of oil and water was measured in the effluent water from core displacment.
3. Average saturation and effective viscosity was computed using pressure rate and volumetric data from the core displacement.
4. Saturation at outlet and intercept viscosity graphically obtained from average saturation and effective viscosity were used to obtain oil and water relative permeabilities.

Conclusions Reached:
1. Graphical constructions can easily and accurately calculate relative permeabilities from unsteady state displacements using irreducible oil saturation and effective viscosity.
2. Waterflood displacements derived fractional flow curves concave downwards and do not give multiple values saturation.

Comments:
This new method provided is more practical using field data to calculate relative permeability from displacement data than the differential Johnson et al method.
The method involves rigourous and tedious tangent construction methods.

APPENDIX B

B.1 Rock Curves Correlation

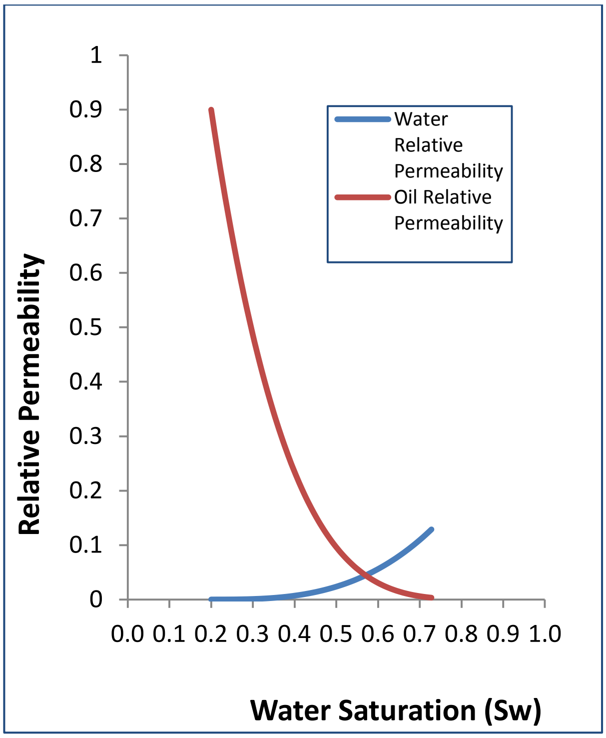
We obtained our initial rock curves table of relative permeability of oil and water against water saturation using the power law relationships of relative permeability and water saturation to obtain Corey type correlations.

$$Kro = 0.9\left[\frac{So-0.1}{1-Swc-Sor}\right]^4 \qquad for\ Oil\ Relative\ Permeability$$

$$Krw = 0.3\left[\frac{Sw-0.2}{1-Swc-Sor}\right]^3 \qquad for\ Water\ Relative\ Permeability$$

K_{ro} and K_{rw} are the oil and water relative permeabilities. 0.9 and 0.3 are end point values of the oil and water relative permeabilities used. S_w and S_{wc} are the individual saturations in the rock table and connate water saturation respectively. 4 and 3 are Corey exponents for the oil and water phases. Sor is the residual oil saturation. Connate water and residual oil saturations used were 0.2 and 0.1 respectively. Relative permeability data was obtained for a given saturaton table. A plot of oil and water relative permeability versus water saturation was done. Using an oil water viscosity ratio of 4 the fractional flow of water is calculated using equation 4.From fig 3 The fractional flow curve was plotted and the saturation at the shock front S_{wsh} of 0.598 was obtained using Welge constructon Method (Welge, 1952). The average saturation behind the shock front S_{wsh} of 0.656 was also obtained when fw is 1. These data were documented in the rock curve table.

Figure B.1(a) Rock Curve Relative Permeability Plot



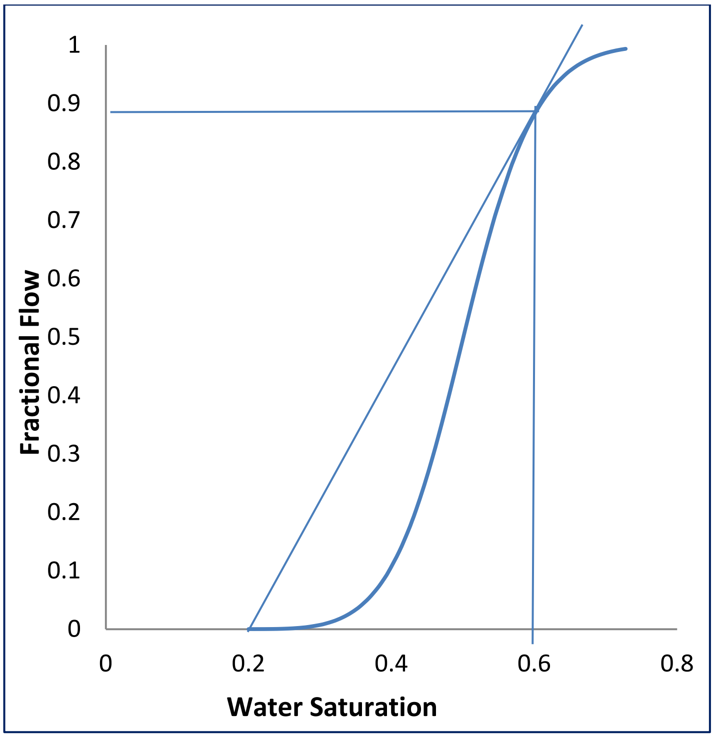


Figure B.1(b) Fractional Flow Plot

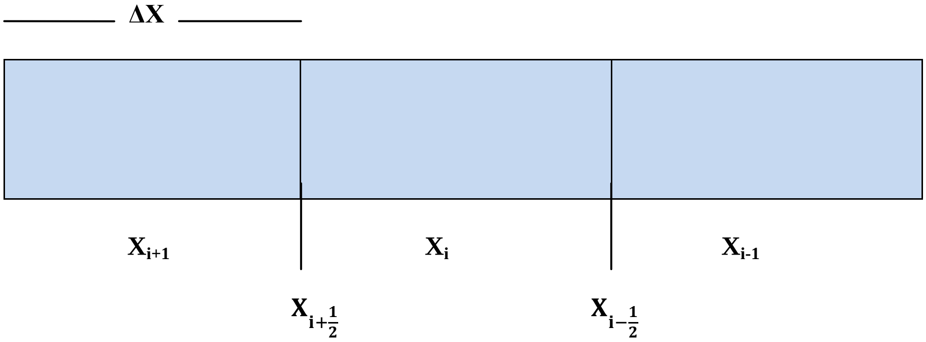
B.2 Analytic Equations For Formulation of Pseudo-relative permeability

Injector Wellblock Pseudos

Following the methodology by Muggeridge (private communication) Our one dimensional coarse grid system having incompressible immiscible displacement of oil by water in the horizontal X direction during a waterflood is defined below.

The notation of the gridblocks is as shown below. The size of each gridblock is given as ΔX.

Figure B.2 Coarse Gridblock System



The system is homogeneous and the oil and rock are assumed to be incompressible. With uniform water saturation distribution with distance and constant cross-sectional area within a gridblock of size Δx. The Darcy total flow through the porous system is following the derivation by Muggeridge (private communication) described the displacement of oil by water; with velocity of displacement $V_{i+\frac{1}{2}}$ through gridblock $\boldsymbol{i}$ is a function of the mobility of water and oil and occurs within the same pressure gradient for both.

$$V_{i+\frac{1}{2}} = -K_{i+\frac{1}{2}}\left(\frac{K_{rw}(S_w)}{\mu_w} + \frac{K_{ro}(S_o)}{\mu_o}\right)\frac{P_{i+1} - P_i}{\Delta x}$$

Where subscript $i + {}^1/_2$ denotes the boundary between upstream block $\boldsymbol{i}$ and downstream block $i + 1$. $K_{i+{}^1/_2}$ is the absolute permeability at the gridblock boundary. $Krw(Sw)$ and $Kro(Sw)$ are the relative permeabilities of oil and water respectively. μ_w and μ_o represent the viscosities of water and oil respectively. P_{i+1} and P_i are the pressures between adjacent gridblocks

Now the velocity of flow between gridblock j and $j + 1$ is governed by the pressure gradient between them and a function of the distance averaged water saturation between the inlet face and outlet face of gridblock j. Combining equation 15 and 16 for flow for saturations less than the shock front saturation

$$P_j - P_{j+1} = \frac{V_{j+\frac{1}{2}}}{K_{j+\frac{1}{2}}\left(\frac{K_{rw}(S_W)}{\mu_W} + \frac{K_{ro}(S_W)}{\mu_O}\right)}$$

The size of the gridblock ΔX can be integrated from the inlet to the outlet of the gridblock j

$$\Delta X = \int_{x_{j-\frac{1}{2}}}^{x_{j+\frac{1}{2}}} \mathrm{dx}$$

Combining equations 5, 6, 7, and 20 and defining a distance averaged modified oil mobility at the outlet face of the gridblock, equation 19 becomes

$$P_j - P_{j+1} = \frac{V_{j+\frac{1}{2}}}{K_{j+\frac{1}{2}}\Psi_\mathrm{o}(\mathrm{S_W})}$$

Where S_{wf} is the shock front saturation and S_{wj} is the individual saturation from the rock curve table. From equation 5, 6 and 7 we maintain total mobility with the increase of the oil mobility for water saturations less than S_{wf} by adding the pseudo-water mobility and pseudo -oil mobility at water saturations less than the mean average saturation in the gridblock. Muggeridge (2007) showed that the pseudo oil mobility in gridblock i is

$$\frac{1}{\Psi_\mathrm{o}(\overline{\mathrm{S_{wi}}})} = \frac{1}{\Delta X}\int_{x_{i+\frac{1}{2}}}^{x_{i+\frac{1}{2}}} \frac{dx}{\left(\frac{Krw(\overline{Swi})}{\mu_W} + \frac{Kro(\overline{Swi})}{\mu_O}\right)}$$

Similarly the pseudo-total mobility is given as

$$\frac{1}{\Psi_T(\overline{S_{wi}})} = \frac{1}{\Delta X} \int_{x_{i+\frac{1}{2}}}^{x_{i+\frac{1}{2}}} \frac{dx}{\left(\frac{Krw(\overline{Swi})}{\mu_w} + \frac{Kro(\overline{Swi})}{\mu_o}\right)}$$

Where $Krw(\overline{Swi})$ and $Kro(\overline{Swi})$ are water and oil relative permeability as a function of gridblock average saturation; μ_w and μ_o are oil and water viscosities; and ΔX is the gridblock size.

For water saturations higher than gridblock average water saturation in the rock table when the shock front reaches the outlet face of the gridblock the modified total mobility is obtained by equation 23.

She added that pseudo-water mobility is obtained by

$$\frac{\lambda_w}{\lambda_T} = \frac{\Psi_w(S_w)}{\Psi_T(S_w)}$$

Where λ_w and λ_T are the rock water and rock total mobilities and $\Psi_w(S_w)$ is the modified water mobility. We calculate water and oil pseudo-relative permeability by

$$\text{Krwp}(S_{wj}) = \Psi_w(S_{wj}) \times \mu_w \qquad S_{wj} \geq \overline{S_{wf}}$$

$$\text{Krop}(Sw) = \mu_o \times \left(\Psi_T(S_w) - \Psi_w(Sw)\right) \qquad S_{wf} \geq \overline{S_{wf}}$$

Approximating the saturation distance profile in fig 1 such that fw tends to 1in this gridblock, we replace our rock table water saturations by average water saturations obtained by Welge method.
(Welge 1952, Dake 1988)

$$\overline{S_{wj}} = S_{wj} + \frac{1-f_w}{df_w/dS_w} \qquad S_{wj} \geq \overline{S_{wf}}$$

where S_{wj} is the individual saturation in the rock curve table.

Non-Injector Wellblock Pseudofunctions

Following the derivation of Muggeridge (private communication) and using Hewitt et al (1998) information that the corrections required for calculating pseudofunctions does not depend on the size of the gridblock but on the ratio between the distance from the inlet face of the gridblock to the injection well and the distance from the injection well block to the outlet face of the gridblock in question and change in fractional flow across gridblock. He used characteristics velocity and distance in his work rather than saturation and fractional flow. (Hewitt et al, 1998). The corrections we usually apply would be to replace the point saturations with mean saturations within a particular gridblock. Now we assume that the average saturation within a gridblock i is calculated by obtaining the difference between average inlet face $\overline{S_{wi}}$ and outlet face $\overline{S_{wo}}$ saturations calculated from the injection wellblock over the simulation model. We refer to the appendix section for a derivation to show this assumption. In the discrete representations of tabulated relative permeability values as a function of tabulated water saturations with relatively constant interval ΔS_w in reservoir simulation models, the change in fractional flow at gridblock outlet face mean saturation S_{wo} is

$$\frac{df_w}{dS_w} = \frac{f_w(S_{wj}) - f_w(S_{wj-1})}{S_{wj} - S_{wj-1}}$$

Where S_{wj} and S_{wj-1} are tabulated saturation values, $S_{wj-1} < S_{wo} \leq S_{wj}$

Also for the mean inlet face gridblock saturation S_{wi}

$$\frac{df_w}{dS_w} = \frac{f_w(S_{wj}) - f_w(S_{wj-1})}{S_{wj} - S_{wj-1}}$$

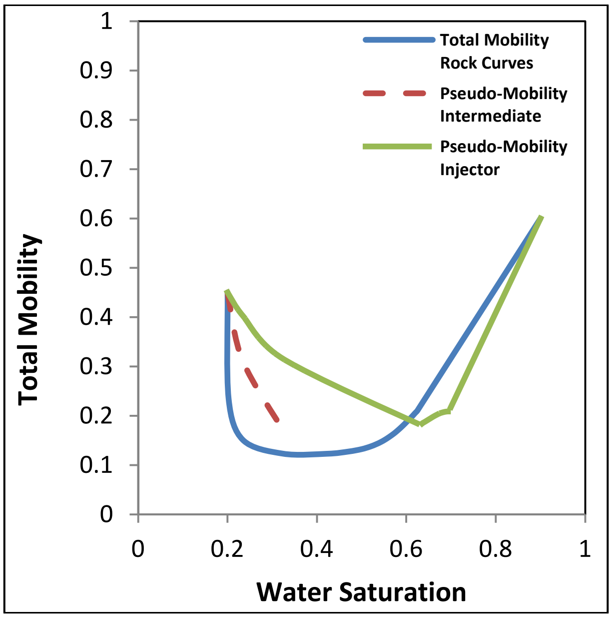
Where $S_{wj-1} < S_{wi} \leq S_{wj}$

We can say that S_{wi} and S_{wo} are probably similar and infer that the saturation in a gridblock is uniform and we do not need to modify the saturations as in injector wellblock.

B.3

The Pseudo-total mobility and Pseudo-relative permeability plots calculated for the channels and layered reservoir model are presented below

Figure B.3 (a) Pseudo-total mobilites using JBN Rock Curves For Channel Model



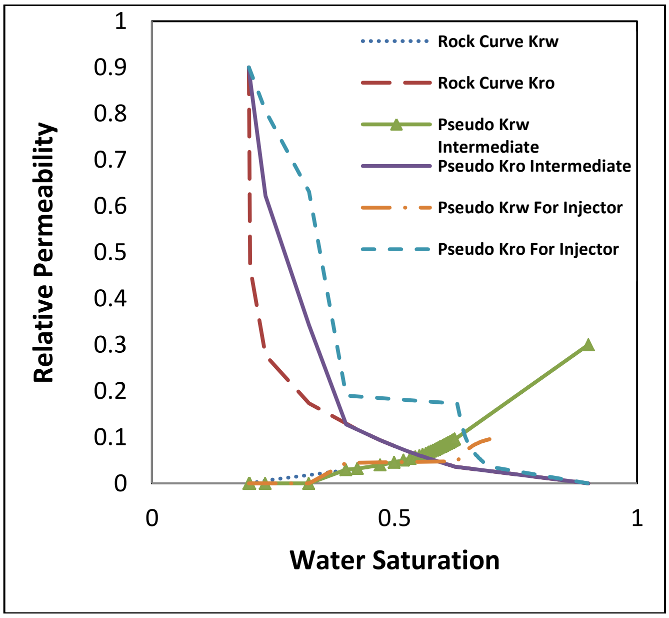
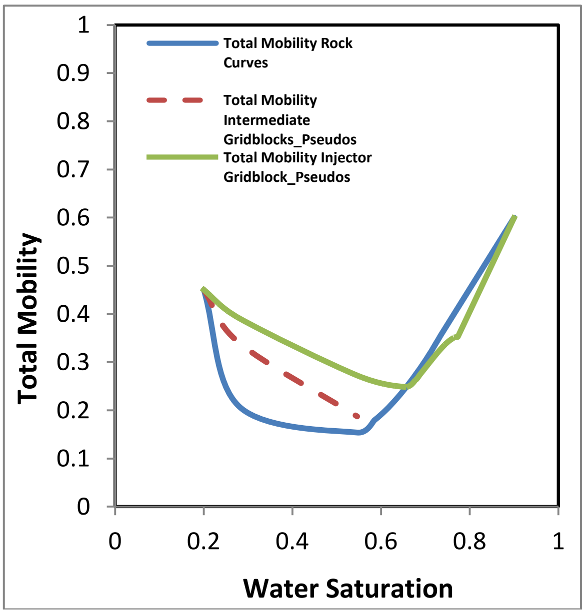


Figure B.3(b) Pseudo-relative Permeability and JBN Rock Curves for the Channel Model

Figure B.3 (c) Pseudo-total mobilites using JBN Rock Curves For Layered Model



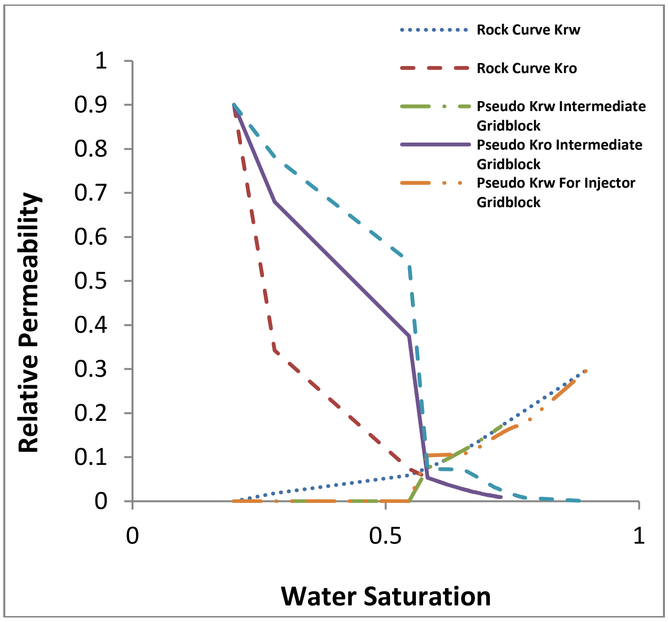
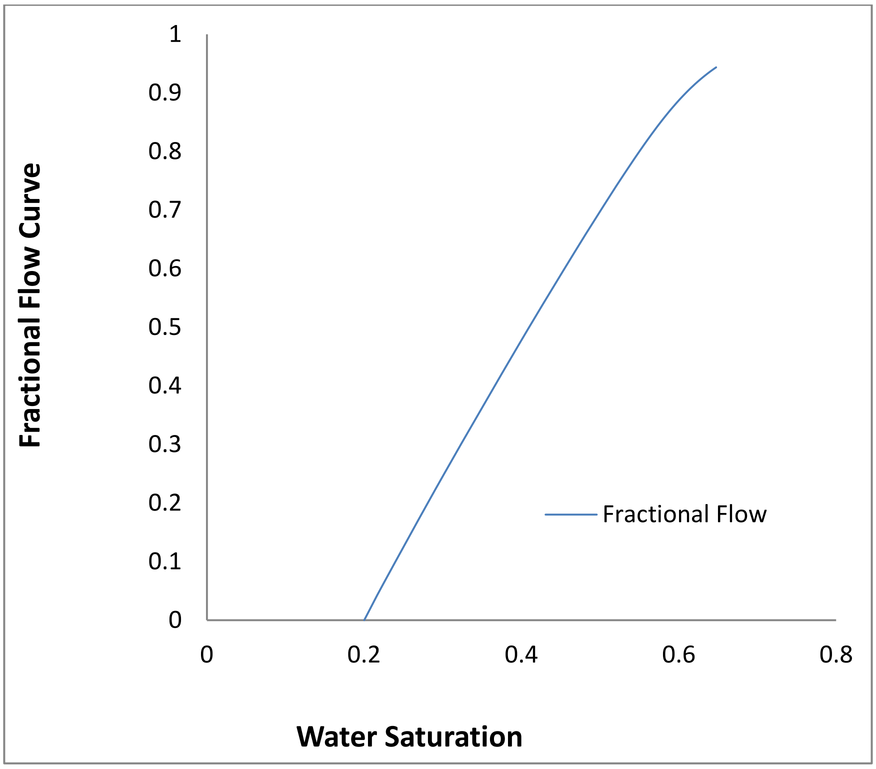


Figure 7(a) Pseudo-relative Permeability and JBN Rock Curves for the Layered Model

B.4

Figure B.4 Fractional flow curve of Effective Relative Permeability obtained using the JBN method. It showed a no shock characteristic shape. It does not give a favourable fractional flow curve.



Appendix C: SAMPLE SIMULATION DATA FILES

UPSCALING OF RELATIVE PERMEABILITY TO REDUCE NUMERICAL DISPERSION CODE INPUT DATAFILES

C1: 1D CODE INPUT

Fine Grid Model

```
RUNSPEC
TITLE
  'REL PERM UPSCALING TO REDUCE NUMERICAL DISPERSION'

START
  1 'AUG' 1975  /

DIMENS

--  nx    ny   nz

   202    1   1  /

CART

NONNC

-- PHASES PRESENT

OIL

WATER

-- UNITS

FIELD


EQLDIMS

-- num    num    max     max    max
-- equ     depth  nodes   tab    tracer
-- reg  nodes  VD tab  tracer nodes
   1    100    1       1      20 /


TABDIMS

-- num  num  max   max   max
-- sat  pvt  sat   press fip
-- tab  tab  nodes nodes regions
```

```
   1    1   100    10    1    1 /

REGDIMS
   1    1    0    0  /

WELLDIMS
   2    1    1    2 /

EQLOPTS
MOBILE /

NSTACK
50 /


UNIFOUT

UNIFIN

FMTOUT

--
--     <----------- PRINT ------------>  <------------ STOP -----------
--     mess  comm  warn  prob  err  bug  mess  comm  warn  prob  err  b
MESSAGES
      2*          1000  5*                       100000   2*  /
--

GRID    ==========================================================

EQUALS
   DX       15 2 201 1 1 1 1 /
   DX       15 1 1 1 1 1 1 /
   DX       15 202 202 1 1 1 1 /
   DY       2000 1 1 1 1 1 1 /
   DY       2000 202 202 1 1 1 1 /
   DY       2000 2 201 1 1 1 1 /
   DZ       100 2 201 1 1 1 1/
   DZ       100 1 1 1 1 1 1 /
   DZ       100 202 202 1 1 1 1 /
   PORO     0.2 1 202 1 1 1 1 /
   PERMX     200 2 201 1 1 1 1 /
   PERMX     200 1 1 1 1 1 1 /
   PERMX     200 202 202 1 1 1 1 /
   PERMY     200 2 201 1 1 1 1 /
   PERMY     200 1 1 1 1 1 1 /
   PERMY     200 202 202 1 1 1 1 /
   PERMZ     200 2 201 1 1 1 1 /
   PERMZ     200 1 1 1 1 1 1 /
   PERMZ     200 202 202 1 1 1 1 /
   TOPS     0.0 1 202 1 1 1 1 /
```

```
/
RPTGRID
-- Report Levels for Grid Section Data

 /
EDIT

PROPS    ===============================================================
-- SECTION REPORTS DEF. OF REL. PERMEABILITIES, CAPILLARY PRESSRES AND PVT
-- PROPERTIES
---------------------------------------------------------------------

INCLUDE
‘Fluid_Property_File.DATA’   /

/

RPTPROPS
   'PVTW'
/
REGIONS  ===============================================================
-- SECTION DEFINES HOW RESERVOIR IS SPLIT INTO REGIONS BY SATURATION FUNCTION,
-- PVT FUNCTION, FLUID IN PLACE ETC.



SOLUTION =================================================================
-------  SECTION DEFINES INITIAL STATE OF THE SOLUTION VARIABLES - PHASE
-------  SATURATIONS AND GAS-OIL RATIO
-------------------------------------------------------------------------


EQUIL

 50.0  4000  2000  0   0   0   0   0   -2  /


RPTSOL
  'PRES' 'SWAT' 'SOIL' /


SUMMARY  =================================================================
-------  SECTION SPECIFIES DATA TO BE WRITTEN TO SUMMARY FILES AND WHICH MAY
-------  LATER BE USED WITH THE ECLIPSE GRAPHICS PACKAGE

FOPR

RPTONLY

WBHP
P /

WBHP
```

```
I /

FLPT

FOPT

FOE

FWIR

FWCT

FWIR

FPR

EXCEL

RUNSUM



SCHEDULE ===================================================================
------- SECTION DEFINES THE OPERATIONS TO BE SIMULATED



WELSPECS

--  WELL      GROUP  LOCATION   BHP    PHASE
--  NAME      NAME    I    J    DEPTH  DEFN
   'P       ' 'G'    202  1    0.0   'OIL'  /
   'I       ' 'G'    1    1    0.0   'WATER'  /
/
COMPDAT
--  WELL          LOCATION     OPEN/  SAT   CONN WELL
--  NAME         I    J K1 K2  SHUT   TABLE FACT ID

   'P       '   202  1 1  1   'OPEN' 1     1*   0.5  /
   'I       '   1    1 1  1   'OPEN' 1     1*   0.5  /
  /

WCONPROD

   'P       ' 'OPEN' 'LRAT' 3* 6500  1*  1110.0 /
/

WCONINJE
    'I       ' 'WAT' 'OPEN' 'RATE'  6500  1*  8000 /
  /


RPTSCHED
```

```
 'PRES' 'SOIL' 'SWAT'  'RESTART= 1' 'CPU=2' 'NEWTON=2' /

RPTRST
 'BASIC=2' /


TSTEP
60*100 /

END
```

C2: CODE INPUT DATA – 2D

Fine Grid

```
RUNSPEC
TITLE
  'REL PERM UPSCALING TO REDUCE NUMERICAL DISPERSION'

START
  1 'AUG' 1975  /

DIMENS

--  nx    ny   nz

   26    26   1  /

CART

NONNC

-- PHASES PRESENT

OIL

WATER

-- UNITS

FIELD


EQLDIMS

-- num    num    max     max    max
-- equ     depth  nodes   tab    tracer
-- reg  nodes  VD tab  tracer nodes
  1    100    1       1      20 /


TABDIMS

-- num  num  max   max   max
-- sat  pvt  sat   press fip
-- tab  tab  nodes nodes regions

   1    1   100    10    1    1 /

REGDIMS
   1    1    0    0  /

WELLDIMS
   2    1    1    2 /

EQLOPTS
MOBILE /

NSTACK
```

```
50 /


UNIFOUT

UNIFIN

FMTOUT


--
--     <----------- PRINT ------------>  <------------ STOP -----------
--     mess  comm  warn  prob  err  bug  mess  comm  warn  prob  err  b
MESSAGES
      2*         1000  5*                       100000   2*  /
--

GRID     ==============================================================


EQUALS

   DX        150 1 26 1 26 1 1 /
   DY         50 1 26 1 26 1 1 /
   DZ        100 1 26 1 26 1 1 /
   PORO      0.2 1 26 1 26 1 1 /
   PERMX     400 1 26 1 26 1 1 /
   PERMY     400 1 26 1 26 1 1 /
   PERMZ     400 1 26 1 26 1 1 /
   TOPS      0.0 1 26 1 26 1 1 /

/


RPTGRID
-- Report Levels for Grid Section Data

 /
EDIT

PROPS    ==============================================================
-- SECTION REPORTS DEF. OF REL. PERMEABILITIES, CAPILLARY PRESSRES AND PVT
-- PROPERTIES
------------------------------------------------------------------------

INCLUDE
'Fluid_Property_File.DATA'   /

/

RPTPROPS
   'PVTW'
/
REGIONS  ==============================================================
-- SECTION DEFINES HOW RESERVOIR IS SPLIT INTO REGIONS BY SATURATION FUNCTION,
-- PVT FUNCTION, FLUID IN PLACE ETC.


SOLUTION ==============================================================
-------  SECTION DEFINES INITIAL STATE OF THE SOLUTION VARIABLES - PHASE
```

```
------- SATURATIONS AND GAS-OIL RATIO
------------------------------------------------------------------------


EQUIL

  50.0  4000  2000  0    0    0    0    0    -2/


RPTSOL
 'PRES' 'SWAT' 'SOIL' /


SUMMARY  ===============================================================
------- SECTION SPECIFIES DATA TO BE WRITTEN TO SUMMARY FILES AND WHICH MAY
------- LATER BE USED WITH THE ECLIPSE GRAPHICS PACKAGE

FOPR

FOE

FWIR

FWCT

FPR

EXCEL

RUNSUM



SCHEDULE ===============================================================
------- SECTION DEFINES THE OPERATIONS TO BE SIMULATED


WELSPECS

--  WELL     GROUP  LOCATION   BHP    PHASE
--  NAME     NAME    I    J    DEPTH  DEFN
   'P      ' 'G'    26   1    0.0   'OIL'  /
   'I      ' 'G'    1    26   0.0   'WATER'  /
/

COMPDAT
--  WELL        LOCATION     OPEN/  SAT   CONN WELL
--  NAME        I    J K1 K2  SHUT   TABLE FACT ID

   'P      '   26   1 1  1   'OPEN' 1     1*   0.5  /
   'I      '   1   26 1  1   'OPEN' 1     1*   0.5  /

/

WCONPROD

   'P      ' 'OPEN' 'LRAT' 3* 7500  1*  1110.0 /
 /

WCONINJE
```

```
    'I       ' 'WAT' 'OPEN' 'RATE'  7500  1*  8000 /
/

RPTSCHED
 'PRES' 'SOIL' 'SWAT'  'RESTART= 1' 'CPU=2' 'NEWTON=2' /

RPTRST
 'BASIC=2' /

TUNING

1 100 0.1 0.15 3 0.3 0.1 1.25 0.75 /
0.1 0.001 1E-7 0.0001 10 0.01 1E-6 0.001 0.001  /
12 1 1000 1 8 8 4*1E6        /


TSTEP
40*100 /

END
```

C3: Code Input 2D Heterogeneous

Channel Model

```
RUNSPEC
TITLE
   'REL PERM UPSCALING TO REDUCE NUMERICAL DISPERSION'

START
   1 'AUG' 1975  /

DIMENS

--  nx    ny   nz

    20   1   10  /

CART

NONNC

-- PHASES PRESENT

OIL

WATER

-- UNITS

FIELD


EQLDIMS

-- num    num    max     max    max
-- equ     depth  nodes   tab    tracer
-- reg  nodes  VD tab  tracer nodes
```

```
  1    100    1       1      20 /


TABDIMS

-- num  num  max   max   max
-- sat  pvt  sat   press fip
-- tab  tab  nodes nodes regions

   1    1   80    10    1    1 /

REGDIMS
   1    1    0    0  /

WELLDIMS
   2    10    1    2 /

EQLOPTS
MOBILE /

NSTACK
50 /


UNIFOUT

UNIFIN

FMTOUT


--
--     <----------- PRINT ------------>  <------------ STOP -----------
--     mess  comm  warn  prob  err  bug  mess  comm  warn  prob  err  b
MESSAGES
      2*          1000  5*                        100000   2*  /
--

GRID     ==============================================================

EQUALS


DX      150 1 20 1 1 1 10 /
DY      1000 1 20 1 1 1 10 /
DZ     10 1 20 1 1 1 10 /
PORO    0.2 1 20 1 1 1 10 /
TOPS    0.0 1 20 1 1 1 1 /

/

INCLUDE                             -- Generated : Petrel
'Channel_Include_File.DATA' /



/
RPTGRID
-- Report Levels for Grid Section Data
```

```
 /
EDIT

PROPS    ==============================================================
-- SECTION REPORTS DEF. OF REL. PERMEABILITIES, CAPILLARY PRESSRES AND PVT
-- PROPERTIES
------------------------------------------------------------------------

--
--      OIL      WATER      GAS
--    (LBS/FT3) (LBS/FT3) (LBS/FT3)
--
DENSITY

       52.000  64.000  0.044  /
--
--   OIL PHASE PRES.   OIL FVF   OIL VISCOSITY
--       (PSIA)        (RB/STB)      (CP)
--
PVDO
 1100       1.001   2.0
 4000     1.000   2.0
 8000     0.999   2.0


  /
--
--   REF.PRES.  FVF-WATER  COMPRESSIBILITY  VISCOSITY  VISCOSIBILITY
--    (PSIA)     (RB/STB)      (1/PSI)      (CP)        (1/PSI)
--
PVTW

      4000.0    1.0     3.03E-6    0.5000     0.0     /
--
--
--   REF.PRES   ROCK-COMPRESSIBILITY
--    (PSIA)          (1/PSI)
--
ROCK

 4000.0        0.30E-05 /
--
--
SOF2

0.1000   0
0.1200   5.9975E-07
0.1300   3.03623E-06
0.1430   1.28152E-05
0.1550   3.43006E-05
0.1650   6.6912E-05
0.1880   0.000224792
0.2000   0.000374844
0.2150   0.000655604
0.2250   0.000915146
0.2330   0.001172889
0.2450   0.001656999
0.2600   0.002456576
0.2720   0.003280682
0.2850   0.004390735
```

0.3000 0.005997501
0.3125 0.007643391
0.3188 0.008583069
0.3250 0.009606837
0.3309 0.010654819
0.3368 0.011786291
0.3432 0.013102297
0.3543 0.015663694
0.3590 0.016867449
0.3685 0.01948173
0.3750 0.021437845
0.3813 0.023454192
0.3875 0.025609538
0.3950 0.028368995
0.4024 0.031345666
0.4122 0.035610818
0.4204 0.039477466
0.4285 0.043650764
0.4350 0.047209519
0.4521 0.057612199
0.4607 0.063415306
0.4692 0.069646151
0.4766 0.075400046
0.4840 0.08150331
0.4905 0.087163468
0.4970 0.093113441
0.5047 0.100550253
0.5098 0.105689583
0.5149 0.111023452
0.5250 0.122294259
0.5339 0.132864498
0.5428 0.14410558
0.5540 0.159247917
0.5652 0.175553371
0.5712 0.184708606
0.5771 0.194217346
0.5890 0.214331393
0.6043 0.242344951
0.6119 0.257339247
0.6195 0.273018802
0.6313 0.298682387
0.6431 0.326114088
0.6494 0.34157338
0.6558 0.357575895
0.6621 0.374134214
0.6684 0.391261059
0.6755 0.41103682
0.6825 0.431552929
0.6925 0.461959357
0.7000 0.485797584
0.7150 0.536229636
0.7250 0.571966271
0.7330 0.601818023
0.7450 0.648767682
0.7600 0.711256243
0.7720 0.764411904
0.7850 0.825301502
0.8000 0.900000000 /

--

```
--  WATER SAT WATER REL PERM
--  (Sw)      (Krw)
--
SWFN

0.2000  0            0.0000
0.2150  2.9519E-06          0.0000
0.2280  0.0000192           0.0000
0.2400  5.59767E-05         0.0000
0.2550  0.000145517         0.0000
0.2670  0.000263058         0.0000
0.2750  0.000368987         0.0000
0.2850  0.000537136         0.0000
0.3000  0.000874636         0.0000
0.3075  0.001086557         0.0000
0.3175  0.001418864         0.0000
0.3246  0.00168989          0.0000
0.3316  0.001993402         0.0000
0.3379  0.00229486          0.0000
0.3443  0.002625274         0.0000
0.3506  0.002985972         0.0000
0.3569  0.003378283         0.0000
0.3687  0.004199256         0.0000
0.3805  0.0051435           0.0000
0.3881  0.005823267         0.0000
0.3958  0.006560432         0.0000
0.4110  0.008216266         0.0000
0.4229  0.009686287         0.0000
0.4289  0.010482862         0.0000
0.4348  0.011321955         0.0000
0.4460  0.013020644         0.0000
0.4572  0.014881271         0.0000
0.4661  0.016480173         0.0000
0.4750  0.018189687         0.0000
0.4852  0.020279034         0.0000
0.4902  0.021381176         0.0000
0.4953  0.022522546         0.0000
0.5030  0.024330723         0.0000
0.5095  0.025930393         0.0000
0.5160  0.027598685         0.0000
0.5234  0.029583338         0.0000
0.5308  0.031660928         0.0000
0.5394  0.034179893         0.0000
0.5479  0.036829042         0.0000
0.5650  0.042531013         0.0000
0.5715  0.044843922         0.0000
0.5797  0.047860513         0.0000
0.5878  0.051009439         0.0000
0.5976  0.05497513          0.0000
0.6051  0.058123672         0.0000
0.6125  0.061390192         0.0000
0.6188  0.064223149         0.0000
0.6250  0.067141946         0.0000
0.6315  0.070269932         0.0000
0.6410  0.0750141           0.0000
0.6458  0.077464227         0.0000
0.6569  0.083396538         0.0000
0.6632  0.086922616         0.0000
0.6691  0.090286628         0.0000
0.6750  0.093736334         0.0000
```

```
0.6813   0.097485352      0.0000
0.6875   0.101333022      0.0000
0.7000   0.109329446      0.0000
0.7150   0.119467238      0.0000
0.7280   0.128744564      0.0000
0.7400   0.137723615      0.0000
0.7550   0.14952234       0.0000
0.7670   0.1594323        0.0000
0.7750   0.166276421      0.0000
0.7850   0.175103462      0.0000
0.8000   0.188921283      0.0000
0.8120   0.200484777      0.0000
0.8350   0.223948579      0.0000
0.8450   0.234696319      0.0000
0.8570   0.248040869      0.0000
0.8700   0.263058017      0.0000
0.8800   0.275013411      0.0000
0.9000   0.30000000       0.0000
 /

RPTPROPS
   'PVTW'
/
REGIONS  ==============================================================
-- SECTION DEFINES HOW RESERVOIR IS SPLIT INTO REGIONS BY SATURATION FUNCTION,
-- PVT FUNCTION, FLUID IN PLACE ETC.



SOLUTION ==============================================================
-------  SECTION DEFINES INITIAL STATE OF THE SOLUTION VARIABLES - PHASE
-------  SATURATIONS AND GAS-OIL RATIO
-----------------------------------------------------------------------------


EQUIL

50.0  4000  2000  0   0   0   0   0   -2  /


RPTSOL
  'PRES' 'SWAT' 'SOIL' /


SUMMARY  ===============================================================
-------  SECTION SPECIFIES DATA TO BE WRITTEN TO SUMMARY FILES AND WHICH MAY
-------  LATER BE USED WITH THE ECLIPSE GRAPHICS PACKAGE

FOPR

FOPT

FOE

WBP
P /

WBP
I /
```

```
FWCT

FLPR

FLPT

FWIR

FPR
FVIT
FVPT

EXCEL

RUNSUM



SCHEDULE ===================================================================
------- SECTION DEFINES THE OPERATIONS TO BE SIMULATED

WELSPECS

--  WELL      GROUP  LOCATION   BHP    PHASE
--  NAME      NAME    I    J    DEPTH  DEFN
   'P       ' 'G'    20   1    0.0   'OIL'  /
   'I       ' 'G'    1    1    0.0   'WATER'  /
/
COMPDAT
--  WELL          LOCATION     OPEN/  SAT   CONN WELL
--  NAME         I    J K1 K2  SHUT   TABLE FACT ID

   'P       '   20   1  1  10   'OPEN' 1     1*   0.5  /
   'I       '   1    1  1  10   'OPEN' 1     1*   0.5  /
  /

WCONPROD

   'P       ' 'OPEN' 'LRAT' 3* 1450  1*  1110.0 /
/

WCONINJE
    'I       ' 'WAT' 'OPEN' 'RATE'  1450  1*  8000 /
  /

WPAVE

 1* 0.0 1* OPEN /

/
RPTSCHED
 'PRES' 'SOIL' 'SWAT'  'RESTART= 1' 'CPU=2' 'NEWTON=2' /

RPTRST
 'BASIC=2' /

TUNING
1 100 0.1 0.15 3 0.3 0.1 1.25 0.75 /
0.1 0.001 1E-7 0.0001 10 0.01 1E-6 0.001 0.001  /
12 1 1000 1 8 8 4*1E6        /
```

```
TSTEP
60*100 /

END
```

Layer Model

```
RUNSPEC
TITLE
  'REL PERM UPSCALING TO REDUCE NUMERICAL DISPERSION'

START
  1 'AUG' 1975  /

DIMENS

--  nx    ny   nz

    20   1   10  /

CART

NONNC

-- PHASES PRESENT

OIL

WATER

-- UNITS

FIELD


EQLDIMS

-- num    num    max     max    max
-- equ     depth  nodes   tab    tracer
-- reg  nodes  VD tab  tracer nodes
   1    100    1       1      20 /


TABDIMS

-- num  num  max   max   max
-- sat  pvt  sat   press fip
-- tab  tab  nodes nodes regions

    1    1   80    10    1    1 /

REGDIMS
    1    1    0    0  /

WELLDIMS
    2    10    1    2 /

EQLOPTS
MOBILE /
```

```
NSTACK
50 /

UNIFOUT

UNIFIN

FMTOUT


--
--     <----------- PRINT ------------>  <------------ STOP -----------
--     mess  comm  warn  prob  err  bug  mess  comm  warn  prob  err  b
MESSAGES
      2*         1000  5*                      100000   2*  /
--

GRID    ==============================================================

EQUALS

   DX       150 1 20 1 1 1 10 /
   DY       1000 1 20 1 1 1 10 /
   DZ       10 1 20 1 1 1 10 /
   PORO     0.2 1 20 1 1 1 10 /
   PERMX    50 1 20 1 1 1 1 /
   PERMY    50 1 20 1 1 1 1 /
   PERMZ    50 1 20 1 1 1 1 /
   PERMX    100 1 20 1 1 1 2 /
   PERMY    100 1 20 1 1 1 2 /
   PERMZ    100 1 20 1 1 1 2 /
   PERMX    150 1 20 1 1 1 3 /
   PERMY    150 1 20 1 1 1 3 /
   PERMZ    150 1 20 1 1 1 3 /
   PERMX    200 1 20 1 1 1 4 /
   PERMY    200 1 20 1 1 1 4 /
   PERMZ    200 1 20 1 1 1 4 /
   PERMX    250 1 20 1 1 1 5 /
   PERMY    250 1 20 1 1 1 5 /
   PERMZ    250 1 20 1 1 1 5 /
   PERMX    300 1 20 1 1 1 6 /
   PERMY    300 1 20 1 1 1 6 /
   PERMZ    300 1 20 1 1 1 6 /
   PERMX    350 1 20 1 1 1 7 /
   PERMY    350 1 20 1 1 1 7 /
   PERMZ    350 1 20 1 1 1 7 /
   PERMX    400 1 20 1 1 1 8 /
   PERMY    400 1 20 1 1 1 8 /
   PERMZ    400 1 20 1 1 1 8 /
   PERMX    450 1 20 1 1 1 9 /
   PERMY    450 1 20 1 1 1 9 /
   PERMZ    450 1 20 1 1 1 9 /
   PERMX    500 1 20 1 1 1 10 /
   PERMY    500 1 20 1 1 1 10 /
   PERMZ    500 1 20 1 1 1 10 /
   TOPS     0.0 1 20 1 1 1 1 /

/
RPTGRID
```

```
-- Report Levels for Grid Section Data

 /
EDIT

PROPS    ===============================================================
-- SECTION REPORTS DEF. OF REL. PERMEABILITIES, CAPILLARY PRESSRES AND PVT
-- PROPERTIES
---------------------------------------------------------------------------

--
--       OIL      WATER      GAS
--    (LBS/FT3) (LBS/FT3) (LBS/FT3)
--
DENSITY

        52.000  64.000  0.044  /
--
--    OIL PHASE PRES.   OIL FVF   OIL VISCOSITY
--       (PSIA)        (RB/STB)      (CP)
--
PVDO
 1100.0   1.001     2.0
 4000.0   1.000     2.0
 8000.0   0.999     2.0

  /
--
--    REF.PRES.  FVF-WATER  COMPRESSIBILITY  VISCOSITY  VISCOSIBILITY
--     (PSIA)     (RB/STB)      (1/PSI)      (CP)        (1/PSI)
--
PVTW

      4000.0    1.0     3.03E-6    0.5000     0.0     /
--

--
--    REF.PRES   ROCK-COMPRESSIBILITY
--     (PSIA)          (1/PSI)
--
ROCK

 4000.0        .30E-05 /
--
--
SOF2

0.1000   0.00000000
0.1200   5.9975E-07
0.1300   3.03623E-06
0.1430   1.28152E-05
0.1550   3.43006E-05
0.1650   6.6912E-05
0.1880   0.000224792
0.2000   0.000374844
0.2150   0.000655604
0.2250   0.000915146
0.2330   0.001172889
0.2450   0.001656999
0.2600   0.002456576
```

0.2720	0.003280682
0.2850	0.004390735
0.3000	0.005997501
0.3125	0.007643391
0.3188	0.008583069
0.3250	0.009606837
0.3309	0.010654819
0.3368	0.011786291
0.3432	0.013102297
0.3543	0.015663694
0.3590	0.016867449
0.3685	0.01948173
0.3750	0.021437845
0.3813	0.023454192
0.3875	0.025609538
0.3950	0.028368995
0.4024	0.031345666
0.4122	0.035610818
0.4204	0.039477466
0.4285	0.043650764
0.4350	0.047209519
0.4521	0.057612199
0.4607	0.063415306
0.4692	0.069646151
0.4766	0.075400046
0.4840	0.08150331
0.4905	0.087163468
0.4970	0.093113441
0.5047	0.100550253
0.5098	0.105689583
0.5149	0.111023452
0.5250	0.122294259
0.5339	0.132864498
0.5428	0.14410558
0.5540	0.159247917
0.5652	0.175553371
0.5712	0.184708606
0.5771	0.194217346
0.5890	0.214331393
0.6043	0.242344951
0.6119	0.257339247
0.6195	0.273018802
0.6313	0.298682387
0.6431	0.326114088
0.6494	0.34157338
0.6558	0.357575895
0.6621	0.374134214
0.6684	0.391261059
0.6755	0.41103682
0.6825	0.431552929
0.6925	0.461959357
0.7000	0.485797584
0.7150	0.536229636
0.7250	0.571966271
0.7330	0.601818023
0.7450	0.648767682
0.7600	0.711256243
0.7720	0.764411904
0.7850	0.825301502
0.8000	0.900000000 /

```
--
--  WATER SAT WATER REL PERM
--  (Sw)       (Krw)
--
SWFN

0.2000   0.0000000         0.0000
0.2150   2.9519E-06        0.0000
0.2280   0.0000192         0.0000
0.2400   5.59767E-05       0.0000
0.2550   0.000145517       0.0000
0.2670   0.000263058       0.0000
0.2750   0.000368987       0.0000
0.2850   0.000537136       0.0000
0.3000   0.000874636       0.0000
0.3075   0.001086557       0.0000
0.3175   0.001418864       0.0000
0.3246   0.00168989        0.0000
0.3316   0.001993402       0.0000
0.3379   0.00229486        0.0000
0.3443   0.002625274       0.0000
0.3506   0.002985972       0.0000
0.3569   0.003378283       0.0000
0.3687   0.004199256       0.0000
0.3805   0.0051435         0.0000
0.3881   0.005823267       0.0000
0.3958   0.006560432       0.0000
0.4110   0.008216266       0.0000
0.4229   0.009686287       0.0000
0.4289   0.010482862       0.0000
0.4348   0.011321955       0.0000
0.4460   0.013020644       0.0000
0.4572   0.014881271       0.0000
0.4661   0.016480173       0.0000
0.4750   0.018189687       0.0000
0.4852   0.020279034       0.0000
0.4902   0.021381176       0.0000
0.4953   0.022522546       0.0000
0.5030   0.024330723       0.0000
0.5095   0.025930393       0.0000
0.5160   0.027598685       0.0000
0.5234   0.029583338       0.0000
0.5308   0.031660928       0.0000
0.5394   0.034179893       0.0000
0.5479   0.036829042       0.0000
0.5650   0.042531013       0.0000
0.5715   0.044843922       0.0000
0.5797   0.047860513       0.0000
0.5878   0.051009439       0.0000
0.5976   0.05497513        0.0000
0.6051   0.058123672       0.0000
0.6125   0.061390192       0.0000
0.6188   0.064223149       0.0000
0.6250   0.067141946       0.0000
0.6315   0.070269932       0.0000
0.6410   0.0750141         0.0000
0.6458   0.077464227       0.0000
0.6569   0.083396538       0.0000
0.6632   0.086922616       0.0000
```

```
0.6691   0.090286628     0.0000
0.6750   0.093736334     0.0000
0.6813   0.097485352     0.0000
0.6875   0.101333022     0.0000
0.7000   0.109329446     0.0000
0.7150   0.119467238     0.0000
0.7280   0.128744564     0.0000
0.7400   0.137723615     0.0000
0.7550   0.14952234      0.0000
0.7670   0.1594323       0.0000
0.7750   0.166276421     0.0000
0.7850   0.175103462     0.0000
0.8000   0.188921283     0.0000
0.8120   0.200484777     0.0000
0.8350   0.223948579     0.0000
0.8450   0.234696319     0.0000
0.8570   0.248040869     0.0000
0.8700   0.263058017     0.0000
0.8800   0.275013411     0.0000
0.9000   0.30000000      0.0000 /

/
RPTPROPS
   'PVTW'
/
REGIONS  ==============================================================
-- SECTION DEFINES HOW RESERVOIR IS SPLIT INTO REGIONS BY SATURATION FUNCTION,
-- PVT FUNCTION, FLUID IN PLACE ETC.



SOLUTION ==============================================================
-------  SECTION DEFINES INITIAL STATE OF THE SOLUTION VARIABLES - PHASE
-------  SATURATIONS AND GAS-OIL RATIO
------------------------------------------------------------------------


EQUIL

50.0  4000  2000  0   0   0   0   0   -2  /


RPTSOL
  'PRES' 'SWAT' 'SOIL' /


SUMMARY  ==============================================================
-------  SECTION SPECIFIES DATA TO BE WRITTEN TO SUMMARY FILES AND WHICH MAY
-------  LATER BE USED WITH THE ECLIPSE GRAPHICS PACKAGE

RPTONLY

FOPR

FOPT

FOE

WBP
P /
```

```
WBP
I /

FWCT

FLPR

FLPT

FWIR

FPR
FVIT
FVPT

EXCEL

RUNSUM



SCHEDULE ===================================================================
------- SECTION DEFINES THE OPERATIONS TO BE SIMULATED


WELSPECS

--  WELL     GROUP  LOCATION   BHP    PHASE
--  NAME      NAME    I    J    DEPTH  DEFN
   'P      ' 'G'    20   1    0.0   'OIL'  /
   'I      ' 'G'    1    1    0.0   'WATER'  /
/
COMPDAT
--  WELL         LOCATION     OPEN/  SAT   CONN WELL
--  NAME        I    J K1 K2  SHUT   TABLE FACT ID

   'P      '   20    1  1  10   'OPEN' 1     1*   0.5  /
   'I      '   1     1  1  10   'OPEN' 1     1*   0.5  /
  /

WCONPROD

   'P      ' 'OPEN' 'LRAT' 3* 9800  1*  1110.0 /
/

WCONINJE
    'I      ' 'WAT' 'OPEN' 'RATE' 9800  1*  8000 /
  /

WPAVE

 1* 0.0 1* OPEN /

/

RPTSCHED
 'PRES' 'SOIL' 'SWAT'  'RESTART= 1' 'CPU=2' 'NEWTON=2' /

RPTRST
```

```
 'BASIC=2' /

TUNING
1 100 0.1 0.15 3 0.3 0.1 1.25 0.75 /
0.1 0.001 1E-7 0.0001 10 0.01 1E-6 0.001 0.001  /
12 1 1000 1 8 8 4*1E6        /

TSTEP
40*100 /
```

Random Permeability Model

```
RUNSPEC
TITLE
   'REL PERM UPSCALING TO REDUCE NUMERICAL DISPERSION'

START
   1 'AUG' 1975  /

DIMENS

--  nx    ny   nz

    20   1   10  /

CART

NONNC

-- PHASES PRESENT

OIL

WATER

-- UNITS

FIELD


EQLDIMS

-- num    num    max     max    max
-- equ     depth  nodes   tab    tracer
-- reg  nodes  VD tab  tracer nodes
   1    100    1       1      20 /


TABDIMS

-- num  num  max   max   max
-- sat  pvt  sat   press fip
-- tab  tab  nodes nodes regions

    1    1   80    10    1    1 /

REGDIMS
    1    1    0    0  /
```

```
WELLDIMS
   2    10    1    2 /

EQLOPTS
MOBILE /

NSTACK
50 /


UNIFOUT

UNIFIN

FMTOUT


--
--      <----------- PRINT ------------> <------------ STOP -----------
--      mess  comm  warn  prob  err  bug  mess  comm  warn  prob  err  b
MESSAGES
       2*          1000  5*                       100000   2*  /
--

GRID     =============================================================

EQUALS

DX      150 1 20 1 1 1 10 /
DY      1000 1 20 1 1 1 10 /
DZ      10 1 20 1 1 1 10 /
PORO    0.2 1 20 1 1 1 10 /
TOPS    0.0 1 20 1 1 1 1 /

/

INCLUDE
'Incude_Random_Perm.DATA' /

/
RPTGRID
-- Report Levels for Grid Section Data

 /
EDIT

PROPS    =============================================================
-- SECTION REPORTS DEF. OF REL. PERMEABILITIES, CAPILLARY PRESSRES AND PVT
-- PROPERTIES
-----------------------------------------------------------------------

---
--       OIL      WATER      GAS
--     (LBS/FT3) (LBS/FT3) (LBS/FT3)
--
DENSITY

        52.000  64.000  0.044  /
--
--    OIL PHASE PRES.   OIL FVF   OIL VISCOSITY
```

```
--      (PSIA)       (RB/STB)     (CP)
--
PVDO
 1100       1.001    2.0
 4000     1.000    2.0
 8000     0.999    2.0


  /
--
--   REF.PRES.  FVF-WATER  COMPRESSIBILITY  VISCOSITY  VISCOSIBILITY
--    (PSIA)     (RB/STB)      (1/PSI)      (CP)        (1/PSI)
--
PVTW

      4000.0    1.0     3.03E-6    0.5000     0.0     /
--
--
--   REF.PRES   ROCK-COMPRESSIBILITY
--    (PSIA)          (1/PSI)
--
ROCK

 4000.0         .30E-05 /
--
--
SOF2

0.1000   0
0.1200   5.9975E-07
0.1300   3.03623E-06
0.1430   1.28152E-05
0.1550   3.43006E-05
0.1650   6.6912E-05
0.1880   0.000224792
0.2000   0.000374844
0.2150   0.000655604
0.2250   0.000915146
0.2330   0.001172889
0.2450   0.001656999
0.2600   0.002456576
0.2720   0.003280682
0.2850   0.004390735
0.3000   0.005997501
0.3125   0.007643391
0.3188   0.008583069
0.3250   0.009606837
0.3309   0.010654819
0.3368   0.011786291
0.3432   0.013102297
0.3543   0.015663694
0.3590   0.016867449
0.3685   0.01948173
0.3750   0.021437845
0.3813   0.023454192
0.3875   0.025609538
0.3950   0.028368995
0.4024   0.031345666
0.4122   0.035610818
0.4204   0.039477466
```

```
0.4285   0.043650764
0.4350   0.047209519
0.4521   0.057612199
0.4607   0.063415306
0.4692   0.069646151
0.4766   0.075400046
0.4840   0.08150331
0.4905   0.087163468
0.4970   0.093113441
0.5047   0.100550253
0.5098   0.105689583
0.5149   0.111023452
0.5250   0.122294259
0.5339   0.132864498
0.5428   0.14410558
0.5540   0.159247917
0.5652   0.175553371
0.5712   0.184708606
0.5771   0.194217346
0.5890   0.214331393
0.6043   0.242344951
0.6119   0.257339247
0.6195   0.273018802
0.6313   0.298682387
0.6431   0.326114088
0.6494   0.34157338
0.6558   0.357575895
0.6621   0.374134214
0.6684   0.391261059
0.6755   0.41103682
0.6825   0.431552929
0.6925   0.461959357
0.7000   0.485797584
0.7150   0.536229636
0.7250   0.571966271
0.7330   0.601818023
0.7450   0.648767682
0.7600   0.711256243
0.7720   0.764411904
0.7850   0.825301502
0.8000   0.900000000 /

--
--  WATER SAT WATER REL PERM
--  (Sw)       (Krw)
--
SWFN

0.2000   0              0.0000
0.2150   2.9519E-06     0.0000
0.2280   0.0000192      0.0000
0.2400   5.59767E-05    0.0000
0.2550   0.000145517    0.0000
0.2670   0.000263058    0.0000
0.2750   0.000368987    0.0000
0.2850   0.000537136    0.0000
0.3000   0.000874636    0.0000
0.3075   0.001086557    0.0000
0.3175   0.001418864    0.0000
0.3246   0.00168989     0.0000
```

0.3316	0.001993402	0.0000
0.3379	0.00229486	0.0000
0.3443	0.002625274	0.0000
0.3506	0.002985972	0.0000
0.3569	0.003378283	0.0000
0.3687	0.004199256	0.0000
0.3805	0.0051435	0.0000
0.3881	0.005823267	0.0000
0.3958	0.006560432	0.0000
0.4110	0.008216266	0.0000
0.4229	0.009686287	0.0000
0.4289	0.010482862	0.0000
0.4348	0.011321955	0.0000
0.4460	0.013020644	0.0000
0.4572	0.014881271	0.0000
0.4661	0.016480173	0.0000
0.4750	0.018189687	0.0000
0.4852	0.020279034	0.0000
0.4902	0.021381176	0.0000
0.4953	0.022522546	0.0000
0.5030	0.024330723	0.0000
0.5095	0.025930393	0.0000
0.5160	0.027598685	0.0000
0.5234	0.029583338	0.0000
0.5308	0.031660928	0.0000
0.5394	0.034179893	0.0000
0.5479	0.036829042	0.0000
0.5650	0.042531013	0.0000
0.5715	0.044843922	0.0000
0.5797	0.047860513	0.0000
0.5878	0.051009439	0.0000
0.5976	0.05497513	0.0000
0.6051	0.058123672	0.0000
0.6125	0.061390192	0.0000
0.6188	0.064223149	0.0000
0.6250	0.067141946	0.0000
0.6315	0.070269932	0.0000
0.6410	0.0750141	0.0000
0.6458	0.077464227	0.0000
0.6569	0.083396538	0.0000
0.6632	0.086922616	0.0000
0.6691	0.090286628	0.0000
0.6750	0.093736334	0.0000
0.6813	0.097485352	0.0000
0.6875	0.101333022	0.0000
0.7000	0.109329446	0.0000
0.7150	0.119467238	0.0000
0.7280	0.128744564	0.0000
0.7400	0.137723615	0.0000
0.7550	0.14952234	0.0000
0.7670	0.1594323	0.0000
0.7750	0.166276421	0.0000
0.7850	0.175103462	0.0000
0.8000	0.188921283	0.0000
0.8120	0.200484777	0.0000
0.8350	0.223948579	0.0000
0.8450	0.234696319	0.0000
0.8570	0.248040869	0.0000
0.8700	0.263058017	0.0000
0.8800	0.275013411	0.0000

```
0.9000   0.30000000        0.0000 /

/
RPTPROPS
   'PVTW'
/
REGIONS  ===============================================================
-- SECTION DEFINES HOW RESERVOIR IS SPLIT INTO REGIONS BY SATURATION FUNCTION,
-- PVT FUNCTION, FLUID IN PLACE ETC.



SOLUTION ================================================================
-------  SECTION DEFINES INITIAL STATE OF THE SOLUTION VARIABLES - PHASE
-------  SATURATIONS AND GAS-OIL RATIO
---------------------------------------------------------------------------


EQUIL

   50  4000  2000  0    0    0    0    0    -2/


RPTSOL
  'PRES' 'SWAT' 'SOIL' /


SUMMARY  ===================================================================
-------  SECTION SPECIFIES DATA TO BE WRITTEN TO SUMMARY FILES AND WHICH MAY
-------  LATER BE USED WITH THE ECLIPSE GRAPHICS PACKAGE

RPTONLY

FOPR

FOPT

FOE

WBP
P /

WBP
I /

FWCT

FLPR

FLPT

FWIR

FPR
FVIT
FVPT

EXCEL

RUNSUM
```

```
SCHEDULE ===================================================================
------- SECTION DEFINES THE OPERATIONS TO BE SIMULATED


WELSPECS

--  WELL     GROUP  LOCATION   BHP    PHASE
--  NAME     NAME    I    J    DEPTH  DEFN
   'P      ' 'G'    20   1    0.0   'OIL'  /
   'I      ' 'G'    1    1    0.0   'WATER'  /
/
COMPDAT
--  WELL        LOCATION     OPEN/  SAT   CONN WELL
--  NAME        I    J K1 K2  SHUT   TABLE FACT ID

   'P      '   20   1  1  10   'OPEN' 1     1*   0.5  /
   'I      '   1    1  1  10   'OPEN' 1     1*   0.5  /
  /

WCONPROD

   'P      ' 'OPEN' 'LRAT' 3* 2000  1*  1110.0 /
/

WCONINJE
    'I      ' 'WAT' 'OPEN' 'RATE'  2000  1*  8000 /
  /

WPAVE

 1* 0.0 1* OPEN /

RPTSCHED
 'PRES' 'SOIL' 'SWAT'  'RESTART= 1' 'CPU=2' 'NEWTON=2' /

RPTRST
 'BASIC=2' /

TUNING
1 100 0.1 0.15 3 0.3 0.1 1.25 0.75 /
0.1 0.001 1E-7 0.0001 10 0.01 1E-6 0.001 0.001  /
12 1 1000 1 8 8 4*1E6        /

TSTEP
60*100 /

END
```

Appendix D

Table D1 Pseudo-Relative and Pseudo-Mobility Calculation

1D Pseudos

Intermediate Gridblock

Rock Curves Table			Pseudo Relative Permeability Table			Rock Curve Mobility				Pseudo-Mobility	
Sw	Krw	kro	SW	KRW	KRO	λo	λw	λt	λ^{-1}		
0.2	0	0.9	0.2	0	0.9000	0.4500	0.0000	0.4500	2.2222	Loj	1/Loj
0.215	2.95E-06	0.825302	0.215	0	0.8204	0.4127	0.0000	0.4127	2.4233	0.4500	2.2222
0.228	1.92E-05	0.764412	0.228	0	0.7620	0.3822	0.0000	0.3822	2.6161	0.4102	2.4379
0.24	5.6E-05	0.711256	0.24	0	0.7150	0.3556	0.0001	0.3557	2.8110	0.3810	2.6248
0.255	0.000146	0.648768	0.255	0	0.6638	0.3244	0.0003	0.3247	3.0800	0.3575	2.7973
0.267	0.000263	0.601818	0.267	0	0.6278	0.3009	0.0005	0.3014	3.3175	0.3319	3.0130
0.275	0.000369	0.571966	0.275	0	0.6060	0.2860	0.0007	0.2867	3.4877	0.3139	3.1855
0.285	0.000537	0.53623	0.285	0	0.5807	0.2681	0.0011	0.2692	3.7149	0.3030	3.3005
0.3	0.000875	0.485798	0.3	0	0.5464	0.2429	0.0017	0.2446	4.0875	0.2903	3.4443
0.3075	0.001087	0.461959	0.308	0	0.5308	0.2310	0.0022	0.2332	4.2890	0.2732	3.6600
0.3175	0.001419	0.431553	0.318	0	0.5113	0.2158	0.0028	0.2186	4.5743	0.2654	3.7678
0.3246	0.001692	0.410894	0.325	0	0.4983	0.2054	0.0034	0.2088	4.7886	0.2556	3.9116
0.3316	0.001993	0.391261	0.332	0	0.4861	0.1956	0.0040	0.1996	5.0096	0.2491	4.0137
0.3379	0.002294	0.374201	0.338	0	0.4756	0.1871	0.0046	0.1917	5.2168	0.2431	4.1143
0.3443	0.002628	0.357447	0.344	0	0.4654	0.1787	0.0053	0.1840	5.4354	0.2378	4.2049
0.3506	0.002987	0.341511	0.351	0	0.4558	0.1708	0.0060	0.1767	5.6583	0.2327	4.2969
0.3569	0.003378	0.326114	0.357	0	0.4466	0.1631	0.0068	0.1698	5.8888	0.2279	4.3875
0.3687	0.004199	0.298682	0.369	0	0.4303	0.1493	0.0084	0.1577	6.3396	0.2233	4.4781
0.3805	0.005144	0.273019	0.381	0	0.4152	0.1365	0.0103	0.1468	6.8122	0.2152	4.6477
0.3881	0.005821	0.25739	0.388	0	0.4060	0.1287	0.0116	0.1403	7.1257	0.2076	4.8174
0.3958	0.006565	0.242249	0.396	0	0.3970	0.1211	0.0131	0.1343	7.4485	0.2030	4.9267
0.411	0.008216	0.214331	0.411	0	0.3805	0.1072	0.0164	0.1236	8.0907	0.1985	5.0374
0.4229	0.009686	0.194217	0.423	0	0.3685	0.0971	0.0194	0.1165	8.5851	0.1903	5.2559
0.4289	0.01049	0.18463	0.429	0	0.3628	0.0923	0.0210	0.1133	8.8265	0.1843	5.4270
0.4348	0.011322	0.175553	0.435	0	0.3573	0.0878	0.0226	0.1104	9.0563	0.1814	5.5133
0.446	0.013021	0.159248	0.446	0	0.3473	0.0796	0.0260	0.1057	9.4638	0.1786	5.5981
0.4572	0.014881	0.144106	0.457	0	0.3378	0.0721	0.0298	0.1018	9.8217	0.1736	5.7591
0.4661	0.01648	0.132864	0.466	0	0.3307	0.0664	0.0330	0.0994	10.0611	0.1689	5.9202
0.475	0.01819	0.122294	0.475	0	0.3238	0.0611	0.0364	0.0975	10.2536	0.1653	6.0481
0.4852	0.02029	0.11097	0.485	0	0.3163	0.0555	0.0406	0.0961	10.4097	0.1619	6.1761
0.4902	0.021376	0.105715	0.49	0	0.3128	0.0529	0.0428	0.0956	10.4593	0.1582	6.3227
0.4953	0.022523	0.10055	0.495	0	0.3092	0.0503	0.0450	0.0953	10.4910	0.1564	6.3946
0.503	0.024331	0.093113	0.503	0	0.3040	0.0466	0.0487	0.0952	10.5022	0.1546	6.4680
0.5095	0.02593	0.087163	0.51	0	0.2998	0.0436	0.0519	0.0954	10.4775	0.1520	6.5787
0.516	0.027599	0.081503	0.516	0	0.2956	0.0408	0.0552	0.0959	10.4222	0.1499	6.6721

0.5234	0.029583	0.0754	0.523	0	0.2910	0.0377	0.0592	0.0969	10.3235	0.1478	6.7656
0.5308	0.031661	0.069646	0.531	0	0.2866	0.0348	0.0633	0.0981	10.1890	0.1455	6.8720
0.5394	0.034195	0.06338	0.539	0	0.2816	0.0317	0.0684	0.1001	9.9920	0.1433	6.9784
0.5479	0.036829	0.057612	0.548	0	0.2768	0.0288	0.0737	0.1025	9.7595	0.1408	7.1020
0.565	0.042531	0.04721	0.565	0	0.2677	0.0236	0.0851	0.1087	9.2024	0.1384	7.2242
0.5715	0.044844	0.043651	0.572	0	0.2644	0.0218	0.0897	0.1115	8.9675	0.1339	7.4701
0.5797	0.047879	0.039453	0.58	0	0.2604	0.0197	0.0958	0.1155	8.6591	0.1322	7.5635
0.5878	0.051009	0.035611	0.588	0	0.2565	0.0178	0.1020	0.1198	8.3456	0.1302	7.6814
0.5976	0.054975	0.031346	0.598	0	0.2519	0.0157	0.1100	0.1256	7.9603	0.1282	7.7979
0.6051	0.058145	0.02835	0.605	0.058	0.0283	0.0142	0.1163	0.1305	7.6649	0.1260	7.9388
0.6125	0.06139	0.02561	0.613	0.061	0.0256	0.0128	0.1228	0.1356	7.3754	0.1243	8.0466
0.6188	0.064246	0.023438	0.619	0.064	0.0234	0.0117	0.1285	0.1402	7.1321	0.1228	
0.625	0.067142	0.021438	0.625	0.067	0.0214	0.0107	0.1343	0.1450	6.8964	0.1285	
0.6315	0.07027	0.019482	0.632	0.07	0.0195	0.0097	0.1405	0.1503	6.6542	0.1343	
0.6458	0.07749	0.015651	0.646	0.077	0.0157	0.0078	0.1550	0.1628	6.1423	0.1405	
0.6569	0.083424	0.013092	0.657	0.083	0.0131	0.0065	0.1668	0.1734	5.7672	0.1628	
0.6632	0.086923	0.011786	0.663	0.087	0.0118	0.0059	0.1738	0.1797	5.5636	0.1734	
0.6691	0.090287	0.010655	0.669	0.09	0.0107	0.0053	0.1806	0.1859	5.3792	0.1797	
0.675	0.093736	0.009607	0.675	0.094	0.0096	0.0048	0.1875	0.1923	5.2009	0.1859	
0.6813	0.097516	0.008575	0.681	0.098	0.0086	0.0043	0.1950	0.1993	5.0171	0.1923	
0.6875	0.101333	0.007643	0.688	0.101	0.0076	0.0038	0.2027	0.2065	4.8429	0.1993	
0.7	0.109329	0.005998	0.7	0.109	0.0060	0.0030	0.2187	0.2217	4.5115	0.2065	
0.715	0.119467	0.004391	0.715	0.119	0.0044	0.0022	0.2389	0.2411	4.1471	0.2217	
0.728	0.128745	0.003281	0.728	0.129	0.0033	0.0016	0.2575	0.2591	3.8591	0.2411	
0.74	0.137724	0.002457	0.74	0.138	0.0025	0.0012	0.2754	0.2767	3.6143	0.2591	
0.755	0.149522	0.001657	0.755	0.15	0.0017	0.0008	0.2990	0.2999	3.3347	0.2767	
0.767	0.159432	0.001173	0.767	0.159	0.0012	0.0006	0.3189	0.3195	3.1304	0.2999	
0.775	0.166276	0.000915	0.775	0.166	0.0009	0.0005	0.3326	0.3330	3.0029	0.3195	
0.785	0.175103	0.000656	0.785	0.175	0.0007	0.0003	0.3502	0.3505	2.8528	0.3330	
0.8	0.188921	0.000375	0.8	0.189	0.0004	0.0002	0.3778	0.3780	2.6453	0.3505	
0.812	0.200485	0.000225	0.812	0.2	0.0002	0.0001	0.4010	0.4011	2.4933	0.3780	
0.835	0.223949	6.69E-05	0.835	0.224	0.0001	0.0000	0.4479	0.4479	2.2325	0.4011	
0.845	0.234696	3.43E-05	0.845	0.235	0.0000	0.0000	0.4694	0.4694	2.1303	0.4479	
0.857	0.248041	1.28E-05	0.857	0.248	0.0000	0.0000	0.4961	0.4961	2.0158	0.4694	
0.87	0.263058	3.04E-06	0.87	0.263	0.0000	0.0000	0.5261	0.5261	1.9007	0.4961	
0.88	0.275013	6E-07	0.88	0.275	0.0000	0.0000	0.5500	0.5500	1.8181	0.5261	
0.9	0.3	0	0.9	0.3	0.0000	0.0000	0.6000	0.6000	1.6667	0.5500	
0.598	0.055141	0.03118	0.598	0.055	0.0312	0.0156	0.1103	0.1259	7.9445	0.6000	
										0.1259	Swf
0.656	0.082932	0.013286	0.656	0.083	0.0133	0.0066	0.1659	0.1725	5.7969		
										0.1725	Swf(avg)

Injector Gridblock

Pseudo Function Table			Rock Mobility				Pseudo Oil Mobility			
SW	**KRW**	**KRO**	**λo**	**λw**	**λt**	**λ-1**	**Lwj**	**Loj**	**1/Loj**	**LTj**
0.2000	0.0000	0.9000	0.4500	0.0000	0.4500	2.2222	0.000000	0.450000	2.2222	0.4500
0.2150	0.0000	0.8465	0.4127	0.0000	0.4127	2.4233	0.000000	0.423239	2.3627	0.4232
0.2280	0.0000	0.8050	0.3822	0.0000	0.3822	2.6161	0.000000	0.402495	2.4845	0.4025
0.2400	0.0000	0.7701	0.3556	0.0001	0.3557	2.8110	0.000000	0.385073	2.5969	0.3851
0.2550	0.0000	0.7306	0.3244	0.0003	0.3247	3.0800	0.000000	0.365308	2.7374	0.3653
0.2670	0.0000	0.7018	0.3009	0.0005	0.3014	3.3175	0.000000	0.350899	2.8498	0.3509
0.2750	0.0000	0.6838	0.2860	0.0007	0.2867	3.4877	0.000000	0.341909	2.9248	0.3419
0.2850	0.0000	0.6626	0.2681	0.0011	0.2692	3.7149	0.000000	0.331298	3.0184	0.3313
0.3000	0.0000	0.6331	0.2429	0.0017	0.2446	4.0875	0.000000	0.316562	3.1589	0.3166
0.3075	0.0000	0.6194	0.2310	0.0022	0.2332	4.2890	0.000000	0.309675	3.2292	0.3097
0.3175	0.0000	0.6019	0.2158	0.0028	0.2186	4.5743	0.000000	0.300946	3.3229	0.3009
0.3246	0.0000	0.5901	0.2054	0.0034	0.2088	4.7886	0.000000	0.295040	3.3894	0.2950
0.3316	0.0000	0.5789	0.1956	0.0040	0.1996	5.0096	0.000000	0.289441	3.4549	0.2894
0.3379	0.0000	0.5692	0.1871	0.0046	0.1917	5.2168	0.000000	0.284580	3.5140	0.2846
0.3443	0.0000	0.5596	0.1787	0.0053	0.1840	5.4354	0.000000	0.279806	3.5739	0.2798
0.3506	0.0000	0.5505	0.1708	0.0060	0.1767	5.6583	0.000000	0.275261	3.6329	0.2753
0.3569	0.0000	0.5417	0.1631	0.0068	0.1698	5.8888	0.000000	0.270861	3.6919	0.2709
0.3687	0.0000	0.5260	0.1493	0.0084	0.1577	6.3396	0.000000	0.262988	3.8025	0.2630
0.3805	0.0000	0.5111	0.1365	0.0103	0.1468	6.8122	0.000000	0.255559	3.9130	0.2556
0.3881	0.0000	0.5020	0.1287	0.0116	0.1403	7.1257	0.000000	0.250993	3.9842	0.2510
0.3958	0.0000	0.4931	0.1211	0.0131	0.1343	7.4485	0.000000	0.246530	4.0563	0.2465
0.4110	0.0000	0.4763	0.1072	0.0164	0.1236	8.0907	0.000000	0.238170	4.1987	0.2382
0.4229	0.0000	0.4640	0.0971	0.0194	0.1165	8.5851	0.000000	0.232010	4.3102	0.2320
0.4289	0.0000	0.4580	0.0923	0.0210	0.1133	8.8265	0.000000	0.229024	4.3664	0.2290
0.4348	0.0000	0.4523	0.0878	0.0226	0.1104	9.0563	0.000000	0.226161	4.4216	0.2262
0.4460	0.0000	0.4418	0.0796	0.0260	0.1057	9.4638	0.000000	0.220919	4.5265	0.2209
0.4572	0.0000	0.4318	0.0721	0.0298	0.1018	9.8217	0.000000	0.215915	4.6314	0.2159
0.4661	0.0000	0.4242	0.0664	0.0330	0.0994	10.0611	0.000000	0.212097	4.7148	0.2121
0.4750	0.0000	0.4168	0.0611	0.0364	0.0975	10.2536	0.000000	0.208412	4.7982	0.2084
0.4852	0.0000	0.4087	0.0555	0.0406	0.0961	10.4097	0.000000	0.204343	4.8937	0.2043
0.4902	0.0000	0.4048	0.0529	0.0428	0.0956	10.4593	0.000000	0.202406	4.9406	0.2024
0.4953	0.0000	0.4009	0.0503	0.0450	0.0953	10.4910	0.000000	0.200468	4.9883	0.2005
0.5030	0.0000	0.3952	0.0466	0.0487	0.0952	10.5022	0.000000	0.197610	5.0605	0.1976
0.5095	0.0000	0.3905	0.0436	0.0519	0.0954	10.4775	0.000000	0.195261	5.1214	0.1953
0.5160	0.0000	0.3859	0.0408	0.0552	0.0959	10.4222	0.000000	0.192967	5.1822	0.1930
0.5234	0.0000	0.3808	0.0377	0.0592	0.0969	10.3235	0.000000	0.190420	5.2516	0.1904
0.5308	0.0000	0.3759	0.0348	0.0633	0.0981	10.1890	0.000000	0.187939	5.3209	0.1879
0.5394	0.0000	0.3703	0.0317	0.0684	0.1001	9.9920	0.000000	0.185136	5.4014	0.1851
0.5479	0.0000	0.3649	0.0288	0.0737	0.1025	9.7595	0.000000	0.182447	5.4810	0.1824
0.5650	0.0000	0.3545	0.0236	0.0851	0.1087	9.2024	0.000000	0.177266	5.6412	0.1773

0.5715	0.0000	0.3507	0.0218	0.0897	0.1115	8.9675	0.000000	0.175374	5.7021	0.1754
0.5797	0.0000	0.3461	0.0197	0.0958	0.1155	8.6591	0.000000	0.173043	5.7789	0.1730
0.5878	0.0000	0.3416	0.0178	0.1020	0.1198	8.3456	0.000000	0.170800	5.8548	0.1708
0.5976	0.0000	0.3363	0.0157	0.1100	0.1256	7.9603	0.000000	0.168163	5.9466	0.1682
0.6452	0.0735	0.0358	0.0142	0.1163	0.1305	7.6649	0.147011	0.017919		0.1649
0.6617	0.0770	0.0321	0.0128	0.1228	0.1356	7.3754	0.153977	0.016058		0.1700
0.6673	0.0801	0.0292	0.0117	0.1285	0.1402	7.1321	0.160172	0.014608		0.1748
0.6725	0.0832	0.0266	0.0107	0.1343	0.1450	6.8964	0.166458	0.013287		0.1797
0.6778	0.0882	0.0244	0.0097	0.1405	0.1503	6.6542	0.176368	0.012224		0.1886
0.6868	0.0961	0.0194	0.0078	0.1550	0.1628	6.1423	0.192287	0.009709		0.2020
0.6975	0.1016	0.0159	0.0065	0.1668	0.1734	5.7672	0.203157	0.007970		0.2111
0.7048	0.1050	0.0142	0.0059	0.1738	0.1797	5.5636	0.209939	0.007117		0.2171
0.7100	0.1082	0.0128	0.0053	0.1806	0.1859	5.3792	0.216393	0.006384		0.2228
0.7151	0.1115	0.0114	0.0048	0.1875	0.1923	5.2009	0.222999	0.005714		0.2287
0.7203	0.1149	0.0101	0.0043	0.1950	0.1993	5.0171	0.229770	0.005051		0.2348
0.7257	0.1198	0.0090	0.0038	0.2027	0.2065	4.8429	0.239697	0.004520		0.2442
0.7340	0.1287	0.0071	0.0030	0.2187	0.2217	4.5115	0.257401	0.003530		0.2609
0.7459	0.1387	0.0051	0.0022	0.2389	0.2411	4.1471	0.277330	0.002548		0.2799
0.7577	0.1475	0.0038	0.0016	0.2575	0.2591	3.8591	0.294903	0.001879		0.2968
0.7682	0.1571	0.0028	0.0012	0.2754	0.2767	3.6143	0.314164	0.001401		0.3156
0.7797	0.1679	0.0019	0.0008	0.2990	0.2999	3.3347	0.335783	0.000930		0.3367
0.7908	0.1753	0.0013	0.0006	0.3189	0.3195	3.1304	0.350678	0.000645		0.3513
0.7988	0.1811	0.0010	0.0005	0.3326	0.3330	3.0029	0.362226	0.000498		0.3627
0.8063	0.1896	0.0007	0.0003	0.3502	0.3505	2.8528	0.379252	0.000355		0.3796
0.8169	0.2002	0.0004	0.0002	0.3778	0.3780	2.6453	0.400358	0.000199		0.4006
0.8276	0.2130	0.0002	0.0001	0.4010	0.4011	2.4933	0.426090	0.000119		0.4262
0.8434	0.2327	0.0001	0.0000	0.4479	0.4479	2.2325	0.465304	0.000035		0.4653
0.8546	0.2415	0.0000	0.0000	0.4694	0.4694	2.1303	0.482934	0.000018		0.4830
0.8636	0.2528	0.0000	0.0000	0.4961	0.4961	2.0158	0.505566	0.000007		0.5056
0.8737	0.2644	0.0000	0.0000	0.5261	0.5261	1.9007	0.528794	0.000002		0.5288
0.8823	0.2750	0.0000	0.0000	0.5500	0.5500	1.8181	0.550027	0.000000		0.5500
0.9000	0.3000	0.0000	0.0000	0.6000	0.6000	1.6667	0.600000	0.000000		0.6000

Table D2 Relative Permeability Calculation (JBN Method)

Channels

Total Water Injected	Total Oil	Delta Pressure	Pore Volume of Water Injected	Pore Volume of Oil Produced	Average saturation	Effective Viscosity	Intercept Saturation	Intercept Effective Viscosity	fo	fw	Kro	Krw
0	0	0	0	0	0.2	2	0.2	4				
150000	149999.9	1126.502	0.014037	0.014036	0.2140365	2.25085	0.2	2.025868	1	5E-07	0.98723	1.3E-07
300000	299999.8	1239.1	0.028073	0.028073	0.228073	2.47583	0.2	2.16903	1	6E-07	0.92207	1.4E-07
450000	449999.8	1315.873	0.04211	0.042109	0.2421095	2.62923	0.2	2.245695	1	4E-07	0.89059	8.9E-08
600000	599999.7	1379.856	0.056146	0.056146	0.256146	2.75707	0.2	2.255404	1	9E-07	0.88676	1.9E-07
750000	749999.6	1442.624	0.070183	0.070182	0.27018249	2.88249	0.2	2.326347	1	4E-07	0.85972	8.6E-08
900000	899999.5	1498.291	0.084219	0.084219	0.28421899	2.99371	0.2	2.33445	1	7E-07	0.85673	1.4E-07
1050000	1049999	1553.283	0.098256	0.098255	0.29825549	3.10359	0.2	2.387233	1	7E-07	0.83779	1.4E-07
1200000	1199999	1604.5	0.112292	0.112292	0.31229198	3.20593	0.1999999	2.409829	1	2E-15	0.82993	4.1E-16
1350000	1349999	1654.304	0.126329	0.126328	0.32632849	3.30544	0.2000001	2.315171	1	1E-06	0.86387	2.9E-07
1500000	1499999	1709.372	0.140365	0.140365	0.34036498	3.41547	0.2	2.268016	1	7E-07	0.88183	1.5E-07
1650000	1649999	1766.799	0.154402	0.154401	0.35440147	3.53022	0.2	2.377148	1	7E-07	0.84134	1.4E-07
1800000	1799999	1819.262	0.168438	0.168438	0.36843797	3.63504	0.2	2.423774	1	7E-07	0.82516	1.4E-07
1950000	1949999	1869.78	0.182475	0.182474	0.38247447	3.73598	0.2000003	2.718064	1	2E-06	0.73582	3.7E-07
2100000	2099999	1908.968	0.196511	0.196511	0.39651095	3.81428	0.1999999	2.680191	1	2E-15	0.74622	3.7E-16
2250000	2249999	1949.51	0.210548	0.210547	0.41054745	3.89529	0.2000001	2.863196	1	1E-06	0.69852	2.3E-07
2400000	2399998	1983.946	0.224584	0.224584	0.42458394	3.96409	0.1999998	2.741323	1	0	0.72957	0
2550000	2549998	2022.194	0.238621	0.23862	0.43862045	4.04052	0.2000003	2.993521	1	2E-06	0.66811	3.3E-07
2700000	2699998	2053.017	0.252657	0.252657	0.45265692	4.1021	0.2000001	3.201865	1	1E-06	0.62464	2.1E-07
2850000	2849998	2078.048	0.266694	0.266693	0.46669341	4.15212	0.1999998	2.802891	1	0	0.71355	0
3000000	2999998	2113.588	0.28073	0.28073	0.48072992	4.22313	0.2000004	2.813085	1	2E-06	0.71096	3.6E-07
3150000	3149998	2148.873	0.294767	0.294766	0.4947664	4.29363	0.2000004	2.610087	1	2E-06	0.76626	3.8E-07
3300000	3299997	2188.996	0.308803	0.308803	0.50880287	4.3738	0.1999995	2.318084	1	-0	0.86278	-1E-07

3450000	3449997	2235.761	0.32284	0.322839	0.52283939	4.46724	0.2000004	1.944848	1	2E-06	1.02836	5.1E-07
3600000	3599997	2290.648	0.336876	0.336876	0.53687587	4.57691	0.2000002	1.983398	1	1E-06	1.00837	3.4E-07
3750000	3749997	2344.732	0.350913	0.350912	0.55091235	4.68498	0.2000004	2.044375	1	2E-06	0.97829	4.9E-07
3900000	3899997	2397.594	0.364949	0.364949	0.56494883	4.7906	0.2000002	2.311238	1	1E-06	0.86534	2.9E-07
4050000	4049996	2445.32	0.378986	0.378985	0.57898532	4.88596	0.2000013	2.756959	1	4E-05	0.72541	6.4E-06
4200000	4199991	2484.784	0.393022	0.393021	0.59302133	4.96481	0.2022892	4.254555	0.99	0.006	0.46735	0.00068
4350000	4349117	2497.479	0.407059	0.406976	0.60697605	4.99018	0.2339638	6.609332	0.92	0.084	0.27729	0.00633
4500000	4486571	2469.536	0.421095	0.419839	0.61983854	4.93434	0.323723	8.121599	0.7	0.297	0.17317	0.01827
4650000	4592052	2416.364	0.435132	0.429709	0.62970906	4.8281	0.4235089	8.129366	0.47	0.526	0.11658	0.03236
4800000	4663134	2363.067	0.449168	0.436361	0.63636068	4.72161	0.4703766	7.84973	0.37	0.63	0.09415	0.04016
4950000	4718564	2314.143	0.463205	0.441548	0.64154768	4.62386	0.499526	7.565239	0.31	0.693	0.08106	0.04583
5100000	4764555	2269.534	0.477241	0.445851	0.64585137	4.53472	0.5188289	7.280802	0.27	0.734	0.07311	0.0504
5250000	4804479	2229.112	0.491278	0.449587	0.64958733	4.45396	0.5325879	7.030295	0.24	0.762	0.06775	0.05418
5400000	4840202	2192.272	0.505314	0.45293	0.65293017	4.38035	0.5431052	6.813006	0.22	0.783	0.0638	0.05744
5550000	4872803	2158.452	0.519351	0.455981	0.65598086	4.31277	0.5515464	6.619016	0.2	0.799	0.06076	0.06035
5700000	4902966	2127.257	0.533387	0.458803	0.65880342	4.25044	0.5585817	6.446251	0.19	0.812	0.0583	0.06299
5850000	4931151	2098.337	0.547424	0.461441	0.66144083	4.19266	0.5646271	6.293244	0.18	0.823	0.0562	0.0654
6000000	4957679	2071.381	0.56146	0.463923	0.66392323	4.1388	0.5699666	6.157638	0.17	0.833	0.05435	0.06761
6150000	4982780	2046.121	0.575497	0.466272	0.66627215	4.08833	0.5747586	6.034265	0.16	0.841	0.0527	0.06968
6300000	5006633	2022.367	0.589533	0.468504	0.66850419	4.04086	0.5791152	5.916274	0.15	0.848	0.05126	0.0717
6450000	5029377	2000.02	0.60357	0.470632	0.67063249	3.99621	0.5831249	5.805758	0.14	0.855	0.04994	0.07364
6600000	5051124	1978.958	0.617606	0.472668	0.67266755	3.95413	0.5868368	5.705472	0.14	0.861	0.04872	0.07546
6750000	5071970	1959.038	0.631643	0.474618	0.67461825	3.91433	0.5902982	5.611908	0.13	0.867	0.04758	0.0772
6900000	5091994	1940.158	0.645679	0.476492	0.67649203	3.8766	0.593561	5.522579	0.13	0.872	0.04651	0.07891
7050000	5111260	1922.249	0.659716	0.478295	0.67829488	3.84082	0.5966507	5.440069	0.12	0.876	0.0455	0.08054
7200000	5129824	1905.22	0.673752	0.480032	0.68003199	3.80679	0.5995658	5.361885	0.12	0.881	0.04455	0.08211
7350000	5147738	1889.005	0.687789	0.481708	0.68170837	3.77439	0.602333	5.288583	0.12	0.885	0.04364	0.08363
7500000	5165049	1873.54	0.701825	0.483328	0.68332828	3.74349	0.6049765	5.225423	0.11	0.888	0.04273	0.085

7650000	5181795	1858.706	0.715862	0.484895	0.68489532	3.71385	0.6075178	5.16475	0.11	0.892	0.04186	0.08635
7800000	5198009	1844.468	0.729898	0.486413	0.68641252	3.68541	0.6099532	5.107231	0.1	0.895	0.04102	0.08765
7950000	5213722	1830.784	0.743935	0.487883	0.68788289	3.65806	0.6122842	5.048743	0.1	0.898	0.04026	0.08897
8100000	5228965	1817.651	0.757971	0.489309	0.68930928	3.63182	0.6145304	4.992896	0.1	0.901	0.03952	0.09026
8250000	5243763	1805.037	0.772008	0.490694	0.69069408	3.60662	0.6166765	4.939762	0.1	0.904	0.03882	0.09151
8400000	5258145	1792.906	0.786044	0.49204	0.69203985	3.58238	0.6187517	4.888067	0.09	0.907	0.03815	0.09275
8550000	5272130	1781.237	0.800081	0.493349	0.69334857	3.55906	0.6207706	4.842329	0.09	0.909	0.03747	0.09389
8700000	5285737	1769.969	0.814117	0.494622	0.69462187	3.53655	0.6227217	4.802046	0.09	0.912	0.03678	0.09493
8850000	5298985	1759.049	0.828154	0.495862	0.69586152	3.51473	0.6246016	4.755716	0.09	0.914	0.03619	0.09609
9000000	5311892	1748.522	0.84219	0.497069	0.69706932	3.4937	0	0	0.83	0.172	0	0.3

Table D3: Layer Model

Time (days)	Total Water Injected	Total Oil Produced	Delta Pressure	Pore Volume of Water Injected	Pore Volume of Oil Produced	Average saturation	Effective Viscosity	Intercept Saturation	Intercept Effective Viscosity	fo	fw	Kro	Krw
0	0	0	4000	0	0	0.2	6.57	0.2	6.57	###	#####	#DIV/0!	#DIV/0!
100	980000	979999	1834.07	0.091705	0.0917	0.29	3.01	0.2	2.42	1	0	0.8252	2E-07
200	1960000	1959999	2192.95	0.18341	0.1834	0.38	3.6	0.2	2.62	1	0	0.7628	2E-07
300	2940000	2939997	2491.41	0.275116	0.2751	0.48	4.09	0.2	2.82	1	0	0.7094	2E-07
400	3920000	3919996	2749.88	0.366821	0.3668	0.57	4.52	0.26	4.82	0.8	0.17	0.3427	0.0181
500	4900000	4728823	2704.36	0.458526	0.4425	0.64	4.44	0.53	6.5	0.2	0.76	0.0736	0.0586
600	5880000	4963199	2454.29	0.550231	0.4644	0.66	4.03	0.59	5.56	0.1	0.86	0.0518	0.0769
700	6860000	5104428	2299.04	0.641936	0.4777	0.68	3.78	0.61	5.03	0.1	0.89	0.0427	0.0887
800	7840000	5209609	2189.97	0.733641	0.4875	0.69	3.6	0.62	4.74	0.1	0.91	0.0378	0.0961
900	8820000	5297319	2103.19	0.825347	0.4957	0.7	3.46	0.63	4.51	0.1	0.92	0.034	0.1024
1000	9800000	5372357	2031.92	0.917052	0.5027	0.7	3.34	0.64	4.32	0.1	0.93	0.0309	0.1079
1100	10780000	5437746	1971.97	1.008757	0.5088	0.71	3.24	0.65	4.17	0.1	0.94	0.0283	0.1129
1200	11760000	5495553	1920.69	1.100462	0.5143	0.71	3.16	0.66	4.03	0.1	0.95	0.0261	0.1174

1300	12740000	5547216	1876.12	1.192167	0.5191	0.72	3.08	0.66	3.92	0	0.95	0.0243	0.1216
1400	13720000	5593832	1837.01	1.283872	0.5235	0.72	3.02	0.67	3.82	0	0.96	0.0226	0.1254
1500	14700000	5636174	1802.3	1.375578	0.5274	0.73	2.96	0.67	3.73	0	0.96	0.0212	0.1288
1600	15680000	5674901	1771.21	1.467283	0.531	0.73	2.91	0.68	3.65	0	0.96	0.0199	0.1322
1700	16660000	5710516	1743.22	1.558988	0.5344	0.73	2.86	0.68	3.57	0	0.97	0.0188	0.1352
1800	17640000	5743409	1717.8	1.650693	0.5374	0.74	2.82	0.69	3.51	0	0.97	0.0177	0.138
1900	18620000	5773930	1694.55	1.742398	0.5403	0.74	2.78	0.69	3.45	0	0.97	0.0168	0.1407
2000	19600000	5802383	1673.19	1.834103	0.543	0.74	2.75	0.69	3.4	0	0.97	0.016	0.1432
2100	20580000	5829005	1653.5	1.925809	0.5455	0.75	2.72	0.7	3.35	0	0.97	0.0152	0.1456
2200	21560000	5853980	1635.26	2.017514	0.5478	0.75	2.69	0.7	3.3	0	0.98	0.0145	0.1479
2300	22540000	5877481	1618.28	2.109219	0.55	0.75	2.66	0.7	3.26	0	0.98	0.0139	0.15
2400	23520000	5899674	1602.43	2.200924	0.5521	0.75	2.63	0.7	3.22	0	0.98	0.0133	0.1521
2500	24500000	5920677	1587.61	2.292629	0.554	0.75	2.61	0.71	3.18	0	0.98	0.0128	0.1541
2600	25480000	5940595	1573.71	2.384335	0.5559	0.76	2.59	0.71	3.14	0	0.98	0.0123	0.1559
2700	26460000	5959522	1560.62	2.47604	0.5577	0.76	2.56	0.71	3.11	0	0.98	0.0118	0.1577
2800	27440000	5977535	1548.25	2.567745	0.5594	0.76	2.54	0.71	3.08	0	0.98	0.0114	0.1594
2900	28420000	5994727	1536.54	2.65945	0.561	0.76	2.52	0.72	3.05	0	0.98	0.011	0.1611
3000	29400000	6011154	1525.49	2.751155	0.5625	0.76	2.51	0.72	3.02	0	0.98	0.0106	0.1628
3100	30380000	6026874	1515.03	2.84286	0.564	0.76	2.49	0.72	2.99	0	0.98	0.0103	0.1644
3200	31360000	6041925	1505.1	2.934566	0.5654	0.77	2.47	0.72	2.97	0	0.99	0.0099	0.1659
3300	32340000	6056355	1495.67	3.026271	0.5667	0.77	2.46	0.72	2.94	0	0.99	0.0096	0.1674
3400	33320000	6070200	1486.67	3.117976	0.568	0.77	2.44	0.73	2.92	0	0.99	0.0093	0.1688
3500	34300000	6083503	1478.1	3.209681	0.5693	0.77	2.43	0.73	2.9	0	0.99	0.009	0.1701
3600	35280000	6096296	1469.89	3.301386	0.5705	0.77	2.41	0.73	2.88	0	0.99	0.0087	0.1714
3700	36260000	6108621	1462.01	3.393091	0.5716	0.77	2.4	0.73	2.86	0	0.99	0.0085	0.1726
3800	37240000	6120513	1454.45	3.484797	0.5727	0.77	2.39	0.73	2.84	0	0.99	0.0082	0.1739
3900	38220000	6131998	1447.2	3.576502	0.5738	0.77	2.38	0.73	2.82	0	0.99	0.008	0.175
4000	39200000	6143100	1440.23	3.668207	0.5749	0.77	2.37	0.9	0	-0	1.03	#DIV/0!	#DIV/0!

Table D5 – Pseudo-Relative Permeability Calculation

Channels Model

Intermediate Gridblock

Rock Curves Table			Pseudo Relative Permeability Table			Rock Curve Mobility				Pseudo Mobility		
Sw	Krw	kro	SW	KRW	KRO	λo	λw	λt	λ-1	Lwj	Loj	1/Loj
0.2	0	0.9	0.2	0	0.9	0.45	0	0.45	2.2222222	0	0.45	2.2222222
0.2022892	0.0006848	0.4673454	0.2022892	0	0.8737088	0.2336727	0.0013695	0.2350422	4.2545546	0	0.4368544	2.2890922
0.2339638	0.0063274	0.2772928	0.2339638	0	0.6222091	0.1386464	0.0126548	0.1513012	6.6093316	0	0.3111045	3.2143536
0.323723	0.0182721	0.1731687	0.323723	0	0.3426798	0.0865843	0.0365441	0.1231285	8.1215988	0	0.1713399	5.836353
0.4235089	0.0323592	0.1165847	0.4235089	0.0323592	0.1165847	0.0582924	0.0647185	0.1230108	8.1293661		0.0582924	
0.4703766	0.0401583	0.0941527	0.4703766	0.0401583	0.0941527	0.0470764	0.0803166	0.1273929	7.84973		0.0470764	
0.499526	0.0458276	0.0810567	0.499526	0.0458276	0.0810567	0.0405284	0.0916552	0.1321835	7.565239		0.0405284	
0.5188289	0.0503955	0.0731128	0.5188289	0.0503955	0.0731128	0.0365564	0.1007911	0.1373475	7.2808023		0.0365564	
0.5325879	0.0541831	0.0677506	0.5325879	0.0541831	0.0677506	0.0338753	0.1083662	0.1422415	7.0302953		0.0338753	
0.5431052	0.0574387	0.0638015	0.5431052	0.0574387	0.0638015	0.0319008	0.1148773	0.1467781	6.8130059		0.0319008	
0.5515464	0.0603499	0.0607603	0.5515464	0.0603499	0.0607603	0.0303801	0.1206997	0.1510799	6.6190157		0.0303801	
0.5585817	0.0629904	0.0582964	0.5585817	0.0629904	0.0582964	0.0291482	0.1259807	0.1551289	6.4462508		0.0291482	
0.5646271	0.0653992	0.0562042	0.5646271	0.0653992	0.0562042	0.0281021	0.1307985	0.1589006	6.2932444		0.0281021	
0.5699666	0.0676117	0.0543531	0.5699666	0.0676117	0.0543531	0.0271765	0.1352234	0.1623999	6.1576383		0.0271765	
0.5747586	0.069684	0.0527046	0.5747586	0.069684	0.0527046	0.0263523	0.139368	0.1657203	6.0342645		0.0263523	
0.5791152	0.0716983	0.0512575	0.5791152	0.0716983	0.0512575	0.0256287	0.1433966	0.1690253	5.9162736		0.0256287	
0.5831249	0.0736352	0.0499447	0.5831249	0.0736352	0.0499447	0.0249723	0.1472705	0.1722428	5.8057577		0.0249723	
0.5868368	0.0754562	0.0487158	0.5868368	0.0754562	0.0487158	0.0243579	0.1509124	0.1752703	5.7054721		0.0243579	
0.5902982	0.0772025	0.047575	0.5902982	0.0772025	0.047575	0.0237875	0.154405	0.1781925	5.6119078		0.0237875	
0.593561	0.0789088	0.0465145	0.593561	0.0789088	0.0465145	0.0232573	0.1578176	0.1810748	5.5225785		0.0232573	
0.5966507	0.080536	0.0454982	0.5966507	0.080536	0.0454982	0.0227491	0.1610721	0.1838212	5.4400692		0.0227491	
0.5995	0.0821	0.0445	0.5995	0.0821	0.0445	0.0222	0.1642	0.1865	5.3618		0.0222	

658	138	478	658	138	478	739	277	016	849		739	
0.602333	0.0836324	0.0436437	0.602333	0.0836324	0.0436437	0.0218219	0.1672647	0.1890866	5.2885825		0.0218219	
0.6049765	0.0850036	0.0427296	0.6049765	0.0850036	0.0427296	0.0213648	0.1700073	0.1913721	5.225423		0.0213648	
0.6075178	0.0863459	0.0418568	0.6075178	0.0863459	0.0418568	0.0209284	0.1726918	0.1936202	5.1647504		0.0209284	
0.6099532	0.087645	0.0410216	0.6099532	0.087645	0.0410216	0.0205108	0.17529	0.1958008	5.1072311		0.0205108	
0.6122842	0.0889707	0.0402556	0.6122842	0.0889707	0.0402556	0.0201278	0.1779413	0.1980691	5.0487433		0.0201278	
0.6145304	0.0902626	0.0395188	0.6145304	0.0902626	0.0395188	0.0197594	0.1805252	0.2002846	4.992896		0.0197594	
0.6166765	0.0915149	0.0388183	0.6166765	0.0915149	0.0388183	0.0194092	0.1830297	0.2024389	4.9397619		0.0194092	
0.6187517	0.0927527	0.0381487	0.6187517	0.0927527	0.0381487	0.0190743	0.1855055	0.2045798	4.8880674		0.0190743	
0.6207706	0.0938894	0.0374668	0.6207706	0.0938894	0.0374668	0.0187334	0.1877788	0.2065122	4.8423289		0.0187334	
0.6227217	0.0949266	0.0367829	0.6227217	0.0949266	0.0367829	0.0183915	0.1898531	0.2082446	4.8020458		0.0183915	
0.6246016	0.09609	0.0361866	0.6246016	0.09609	0.0361866	0.0180933	0.19218	0.2102733	4.7557162		0.0180933	
0.9	0.3	0	0.9	0.3	0	0	0.6	0.6	1.6666667		0	
0.4	0.03	0.128	0.4	0.03	0.128	0.064	0.06	0.124	8.0645161		0.124	
0.62	0.093	0.036	0.62	0.093	0.036	0.018	0.186	0.204	4.9019608		0.204	

Injector Wellblock

Rock Curve Table		Pseudo Function Table				Rock Mobility				Pseudo Oil Mobility			
Sw	Krw	kro	SW	KRW	KRO	λo	λw	λt	λ-1	Lwj	Loj	1/Loj	LTj
0.2	0	0.9	0.2	0	0.9	0.45	0	0.45	2.2222222	0	0.45	2.2222222	0.45
0.2022892	0.0006848	0.4673454	0.2022892	0	0.8929729	0.2336727	0.0013695	0.2350422	4.2545546	0	0.4464865	2.2397095	0.4464865
0.2339638	0.0063274	0.2772928	0.2339638	0	0.8059067	0.1386464	0.0126548	0.1513012	6.6093316	0	0.4029534	2.4816768	0.4029534
0.323723	0.0182721	0.1731687	0.323723	0	0.6314403	0.0865843	0.0365441	0.1231285	8.1215988	0	0.3157201	3.167362	0.3157201
0.4235089	0.0323592	0.1165847	0.6293547	0.0479841	0.1728785	0.0582924	0.0647185	0.1230108	8.1293661	0.0959682	0.0864392		0.1824074
0.4703766	0.0401583	0.0941527	0.6363607	0.0583815	0.1368779	0.0470764	0.0803166	0.1273929	7.84973	0.1167631	0.0684389		0.185202
0.499526	0.0458276	0.0810567	0.6415477	0.0651042	0.1151518	0.0405284	0.0916552	0.1321835	7.565239	0.1302083	0.0575759		0.1877842
0.5188289	0.0503955	0.0731128	0.6458514	0.0697649	0.1012135	0.0365564	0.1007911	0.1373475	7.2808023	0.1395298	0.0506067		0.1901365
0.5325879	0.0541831	0.0677506	0.6495873	0.0732316	0.0915688	0.0338753	0.1083662	0.1422415	7.0302953	0.1464632	0.0457844		0.1922476

0.543 1052	0.057 4387	0.063 8015	0.652 9302	0.075 9742	0.084 3903	0.031 9008	0.114 8773	0.146 7781	6.813 0059	0.151 9484	0.042 1952		0.194 1436
0.551 5464	0.060 3499	0.060 7603	0.655 9809	0.078 2343	0.078 7663	0.030 3801	0.120 6997	0.151 0799	6.619 0157	0.156 4685	0.039 3832		0.195 8517
0.558 5817	0.062 9904	0.058 2964	0.658 8034	0.080 151	0.074 1782	0.029 1482	0.125 9807	0.155 1289	6.446 2508	0.160 3019	0.037 0891		0.197 3911
0.564 6271	0.065 3992	0.056 2042	0.661 4408	0.081 8124	0.070 3097	0.028 1021	0.130 7985	0.158 9006	6.293 2444	0.163 6248	0.035 1548		0.198 7796
0.569 9666	0.067 6117	0.054 3531	0.663 9232	0.083 2801	0.066 9489	0.027 1765	0.135 2234	0.162 3999	6.157 6383	0.166 5602	0.033 4745		0.200 0347
0.574 7586	0.069 684	0.052 7046	0.666 2721	0.084 591	0.063 9793	0.026 3523	0.139 368	0.165 7203	6.034 2645	0.169 1821	0.031 9897		0.201 1718
0.579 1152	0.071 6983	0.051 2575	0.668 5042	0.085 7712	0.061 3183	0.025 6287	0.143 3966	0.169 0253	5.916 2736	0.171 5425	0.030 6592		0.202 2017
0.583 1249	0.073 6352	0.049 9447	0.670 6325	0.086 8393	0.058 9006	0.024 9723	0.147 2705	0.172 2428	5.805 7577	0.173 6786	0.029 4503		0.203 1289
0.586 8368	0.075 4562	0.048 7158	0.672 6676	0.087 8075	0.056 69	0.024 3579	0.150 9124	0.175 2703	5.705 4721	0.175 6151	0.028 345		0.203 9601
0.590 2982	0.077 2025	0.047 575	0.674 6183	0.088 689	0.054 6534	0.023 7875	0.154 405	0.178 1925	5.611 9078	0.177 378	0.027 3267		0.204 7047
0.593 561	0.078 9088	0.046 5145	0.676 492	0.089 4957	0.052 7552	0.023 2573	0.157 8176	0.181 0748	5.522 5785	0.178 9914	0.026 3776		0.205 369
0.596 6507	0.080 536	0.045 4982	0.678 2949	0.090 2342	0.050 9771	0.022 7491	0.161 0721	0.183 8212	5.440 0692	0.180 4683	0.025 4885		0.205 9569
0.599 5658	0.082 1138	0.044 5478	0.680 032	0.090 9078	0.049 3186	0.022 2739	0.164 2277	0.186 5016	5.361 8849	0.181 8156	0.024 6593		0.206 4749
0.602 333	0.083 6324	0.043 6437	0.681 7084	0.091 5232	0.047 7615	0.021 8219	0.167 2647	0.189 0866	5.288 5825	0.183 0464	0.023 8808		0.206 9271
0.604 9765	0.085 0036	0.042 7296	0.683 3283	0.092 0867	0.046 29	0.021 3648	0.170 0073	0.191 3721	5.225 423	0.184 1733	0.023 145		0.207 3184
0.607 5178	0.086 3459	0.041 8568	0.684 8953	0.092 606	0.044 8914	0.020 9284	0.172 6918	0.193 6202	5.164 7504	0.185 2119	0.022 4457		0.207 6576
0.609 9532	0.087 645	0.041 0216	0.686 4125	0.093 0822	0.043 5664	0.020 5108	0.175 29	0.195 8008	5.107 2311	0.186 1644	0.021 7832		0.207 9476
0.612 2842	0.088 9707	0.040 2556	0.687 8829	0.093 5174	0.042 3128	0.020 1278	0.177 9413	0.198 0691	5.048 7433	0.187 0349	0.021 1564		0.208 1912
0.614 5304	0.090 2626	0.039 5188	0.689 3093	0.093 9148	0.041 1178	0.019 7594	0.180 5252	0.200 2846	4.992 896	0.187 8295	0.020 5589		0.208 3885
0.616 6765	0.091 5149	0.038 8183	0.690 6941	0.094 2738	0.039 9886	0.019 4092	0.183 0297	0.202 4389	4.939 7619	0.188 5476	0.019 9943		0.208 5419
0.618 7517	0.092 7527	0.038 1487	0.692 0399	0.094 6	0.038 9084	0.019 0743	0.185 5055	0.204 5798	4.888 0674	0.189 2	0.019 4542		0.208 6542
0.620 7706	0.093 8894	0.037 4668	0.693 3486	0.094 8964	0.037 8687	0.018 7334	0.187 7788	0.206 5122	4.842 3289	0.189 7928	0.018 9343		0.208 7271
0.622 7217	0.094 9266	0.036 7829	0.694 6219	0.095 1641	0.036 875	0.018 3915	0.189 8531	0.208 2446	4.802 0458	0.190 3282	0.018 4375		0.208 7657
0.624 6016	0.096 09	0.036 1866	0.695 8615	0.096 09	0.036 1866	0.018 0933	0.192 18	0.210 2733	4.755 7162	0.192 18	0.018 0933		0.210 2733
0.9	0.3	0	0.9	0.3	0	0	0.6	0.6	1.666 6667	0.6	0		0.6
0.4	0.03	0.128	0.4	0.044 5498	0.190 0793	0.064	0.06	0.124	8.064 5161	0.089 0997	0.095 0397		0.184 1394
0.62	0.093	0.036	0.62	0.084 4303	0.032 6827	0.018	0.186	0.204	4.901 9608	0.168 8606	0.016 3414	61.19 4447	0.185 202

Table D6 Layered Model

Intermediate Wellblock

Rock Curves Table			Pseudo Relative Permeability Table			Rock Curve Mobility				Pseudo Mobility		
Sw	**Krw**	**kro**	**SW**	**KRW**	**KRO**	**λo**	**λw**	**λt**	**λ-1**	**Lwj**	**Loj**	**1/Loj**
0.2	0	0.9	0.2	0	0.9	0.45	0	0.45	2.2222222	0	0.45	2.2222222
0.280071	0.018131	0.3426895	0.280071	0	0.6794752	0.1713448	0.036262	0.2076068	4.8167985	0	0.3397376	2.943448
0.545847	0.0585522	0.0736201	0.545847	0	0.3747158	0.03681	0.1171043	0.1539144	6.4971187	0	0.1873579	5.3373781
0.5851453	0.0769358	0.0518166	0.5851453	0.0769358	0.0518166	0.0259083	0.1538716	0.1797799	5.5623575	0		
0.6087581	0.0887116	0.0426638	0.6087581	0.0887116	0.0426638	0.0213319	0.1774233	0.1987552	5.031315	0		
0.6218371	0.0960748	0.0377757	0.6218371	0.0960748	0.0377757	0.0188878	0.1921495	0.2110374	4.7384975	0		
0.6325093	0.1023992	0.0339631	0.6325093	0.1023992	0.0339631	0.0169815	0.2047983	0.2217799	4.5089753	0		
0.6415386	0.1079387	0.0308678	0.6415386	0.1079387	0.0308678	0.0154339	0.2158773	0.2313112	4.3231796	0		
0.649343	0.1129294	0.0283156	0.649343	0.1129294	0.0283156	0.0141578	0.2258588	0.2400166	4.1663779	0		
0.6562417	0.1174087	0.026136	0.6562417	0.1174087	0.026136	0.013068	0.2348173	0.2478853	4.0341234	0		
0.6623826	0.1215627	0.0242845	0.6623826	0.1215627	0.0242845	0.0121423	0.2431254	0.2552676	3.9174569	0		
0.6679805	0.1253594	0.0226438	0.6679805	0.1253594	0.0226438	0.0113219	0.2507188	0.2620407	3.8162008	0		
0.6730561	0.1288482	0.0212046	0.6730561	0.1288482	0.0212046	0.0106023	0.2576963	0.2682986	3.72719	0		
0.677714	0.132168	0.0199378	0.677714	0.132168	0.0199378	0.0099689	0.2643361	0.274305	3.6455774	0		
0.682045	0.135206	0.0187828	0.682045	0.135206	0.0187828	0.0093914	0.2704121	0.2798035	3.5739372	0		
0.6860403	0.1380286	0.0177477	0.6860403	0.1380286	0.0177477	0.0088739	0.2760571	0.284931	3.5096217	0		
0.689718	0.1406926	0.0168276	0.689718	0.1406926	0.0168276	0.0084138	0.2813853	0.2897991	3.4506667	0		
0.6931439	0.1432354	0.0159987	0.6931439	0.1432354	0.0159987	0.0079994	0.2864708	0.2944702	3.3959295	0		
0.6963794	0.1456364	0.0152346	0.6963794	0.1456364	0.0152346	0.0076173	0.2912729	0.2988901	3.3457109	0		
0.699415	0.1478691	0.0145325	0.699415	0.1478691	0.0145325	0.0072662	0.2957381	0.3030044	3.3002825	0		
0.7022312	0.1500263	0.0139045	0.7022312	0.1500263	0.0139045	0.0069522	0.3000525	0.3070048	3.2572782	0		
0.7049026	0.1520931	0.013324	0.7049026	0.1520931	0.013324	0.006662	0.3041861	0.3108481	3.2170055	0		
0.7074409	0.1540719	0.0127856	0.7074409	0.1540719	0.0127856	0.0063928	0.3081437	0.3145365	3.1792811	0		

0.709852	0.155931	0.0122834	0.709852	0.155931	0.0122834	0.0061417	0.3118619	0.3180036	3.1446181	0		
0.7121613	0.1576816	0.0118102	0.7121613	0.1576816	0.0118102	0.0059051	0.3153632	0.3212683	3.112663	0		
0.7143124	0.1593935	0.0113846	0.7143124	0.1593935	0.0113846	0.0056923	0.318787	0.3244793	3.0818611	0		
0.7163884	0.1611416	0.0109886	0.7163884	0.1611416	0.0109886	0.0054943	0.3222832	0.3277775	3.0508501	0		
0.7183732	0.1628138	0.010617	0.7183732	0.1628138	0.010617	0.0053085	0.3256276	0.3309361	3.0217318	0		
0.7203139	0.1643992	0.010257	0.7203139	0.1643992	0.010257	0.0051285	0.3287983	0.3339268	2.9946681	0		
0.7221734	0.1659341	0.0099192	0.7221734	0.1659341	0.0099192	0.0049596	0.3318682	0.3368278	2.9688764	0		
0.7239784	0.1674016	0.0095958	0.7239784	0.1674016	0.0095958	0.0047979	0.3348032	0.3396011	2.9446315	0		
0.7257044	0.1688172	0.0092926	0.7257044	0.1688172	0.0092926	0.0046463	0.3376344	0.3422807	2.9215791	0		
0.7273747	0.1701429	0.0090017	0.7273747	0.1701429	0.0090017	0.0045009	0.3402858	0.3447867	2.9003441			
0.728953	0.1713849	0.0087312	0.728953	0.1713849	0.0087312	0.0043656	0.3427698	0.3471354	2.8807204			
0.7304487	0.172623	0.0084822	0.7304487	0.172623	0.0084822	0.0042411	0.345246	0.3494871	2.8613356			
0.7318978	0.1738537	0.0082465	0.7318978	0.1738537	0.0082465	0.0041232	0.3477075	0.3518307	2.842276			
0.7332955	0.1750316	0.0080223	0.7332955	0.1750316	0.0080223	0.0040112	0.3500632	0.3540744	2.8242654			
0.9	0.3	0	0.9	0.3	0	0	0.6	0.6	1.6666667			
0.5823	0.075	0.053	0.5823	0.075	0.053	0.0265	0.15	0.1765	5.6657224		0.1765	
0.649	0.112	0.0275	0.649			0.01375	0.224	0.23775	4.2060988		0.23775	

Injector Wellblock

Rock Curve Table			Pseudo Function Table			Rock Mobility				Pseudo Oil Mobility			
Sw	Krw	kro	SW	KRW	KRO	λo	λw	λt	λ-1	Lwj	Loj	1/Loj	LTj
0.2	0	0.9	0.2	0	0.9	0.45	0	0.45	2.2222222	0	0.45	2.2222222	0.45
0.280071	0.018131	0.3426895	0.280071	0	0.7819346	0.1713448	0.036262	0.2076068	4.8167985	0	0.3909673	2.5577587	0.3909673
0.545847	0.0585522	0.0736201	0.545847	0	0.5447382	0.03681	0.1171043	0.1539144	6.4971187	0	0.2723691	3.6714886	0.2723691
0.5851453	0.0769358	0.0518166	0.6531407	0.1064225	0.071676	0.0259083	0.1538716	0.1797799	5.5623575	0.2128449	0.035838		0.2486829
0.6087581	0.0887116	0.0426638	0.6776555	0.1174255	0.0564731	0.0213319	0.1774233	0.1987552	5.031315	0.234851	0.0282365		0.2630875
0.6218371	0.0960748	0.0377757	0.687498	0.1248208	0.0490783	0.0188878	0.1921495	0.2110374	4.7384975	0.2496415	0.0245392		0.2741807

0.6325093	0.1023992	0.0339631	0.6957056	0.1309467	0.0434316	0.0169815	0.2047983	0.2217799	4.5089753	0.2618935	0.0217158		0.2836093
0.6415386	0.1079387	0.0308678	0.7027274	0.1361383	0.0389322	0.0154339	0.2158773	0.2313112	4.3231796	0.2722766	0.0194661		0.2917427
0.649343	0.1129294	0.0283156	0.7088463	0.1406064	0.0352552	0.0141578	0.2258588	0.2400166	4.1663779	0.2812127	0.0176276		0.2988403
0.6562417	0.1174087	0.026136	0.7142557	0.1444941	0.0321654	0.013068	0.2348173	0.2478853	4.0341234	0.2889882	0.0160827		0.3050709
0.6623826	0.1215627	0.0242845	0.7190902	0.1479045	0.0295468	0.0121423	0.2431254	0.2552676	3.9174569	0.295809	0.0147734		0.3105824
0.6679805	0.1253594	0.0226438	0.7234523	0.1509175	0.0272604	0.0113219	0.2507188	0.2620407	3.8162008	0.301835	0.0136302		0.3154652
0.6730561	0.1288482	0.0212046	0.7274146	0.1535871	0.0252759	0.0106023	0.2576963	0.2682986	3.72719	0.3071741	0.012638		0.3198121
0.677714	0.132168	0.0199378	0.7310385	0.1559663	0.0235278	0.0099689	0.2643361	0.274305	3.6455774	0.3119326	0.0117639		0.3236964
0.682045	0.135206	0.0187828	0.7343713	0.1580904	0.0219619	0.0093914	0.2704121	0.2798035	3.5739372	0.3161807	0.0109809		0.3271617
0.6860403	0.1380286	0.0177477	0.7374493	0.1599907	0.0205716	0.0088739	0.2760571	0.284931	3.5096217	0.3199814	0.0102858		0.3302672
0.689718	0.1406926	0.0168276	0.7403054	0.1616933	0.0193394	0.0084138	0.2813853	0.2897991	3.4506667	0.3233866	0.0096697		0.3330563
0.6931439	0.1432354	0.0159987	0.7429679	0.1632226	0.0182312	0.0079994	0.2864708	0.2944702	3.3959295	0.3264451	0.0091156		0.3355607
0.6963794	0.1456364	0.0152346	0.745459	0.1645982	0.0172181	0.0076173	0.2912729	0.2988901	3.3457109	0.3291963	0.008609		0.3378054
0.699415	0.1478691	0.0145325	0.7477962	0.1658337	0.016298	0.0072662	0.2957381	0.3030044	3.3002825	0.3316674	0.008149		0.3398164
0.7022312	0.1500263	0.0139045	0.7499953	0.1669424	0.0154723	0.0069522	0.3000525	0.3070048	3.2572782	0.3338848	0.0077361		0.341621
0.7049026	0.1520931	0.013324	0.752072	0.1679387	0.0147121	0.006662	0.3041861	0.3108481	3.2170055	0.3358774	0.0073561		0.3432335
0.7074409	0.1540719	0.0127856	0.7540374	0.1688323	0.0140105	0.0063928	0.3081437	0.3145365	3.1792811	0.3376646	0.0070052		0.3446699
0.709852	0.155931	0.0122834	0.7559013	0.1696316	0.0133626	0.0061417	0.3118619	0.3180036	3.1446181	0.3392633	0.0066813		0.3459446
0.7121613	0.1576816	0.0118102	0.7576724	0.1703473	0.0127589	0.0059051	0.3153632	0.3212683	3.112663	0.3406946	0.0063794		0.347074
0.7143124	0.1593935	0.0113846	0.759358	0.1709832	0.0122124	0.0056923	0.318787	0.3244793	3.0818611	0.3419664	0.0061062		0.3480725
0.7163884	0.1611416	0.0109886	0.7609668	0.1715492	0.0116983	0.0054943	0.3222832	0.3277775	3.0508501	0.3430983	0.0058491		0.3489475
0.7183732	0.1628138	0.010617	0.762504	0.1720454	0.011219	0.0053085	0.3256276	0.3309361	3.0217318	0.3440908	0.0056095		0.3497003
0.7203139	0.1643992	0.010257	0.763975	0.1724803	0.0107612	0.0051285	0.3287983	0.3339268	2.9946681	0.3449605	0.0053806		0.3503411
0.7221734	0.1659341	0.0099192	0.7653834	0.1728568	0.0103331	0.0049596	0.3318682	0.3368278	2.9688764	0.3457136	0.0051665		0.3508801
0.7239784	0.1674016	0.0095958	0.7667337	0.1731804	0.0099271	0.0047979	0.3348032	0.3396011	2.9446315	0.3463607	0.0049635		0.3513243
0.7257044	0.1688172	0.0092926	0.7680293	0.1734537	0.0095478	0.0046463	0.3376344	0.3422807	2.9215791	0.3469074	0.0047739		0.3516813
0.7273747	0.1701429	0.0090017	0.7692742	0.1736815	0.009189	0.0045009	0.3402858	0.3447867	2.9003441	0.347363	0.0045945		0.3519575
0.728953	0.1713849	0.0087312	0.7704713	0.1738661	0.0088576	0.0043656	0.3427698	0.3471354	2.8807204	0.3477322	0.0044288		0.352161

0.7304487	0.172623	0.0084822	0.7716246	0.1740118	0.0085504	0.0042411	0.345246	0.3494871	2.8613356	0.3480236	0.0042752		0.3522988
0.7318978	0.1738537	0.0082465	0.7727375	0.1741219	0.0082592	0.0041232	0.3477075	0.3518307	2.842276	0.3482438	0.0041296		0.3523734
0.7332955	0.1750316	0.0080223	0.7738122	0.1750316	0.0080223	0.0040112	0.3500632	0.3540744	2.8242654	0.3500632	0.0040112		0.3540744
0.9	0.3	0	0.9	0.3	0	0	0.6	0.6	1.6666667	0.6	0		0.6
0.5823	0.075	0.053	0.5823	0.1035466	0.0731729	0.0265	0.15	0.1765	5.6657224	0.2070931	0.0365865		0.2436796
0.649	0.112	0.0275	0.649	0.1239361	0.0304307	0.01375	0.224	0.23775	4.2060988	0.2478721	0.0152154		0.2630875