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THE INVESTIGATION OF NUMERICAL SIMULATION SOFTWARE FOR FRACTURED RESERVOIRS

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Abstract. Based on percolation mechanism of fractured reservoirs and simulation technique, the numerical simulation software of fractured reservoirs has been developed on PC-Linux environment, which is on the basis of DQHY simulator of three dimensions and three phases. It can treat dual-porosity/single-permeability and dual-porosity/dual-permeability model. The results of examples indicate that the performance of fractured reservoirs could be simulated with the software.

Key Words. the numerical simulation, fractured reservoirs, DQHY simulator, PC-Linux, dual-porosity.

1. Introduction

The concept of dual-porosity media was put forward by Barenblatt, G.I in Russian when he studied single-phase flow crossing fractured porous media in 1960. Later this concept was applied into fractured reservoir simulation, and popularized to multiphase flow.

The use of the dual-porosity approach for the modeling of naturally fractured reservoirs has become widely accepted in the oil industry. In this approach, it is assumed that fractured porous media can be represented by two collocated continua called matrix and fracture. The original idealized models assumed that the fracture is the primary conduit for flow whereas the matrix acts as distributed sources and sinks. Since the introduction of idealized model into the petroleum literature some 40 ago, so several improvements and refinements have been proposed. For example, the dual-permeability model was introduced when it become evident for some fractured reservoirs, the continuity of the matrix is very important consideration. Much of the recent works on dual-permeability modeling are directed towards the more accurate representation of matrix-fracture transfers for porosity model.

There are natural and artificial fractures in periphery oil field of Daqing, such as Fuyang oil layer, Putaohua layer and Toutai oil field, there are also fractures since old oil wells was fractured in interior of Daqing oil field. In order to improve waterflood recovery and development level of periphery oil field at late period of high water-cut, Daqing oil field requires the support of numerical simulation technique for fractured reservoirs.

Based on mature percolation mechanism of fractured reservoirs inland and overseas, the numerical simulation software of fractured reservoirs has been developed on PC-Linux environment, which is on the basis of DQHY simulator of three dimensions and three phases.

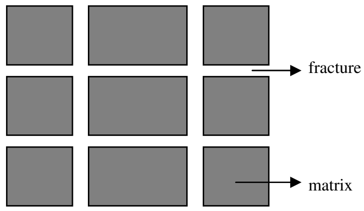


FIGURE 1. Dual porosity system.

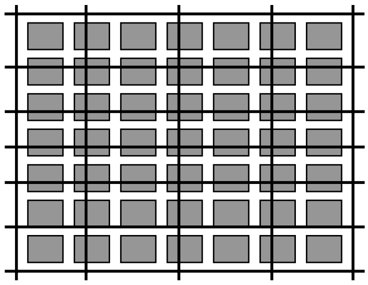


FIGURE 2. Partition of grids for dual porous media.

2. General theories

In order to describe fractures, it is first assumed that there is an ideal fractured system with only vertical and horizontal fractures in reservoir (for 2-D problem), showed by FIGURE 1, the matrix is surrounded by fractures, so dual porous media consists of the fractured system (grid) and the matrix. In general, the most fluids exist in matrixes for reservoirs, the volume of fracture is very small, there is only a small quantity of fluids in it, but the conductive capability of the fracture is much better than the matrix. Therefore the matrix blocks only acts as distributed sources and sinks, the fracture is the primary conduit in the idealized dual porosity model.

The flow equations can be described by the following mathematical modeling when multiphase fluids are flowing through the ideal media above [1]:

$$(1)\qquad \begin{cases} \dfrac{\partial}{\partial t}(\dfrac{\Phi S_\alpha}{B_\alpha})_f = \bigtriangledown \cdot [\dfrac{KKr_\alpha}{\mu_\alpha B_\alpha}(\bigtriangledown P_\alpha - \rho_\alpha g \bigtriangledown D)]_f - \tau_{\alpha maf} + q_{\alpha f}, \\ \dfrac{\partial}{\partial t}(\dfrac{\Phi S_\alpha}{B_\alpha})_{ma} = \tau_{\alpha maf}, \end{cases}$$

where the subscripts f and ma refer to the fracture and matrix respectively, the $\tau_{\alpha maf}$ is the matrix-fracture transfer term and has the form:

$$(2)\qquad \tau_{\alpha maf} = \sigma V_b(1-\Phi_f)\lambda_\alpha(\varphi_f - \varphi_{ma})_\alpha,$$

where σ is the shape factor, λ_α is the phase mobility of phase α, Φ_f is the fracture porosity and φ is flow potential.

We can obtain different fractured model if we choose different $\tau_{\alpha maf}$, such as: the gravity model, the subdomain model, pseudo function method and dual permeability model or any combination above, etc..

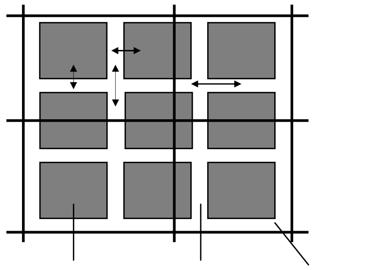


FIGURE 3. Dual porosity/single permeability model.

3. Numerical technique

Substantively, numerical simulation for fractured reservoirs is solving (1) and (2) simultaneous partial difference equations. Showed as FIGURE 2, partition of grids first is performed for dual porous media reservoir (for two dimensions). Each calculating grid block includes many matrix blocks (it is not always integer) and many fractures, but the borderline is not always superposed on fractures. Each physical parameter has two different numerical values in each calculating grid block, the two values respectively correspond to matrix and fracture. They are average values of physical parameters including the matrix or the fracture in this grid. For example, in the input model, the average matrix porosity and the average fractured porosity for every grid must be respectively given, we can obtain the average matrix pressure and the average fractured porosity in results, etc.

The contents above are the numerical description of geometric property about fractured reservoirs. In addition, the relative permeability curve and capillary pressure curve also should be respectively given for fractured reservoir simulation. Generally, the experiment results can be used directly for the matrix. Whereas relative permeability curve is usually linear form for the fractures, but different end-scale value and slope are only used for different reservoir.

It has mentioned that the different select for fracture-matrix transfer term would derived different model, therefore the select of $\tau_{\alpha maf}$ - namely treating the flow problem between fracture and matrix-will be the quick to establish fractured reservoir simulation.

The simulator can treat two kinds of flow. They all synthetically use the gravity model and pseudo capillary pressure function method.

The model for the first flow is dual porosity/single permeability. It is assumed that the flow only occurs between fracture and matrix. The direct flow between matrixes is left out of consideration, shown as the arrowhead in FIGURE 3. The model for second flow is dual porosity/dual permeability. It is assumed that the flow not only occurs between fracture and matrix, but also between matrixes, shown as the arrowhead in FIGURE 4.

In addition, full implicit difference scheme should be used in dual porosity/single permeability model and IMPES difference scheme should be used in dual porosity/dual permeability model. If we treat the high velocity flow problems, the former always has good stability, but the later maybe becomes unstable. So the latter usually is used to treat those fractured problems that the matrix permeability is not over five percent of fractured permeability.

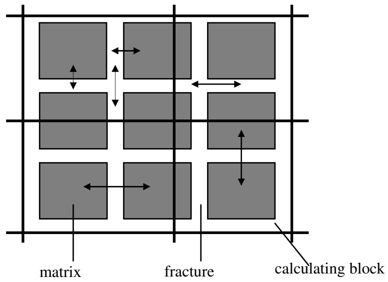


FIGURE 4. Dual porosity/dual permeability model.

We know there are only three equations and three unknowns in each grid for a single porous media black oil simulation, but it needs to add three additional equations to describe fluids flow in another media for dual porous media simulation and then adds three unknowns. Therefore the order of one simulation problem will be increased by 2 times from single porous media to dual porous media. Based on current solving technique, work load will be increased by 4∼9 times, so the simulating speed of dual-porosity media is much slower than single-porosity media.

4. The software development of fractured reservoirs

The DQHY simulator was developed by Exploration & Development Research Institute of Daqing Oilfield Co. Ltd. in 1987, the developed period of fractured reservoir simulator would be curtailed based on this simulator. The fractured parameters had added into input and output options, for dual porosity/single permeability model and dual porosity/dual permeability model, we reprogramed for the module of finite difference scheme and solving linear equations with linear equation solver (SLES) in PETSc software package.

Because there are PETSc, MPI and pgi compiling environment for the assembly PC-Linux system, the simulation software of fractured reservoirs has been developed on PC-Linux environment.

5. Application for examples

The concept model was computed with the simulation software for fractured reservoirs. The concept model is described as followed:

The grid number is: 11×11×3, the size of uniform grid in horizon direction is: 60m×60m, the size of the matrix grid in horizon direction is: 30.3m×3m; The sizes of three-layer grids in vertical direction respectively are: 57m,90m,90m, and the net thickness in vertical direction respectively are: 5m,4m,4m, matrix and fractured permeability is 1md, except the fractured permeability in the center horizon direction is 100md, matrix porosity is 0.114, fractured porosity is 0.001, nine wells are arranged with 300m well space, the center well is injection-water well, the others are production wells, 8000 days production history are calculated.

CPU calculated time are showed as follows:

It takes 17.26s for full implicit solution of single porous media model, 31.97s for full implicit solution of dual porous media/single permeability model, 5306.85s for IMPES solution of dual porous media/dual permeability model. By this token, the calculated time of dual porous media is much slower than one of single porous media, especially for dual permeability model.

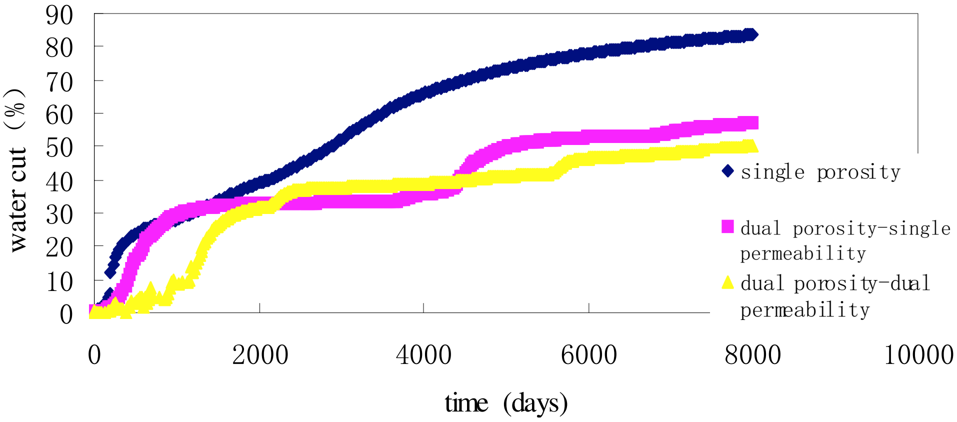
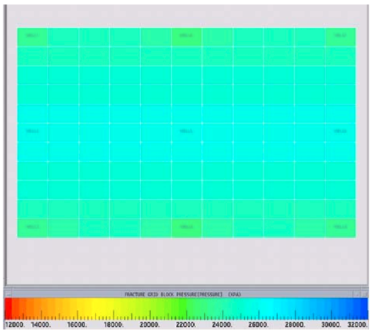


FIGURE 5. Water cut changes with time for different media.



Fractured grid pressure field computing for 1500 days for dual porous media/dual permeability model

FIGURE 6. Fractured grid pressure field computing for 1500 days for dual porous media/dual permeability model.

Water cut curve is showed as follows FIGURE 5. The water cut change is smart and presents ladderlike for dual porous media model because of the influence of fractured permeability. It is different from single porous media model whose water cut change is gentle.

Computing for 1500 days, matrix-fracture pressure and saturation figures are showed by FIGURE 6 to FIGURE 13.

Because there are material exchange between matrix-matrix and matrix-fracture for dual permeability model, their field distributions are uniform, which was seen obviously by FIGURE 6 to FIGURE 13.

6. Conclusions

(1). The numerical Simulation software for Fractured Reservoirs in this paper can simulate waterflood behavior and make the function of black oil simulator extend, the result is reasonable and credible.

(2). On the basis of DQHY simulator of three dimensions and three phases, making use of PETSc to develop the simulator on PC-Linux environment is feasible, which could treat dual porosity/single permeability and dual porosity/dual permeability model.

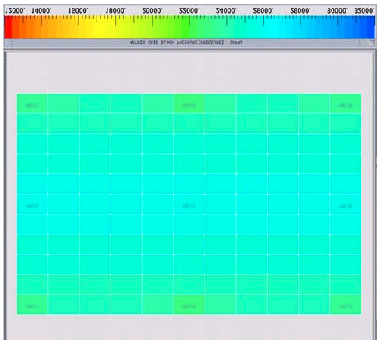


FIGURE 7. Matrix grid pressure field computing for 1500 days for dual porous media/dual permeability model.

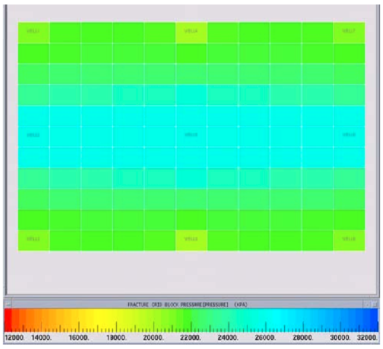


FIGURE 8. Fractured grid pressure field computing for 1500 days for dual porous media/single permeability model.

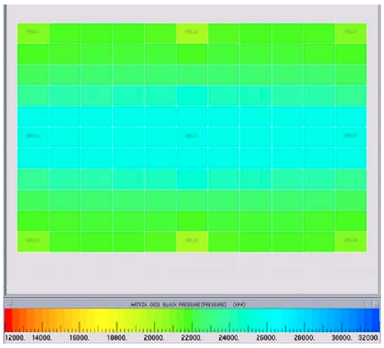


FIGURE 9. Matrix grid pressure field computing for 1500 days for dual porous media/single permeability model.

(3). The software has been combined with the local preprocess and postprocess system and directly applied to practical problem for fractured reservoirs and has good practicability.

References

[1] Numerical Simulation of Naturally Fractured Reservoirs, L. S-K. Fung, SPE25616, April 1993.

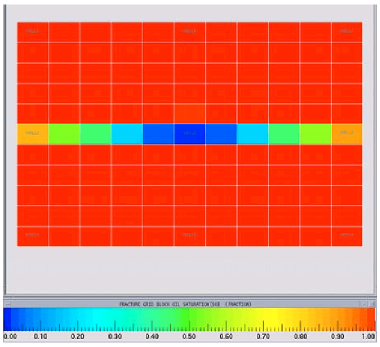


FIGURE 10. Fractured grid oil saturation field computing for 1500 days for dual porous media/dual permeability model.

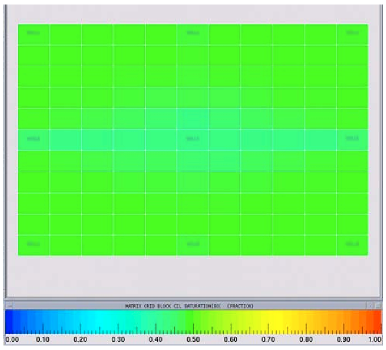


FIGURE 11. Matrix grid oil saturation field computing for 1500 days for dual porous media/dual permeability model.

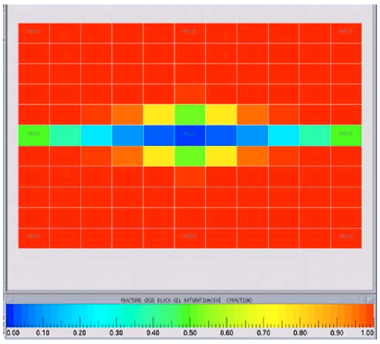


FIGURE 12. Fractured grid oil saturation field computing for 1500 days for dual porous media/single permeability model.

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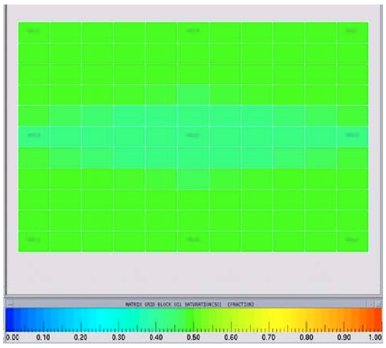

FIGURE 13. Matrix grid oil saturation field computing for 1500 days for dual porous media/single permeability model.