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LARGE-SCALE RESERVOIR SIMULATIONS USING PC-CLUSTERS

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Abstract. Going through the development more than forty years, the overall water-cut to Daqing Oilfield has almost reached 90%. But there is still considerable residual oil in the place. Reservoir engineers want to know the residual oil spatial distribution and how to dig it. This requires large-scale reservoir simulation within limited time. Enlarged scale and highly expected efficiency need higher technical capability for reservoir simulation. By using PC-Cluster technique developed in recent years, large-scale reservoir simulation can be carried out at a relatively low cost. The first PC-Cluster used for reservoir simulation in Daqing Oilfield was designed and built. Based on this developing environment, the serial black oil simulator was parallelized by using the SLES components in PETSc. Then this parallel simulating technique was applied in seven oil production districts of Daqing Oilfield, where the PC-Clusters were configured and the parallel black oil simulator PBRS2.1 we had developed was installed and good results were achieved. In this paper, the hardware and system software configuration of PC-Clusters built is briefly introduced, the idea and method for parallelizing the serial black oil simulator is discussed, and the simulation study at seven typical field blocks and their application results are described and presented.

Key Words. residual oil, large-scale reservoir simulation, PC-Linux, PETSc, parallel black reservoir simulation (PBRS).

1. Introduction

Since reservoir simulation came to be used it had always followed the computer's development to satisfy technical requirements of the oil exploitation industry, with the problem scale being larger, the simulator's main purpose expands to research fine distribution of fluid under ground from the past trends of studying the whole reservoir performance, so that the expenditure for every simulation is bigger and bigger. The parallel computation environment (shared and distributed) came forth ten years ago, synchronously some developers of reservoir simulator began to research how the serial simulator was parallelized, and the commercial version came onto the market later. Taking account of the application convenience and the computation cost, it is necessary to us to parallel the existing serial simulator, and then the independent parallel simulation technique is performed to satisfy the requirements of large scale reservoir simulation in our Oilfield.

In the procedure of reservoir numerical simulation, the computation can be divided into coupled and uncoupled parts. Parallelization of uncoupled part only involves the program technique, the important thing to do is on data decomposition by regions, and most of the serial source code for this part can be adopted for

parallel program. The coupled part is mostly executed in the process for solving linear equations, where the parallel solving method we use must be different from the serial case. Therefore, the key work is the development and implementation of the parallel solving method for large, sparse and unsymmetrical linear system. By the use of the differential equation parallel solver package-PETSc(Portable, Parallel, Extended Toolkit for Scientific Computation) coming forth from Argonne National Lab of America, for the developer of reservoir simulators, it is possible to realize that the existing serial simulator is parallelized quickly. Therefore, in terms of the use of PETSc's options on the LINUX PC-cluster, we made the serial black oil simulator be parallelized and developed the parallel black oil simulator PBRS, and successfully applied it in seven oil production areas of the current reservoir studies in Daqing.

2. The hardware and system software configurations of PC-Clusters in Daqing

The scale of PC-Cluster is from several nodes to thousands, if we keep extensibility, the more nodes, higher the expense. The first PC-Cluster to be built in Daqing was mainly used for experiment and software development, its function was primary, and its performance was secondary. In order to enhance the probability of success, we reduced the cost as much as possible, so the number of nodes is not large. Hardware and system configuration of the integrated PC-Clusters is as follows:

Hardware configuration

(1) Node: one master (control) node, eight slave (computation) nodes;
(2) CPU: Intel Pentium III 800EB or higher;
(3) Memory: 2GB for master node, 1GB per slave node;
(4) Network card: two Intel 100/1000M PC cards, teaming, for master node, one Intel 100/1000M PC card per slave node;
(5) Switch: 24/12Port 100/1000M Switch;
(6) Hard disk: 18GB inside for every node, 200GB RAID connected to master node;
(7) Display: 21 inches display linked to master node.

System software configuration:

(1) Linux operating system RH7.1 or higher;
(2) MPI (Message Passing Interface) 1.2;
(3) The differential equation parallel solver package-PETSc (Portable, Parallel-Extended Toolkit for Scientific Computation) from American National Lab.

3. Parallel solving strategies in PBRS software

Most computation examples indicated that it took 98 percent of all simulation time when we used serial simulator to calculate Jacobian coefficients and to solve the linear system coupled by grid equations and well equations. In order to obtain good parallel efficiency, the computation and data involved in the two steps above must be distributed into every parallel node. It is possible to realize parallel computing for the other portions, but we have to consider that the higher communication expense is not worth the candle.

In order to reduce the workload of parallel coding, it is convenient to adopt Master/Slave parallel solution strategies. A more brief account of it is as follows: slave process takes charge of Jacobian computation, performs the calculating task of linear system and couples grid equations with well equations to solve linear