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PARALLEL NUMERICAL MODELING OF TWO-PHASE FLOW PROCESS IN POROUS MEDIUM

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INTRODUCTION

The carbon capture and storage (CCS) concept [1] is under discussion as a promising transition technology fostering the reduction of the increasing CO_2 amount in the atmosphere being an important factor in the global warming [2]. It is suggested to capture CO_2 from fossil fuel power plants or other producers and to store it into deep geological formations, or in the form of mineral carbonates. The motivation of this work is driven by the requirement to improve the computational efficiency in the numerical modeling of the hydraulic processes during CO_2 injection and storage [3, 4], especially into real sites such as the Ketzin research site for CO_2 storage in Germany [5, 6]. Concerning numerical modeling of such problems, a very fine level of spatial discretization is needed in order to cover the real medium properties of the geological formations, which exhibits strong heterogeneity. This leads to a system of linear equations with millions of unknowns to be built up and solved. Moreover, the computational tasks of assembling and solving of the linear equation systems have to be carried out for many time steps due to the long time interval of the CO_2 injection and storage to be simulated, and meanwhile due to the complexity of the problem such as the nonlinearity of coupled processes and heterogeneity of the material properties. This gives a big challenge to perform such numerical modeling in the conventional sequential manner on a single computer or using a single core of a computer. Based on the previous experience in the parallelization of the finite element method implemented in the framework of OGS in C++ [7, 8] with MPI, we use PETSc routines to parallelize the finite element scheme for the simulation of two-phase flow in large scale applications. In this work, the parallelized FEM is applied to numerical simulate the CO_2 storage in the Ketzin pilot.

PARALLEL FEM SCHEME

A distributed parallel FEM scheme is realized by the following general procedure:

1. Partition mesh by using METIS,
2. Start the parallel finite element program,
3. Read subdomain mesh or partition generated in step (1) in the parallel manner such that the memory usage of the mesh is distributed to computer nodes,

4. Assemble the matrix and the right-hand side vector belonging to the subdomain in a parallelized manner,
5. Assign boundary conditions locally,
6. Solve the system of equations by using PETSc

MODELING RESULTS

The domain with an area of 5×5 km2 20 is discretized into 4,043,119 tetrahedra, which gives 707,713 nodes as shown in Fig. 1.

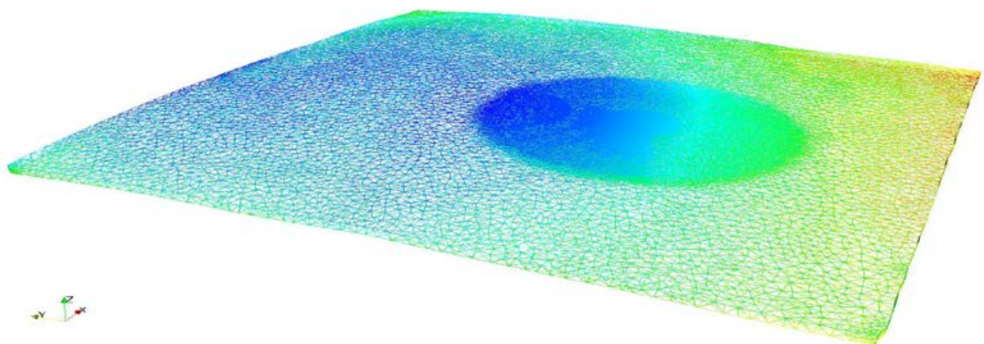

Fig. 1: Mesh of the study domain of the Ketzin site

The two-phase flow during the injection duration of 1,595 days is simulated. Two sets of simulations have been conducted as: simulations with homogeneous hydraulic properties, and simulations with heterogeneous hydraulic properties. The speedup achieved in the simulations with homogeneous hydraulic properties is illustrated in Fig. 2.

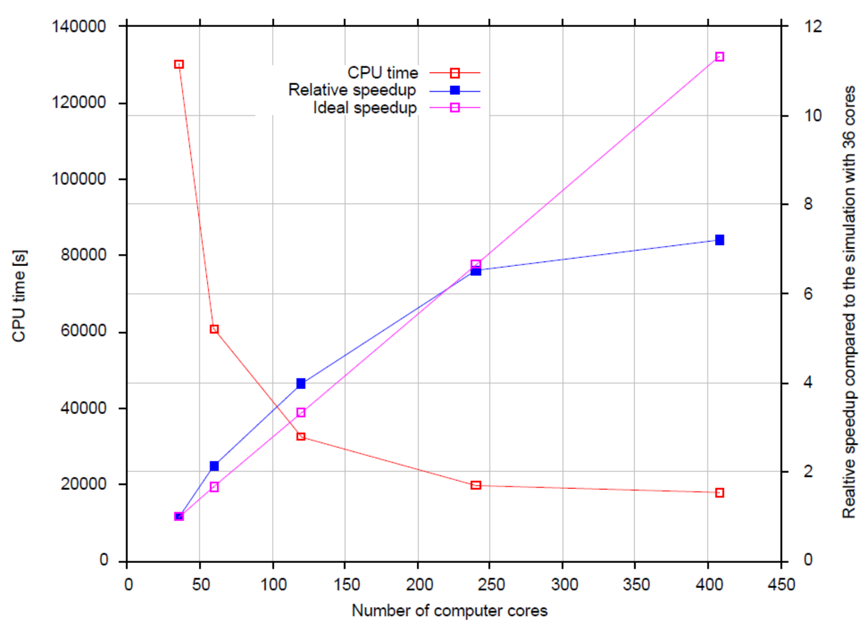

Fig. 2: Speedup of the simulations with homogeneous material properties

While for the case with heterogeneous hydraulic properties, two simulations have been conducted with compute cores of 240 and 360, respectively. The simulation with 240 cores took 71,393 seconds of CPU time (3,536 seconds by linear solvers), while with 360 cores it took 33,824 seconds of CPU time (2,005 seconds by linear solver).

The simulated injection pressure variation at a specified observation point is close to the measured curve as shown in Fig. 3.

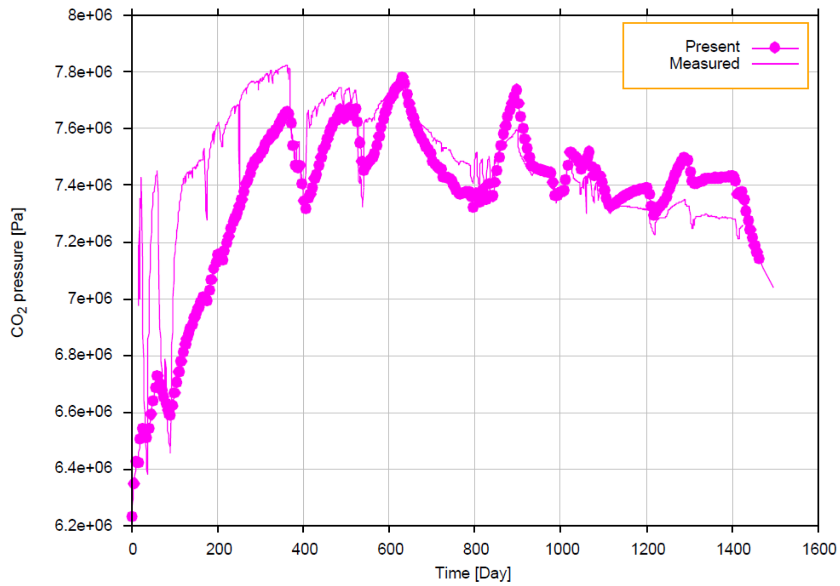

Fig. 3: Pressure variation at a specified observation point

A more detailed presentation of this material will be available through *Wang et al.* [9], forthcoming.

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