Study on IDEAL Algorithm for Macroscopic Model of Fluid Flow and Heat Transfer in Porous Media

Shangmin Ao, Peng Wang*, Lin Zhang, Yajun Deng, Dongliang Sun* and Bo Yu

School of Mechanical Engineering, Beijing Key Laboratory of Pipeline Critical Technology and Equipment for Deepwater Oil & Gas Development, Beijing Institute of Petrochemical Technology, Beijing, 102617, China.

*Corresponding Authors: Peng Wang. Email: wangp@bipt.edu.cn; Dongliang Sun. Email: sundongliang@bipt.edu.cn.

Abstract: The problem of fluid flow and heat transfer in porous media is one common phenomenon in industrial production and daily life. Numerical simulation for the above problem can provide a realistic understanding of transport processes and thus can help to optimize energy consumption. However, in the macroscopic model of fluid flow and heat transfer, the convergence rate of traditional numerical methods is usually poor as the hygroscopic properties of porous media. Therefore, it is of great significance to develop an efficient algorithm for the macroscopic model of fluid flow and heat transfer in porous media. The IDEAL (Inner Doubly-iterative Efficient Algorithm for Linked- equations) algorithm is a full implicit pressure-velocity coupling algorithm, which has great convergence rate and stability of the numerical calculation process. At present, the IDEAL algorithm has been used and achieved good convergence in many physical problems, such as phase changes, two-phase flow and viscoelastic fluids flow, while it is rarely adopted to solve the problems in porous media. In this paper, the IDEAL algorithm for macroscopic model of fluid flow and heat transfer in porous media is implemented in the world's most widely used open source CFD software-OpenFOAM. In the process of the implementation, the resistance term in the momentum equation and the thermal diffusion coefficient in the energy equation are treated specially. Two different discretization of the resistance term have been considered, namely implicit and explicit methods. The thermal diffusion coefficient is calculated differently in the free-flow region and the porous media region. The computational performance of the IDEAL algorithm is analyzed by comparing with a traditional algorithm (SIMPLE algorithm). From Fig. 1 and table 1, the main conclusions are as follows: (1) The convergence of the IDEAL algorithm is better than that of SIMPLE algorithm. When the optimal under-relaxation factor is used, the IDEAL algorithm can reduce the computation time by 51.6-84.7% over the SIMPLE algorithm. (2) The robustness of the IDEAL algorithm is superior to SIMPLE algorithm. In particular, the IDEAL algorithm can reach convergence at larger under-relaxation factor, whereas the SIMPLE algorithm cannot obtain the convergent solution.

Keywords: IDEAL algorithm, porous media, fluid flow and heat transfer, OpenFOAM

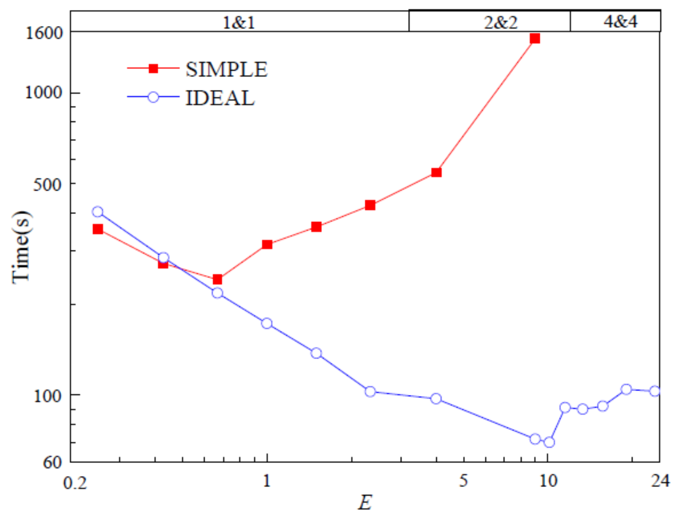

Figure 1: Comparison of the computation time and robustness for the SIMPLE and IDEAL algorithms

Table 1: Reduced ratio of the IDEAL algorithm over the SIMPLE algorithm at their optimal under-relaxation factors

Case	Reduced ratio over SIMPLE
Case 1	67.9%
Case 2	84.7%
Case 3	72.7%
Case 4	51.6%
Case 5	66.9%

Acknowledgements: The study is supported by the National Key R&D Program of China (Grant No. 2018YFD0700200), Beijing Natural Science Foundation and Beijing Municipal Education Commission (KZ201810017023), the Program of Great Wall Scholar (No. CIT&TCD20180313), the Project of Construction of Innovative Teams and Teacher Career Development for Universities and Colleges under Beijing Municipality (No. IDHT20170507).