# Direct Numerical Simulation and Modeling of Turbulent Convection in Porous Media

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### In Short

- Can the PSPH be applied to the problems of turbulent convection in porous media?
- How do the turbulent momentum and thermal dispersion terms influence the porous medium convection?
- How does turbulence influence the local heat/mass transfer between a fluid and a solid matrix?
- How do forced convection and natural convection interact with each other in a porous medium?
- By which parameters is natural convection in a porous medium influenced?

A porous medium is a material containing a porous matrix and pores. The porous matrix is usually solid while the pores are filled with a fluid (liquid or gas). A wide range of materials falls to porous media under this definition, e.g. sponges, wood, sand or body issues. Porous media like materials have been widely used in heat and mass transfer applications since their high surface area to volume ratio may significantly enhance heat and mass transfer. These applications include moisture migration in fiberous insulation, nuclear waste disposal, cooling of electric devices, etc.

Convection in porous media is usually laminar due to its low local Reynolds number (Re). However, when Re is order of 100 or higher, the flow within the pores becomes turbulent. Even at a small local Re number, macroscopic turbulence which is characterized by the domain size instead of the pore size may still occur at some special conditions.

Turbulent convection in porous media receives increasing attentions in recent years with the emergence of some new engineering applications. These applications include long term storage of CO2 in deep saline aquifers, cooling systems of electric devices, and thermal energy storage systems, etc. Turbulence plays an important role in these applications since it can effectively enhance the heat and mass transfer.

Design and optimization of these engineering applications require accurate simulation of turbulent convection in porous media. Porous medium convection can be investigated by an experimental method or a numerical method. The experimental method is believed to be more accurate when the measurement error is small, so that they are often used to validate the numerical results. However, study of porous medium convection with experimental methods is very expensive and technically difficult. With the emergence of high performance computers in recent years, the computational fluid dynamics (CFD) method is becoming a more and more popular tool for analyzing flow and heat transfer problems due to its lower cost and faster solution.

CFD simulations of porous medium convection can be classified as microscopic simulations and macroscopic simulations according to the difference of the scales to be solved. In microscopic simulations, the motions smaller than the representative elementary volume (REV) should be calculated, thus the detailed geometry of the porous elements can be taken into account. A microscopic direct numerical simulation (MIC-DNS) is a typical microscopic simulation. In a MIC-DNS the microscopic governing equations are solved directly without introducing additional models. A MIC-DNS method usually has higher accuracy than other simulation methods. In our previous HLRN projects we have focused on the mass transfer problem for natural convection in porous media and in Fig. 1 the instantaneous temperature field recieved from MIC-DNS for a natural convection case is shown. Whereby the directly recevied microscopic results and the derivied macroscopic results (by volume averaging over each REV ) are shown.

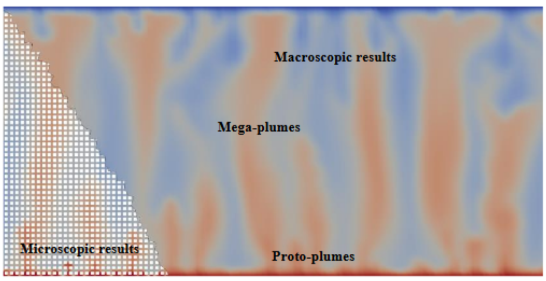


***Figure 1:** MIC-DNS results: Instantaneous temperature field for Ra=20000 and porosity of $\varphi$=0.56 for natural convection*

As mentioned, porous medium convection was traditionally calculated by solving the macroscopic equations. However, the physics of it is still not clear. Significant simplifications and strong assumptions have been made in these macroscopic equations. For example, the turbulent momentum and thermal dispersion terms were often neglected. In addition, there are still contradictory views on whether there is macroscopic turbulence in porous media. As a result, numerical simulation results sometimes have considerable model errors. More efforts are required to develop more accurate macroscopic models and to better understand the physics of turbulent convection in porous media. With the results of our two previous HLRN projects we have developed a macroscopic model for natural convection in porous media, which predicts a much more accurate Sherwood number, than the one predicted by the classical macroscopic DOB equations, if the Sherwood number is compared to the MIC-DNS results.

The main purpose of the proposed project is to further improve the understanding of the physics of turbulent porous medium convection, whereby as a fundamental tool the microscopic direct numerical simulation (MIC-DNS), in which the detailed flows within the porous elements will be taken into account, are used.

In this project we will continue to use the microscopic direct numerical simulation (MIC-DNS) methods, in which the detailed flows within the porous elements will be taken into account. The mass transfer natural convection problems will be continued, whereby we plan to vary the geometrical shape of the obstacles, which build the generic porous matrix (GPM) to broaden the applicability of our proposed macroscopic model, yet particular attention will be paid to mixed convection and forced convection heat transfer problems due to their high complexity and significance in emerging industries, like thermal energy storage systems.The GPM and boundary conditions for our considered MIC-DNS cases for the heat transfer problem (forced and mixed convection) are shown in Fig. 2.

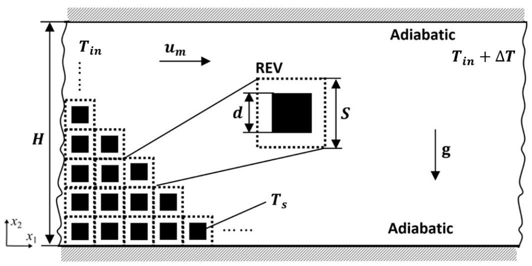


***Figure 2:*** *The 2-dimensional GPM for simulating forced and mixed convection (heat transfer) in a porous medium. Where periodic boundary conditions in the horizontal direction are utilized, with a constant applied temperature difference.*

Through our further improved understanding of the physics of turbulent convection in porous media, the existing macroscopic models for calculating turbulent forced and mixed convection in porous medium can be improved and more comprehensible. Also, the already developed macroscopic model for natural convection in porous media can be as well further improved and its applicability for industrial applications can be enhanced.

## WWW

https://www.zarm.uni-bremen.de

## More Information

## Funding

DFG project number: 408356608