Gray-scale lattice Boltzmann methods – an attempt to bridge multiple length scales

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ABSTRACT

Understanding and controlling the flow of fluids through porous media such as rocks, fibres, granular media and paper is of fundamental significance to a variety of industries such as oil and gas, chemical production, health and sanitary products. Numerical modelling of this physical process can be difficult not only because of the complex, three-dimensional topology of the porous medium but also because of computational limitations. For example, shale rocks which is now being intensively investigated for its oil and gas resources have porosity over a wide range of length scales from nano-metres up to millimetres. It has been shown that the micro-porosity is fundamental to the fluid movement through the rock. However, current numerical models, which work off computed tomographical (CT) scans of the rock will be excessively large if they are to fully model all length scales which may span six or more orders of magnitude.

Here we consider the development of a lattice Boltzmann (LB) technique which may be able to solve the fluid flow over a wide range of length scales. In the past LB techniques have proven to be ideal to model fluid flow in complex porous media since it can readily import and process digital data from CT scans. Hence the fluid flow field is quickly determined and permeabilities can be predicted. However, when the CT data contains micro-porosity, the conventional LB method is not applicable and a modified LB method needs to be developed. Here we consider a gray-scale LB method which works on voxels which are not fully void or solid but something in between, i.e. each voxel is partially resistant to fluid flow. We firstly outline the model, then validate it on test cases and then demonstrate its applicability on real porous media.

We develop models not only for single phase fluid flow, but also multiphase fluid flow (i.e. a gas and a liquid) as well as a temperature model, where the temperature field is advected by the fluid flow. For all these cases the models are developed and validated and then demonstrated on realistic media. It is shown that the gray-scale LB model may be able to solve for fluid flow through multiple length scales – a difficult computational problem which is of increasing significance in many real-world applications.

REFERENCES

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