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Simulation of fluid flow on natural biomass porous medium using COMSOL Multiphysics Software

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ABSTRACT

Modeling and simulation of fluid flow are considered essential for engineers and scientists to better understand, develop, optimize, and control a process. In the fields of the microfluidics and porous media, researchers are constantly trying to develop innovative geometry microchannel to achieve optimum effectiveness. The difficulty in fabricating microchannel also leads to increases in manufacturing costs. Therefore, it becomes difficult or even impossible to use such structures in tests. However, programs for numerical simulation show their advantages in terms of functionality, pricing, and usability. This investigation was focused on a numerical analysis of fluid flows using cider vinegar residues as the porous medium and employing COMSOL Multiphysics Software. The porous medium was modeled from scanning electron microscopy images of the residues, which showed that the surface was irregular and porous. These images were converted to a binary file using ImageJ software and then saved as DXF file utilizing Inkscape software to make them geometry readable in COMSOL. The fluid flow was simulated for different cases. The inflow of a Newtonian fluid into a porous medium was mathematically described by the Navier–Stokes equation and the continuity equation. The results demonstrated the application of boundary conditions, thus making it possible to trace the streamlines, velocity, and pressure.

Keywords: Simulation; Fluid flow; Cider vinegar residue; Velocity.

1. Introduction

Computational fluid dynamics (CFD) has emerged as an advanced tool for studying detailed behavior of fluid flow characteristics in many chemical engineering applications such as groundwater remediation [1]. The simulations are very important for creating empirical correlations that help continuum-based models perform better because the macroscopic properties are a strong function of pore-scale liquid–liquid and solid–liquid interactions [2]. In this context, numerous studies on imaging techniques have shown that the permeability of the porous medium is determined using the pore network models (PNM) [3,4]. Recently, different properties such as velocity, pressure, relative permeability-saturation could be predicted by different software such as COMSOL Multiphysics [5]. The CFD module is an optional package that adds specialized physics interfaces and capability to the COMSOL Multiphysics modeling system, which is designed to analyze various varieties of fluid flow [6].

This investigation was focused on a numerical analysis of fluid flows using cider vinegar residues as the porous medium and employing COMSOL Multiphysics Software.

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The porous medium was modeled from scanning electron microscopy (SEM) images of the residues. These images were converted to a binary file using ImageJ Software and then saved as DXF file utilizing Inkscape software to make them geometry readable in COMSOL. The fluid flow was simulated for different cases.

2. Materials and methods

2.1. Preparation of cider vinegar residue

The cider vinegar residue (CVR) was obtained after the vinegar extraction, which was performed by apple fermentation at room temperature (from 25°C to 30°C) in closed systems for three months. The residues were dried in open air for 6 d until a constant weight was obtained and then stored in darkness in tinted glass bottles prior to their use.

2.2. SEM characterization

The morphology of cider vinegar residue was examined by SEM using MicronsPerPixY operating at 20 and 5 kV.

2.3. Computational model

In this present work, COMSOL Multiphysics 5.5 was used to simulate the fluid flow on the apple cider vinegar residue as a porous medium based on an SEM image. As shown in Fig. 1, this image was converted to a binary file using the ImageJ Software and then saved as a DXF file using Inkscape software to make it readable geometry in COMSOL.

We added the value of porosity in the model before the simulation as a principal characteristic of the solid phase "porous medium: cider vinegar residue" which is determined experimentally in previous study. It is in the order of 0.36 [7].

2.4. Governing equations

In this model, the continuity [Eq. (1)] and momentum equations [Eq. (2)] for an incompressible, Newtonian fluid (water) and laminar flow in a steady case, were computed for both cases inside a microchannel and in a beaker filled with water and contained the biomass CVR, as given below [2].

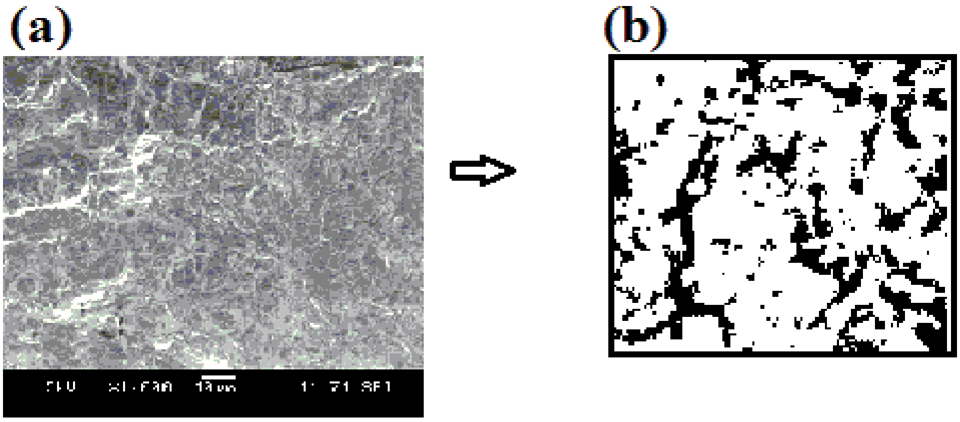

Fig. 1. (a) Scanning electron microscope (SEM) image of cider vinegar residue and (b) image converted to a binary chap by using ImageJ Software.

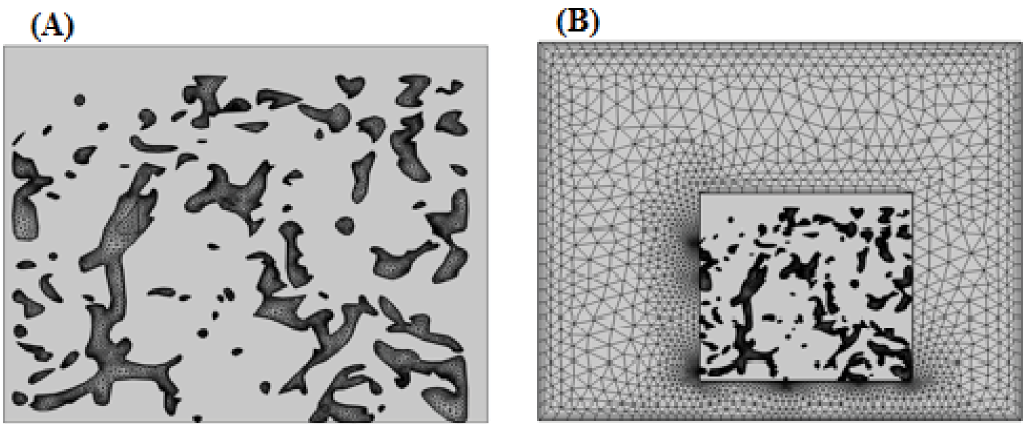

Fig. 2. Finite element mesh (A) inside a pore (microchannel) and (B) in a beaker filled with water contained the biomass CVR).

$$\nabla\left(\rho\vec{\vartheta}\right)=0 \tag{1}$$

$$\nabla\left(\rho\vec{\vartheta}\vec{\vartheta}\right)=-\nabla P+p\vec{g}+\nabla\left[\mu\left(\nabla\vec{\vartheta}+\left(\overline{\nabla\vartheta}\right)^{T}\right)\right]+\vec{F}_{S} \tag{2}$$

The surface tension force as well as the force of gravity „ $p\vec{g}$ „ are assumed to be equal to zero. Indeed, the smaller of the diameter of microchannel, the gravitational force ($p\vec{g}$) tend to zero.

Moreover, the surface tension force is roughly regarded as a body force surrounding the interface line between phases [8].

For both cases, the value of the inlet velocity is in the order of 0.05 m·s^{-1}.

2.5. Meshing

For both cases (inside a pore (microchannel) and in a beaker filled with water contained the biomass CVR), the mesh consists of small triangles; furthermore the normal mesh was used as described in Fig. 2.

3. Results and discussion

Fig. 3 shows the evolution of fluid flow velocity and pressure fields inside a pore (microchannel). It appears that the highest velocities tend to occur in narrow pores with high-pressure drops.

As indicated Fig. 4, the velocity is zero wherever there is a packing (line is passing through the packing). Furthermore, there is a proportional relationship between velocity and shear rate inside a pore of CVR [9].

For the second-case, the same observation as the first case was achieved. The velocity was zero wherever there was a packing. In addition, the maximum value of the velocity was in the order of 0.085 m·s^{-1}. This was in contrast to the pressure, which was maximum at the stagnation point (velocity = 0), in accordance with the momentum equation (Fig. 5) [10].

4. Conclusions

In this research, fluid flow in a porous medium (CVR) was numerically examined to evaluate both the applicability of COMSOL Multiphysics and the impact of the

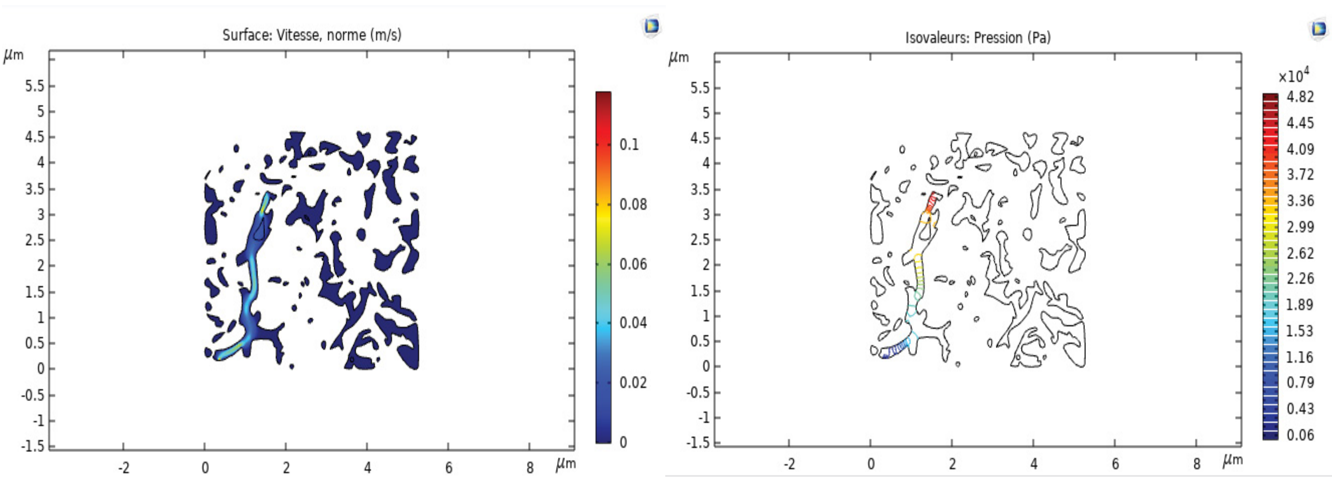

Fig. 3. Evolution of fluid flow velocity and pressure fields inside a pore (microchannel).

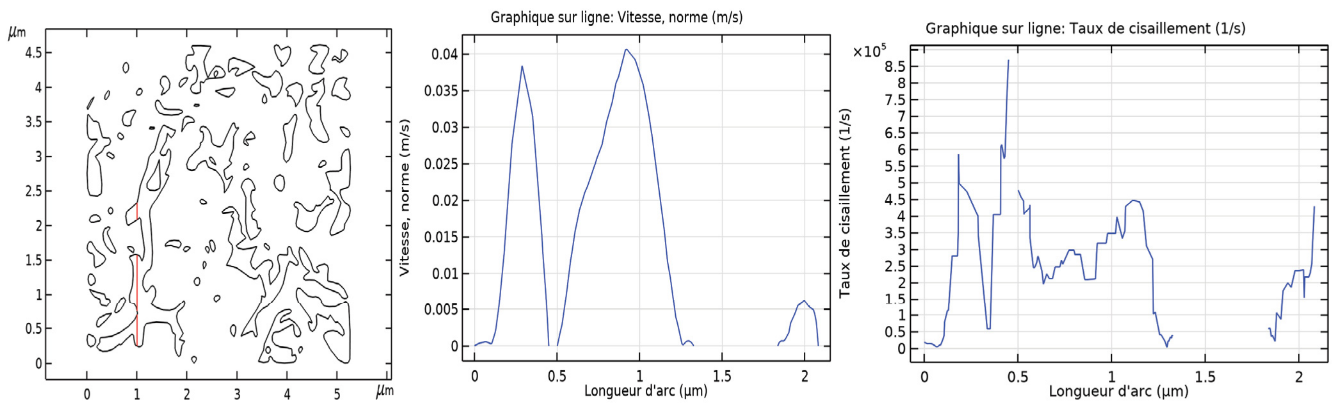

Fig. 4. Velocity and shear rate plot (line) inside a pore (microchannel).

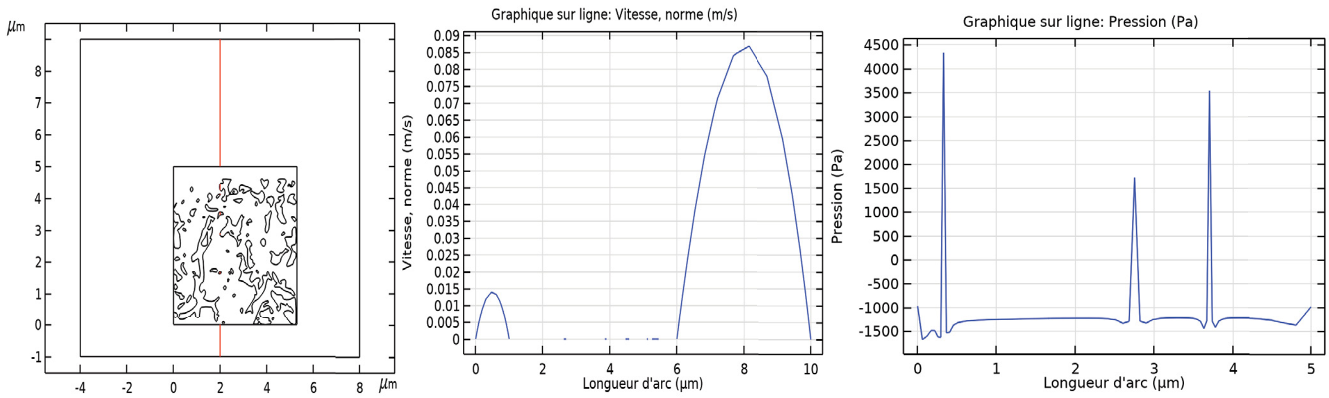

Fig. 5. Velocity and pressure plot (line) in a beaker filled with water contained the biomass CVR

pressure as well as the velocity and shear rate provided by this program.

An increase in the magnitude of the angular velocity is implied by the mass's conservation of angular momentum in the microchannel. Further, wherever there is compaction, the velocity is always zero since the fluid cannot cross the hard limits.

Physically, the microscopic interactions between fluid particles and the microchannel's wall are at least as strong as the interactions between the individual fluid particles. So that the microchannel's wall should have a constant velocity vector field. The computational fluid dynamics software COMSOL allowed determining both velocity and pressure in a complex morphological porous medium.

Symbols

$\vec{F}_s$ — Surface tension force per unit volume, $N \cdot m^{-3}$
P — Pressure, Pa
$\vec{\vartheta}$ — Velocity, $m \cdot s^{-1}$
ρ — Phase volume fraction weighted density, $kg \cdot m^{-3}$
μ — Viscosity, Pa·s
ε — Porosity

References

[1] J. Brodny, M. Tutak, Applying computational fluid dynamics in research on ventilation safety during underground hard coal mining: a systematic literature review, Process Saf. Environ. Prot., 151 (2021) 373–400.

[2] A.S. Ambekar, P. Mattey, V.V. Buwa, Pore-resolved two-phase flow in a pseudo-3D porous medium: measurements and volume-of-fluid simulations, Chem. Eng. Sci., 230 (2021) 116128, doi: 10.1016/j.ces.2020.116128.

[3] D. Wildenschild, A.P. Sheppard, X-ray imaging and analysis techniques for quantifying pore-scale structure and processes in subsurface porous medium systems, Adv. Water Resour., 51 (2013) 217–246.

[4] Q. Xiong, T.G. Baychev, A.P. Jivkov, Review of pore network modelling of porous media: experimental characterisations, network constructions and applications to reactive transport, J. Contam. Hydrol., 192 (2016) 101–117.

[5] M.B. Bird, S.L. Butler, C.D. Hawkes, T. Kotzer, Numerical modeling of fluid and electrical currents through geometries based on synchrotron X-ray tomographic images of reservoir rocks using Avizo and COMSOL, Comput. Geosci., 73 (2014) 6–16.

[6] COMSOL Multiphysics CFD Module User's Guide, 2012.

[7] M. Turkman, N. Moulai-Mostefa, Y. Zouambia, Biosorption of Cu(II) from aqueous solutions by the residues of cider vinegar as new biosorbents: comparative study with modified citrange peels, Desal. Water Treat., 142 (2019) 279–292.

[8] A. Etminan, Y.S. Muzychka, K. Pope, Film thickness and pressure drop for gas-liquid Taylor flow in microchannels, J. Fluid Flow Heat Mass Transfer, 8 (2021) 60–71.

[9] A. Yahia, S. Mantellato, R.J. Flatt, Chapter 7 - Concrete Rheology: A Basis for Understanding Chemical Admixtures, P.-C. Aïtcin, R.J. Flatt, Eds., Science and Technology of Concrete Admixtures, Woodhead Publishing, 2016, pp. 97–127.

[10] S. Sachdev, S. Pareek, B. Mahadevan, A. Deshpande, Modeling and Simulation of Single Phase Fluid Flow and Heat Transfer in Packed Beds, The Proceedings of the 2012 COMSOL Conference, Bangalore, 2012.