Arsenic Removal from Drinking Water

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Introduction

Arsenic is a natural component of the earth's crust and is widely distributed throughout the environment in the air, water and land.

Arsenic is used industrially as an alloying agent, as well as in the processing of glass, pigments, textiles, paper,. Arsenic is also used in the hide tanning process and, to a limited extent, in pesticides, feed additives and pharmaceuticals.

Health Effects

The International Agency for Research on Cancer (IARC) is part of the World Health Organization (WHO). One of its major goals is to identify causes of cancer. IARC classifies arsenic and inorganic arsenic compounds as "carcinogenic to humans."

This is based on sufficient evidence in humans that these compounds can cause:

Lung cancer, Bladder cancer, Skin cancer, Kidney cancer, Liver cancer, Prostate cancer.

Figure1. Arsenic effects on human skin

Objectives:

Our main goal is to save people all around the earth.

Based on these facts, we are trying to design a cheap, effective filtration system that doesn't require any external energy to run.
For that purpose, we decided to design a filtration system which can be fabricated with 3D printers.
In order to design an effective filter, we have developed a model by analytical studies which provides very accurate details an information for arsenic filtration process.
Moreover, Polyurethane foam-base filter is another project that we are working on it. By which, production of cheap and effective filters can be accessible everywhere around the world.

Methods

Adsorption is a process which occurs when a solute accumulates on the surface of an adsorbent, forming a molecular or atomic film (the adsorbate). Adsorption is operative in most natural physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal, synthetic resins and water purification.

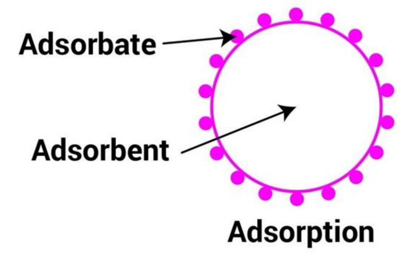

Figure2. Schematic of Adsorption Process

In this study, we consider a single-phase flow occurring through a rigid and homogenous porous medium, as presented in the figure. The stationary and rigid solid particles constitute the σ-phase and the incompressible fluid saturating the pores represents the β-phase. We plan to investigate the mass transport of a dilute chemical species due to convection and diffusion processes with adsorption in effect at the fluid-solid interface.

The governing equation for solute transport within the pore space of an REV can be expressed as the equation that you can see on this slide.

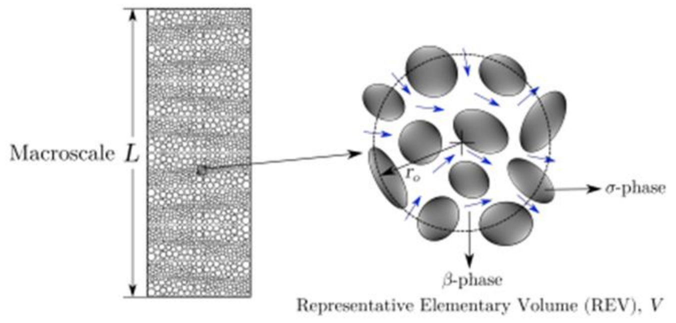

Figure3. Sketch of a macroscopic region of length L and a spherical Representative Elementary Volume (REV) of volume V with radius r0. The REV is composed of solid (σ) and fluid (β) phases.

•Governing equation in microscopic scale:

$$\frac{\partial c_\beta}{\partial t} + \nabla \cdot (c_\beta \mathbf{v}_\beta) = \nabla \cdot (\mathcal{D}_\beta \nabla c_\beta)$$

In order to upscale from the microscopic space to the macroscopic one, volume average method is used. In other words, the governing equations and related boundary conditions for the large scale space has been derived from the governing equations and its boundary conditions for small scale space. Applying this method to the main equation will result in two sets of problems called closure problems.

Problem I:

$$\mathbf{v}_\beta \cdot \nabla \mathbf{b}_\beta + \tilde{\mathbf{v}}_\beta = \mathcal{D}_\beta \nabla^2 \mathbf{b}_\beta$$

$$\text{B.C.1}: \quad -\mathbf{n}_{\beta\sigma} \cdot \nabla \mathbf{b}_\beta = \mathbf{n}_{\beta\sigma}, \quad \text{at } A_{\beta\sigma}$$

$$\text{Periodicity B.C.}: \quad \mathbf{b}_\beta(\mathbf{r}+\mathbf{l}_i) = \mathbf{b}_\beta(\mathbf{r}), \quad i = 1,2,3$$

$$\text{Constraint}: \quad \langle \mathbf{b}_\beta \rangle^\beta = 0$$

Problem II:

$$\mathbf{v}_\beta \cdot \nabla s_\beta = \mathcal{D}_\beta \nabla^2 s_\beta + \frac{a_{\beta\sigma}}{\epsilon_\beta}$$

$$\text{B.C.1}: \quad -\mathbf{n}_{\beta\sigma} \cdot \mathcal{D}_\beta \nabla s_\beta = 1, \quad \text{at } A_{\beta\sigma}$$

$$\text{Periodicity B.C.}: \quad s_\beta(\mathbf{r}+\mathbf{l}_i) = s_\beta(\mathbf{r}), \quad i = 1,2,3$$

$$\text{Constraint}: \quad \langle s_\beta \rangle^\beta = 0$$

the final form of the governing equation, after somehow complex calculations is presented as:

$$\left(1 + \frac{a_{\beta\sigma} K_{eq}}{\epsilon_\beta}\right) \frac{\partial \langle c_\beta \rangle^\beta}{\partial t} + \langle \mathbf{v}_\beta \rangle^\beta \cdot \nabla \langle c_\beta \rangle^\beta + K_{eq}\, \mathbf{u}_\beta \cdot \nabla \left(\frac{\partial \langle c_\beta \rangle^\beta}{\partial t} \right) = \mathbf{D}^*_\beta : \nabla\nabla \langle c_\beta \rangle^\beta$$

Based on these analysis, the path length and station time, are some important parameters in removing arsenic from water. We can relate these parameters with tortuosity.
Tortuosity is defined as the ratio of the lengths, Lp and Lcv of the preferential tortuous fluid pathways and the porous media:
Hence, Tortuosity is an adsorbent material parameter that affects adsorbent performance.
In other words, for higher tortuosity, due to the residence time of the water and also more adsorbent surface area in contact, we can expect a better filtration process, in which more arsenic will be removed from the flow.

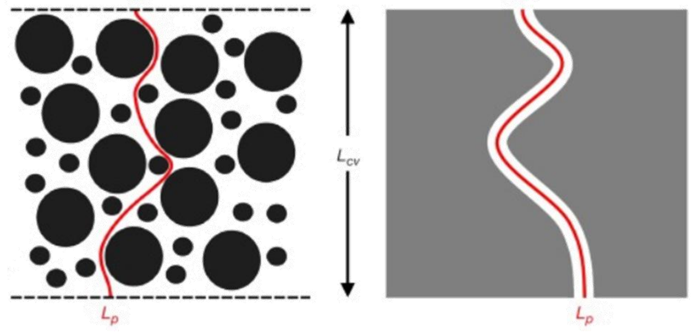

Figure4. Flow path within a porous medium

CFD

Here you can see the modified geometry of a single unit cell. In this study, what is important for us, is the water flow behavior. Therefore, based on our unit-cell design, we generate the fluid domain geometry.
For CFD study, we assumed that water is flowing through the upper surface of the unit cell because of the gravitational force. Also we considered symmetric boundary condition for the walls which are connected to the other unit-cells.
After setting up the boundary conditions and defining the governing equations, we carried out a grid independence study. Here you can see the modified mesh generation.

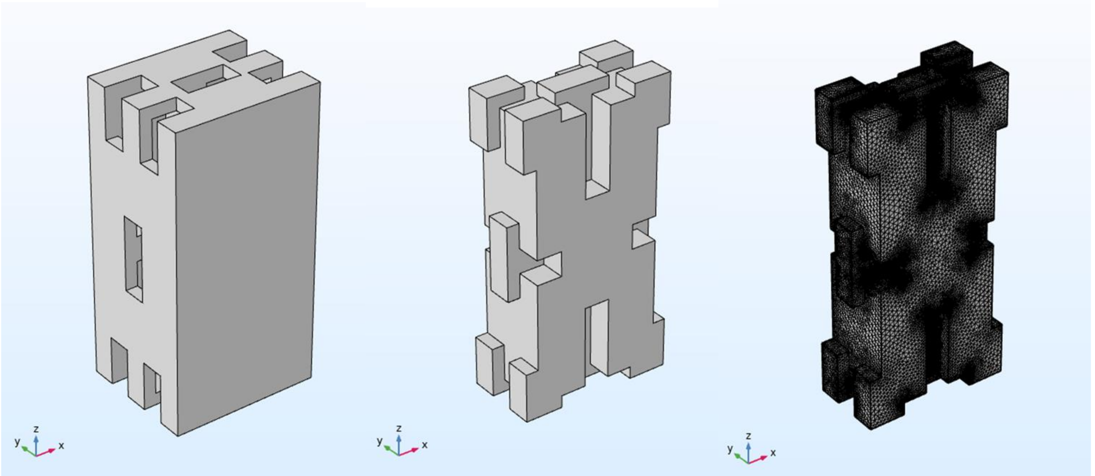

Figure5. Unit-cell and fluid domain geometries and refined generated mesh

Results

As a result, here you can see the streamlines, which represents the path that each particle move through it.

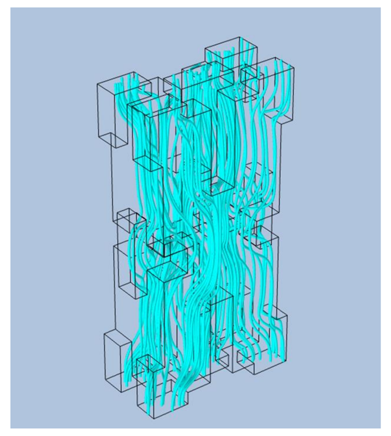

Figure6. Streamline of the fluid particles

These two figures, are velocity and pressure contour in the mid plane of the unit cell.

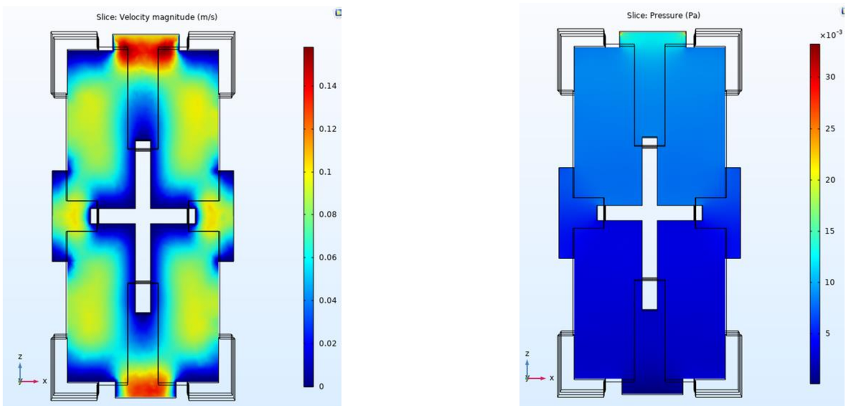

Figure7. Velocity and Pressure contours in the mid plane of the unit-cell

Based on the stream line lengths, the tortuosity of this unit cell is calculated as 1.3.

Conclusion

- Arsenic in the drinking water, can lead to severe health problems.
- Adsorption method has been used to develop a low-cost, easy to produce and install filtration system.
- In order to have accurate results, Volume-average method is used to develop the governing equation in large scale.
- Tortuosity plays an important role in designing the filtration system, regarding the station time and arsenic adsorption