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Battling pollution by navigating particle traffic

by Aleksa Djorović[1] | PhD Student

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[1]: Department of Applied Physics, University of Geneva, Geneva, Switzerland

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The movement of particles in solution through the holes and spaces in a material as the liquid flows through is critical to processes such as underground water contamination and delivery of drugs deep inside tissue. By adjusting the pressure at which they are injected into the material we can now control the traffic of these particles in new ways.

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Humanity is facing a water crisis. Industry requirements exceed our fresh water resources and water scarcity is on the horizon. Underground water is an essential source of freshwater, but it is very susceptible to contamination. As such we need to perfect processes we use to protect or to clean, if already polluted, the water we extract. One way to do it is to use pressure to control which particles are pushed through to the groundwater basins and which are stopped in their tracks before reaching the fresh water.

A porous medium is a material that is full of holes, or pores, throughout - such as sponges and cork (or indeed Swiss cheese!) - and importantly the soil, sand and rock that makes up the ground underneath our feet. Particles of heavy metals, like lead or mercury, flowing in rain water can navigate through these pores and contaminate underground water. Other particles that bind to and clean contaminants also need to travel through soil. Different particles have different properties, such as size, shape, electrical charge, solubility in water and others – they all influence particle transport through pores. What if we could use these differences, as well as other tricks, to control the traffic? A new study investigates the effects of injection pressure (how forcefully the particles in solution enter the material), liquid flow and particle charge on how particles in solution navigate the maze of a porous material.

To simulate the system where contaminated water is pushing through the ground, the scientists used an extremely narrow glass tube packed densely with glass beads, the spaces between the glass beads imitating pores. They then injected the simulated contaminants - electrically charged particles in water

- at speeds comparable to groundwater flow through sand and recorded their movement and navigation through the tube using a microscope.

The glass beads themselves carry a negative electrical charge, so when the injected “contaminant” particles are positively charged they are attracted to the beads and cling on to them as they pass through. In this way, when the injection pressure is sufficiently low, particles clog up the tube close to the entrance by building up a deposit on the glass beads and closing off the spaces between them. When the injected particles carry a negative charge, they are repelled by the beads and instead form clusters in the spaces between them, also effectively building a wall between the beads and reducing the flow of particles. In this case however, the clogging of the tube happens further from the entrance.

Injecting particles at high pressure produces an interesting result: positively and negatively particles behave similarly. Even when the particles are attracted to the beads, the particles do not deposit and clog up the tubes and instead disperse evenly throughout the tube. While the particles still build up and fill up the spaces with a wall, the flow speed is now fast enough that the next incoming particle smashes through it and continues further, taking the broken pieces of the wall - other particles - with it. This process continues over and over, walls are made, then broken, then made further downstream, and the particles push further and further into the material.

These results suggest that at high pressures, the erosion, which is the breaking of particle deposits and pushing them further downstream, is the dominant process, and overshadows any charge attraction or repulsion. At low pressures, however, it does not play a big part. Using this knowledge, we can control particle flow and build-up in porous materials by manipulating the pressure. This has significant repercussions in a broad variety of applications.

By reducing the insertion pressure, we can trap particles close to the entrance to a material. This can be used to capture lead and other heavy metal contaminants and restrict them from reaching underground water, keeping it safe for use. Conversely, one can increase the pressure to force particles to navigate further through materials when long distance transport is needed, for example when particles that eradicate contaminants must be able to reach them deep in the soil.

These results can be extended to other systems where particles travel through porous materials such as the human body. In this case, controlling the injection pressure can aid the delivery of drugs through porous tissue and deep into the body, where they are needed. Humanity is under pressure to find and save fresh water sources before they run out – but it might just be that pressure itself is the answer.