Researchers finger the cause of 'gravity fingers'

CEE team offers elegant solution to long-standing fluid mechanics problem

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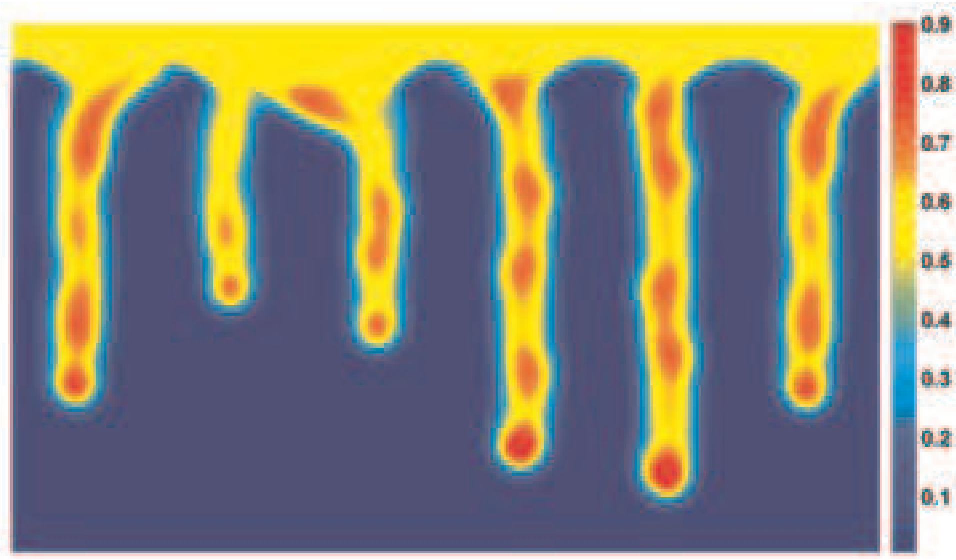


GRAPHIC / **LUIS CUETO-FELGUEROSO**

Saturation maps from a numerical simulation of the proposed model show that the flow dynamics and the distinctive saturation overshoot at the tip of the fingers agree with experimental observations.

MIT researchers have found an elegant solution to a sticky scientific problem in basic fluid mechanics: why water doesn't soak into soil at an even rate, but instead forms what looks like fingers of fluid flowing downward.

Scientists call these rivulets "gravity fingers," and the explanation for their formation has to do with the surface tension where the water — or any liquid — meets the soil (or other medium). Knowing how to account for this phenomenon mathematically will have wide-ranging impact on science problems and engineering applications, including the recovery of oil from reservoirs and the sequestration of carbon underground.

The solution, reported in the Dec. 12 issue of Physical Review Letters, involves borrowing a mathematical phrase from the description of a similar problem — a solution both simple and elegant that had escaped the notice of many researchers in earlier attempts to describe the phenomenon.

Co-authors Luis Cueto-Felgueroso and Ruben Juanes of the MIT Department of Civil and Environmental Engineering discovered the solution while studying the larger question of how water displaces oil in underground reservoirs (petroleum engineers commonly flush oil reservoirs with water to enhance oil recovery).

"Our paper addresses a long-standing issue in soil physics," said Cueto-Felgueroso. "Lab experiments of water infiltration into homogeneous, dry soil, repeatedly show the presence of preferential flow in the form of fingers. Yet, after several decades, the scientific community has been unable to capture this phenomenon using mathematical models."

"This was the type of problem that required someone from a different research discipline to take a look at it and come up with the solution," said Juanes, the ARCO Assistant Professor in Energy Studies. "Luis applied his expertise to a fluid mechanics problem in another medium — porous media flows — and quickly figured out the solution."

Cueto-Felgueroso, a postdoctoral associate who has previously worked primarily on airflow fluid mechanics problems, had a eureka moment when he realized that gravity fingers in soil (or clay or sand) look very similar to water flowing down a window pane, a fairly well-understood phenomenon. He and Juanes then pulled the mathematical explanation (think of it as a phrase of words or music) from the equation describing water on a window, and included that mathematical phrase in the equation describing liquid moving downward through soil.

After rigorous comparison of data produced by the new mathematical model with observed phenomena, the two realized they'd found the solution, a solution described by one scientist reviewing the paper in Physical Review Letters as "simple and elegant" and a "major breakthrough" in the field.

The Cueto-Felgueroso and Juanes solution also describes one aspect of the water-flowing-down-a-windowpane phenomenon that previously was not understood by scientists, who actually refer to this as "the flow of thin films": Why does water build up at the tips of the fingers?

Again, the answer has to with the surface tension. Before the water can flow down the film, it must build up enough energy to overcome the tension that is holding it in place.

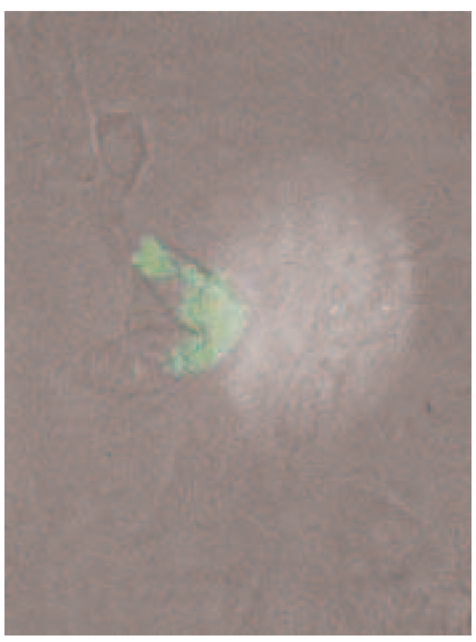
So what was missing from earlier models of water moving downward through soil that made it appear to move as a steady, horizontal front, rather than in finger-like paths — even when the soil was homogenous in particle size and shape?

The missing mathematical phrase describes the surface tension of the entire finger of water, which may be several centimeters in width, as opposed to the tension existing at the micron-scale of pores between soil particles.

And that phrase will sound like music to the ears of physicists and engineers.

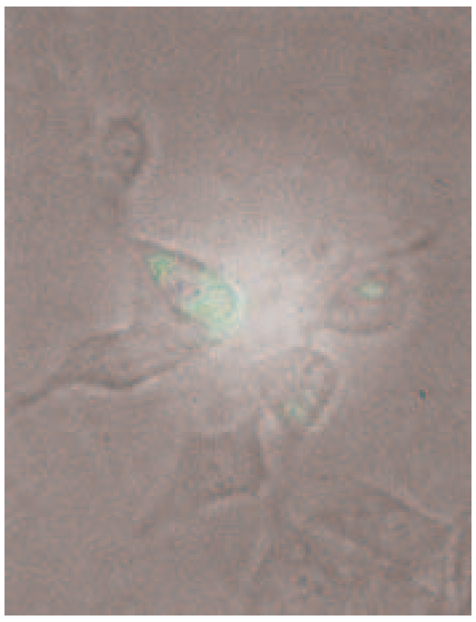
The work was supported by the Italian energy company Eni.

Nanotubes sniff out cancer agents in living cells



IMAGES / **STRANO LAB**

These two images show carbon nanotubes inside a mammalian cell. The nanotubes can detect the presence of certain molecules, in this case, hydrogen peroxide. ABOVE: The cell before hydrogen peroxide is added. BELOW: The cell after hydrogen peroxide is added. The change in fluorescence provides a 'fingerprint' that allows different molecules to be identified.



Chemical engineers use carbon nanotubes to monitor chemotherapy, detect toxins at the single-molecule level

Anne Trafton
News Office

MIT engineers have developed carbon nanotubes into sensors for cancer drugs and other DNA-damaging agents inside living cells.

The sensors, made of carbon nanotubes wrapped in DNA, can detect chemotherapy drugs such as cisplatin as well as environmental toxins and free radicals that damage DNA.

"We've made a sensor that can be placed in living cells, healthy or malignant, and actually detect several different classes of molecules that damage DNA," said Michael Strano, associate professor of chemical engineering and senior author of a paper on the work that appeared in the Dec. 14 online edition of Nature Nanotechnology.

Such sensors could be used to monitor chemotherapy patients to ensure the drugs are effectively battling tumors. Many chemotherapy drugs are very powerful DNA disruptors and can cause serious side effects, so it is important to make sure that the drugs are reaching their intended targets.

"You could figure out not only where the drugs are, but whether a drug is active or not," said Daniel Heller, a graduate student in chemical engineering and lead author of the paper.

See the interview with Strano and Heller at web.mit.edu/newsoffice

The sensor can detect DNA-alkylating agents, a class that includes cisplatin, and oxidizing agents such as hydrogen peroxide and hydroxyl radicals.

Using the sensors, researchers can monitor living cells over an extended period of time. The sensor can pinpoint the exact location of molecules inside cells, and for one agent, hydrogen peroxide, it can detect a single molecule.

The new technology takes advantage of the fact that carbon nanotubes fluoresce in near-infrared light. Human tissue does not, which makes it easier to see the nanotubes light up.

Each nanotube is coated with DNA, which binds to DNA-damaging agents present in the cell. That interaction between the DNA and DNA disruptor changes the intensity and/or wavelength of the fluorescent light emitted by the nanotube. The agents produce different signatures that can be used to identify them.

"We can differentiate between different types of molecules depending on how they interact," Strano said.

Because they are coated in DNA, these nanotube sensors are safe for injection in living cells. (Nanotubes can come in many different lengths and can be coated with different materials, which influences whether they are safe or toxic, Strano said.)

In future studies, the researchers plan to use the sensors to study the effects of various antioxidants, such as the compounds in green tea, and learn how to more effectively use toxic chemotherapy drugs.

Other authors of the paper include MIT graduate student Hong Jin of the Department of Chemical Engineering. Researchers from the University of Illinois at Urbana-Champaign also contributed to the work, which was funded by the National Science Foundation.

Close encounters with 3-D cell growth

Engineers' new microfluidic device could help with drug development

Anne Trafton
News Office

MIT engineers have built a device that gives them an unprecedented view of three-dimensional cell growth and migration, including the formation of blood vessels and the spread of tumor cells.

The microfluidic device, imprinted on a square inch of plastic, could be used to evaluate the potential side effects of drugs in development, or to test the effectiveness of cancer drugs in individual patients.

Roger Kamm, MIT professor of biological and mechanical engineering, and his colleagues reported their observations of angiogenesis — the process by which blood vessels are formed — in the Oct. 31 online issue of the journal Lab on a Chip.

Microfluidic devices have been widely used in recent years to study cells, but most only allow for the study of cells growing on a flat (two-dimensional) surface, or else lack the ability to observe and control cell behavior. With the new device, researchers can observe cells in real time as they grow in a three-dimensional collagen scaffold under precisely controlled chemical or physical conditions.

Observing angiogenesis and other types of cell growth in three dimensions is critical because that is how such growth normally occurs, said Kamm.

Working with researchers around MIT, Kamm has studied growth patterns of many types of cells, including liver cells, stem cells and neurons. He has also used the device to investigate the pressure buildup that causes glaucoma.

The device allows researchers to gain new insight into cell growth patterns. For example, the researchers observed that one type of breast cancer cell tends to migrate in a uniform mass and induces new capillaries to sprout aggressively toward the original tumor, while a type of brain cancer cell breaks from the primary tumor and

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