Clarifying the Dynamics of Clogs

From medical devices to bottles of glue to river canyons, clogs can bring any number of processes to a halt. Alban Sauret investigates how and why stuff gets stuck.

Scan the QR code to access the video

Clogs are a problem nearly everywhere — and anywhere — you care to look, and not just in the expected places, such as pipes, fuel filters, aerosol cans, or that tube of hardened glue in your desk drawer. In a paper titled "Clogging: The self-sabotage of suspensions," published in the February 2023 issue of the journal *Physics Today*, **Alban Sauret**, a UC Santa Barbara associate professor of mechanical engineering who specializes in developing quantitative models describing various flow-dynamics phenomena, and his colleagues write, "Clogging can occur whenever a suspension comprising discrete particles dispersed in a liquid flows through a confined geometry."

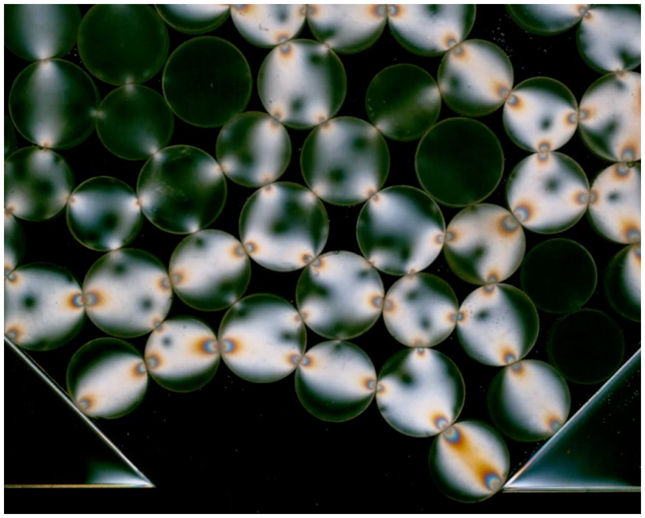
The clog can occur in confined flows of widely diverse dimensions that are carrying either too many particles or particles that are too large. "Channels and the constrictions in them can be microscopic," Sauret notes, "such as the pores of a filter or a bend in a microfluidic device, or macroscopic, such as pipes carrying water or a river carrying logs."

Remember the mega-container ship, the *Ever Given*, that became stuck in the Suez Canal for a week in 2021? Technically, that was a clog. Canyons can become clogged, and so can highways, exit doors in a crowded building, arteries in the body, and the nozzles of 3D printers and auto-injection devices that allow patients to self-administer medicine. Clogs can impede the flow of fresh water through natural aquifers, and can dramatically reduce the efficiency of drip irrigation systems for agriculture, which, when operating effectively, are fifty percent more efficient than sprinklers and furrow irrigation.

Clogs can be expensive. The *Ever Given* froze $10 billion worth of trade assets per day while it blocked the Suez Canal. Bloomberg did a study of a new U.S. Navy aircraft carrier, the toilets of which clogged easily. It cost $400,000 every time the system had to be cleaned.

But regardless of context or scale, for every clog, Sauret says, "The physics are the same."

Despite a long human history of developing clog-prevention methods, the underlying physics of clogging have only recently become an active research topic. Historically, most clog-prevention efforts have reflected trial-and-error approaches. Sauret would like to change that. In nearly any system, he says, "The particulate will flow for some time, but at some point, it's going to clog, so, the question becomes, can you predict when it will stop, and can you come up with guidelines to make a system work longer?" Sauret and researchers in his lab group addressed one common type of clogging — *bridging* — in a paper that was published in the August 2022 issue of *Soft Matter*.

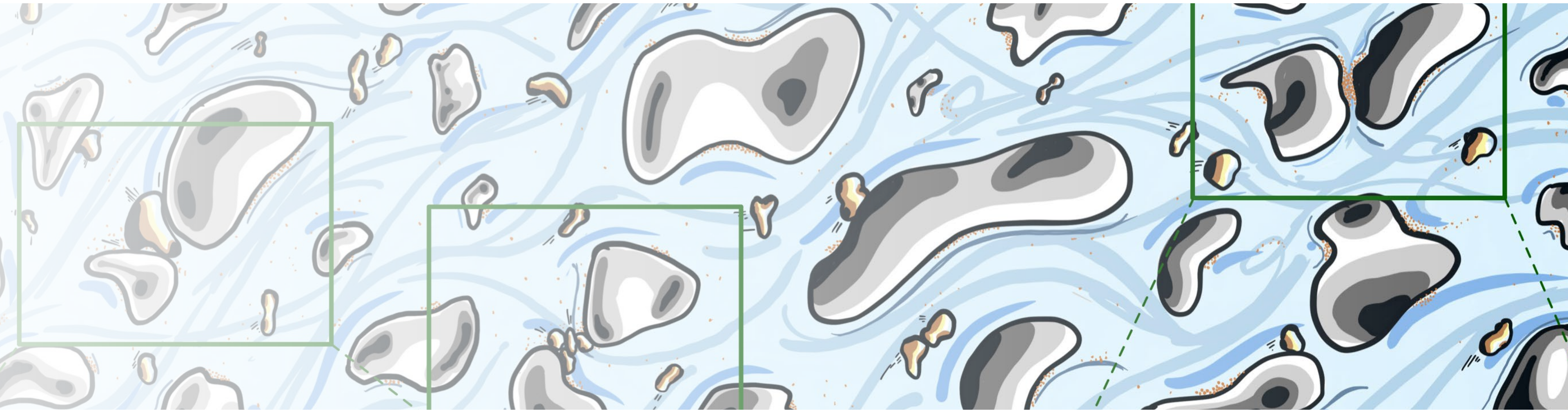


Polyurethane discs viewed through circular polarizers while flowing toward a constriction (as in a hopper) reveal patterns of light indicating the magnitude and direction of pressure. Eventually, a stable bridge clog forms at the opening.

Clogs occur in different forms. The most common are *sieving*, the above-mentioned *bridging*, and *aggregation*. Sieving occurs when a particle is too large to pass through a constriction. This happens with dust in a filter, when an individual dust particle is larger than the pores of the filter, producing a clog. Particles that are not of a uniform size and are free to reorient may enter a system at one orientation and then later reorient, causing a clog. This can happen to a log flowing down a river, which turns sideways and gets stuck between two rocks, as well as to a microfiber used to make the material in a 3D printer more solid. Sieving is also why rain gutters need to be cleaned periodically to prevent leaves and other debris from creating a clog.

In another type of clog — aggregation — particles stick on the wall of the channel and accumulate, eventually clogging it. "It's a long-term problem," Sauret says. "When you have a system that is operating for months, some particles stick to the wall and slowly accrete. That can happen in your body, too."

Bridging, the subject of the paper published in *Soft Matter,* occurs when too many particulates arrive at the opening in a channel and cause a kind of arch, or bridge, to form. The clog is held in place by a kind of keystone, just as an architectural arch is. Similarly, if a particle is removed from the bridge, the system will flow again. Conversely, just as gravity creates the force to make the bridge strong, the



Particles inside the three green-bordered squares in the illustration (above) depict the three main types of clogs (from left): sieving, in which a particle is too big to pass through an opening; bridging, when particles form a kind of arch, or bridge, at a constriction point; and aggregation, the phenomenon of particles accumulating on the walls of a channel.

flow in a channel also strengthens the bridge, which, lacking other changes to the system, has a zero probability of unclogging.

Another example of bridging is a crowd exiting by a single door or sheep trying to run through a narrow chute. Eventually, there are too many bodies pressing against each other, and forward progress stops. Sauret describes such situations as the clogging of "active" particles, i.e., those that can move on their own. Bridging can also clog a silo when dry particles flow in air; a video made by Sauret and his collaborators showing this effect was awarded the Gallery of Soft Matter award at the American Physical Society Meeting in March. (See opposite page.)

In the paper, the authors describe the specific conditions required for a bridge clog of particulate suspension to form. First, enough particles have to be present to form an arch spanning the entire constriction. Then, the arch needs to be stable, with a keystone and convexity in the right direction, that is, with the "high" end of the arch pointing upstream. Finally, the arch must appear.

By working through the probabilities of those steps occurring, Sauret says, "You are able to predict, on average, how many particles can escape as a function of the size of the constriction, the size of the particle, the volume fraction (that is, the number of particles per volume of liquid), and the probability of the arch becoming stable. You can then predict when a clog will occur for different sizes of constriction, with those having a high volume fraction (very concentrated) being likely to clog and those having low volume fraction still being likely to clog but not as fast. A solution is either to dilute the suspension sufficiently or widen the constriction, making it harder or even impossible to form a stable arch."

Sauret explains that in clogs that occur in manufacturing processes, no one knows what is happening inside. X-ray images have been used, but, he says, "It's very hard to know the physics behind what you see. In our experiments, we can actually see the process occur. It's obvious if the particle is too big to fit through the hole. The particle can be small enough in one dimension to flow through but long enough in another dimension to get clogged. You have to think about the alignment of the particles at the constriction. There are many variables."

Sauret would like to be able to predict when and where a clog in a system will occur. "In thinking about whether you can predict the bridging process, and you think of the constricted channel, what would seem to matter is the size of the constriction, the angle (i.e., the sharper the angle of transition from wide to narrow, the more rapidly the narrowing occurs), and the properties of the particles," he explains. "But what actually matters is the volume fraction. That is, if you dilute the liquid enough by controlling for the number of particles in the channel, you prevent, or at least delay, clogging."

While that is theoretically true, Sauret says that his research shows it not to be the case for particles that have a complex shape, such as long fibers used in additive manufacturing. Researchers in his lab ran experiments in which diluted suspensions of micro-scale fibers flowed through constructed channels of various widths to see if the fibers would negotiate the turn or become stuck. The result, according to the article: "Even systems of complex geometry without constrictions can be clogged by fibers."

Sauret's group is now experimenting with adding some kind of perturbation to help keep the particles in suspension before they reach the constriction or even developing ways to remove them from the surface. While it can be extremely difficult to prevent clogs altogether, designing systems so as to delay clogging would be a step in the right direction.

Alban Sauret