FLOATING ON SOUND WAVES WITH ACOUSTIC LEVITATION

Sound is a formidable power. Under the right conditions, it can manipulate and change the state of matter. The pharmaceutical industry is turning to acoustic levitation to address the ever-present need for high-quality medicine delivery systems, especially as technology for treating patients expands and becomes more customized.

BY LAURA BOWEN

At Argonne National Laboratory, part of the United States Department of Energy, Kamlesh Suthar and Chris Benmore are hard at work implementing acoustic technology to transform the manufacturing of pharmaceuticals. The team is turning to multiphysics simulation to improve their acoustic levitator—a device that generates sound waves to lift and manipulate matter.

ACOUSTICALLY MANUFACTURED PHARMACEUTICALS

By mixing chemicals while they spin and float in the air, Argonne is working to facilitate more efficient production and delivery of pharmaceutical products. In a controlled environment, the levitator provides a containerless and contaminant-free space for creating high-purity amorphous chemicals. According to the team at Argonne, "Many amorphous drugs are mixed with a polymer to help keep them stable for a long time." At the midpoint of each node of the standing waves in Suthar's acoustic levitator, molecules gather into droplets and form small spheres (see Figure 1). The droplets float a few millimeters apart and gently rotate, suspended, between two small piezoelectric transducers.

FIGURE 1. The acoustic levitator creates standing sound waves that allow droplets of liquid to levitate. The levitator is made of two transducers, each coated with a thin layer of foam to control the wave pattern.

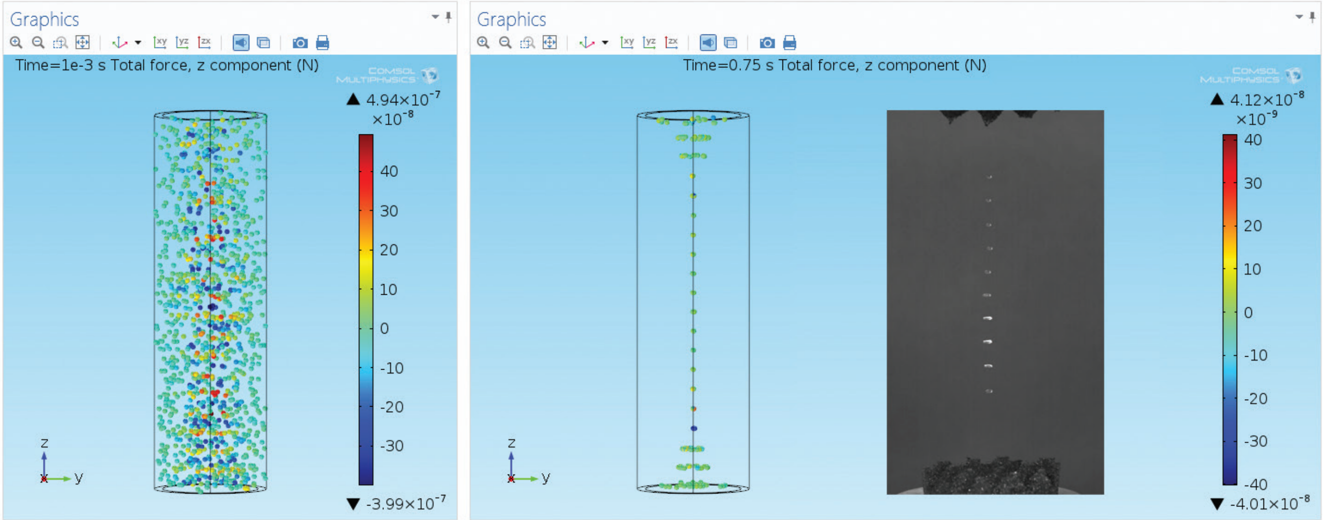


FIGURE 2. The initial distribution of the particles at t=.001 (left). Particles gather into droplets at t=0.75 and photograph of physical particle distribution (right).

A magnitude and frequency slightly above the audible range, 160 dB and 22 KHz, generates standing acoustic waves with pockets of high-pressure zones. The transducers convert electrical energy into acoustic pressure. The method set in place by Suthar and Benmore is a powerful technique for developing medicine. It is easier for human bodies to absorb and process amorphous chemicals because they are more soluble and bioavailable than when in crystalline form.

THE LIFTING POWER OF ACOUSTOPHORETIC FORCE

Designing the geometry just right to control the movement of the particles was crucial to the function of the levitator. In this experiment, several counterbalancing forces work together to create a phenomenon that allows the particles to float in a controlled way (see Figure 2). The acoustophoretic force, particle-particle interaction, drag, gravity, and surface tension of the droplets need to be taken into account. Specific patterns of Gaussian profile foam made of polystyrene were designed to remove any unwanted acoustic waves generated by the transducers and act as a filter along the edge of each one, creating a well-defined standing wave that reflects evenly, with little interference.

These parameters cause the particles to arrange vertically, then rapidly form into droplets. The droplets stay in the desired vertical position because they are constantly moving horizontally.

HOW ACOUSTIC SIMULATION STACKS UP AGAINST EXPERIMENTS

The team created a COMSOL Multiphysics® simulation to verify their synchrotron-based x-ray experiments at APS, the Advanced Photon Source, a facility that holds the brightest storage ring-generated x-ray beams in the western hemisphere. They used the Acoustics Module and Particle Tracing Module, add-ons to COMSOL. They first considered the frequency and material properties of the piezoelectric transducers and any thermal effects that might impact the levitator. They then used a trial-and-error method to find a foam geometry that allowed them to control how individual droplets would form. In addition, they considered how changes to the viscosity and surface tension can affect their shape. The interference creates droplet structures that Suthar mapped with a fluid structure interaction (FSI) simulation. He considered all of the relevant effects using the CFD Module and level set method, a numerical way to keep track of interfaces between different media during the simulation. Using the level set method to control the shape of the droplets at various shifts in acoustic modes helped Suthar to achieve a spherical shape and control the way the droplets interacted.

When the researchers ran the experiment to verify their design, they discovered that the results of the simulation were consistent with the behavior of the droplets in the high-speed photographs that they took at APS. The simulation results showing the acoustic field distribution (see Figure 3) were also similar to the experimental results.

As Suthar explains, "With the constructive interference of pressure waves, we get a standing pressure wave with positive and negative pressure pockets. Within these pockets, the sound reaches roughly the level of water droplet levitation. So if you sprinkle water mist, the droplets are pushed to the center and levitate due to the balancing forces involved."

The researchers at Argonne solidified their design with the help of multiphysics simulation. As the scientists continue to hone the designs of their acoustic levitators, the possibilities for innovation are infinite. Pharmaceutical developers will be able to control the concentration, droplet size, and amount of each chemical in medicine. The discoveries that Argonne is making have wide applications in the global medical community. This is especially true where new resources and machinery could mean truly life-changing advances for patients. ■

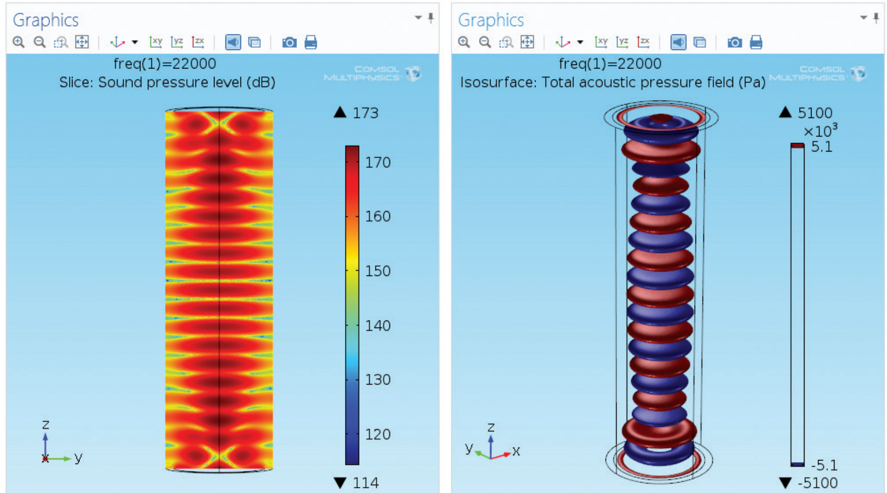
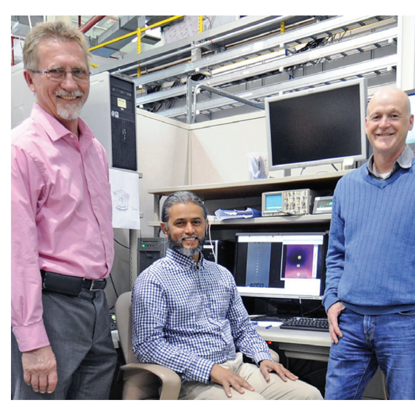


FIGURE 3. Regular sound pressure level generated due to a standing pressure wave at 22 KHz frequency (left) and pressure pockets with alternative pressure value (right).



The Argonne team, from left to right: Patric Den Hartog, Kamlesh Suthar, and Chris Benmore.