Highly concentrated laundry detergents get the job done on Earth and beyond

Katie Cottingham

With the typical US family washing about 300 loads of laundry every year, water and energy usage can be significant. Engineering advances mean that most modern, high-efficiency washing machines need much less water than older models. However, the machines are larger and hold more clothes, requiring detergents to do more per load. Still, consumers often puzzle over how much detergent to use per load, and how all of that water and electricity use is impacting the environment?

- **Highly concentrated detergents typically come in smaller packages and are more eco-friendly than detergents of the past.**
- **Scientists have developed new, extended surfactants that could concentrate products even further.**
- **A detergent formulated for use in space is helping scientists optimize products for use here on Earth.**

Highly concentrated detergents on the market today aim to address all of these concerns in one product, whether it be in the form of a small splash of liquid in a bottle cap or as a single-dose pod, sheet, or tile.

"A concentrated product is more powerful and not watered down, it is convenient, and because it has a smaller dose, it needs less packaging," says Wendy Saladyga, senior manager, R&D, at Henkel Consumer Brands North America in Connecticut. They sell all®, Purex®, and Persil® detergents.

Smaller packages are generally lighter than the huge jugs of the past, which is particularly helpful for differently abled consumers, and they take up less space. Shipping costs and the greenhouse gases involved in transport go down as the product size shrinks. And products such as laundry sheets and tiles are often sold in degradable paper or cardboard packaging.

"About four percent of all of your home electricity goes into heating water for laundry, and so the industry is focusing on using cold water," says Brian Grady, professor at the University of Oklahoma in Norman, Oklahoma.

Rising to the challenge, raw materials companies and formulators are designing new types of surfactants, which are the main cleaning ingredients in detergents, as well as new ways of combining ingredients. Newer detergents are now able to clean a wide range of stains in cold conditions and developing a product for astronauts to use in space could provide a wealth of knowledge that will benefit Earth-bound consumers. Here we consider the latest science behind cleaning laundry more sustainably, using less water and energy.

A RECIPE FOR CLEAN

From the old standby of laundry powder to the now-dominant liquid—and emerging products like pods, sheets, and tiles—the recipe for cleaning clothes has steadily evolved (although some aspects have remained the same). Regardless of the format, detergents work with water and agitation to remove soils from fabrics and keep them tucked away in suds so they can go down the drain with the wastewater.

The surfactant is the workhorse cleaning agent, but detergents also can have builders, or chelators, to sop up metal ions in hard water. In addition, the recipe typically includes dispersion agents to help keep dirt separated from fabrics, fragrances for a fresh smell, and stabilizers to keep the ingredients from separating and to protect enzymes from degrading. Enzymes are often added to break down specific types of stains. Although bleach is unstable in liquid detergents, it works well as a component in powders and is found in many powder formulations.

Detergents usually include three or four surfactants that remove stains by reducing the interfacial tension between the water and the stains on the fabric. To do this, the hydrophilic head—which can be charged or nonionic—binds water, and the hydrophobic tail binds oils at the other end of the molecule. High concentrations of surfactant lead to the formation of micelles, small spherical aggregates of surfactant with the headgroups on the outside and tails in the core. Micelles lock away oils so they can be removed from clothing and

Enzymes digest specific stains

Proteases: Proteins in blood, egg, grass, sweat

Amylases: Starches, such as pasta and chocolate

Lipases: Fats in fatty foods and oils

Cellulases: Natural cotton fibers to remove pills

Mannanases: Sticky gums that are in foods like mayonnaise and cosmetics

washed down the drain. Using multiple surfactants lowers the critical micelle concentration at which these spheres form, boosting the cleaning power of the detergent. Dirt particles are removed when a negatively charged anionic surfactant adsorbs to the particle and the fabric, weakening the attraction between the two.

"You typically have a primary surfactant that is doing the majority of the work," says Larisa Reyes, research scientist at Dow in Freeport, Texas. "It is there because it is very efficient, but you tend to add secondary or co-surfactants to enhance either the cleaning, solubility, or compatibility of that primary surfactant."

Anionic surfactants, such as linear alkylbenzene sulfonates (LAS) and alcohol ether sulfates (AES), have negatively charged heads. These compounds are effective against soil, dirt, clay, and some oils. They foam easily, but are sensitive to hard water, binding calcium and magnesium ions in the water and making it more difficult for them to form micelles. Nonionic surfactants, such as alcohol ethoxylates (AE), do not have a net charge so they are not as sensitive to hard water. They are the least expensive of the surfactants and can remove many types of food stains, oils, and greases.

"Liquid detergents usually contain a combination of LAS, AES, and a nonionic," says George Smith, technology manager, Sasol Chemicals, in Westlake, Louisiana. "Everybody changes the ratios depending on their formulation, style, and other properties that they want in the detergent." Powders are generally based on LAS.

GETTING CONCENTRATED

Making a detergent more concentrated is not as simple as removing most of the water. "As you concentrate, it becomes harder to formulate," says Grady. "The higher the surfactant concentration, the more likely it is going to interact with the other ingredients, particularly enzymes."

To make detergents more concentrated, formulators can use less of some ingredients or optimize others. "For example, if you have an ingredient that is doing two roles instead of just one, then you can make the detergent more compact," says Reyes. "Or you can have one component that is much more efficient so that you can reduce the amount of a less efficient one."

In the 1980s and 1990s, structured liquids were a popular way to concentrate detergents in Europe, says Smith.

PODS, SHEETS, TILES, OH MY!

Single-dose formats are a fast-growing segment of the laundry industry, says Saladyga.

PODS

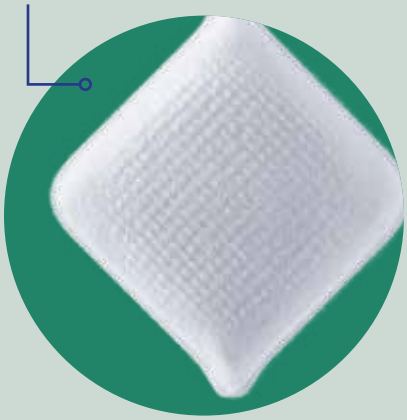
Almost every major detergent brand, including Arm & Hammer™, Tide®, and all® sells detergent pods, sometimes called paks. Smith says they debuted in the 1960s, but did not really take off until they were re-introduced in 2012 by Procter & Gamble. According to Smith and Grady, they contain highly concentrated surfactant enclosed in a polyvinyl alcohol pouch.

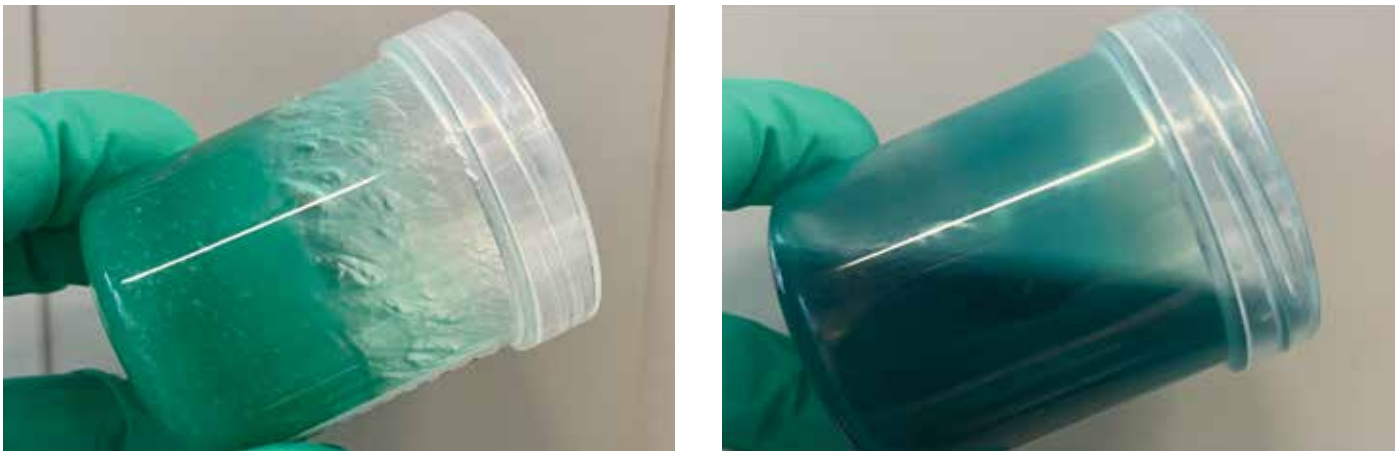
SHEETS

Several brands, such as Arm & Hammer™, Tru Earth, and Clean People, sell laundry sheets. They look like a dryer sheet and are casted layers of detergent with polyvinyl alcohol and other ingredients. About half of a sheet's weight is surfactant, says Smith.

TILES

Still being market-tested, Tide evo® is a non-woven tile. It has six layers and is P&G's most concentrated form with no added fillers, according to Sivik.





A concentrated detergent with a typical surfactant gels (left), whereas one with an extended surfactant does not (right).
Source: Juliana Caixeta Guimarães

"Companies would basically force the surfactant into a lamellar phase," he says. "Because it is a dispersion, it has a unique rheology that allows you to suspend things in it, so it was used as a delivery vehicle for sodium tripolyphosphate." However, phosphates from wastewater cause eutrophication, enriching bodies of water with nutrients that spur algal blooms, which deprive aquatic life of air and sunlight. Thus, phosphate-based materials are no longer used in consumer laundry products.

Mark Sivik's team at Procter & Gamble (P&G) recently developed a highly concentrated tile-shaped product called Tide evo®, which is being test-marketed in Colorado. Sivik is R&D senior director research fellow in Cincinnati, Ohio and his group considered every ingredient, especially surfactants, when creating the material.

"We use a portfolio of surfactants, and we use them in a unique way that drives efficiency," he says. "We look at different structural features and design them to manage the viscosity of our product so that when it hits cold water or it is concentrated, it does not get into the gel phase." He says they have removed many inert ingredients, such as processing and dissolution agents that would be in a typical powder.

Another way to make detergents more compact could be by using extended surfactants, which to these experts' knowledge, are not yet included in products sold today. With such molecules, a linker is inserted where the head and tail of a surfactant meet and it serves as a gradual polarity transition zone. The slightly polar linker extends the reach of the hydrophilic head into water and the hydrophobic tail into oil, which improves solubilization, making the detergent more powerful. Typically, polypropylene oxide (PO) groups are placed at the tail and ethylene oxide groups are placed at the head.

Extended surfactants can work well, but they have limitations, according to Smith. "You can get ultralow interfacial tension between oil and water and get really good cleaning, particularly for cold-water washing," he says. "But once you get more than about four moles of PO on the molecules, it does not pass the biodegradability test, which limits their usefulness."

Undeterred, Reyes and her team took this approach when developing two new extended surfactants they called advanced prototypes 3 and 10 (AP-3 and AP-10). The new molecules are based on PO-modified AE which the researchers tweaked and optimized to meet certain criteria. They found that when concentrating these prototypes into a detergent they averted a potential challenge with gelation that is common with nonionic surfactants, like AE.

"If they have gel issues, they will have some viscosity control issues, and that can impact cleaning by not dissolving easily," says Reyes.

The results for AP-3 and AP-10 so far are promising. "We have superior viscosity control for the formulations we tested, even if you reduce the solvent in them, and they dissolve quickly in water." Reyes says that she thinks these properties make the new molecules ideal for concentrated laundry pods.

The new compounds clean soils as well as or even better than conventional surfactants in cold water in the formulations tested. Both are readily biodegradable. AP-3 shows lower toxicity to aquatic life and less eye irritation hazard compared to commonly used primary AEs. AP-10 carries no aquatic toxicity classification and is not an eye irritant.

The new molecules work well in model formulations in the lab, and they have been tested in commercial detergents. The actual performance may vary with detergent formulations and washing conditions. "The major disclaimer is that formulator and brand owner will have their own proprietary recipe," she says.

SPACE LAUNDRY

When trying to innovate a product that has been in the marketplace for over a century, considering how to clean in extreme environments can bring new perspectives. And you do not get more extreme than living extraterrestrially.

How do astronauts do laundry in space? The answer is that they do not do laundry at all, and that is a real quality-of-life problem for astronauts on long missions. "Astronauts actually have their clothes burned as waste, as no laundry is currently done on the International Space Station (ISS)," says Sivik. Crew members often wear their clothing for as long as two weeks or until they can no longer stand the smell, says William Shearouse, group scientist, who is also at P&G.

Not only is the smell and feel of dirty clothes unpleasant, but with long-term missions planned to the moon and Mars, NASA realized that it would not be cost-effective to periodically ship clean clothing to astronauts. Thus, the agency teamed up with P&G to develop a space-compatible laundry detergent.

To avoid interfering with air handling and water-recycling systems, the detergent could not include volatile organic compounds like fragrances and organic solvents. The final product, called Tide® Infinity, is concentrated in the sense that it is formulated to only contain ingredients that drive cleaning performance. The surfactants in the product were formulated to be stable using only water as a solvent due in part because water will be part of the mission's payload for washing clothing in a modified washing machine. As a result, compacting the detergent by removing the relatively small amount of water in the product that would be shipped to the ISS was not needed.

Tide Infinity detergent is formulated for use in space habitats and is seen here in the International Space Station for stability studies.
Source: NASA

"Instead of going super-compact, we thought about how to maximize the cleaning ingredients and the concentration," says Shearouse. Water was used as a solvent and they leveraged the stabilizing properties of polymers and AEs.

The team removed all unnecessary fillers and kept only ingredients required to perform well in zero or microgravity. This unique environment impacted the surfactant choice. Without gravity to hold down and manage suds, the researchers opted to use surfactants that would not foam as much as typical detergents, avoiding the use of silicone suds suppressants and additional water needed for rinsing. This finding is applicable to product development on Earth, too.

But the detergent also had to clean clothes, so it underwent several tests with cold water in the lab, both on Earth and on the ISS.

In addition to the detergent studies, the ISS crew investigated stain removal with a modified version of the detergent on fabrics with stains from foods and beverages. Curiously, astronauts routinely sport sriracha stains.

"In space, crew members go through a bit of sensory deprivation," says Shearouse. "Because of that, they use a lot of sriracha on their food and it is a common stain." Further crew member testing is now underway at NASA's Crew Health and Performance Exploration Analog in Houston, Texas which simulates long-duration missions.

LIKE A CRISP, CLEAN SHIRT, THE FUTURE IS BRIGHT

According to the experts, concentrated laundry detergents are already powerful and do more with less. But there is always room for improvement, and scientists are busy making detergents more concentrated while also satisfying eco-conscious consumers.

"I think the challenge is how do you keep the cleaning efficiency or effectiveness and incorporate these other targets like sustainability, energy-savings (cold cleaning) and safer materials," says Reyes.

"The opportunities continue to be vast," says Sivik. "There will always be a need to develop more efficient ingredients and deliver them in the most effective way possible in the most concentrated form." He says, just as people became accustomed to coffee pods that pack a lot of flavor into a small cup or pouch, they are growing used to laundry pods.

And Grady and Smith predict there will be even more single-dose products in our future. "I think we are moving toward a pod or sheet future," says Grady.

Reyes emphasizes that regardless of the form or formulation, companies need to remember the needs of the consumer and put those first. "Ultimately, this research is for them," she says.

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