with a grind size that is much too coarse will reach the desired pressure only if the pump is able to provide a sufficiently high flux of incoming water. Otherwise, the pump will simply reach its maximum flow rate and the pressure will rise only to an intermediate value determined by the flow rate and the puck resistance.

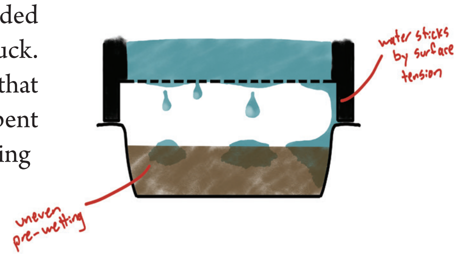
Shower Screens and Headspace

The design of a shower screen can have a significant influence on how evenly the water is allowed to flow through an espresso puck. Water usually comes out from an espresso machine's group head as a single stream, and the role of the shower screen is to disperse it across the entire surface of the espresso puck. This can pose significant challenges, especially in the early stages of espresso extraction when any headspace above the espresso puck is still filled with air.

The surface tension of water plays an important role in determining how it flows through the shower screen. Water tends to stick to the bottom of the shower screen and coalesce into localized streams, thus undoing the work of the shower screen in dispersing the water evenly across the surface of the espresso puck. This problem is often compounded by the fact that shower screens are usually significantly smaller in diameter than the top surface of the espresso puck.

Some shower screens use a superposition of a fine mesh with coarse, round openings to form droplets of water separated enough to avoid their coalescing, therefore achieving better surface coverage of the puck. This strategy is generally imperfect and does not prevent water from coalescing at slow fill rates below approximately 5 mL/s. The Freckles and Dimples shower screens recently developed by Decent Espresso Machines feature small spout shapes across the shower screen to achieve a more uniform spreading of water, especially at low flow rates. It is plausible that the spout shapes may sometimes be less convenient to clean and could be problematic in cases where, without a significant pressure drop, an espresso puck touches the shower screen as it initially swells during prewetting. This situation should be avoided because it can cause an uneven flow of water through the puck. The potential problem can be easily diagnosed by verifying that no imprint of the shower screen remains at the surface of a spent espresso puck. Although the final imprint likely appears during the last phase of the shot, when the pressure is dropped and the puck is allowed to expand, it indicates that the shower screen may also prevent a complete expansion of the puck during prewetting.

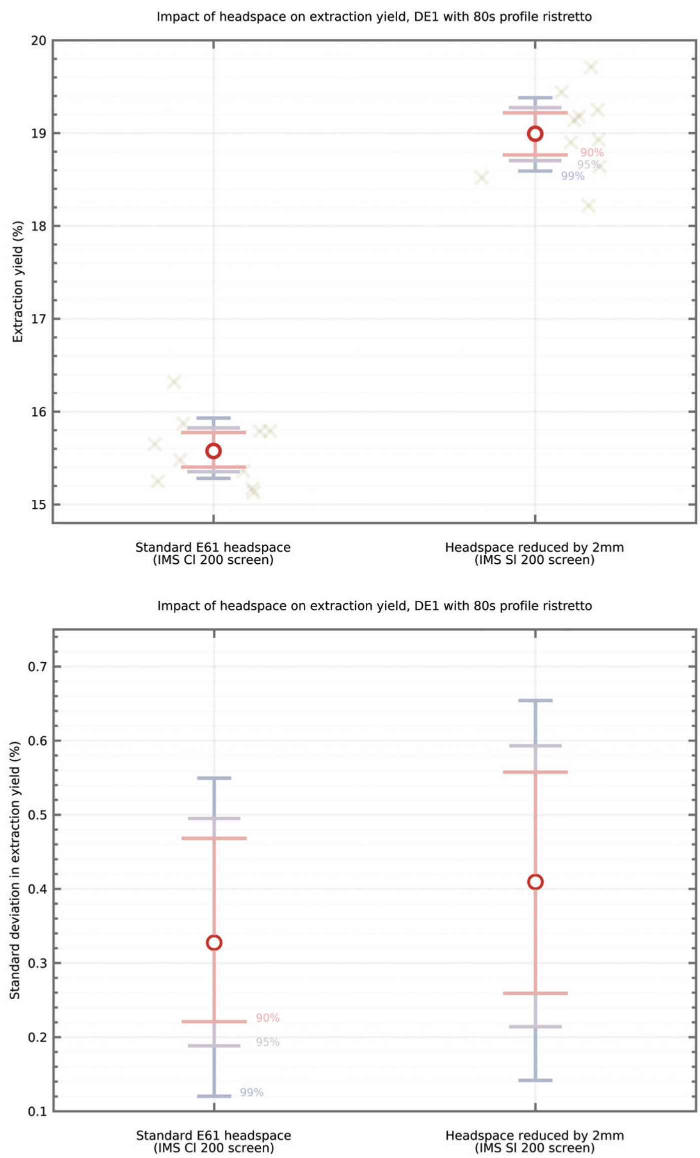
The main problem with the uneven dispersion of water on an espresso puck is that the uneven prewetting will push the air out of some regions of the puck preferentially as the water begins prop-



The surface tension of water can cause it to pool at the bottom surface of a dispersion screen. This can reduce the evenness of water dispersion and cause uneven prewetting of the coffee puck.

agating through the puck by capillary action. Once the headspace is filled with water and the system becomes pressurized, water begins flowing through the puck preferentially through these prewetted regions, causing an uneven flow and an uneven extraction that may continue for a significant fraction of the espresso shot.

This problem also illustrates why it is important for an espresso machine to be positioned on a level surface: a non-level machine may cause water to preferentially coalesce on one side of the shower screen, leading to a systematically uneven prewetting of the espresso puck. Once the headspace is pressurized, however, the impact of a machine's levelness is negligible because the pump



Reducing the headspace on a Decent DE1 espresso machine resulted in an average extraction yield over ten shots that was 3.4% higher (3.0–3.8%, 95% confidence interval) with a dark-roasted coffee prepared with a traditional 1:1 ratio ristretto (top). This is likely caused by an uneven prewetting caused by a long prewetting phase, paired with uneven water distribution. No statistically significant changes in the repeatability of the measured extraction yield were observed with a shallower headspace (bottom). ***Data from Buckman (2023)***

contributes significantly more pressure than the weight of the water itself. Similarly, the surface tension of water does not affect the evenness of water dispersion once the headspace is entirely filled with water. Any imprint of the previously uneven prewetting can, however, still remain during the main part of the espresso shot. Other obstacles to the flow of water, such as unevenly sized or unevenly distributed holes on the shower screen or the basket, will impact the evenness of flow during the entire espresso shot.

A faster flow rate of water through the shower screen can help reduce the coalescing of water into a small number of streams, but most importantly, it allows for faster filling of the headspace. This ensures that the water in the unevenly prewetted regions did not have as much time to propagate and reduce the puck resistance unevenly across the puck. Reducing the headspace is therefore an efficient strategy to improve the evenness of prewetting, especially with slow flow rates during the prewetting stage, unlevel machines, or shower screens that provide uneven dispersion of water.

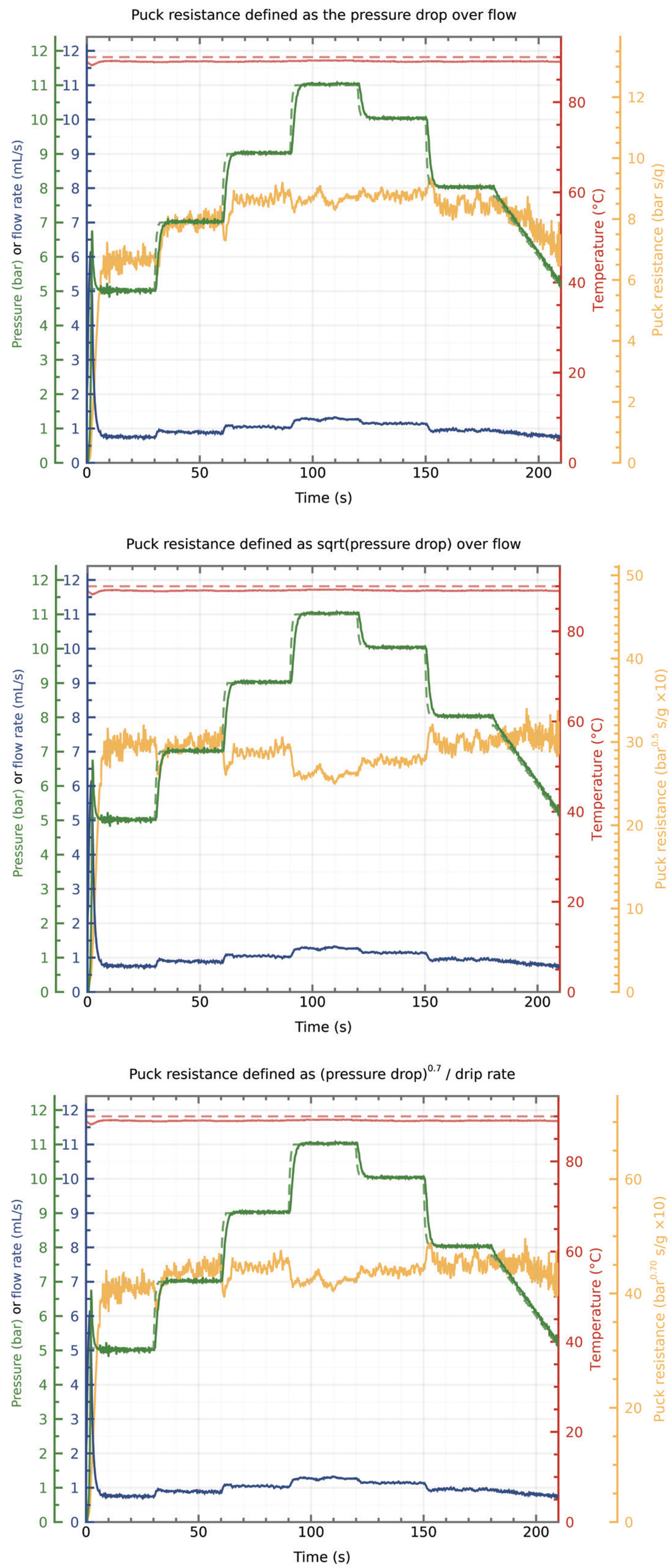
The amount of headspace left above an espresso puck can also affect the efficiency of workflow during the cleaning step. When an espresso shot ends, a pressure release valve is typically opened, causing the headspace to rapidly depressurize and any remaining water in the drip tray of the espresso machine to be sucked out. When the headspace is large enough, however, some water may remain in the basket, making it less convenient for the barista to knock out the puck and clean the basket.

Some espresso machines rely on the use of a gicleur, a small opening that limits the flow of water into the group head, to avoid a spike in pressure when the pump is initially turned on. A gicleur also reduces the maximum filling rate of the headspace, which makes it important to consider whether it might cause uneven prewetting of the espresso puck. In the range of typical espresso parameters, puck resistance is likely most affected by the pressure drop on account of turbulent flow[26] (Mo et al. 2023); consequently, puck resistance depends on the square root of the pressure drop, divided by the drip rate (Champion 2020). This is similar to the case of turbulent flow of water through a small opening such as a gicleur, where the added hydraulic resistance is also a factor of the pressure drop squared divided by the drip rate because of turbulent flow through the small opening. As a consequence of these two factors, the hydraulic resistance of the complete system composed of a gicleur and a typical espresso puck can be visualized as a quadrature sum[27] of the

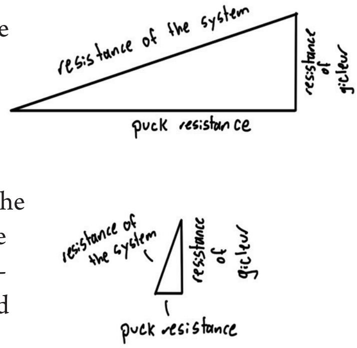
[26] The occurrence of puck compression may also contribute to this effect slightly.

[27] A quadrature sum is a specific operation where two numbers x and y are combined by taking the square root of x^2 plus y^2.

An illustration of three empirical definitions of puck resistance and their reliability at describing the stable, reversible puck resistance of a spent espresso puck. Because of the combination of either puck compression and/or turbulent flow at the microscopic scale, defining the puck resistance empirically as the square root of the pressure drop divided by the drip rate is a good rule of thumb. Using a more precise power of 0.65 applied to the pressure drop (instead of 0.50) results in an even more stable puck resistance across large changes in pressure drop, however. Defining the puck resistance in this manner makes it possible to predict shot dynamics across a wider range of pressures, using Darcy's law. *Data from Champion (2020)*



resistance of the gicleur with the resistance of the puck. Therefore, in a situation where the puck contributes little to the resistance, the system's resistance will tend toward that of the gicleur; in a situation where the puck contributes most, the system's resistance will tend toward that of the puck.



The contributions of the puck resistance and gicleur resistance add up approximately in quadrature to determine the total hydraulic resistance of the system. In a situation where the puck resistance dominates, it is the most important factor in determining the drip rate as a function of the pressure drop. Conversely, in a situation where the puck resistance is very small, the resistance of the gicleur dominates and determines the drip rate. This concept of a quadrature sum can be visualized with the drawing of a right triangle.

Flow Disruptors

The use of a paper filter or a thick, coarse metal mesh above the espresso puck was recently popularized in the context of home espresso preparation. While paper filters are mostly useful to reduce the need to frequently clean the shower screen, most paper filters do not contribute meaningfully to the overall resistance of the system to the flow of water, nor do they significantly affect the extraction yield of traditional espresso (Hedrick 2023f). This suggests that they play little role in redirecting the flow of water.

Coarse metal meshes, often called puck screens, contribute only slightly to the hydraulic resistance of the system, but they can play an important role in modifying the water distribution across the surface of the coffee puck because of their thickness and large pores. Even when combined with modern baskets that do not tend to underextract the edges of an espresso puck, puck screens have been found to increase the average extraction yield of traditional espresso shots by 0.4% (0.2–0.6%, 95% confidence interval; Hedrick 2023f), suggesting that they still enhance the evenness of flow.

This may be explained by the puck screen redirecting some uneven flow from the shower screen itself—because it forces the water through gaps, large enough to distribute the water evenly, between the fused metal spheres. This suggests that without a flow disruptor, any uneven flow from the shower screen will be preserved across the espresso puck when you use a fine grind size typical of traditional espresso. Ribes (2021) investigated the use of a puck screen paired with a traditional basket and found a much more significant increase in extraction yield of approximately 1.8% for a traditional 1:2 espresso shot.

This is likely a consequence of puck screens redirecting some of the water toward the edge of the basket. Otherwise, the equipment used would usually lead to underextracted edges (Ribes 2020), in part because little to no water is distributed near the edges with traditional shower screens but also because the hole patterns of traditional baskets do not reach the basket walls, preventing efficient flow near the edges.