

# Kitchen Flows 2024: New research directions and culinary applications

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## I. INTRODUCTION

The kitchen seems an unlikely environment for fluid dynamics research. Yet, it is a place where culinary experiments are carried out daily, repeatedly, and unavoidably. Flows involving food products and their preparation, though familiar, are scientifically rich and strikingly complex. They are governed by the fundamental equations of fluid dynamics but also involve multiphysics and multiscale processes that often lie at the intersection of physics, chemistry, and biology. They are concerned with soft materials, whose properties are tested across multiple dimensions: rheology and texture, stability and visual presentation, and composition and taste.<sup>1-3</sup>

The current Special Issue follows the success of its predecessor, published in 2022.<sup>4</sup> Since then, a broad range of new research directions and culinary applications has emerged, spanning experimental characterization and exploration of edible materials, numerical studies of complex problems involving gastrophysical flows, and new theoretical models inspired by kitchen phenomena. These

three approaches go hand in hand to shed new light on problems that are often familiar and perhaps intuitive but have not been quantified or understood in a sufficiently detailed way. In doing so, the papers within this issue not only uncover some secrets of kitchen fluids but also pose new paradigms in terms of how we think about cooking. By connecting the familiar with the breadth of scientific approaches, they become valuable tools for education and dissemination of scientific knowledge.

Many of the papers published in this Special Issue have received considerable media attention. For example, the paper by Bartolucci *et al.*<sup>5</sup> about “Phase behavior of Cacio e Pepe sauce” was awarded the 2025 Ig Nobel Physics Prize. The work of Baechle *et al.*<sup>6</sup> about “Foie gras pâté without force-feeding” was discussed in the *New York Times* and other major media outlets across the world. The study by Park *et al.*<sup>7</sup> about pour-over coffee also featured in the *New York Times*, the front page of *USA Today*, and multiple national TV stations. The question of the stability of beer foam, undoubtedly debated in pubs

and bars and analyzed in detail by Chatzigiannakis *et al.*,<sup>8</sup> was echoed by *The Guardian* and other newspapers across Europe.

In this editorial, we highlight the papers from the Special Issue by dividing them into categories that are unavoidably intertwined, just as a gourmet dish connects the ingredients, preparation, presentation, and the general ambiance into a single multifaceted experience.

## II. KITCHEN FLOWS

Flows in the kitchen often begin quietly, with motion so familiar that they are easy to overlook. Some of these flows often emerge in regimes where viscosity, gravity, and geometry compete in ways that are both visually striking and physically rich. A familiar example is the coiling of a viscous liquid such as honey or syrup as it is poured onto toast or a pancake. At typical kitchen viscosities and dispensing heights, slender liquid threads become unstable, buckling into regular coils or folds as they accumulate on a surface. Herczyński and Lisicki<sup>9</sup> synthesize these coiling phenomena into a unified framework, identifying distinct and well-known coiling regimes: viscous, gravitational, inertial–gravitational, and inertial. They consolidate the associated scaling laws for coiling frequency, radius, and kinetic energy. By showing how these regimes can be accessed using common culinary fluids and simple substrates, this study establishes viscous coiling as both a canonical instability and a natural entry point for fluid dynamics experimentation in the kitchen.

When cooking begins, the kitchen comes to life and the pace quickens, so control becomes a challenge. Pouring water into a pan without spilling is a deceptively delicate task, demanding a constant negotiation between inertia and restraint and governed by the coupled effects of gravity, viscosity, surface wettability, and confinement. Roy *et al.*<sup>10</sup> examine this problem, whether “To spill or not,” through the short-time dynamics of a momentarily toppled container, showing that spilling is not inevitable but instead organized into distinct regimes: “not-spilling, on the verge of spilling, and spontaneous spilling,” set by fluid rheology, surface properties, and container dimensions. For Newtonian liquids, the balance of viscous and gravitational forces with wettability produces non-intuitive effects, while non-Newtonian fluids introduce additional control through meniscus retraction and delayed detachment. By mapping when a container will or will not spill upon brief toppling, this study sheds light on the captivating physics of fluid pouring that we experience every day.

Heating the pan introduces a different class of kitchen flows, in which phase change and particulate motion interact on short time-scales. A familiar example is the spluttering of mustard seeds in hot oil, a common cooking practice that produces rapid droplet ejection and poses practical safety concerns. Kumar *et al.*<sup>11</sup> carry out experimental studies to resolve this mustard seed spluttering process as a multiphase, highly unsteady, staged flow driven primarily by the moisture content of the seed. High-speed imaging reveals sequential regimes of microbubble generation, internal oscillatory flows, interface deformation, and, in some cases, seed ejection, with bubble growth beneath the seed playing a central role in pressure buildup and liquid breakup. Variations in oil temperature and depth modulate the extent of ligament formation and droplet size, while a force-balance model captures the onset of seed lift-off. By decomposing spluttering into reproducible dynamical stages, this work demonstrates how localized heating and phase change reorganize fluid motion and produce complex dynamics found in everyday cooking.

It is now time to prepare coffee, one of the most consumed beverages in the world. Pour-over coffee is a commonly used preparation method, in which a water jet impinges on a water layer above a porous granular bed. Park *et al.*<sup>7</sup> performed experiments combining optical access with model granular media, revealing that mixing is governed not simply by turbulence but by jet-induced erosion and gravity-driven avalanches within the bed. As the jet excavates material at the base of the cone, suspended grains destabilize the surrounding bed, triggering intermittent collapse and recirculation that markedly enhance mixing, even for gentle, laminar pours. The extent of this avalanche-mediated mixing increases with pour height and persists in the presence of floating grains, while slower pours prolong the active mixing phase. Measurements with real coffee grounds show that these dynamics translate directly into increased extraction efficiency, demonstrating how controlled jet forcing can tune transport in granular–fluid systems. This work demonstrates a potential method to decrease the quantity of coffee beans required to brew a pour-over coffee, simply by changing the way in which one pours the liquid jet. Beyond brewing, the identified mechanisms connect kitchen-scale coffee preparation to broader problems of jet-driven erosion and resuspension in environmental flows.

Another popular coffee preparation method is espresso brewing, which is an example of pressured flow through a confined granular medium whose properties evolve during extraction. At early times, hot water is forced into an initially dry coffee bed, producing an unsaturated infiltration front that governs how fluid access is established before steady flow begins. Time-resolved x-ray tomography studies by Foster *et al.*<sup>12</sup> directly track this advancing wetting front and show that its dynamics are well described by a reduced porous-media model that couples unsaturated flow within the bed to pump and headspace dynamics. At longer times, however, Waszkiewicz *et al.*<sup>13</sup> show that the extraction process departs from the classical Darcy behavior: systematic measurements reveal a nonlinear pressure–flow relationship in which the steady flow rate saturates at high pressures. A minimal poroelastic model captures this behavior by accounting for the coupled evolution of bed elasticity, porosity, and solute dissolution, identifying that dissolution dynamics is the dominant regulator of flow rate evolution. Together, these studies show that espresso extraction is governed by distinct but connected regimes, in which early-time infiltration and long-time self-regulation jointly shape transport through a dissolving, deformable porous medium.

Souzy *et al.*<sup>14</sup> discuss the formation of particle-cloud deposits, such as salt rings in a pasta pan. These deposits can produce very beautiful and complex patterns, driven by sedimentation and particle–particle interactions. The authors investigate this experimentally, using a viscous fluid at intermediate Reynolds numbers. They find how the patterns are affected by the particle diameter, the settling height, the injection volume, and the method of injection. The authors propose that this intricate sedimentation process can be used as an alternative technique for particle sorting.

Cooking can produce a lot of fumes, smoke, and potentially toxic gases. Liu *et al.*<sup>15</sup> study indoor air quality in confined spaces, especially kitchens. To achieve this, they present a new modeling framework called ChemFlow 3D, which combines computational fluid dynamics of air flow with a chemical reaction module to analyze the dispersion of airborne pollutants. Specifically, they look at

microparticulates, nitrogen oxides, volatile organic compounds, and carbon monoxide under different airflow conditions. This paper could help the design of ventilation systems and improve kitchen health.

Taken together, these studies show that the kitchen is not merely a place where fluids are handled but one where flows are shaped, tested, and felt. From slow viscous folding to violent thermal agitation and pressured infiltration, kitchen flows distill complex fluid mechanics into everyday experiences that are at the same time both ordinary and profound.

### III. INTERFACIAL KITCHEN PHENOMENA

Everyday fluids—from barista milk and beer to ouzo—offer a rich playground for exploring fundamental physics, bridging theory and experiment. These systems reveal intricate interfacial phenomena, phase behavior, and foam dynamics. Five papers<sup>5,8,16–18</sup> in this Special Issue connect microscopic interactions to macroscopic properties, such as surface tension, Marangoni effects, and adsorption dynamics. By combining experiments with theoretical models, they advance understanding of interfacial stresses, phase transitions, and foam stability.

Ouzo's spontaneous emulsification, where clear liquids turn milky upon mixing, is explored using lattice DFT. The study of Sibley *et al.*<sup>17</sup> models the ternary system (ethanol, trans-anethole, and water) along its triple-point line, revealing complex phase behavior and interfacial tensions. Calculations of Neumann angles and droplet shapes bridge microscopic interactions to macroscopic observations, demonstrating how simple models capture the physics of everyday phenomena like the “ouzo effect.”

Another theoretical work by Tran *et al.*<sup>16</sup> focuses on milk foam stability, particularly in cappuccinos, where proteins (caseins) and free fatty acids compete for adsorption at air–water interfaces. Using a statistical mechanical model and Monte Carlo simulations, the authors show how fatty acids inhibit casein adsorption, destabilizing foams. A novel “kinetic degeneracy” concept, with simultaneous positive and negative cooperativity, explains the variability in foamability observed in barista milk. The study highlights the critical role of the fatty acid-to-protein ratio, offering guidelines for optimizing foam stability in food and industrial systems.

Next, thorough experimental work on beers reveals that beer foam stability depends on the beer type: lager foams rely on surface viscosity, while Belgian ales (e.g., tripels) exploit Marangoni stresses, driven by lipid transfer protein 1 (LTP1) and fermentation duration. Using surface rheometry, tensiometry, and thin-film dynamics, Chatzigiannakis *et al.*<sup>8</sup> map stabilization mechanisms to interfacial stresses, visualized in a “stress map.” This framework not only clarifies beer foam physics but also provides a template for engineering multi-component foams, emphasizing the interplay between surface viscosity and Marangoni flows.

Bartolucci *et al.*<sup>5</sup> investigate the phase behavior of *cacio e pepe*, a popular pasta dish with a sauce that uses pecorino cheese and pepper. This might sound simple, but it is challenging to create the perfect, creamy consistency. Moreover, the emulsion sauce can split when it becomes unstable. Here, the authors identify the starch concentration as a key parameter that determines the emulsion stability. After a systematic exploration, the authors present a recipe that will enable chefs and home cooks to reproduce the dish with consistent results.

Finally, Dutta and Tang<sup>18</sup> develop a theoretical framework based on the thin-film equation and use it to predict the drainage of common kitchen fluids such as water, milk, and olive oil. Specifically, they discuss the hydrodynamics of decanting residual fluids from a container, and they study the drainage of leftover water from a cooking pot after washing. In the first example, they explain why the timescale of decantation scales linearly with viscosity, and in the second example, they explain why a two-dump method minimizes rusting. To validate their theoretical model, they conduct simple yet accurate experiments using an old iron wok, a cell phone camera, and a kitchen scale. Such kitchen experiments are readily available, require no formal training, and are ideal for developing intuition about fluid mechanics; as such, they are well suited for hands-on learning and outreach activities.

### IV. KITCHEN RHEOLOGY

This collection of papers also offers a rich and multifaceted view on contemporary food rheology, highlighting how diverse ingredients, processing methods, and biological systems can be understood and optimized through careful physical characterization.

The issue opens with the work of Akbin *et al.*,<sup>19</sup> who examine the replacement of egg whites with legume-based aquafaba in microwave–infrared baked cakes. Their study underscores the growing interest in plant-based alternatives and focuses on the emulsion and foam-stabilizing capabilities of aquafaba—critical attributes for baked product quality. The authors also report that the batter's rheological behavior follows the Herschel–Bulkley model, revealing the presence of yield stress and offering valuable insight into structure formation during baking.

A complementary perspective on plant- vs animal-based systems is provided by Hassan *et al.*,<sup>20</sup> who apply the dripping-onto-substrate (DOS) protocol to compare the extensional flow behavior of animal and plant milks. While shear rheometry confirms that dairy milks behave as Newtonian fluids and plant milks as shear-thinning, DOS measurements reveal even more distinct differences: animal milks exhibit viscocapillary behavior, whereas plant milks show inertio-capillary, power-law, or elastocapillary responses. The authors connect these macroscopic behaviors to underlying microstructural features, offering a deeper understanding of milk analogs.

The structural evolution of starch systems is explored by Liao *et al.*,<sup>21</sup> who focus on gelatinization and retrogradation—two processes that strongly influence the rheology of starch hydrogels yet remain insufficiently studied. Using optical microscopy, cryo-scanning electron microscopy, differential scanning calorimetry, and uniaxial compression, the authors provide a comprehensive picture of how thermal history shapes microstructure and mechanical properties. Their work highlights the pseudoelastic–viscoelastic nature of starch gels and the importance of processing conditions in food and pharmaceutical applications.

Hydrocolloid behavior is further examined by López-Santiago and Castillo,<sup>22</sup> who investigate alginate/Ca<sup>2+</sup> gels using linear and nonlinear rheology alongside particle-tracking microrheology. Their systematic approach captures the transition from sol to gel and clarifies how network formation governs viscoelasticity across multiple deformation regimes. The study reinforces the central role of alginate gels as thickeners, stabilizers, and gelling agents in food systems.

Egg-based systems receive special attention in two contributions. Di Lorenzo *et al.*<sup>23</sup> analyze how different cooking protocols—hard-boiling, sous-vide, and a novel periodic heating method—affect the

rheological properties of eggs. By monitoring the evolution of complex moduli and coupling experiments with mathematical modeling, the authors show how temperature histories can be tuned to optimize yolk and white properties. Notably, they demonstrate that the rheometer itself can serve as a controlled cooking platform.

Marsh *et al.*<sup>24</sup> then use egg yolk as an accessible model for studying sol–gel transitions. By integrating protorheology with linear and nonlinear rheometry, they identify critical gelation temperatures and characteristic signatures such as power-law viscoelasticity, diverging zero-shear viscosity, and the emergence of an equilibrium elastic modulus. Their work illustrates how simple kitchen materials can illuminate fundamental gelation physics.

Biological complexity is addressed in the study by Mishra *et al.*,<sup>25</sup> who investigate the shear- and time-dependent rheology of saliva from healthy individuals. They show that saliva is a viscoelastic, shear-thinning, and thixotropic material whose properties depend strongly on biochemical composition. Elevated mucin levels, as well as calcium and glycoprotein concentrations, correlate with increased viscosity and enhanced viscoelastic moduli. The study clarifies how specific molecular constituents govern the rheological response of this biologically essential fluid.

The theme of plant-based reformulation returns in the work of Mohamed *et al.*,<sup>26</sup> who evaluate the suitability of commercial vegan butter alternatives in traditional Scottish shortbread. By examining fat composition, rheological behavior, baking performance, and sensory attributes, the authors show that plant-based fats with comparable total fat content can successfully replace dairy butter without compromising product quality. Their findings support the development of high-quality vegan baked goods and contribute to reducing the environmental impact of food production.

A process-focused perspective is offered by Purcell *et al.*,<sup>27</sup> who develop a general viscosity model for high-moisture extrudates composed of pea protein isolate and gluten. Using a capillary rheometer with controlled pre-shearing, they show that all samples exhibit power-law shear-thinning behavior without wall slip. They identify an inverse correlation between consistency and flow indices and extend time–temperature superposition by incorporating water content through the mixture’s glass transition temperature. Apparent extensional viscosities yield Trouton numbers around 100, and the resulting model enables reliable computational simulations of die flow, supporting the design of structured plant-based foods.

Finally, Winters and Ianniello<sup>28</sup> present an inventive approach to improving the mechanical properties of vegan gummy candies. By immersing pectin-based gummies in a calcium bath, they induce ion diffusion and cross-linking that form a thin protective crust—an adaptation of classic spherification concepts. This crust enhances mechanical robustness and reduces stickiness, eliminating the need for sugar coatings. Through linear viscoelastic measurements, *in situ* shear tests, and a two-bite texture profile analysis, the authors establish a diffusion-time superposition principle linking ion concentration to mechanical response. Their work provides practical insights for confectionery design and for understanding diffusion-driven cross-linking in polysaccharide systems.

Together, these contributions showcase the breadth and vitality of modern food rheology. They demonstrate how microstructure, composition, and processing conditions converge to shape material

behavior and how rheological tools can guide the development of innovative, sustainable, and high-quality food products.

## V. SUSTAINABLE FOOD

Food production accounts for 26% of global greenhouse emissions<sup>29</sup> (2018 data), of which about 57% comes from animal-based food, while plant-based food accounts for only 29%.<sup>30</sup> Therefore, to combat climate change, it is crucial that we use less energy and transition to a more plant-based diet. However, this green transition turns out to be bumpier than expected, as we are stuck in old cooking and eating habits.

Vilgis and Toulchinski<sup>31</sup> examine how energy can be saved when cooking pasta. Specifically, they test the “hofflon” method proposed by Giorgio Parisi, which involves boiling the water first, adding pasta, putting on the lid, and then turning the heat off. Interestingly, they find that this preparation method affects the interactions between the protein and starch molecules, including the formation of cross-links and gelatinization, which in turn drives variations in mechanical properties, adhesiveness, and cohesion. They find that hofflon pasta exhibits increased softness and reduced cohesion compared to traditionally cooked *al dente* pasta, and presoaked pasta is more sticky and has a mushy texture. The authors write that the hofflon method can save about 60% of energy, but with considerable losses in texture, flavor, and mouthfeel. Therefore, they propose another method: Energy can be saved by reducing the amount of boiling water up to 90%, as long as the pasta is stirred continuously. The benefits of this extra work include a creamy texture because of a higher leached starch concentration, increased taste, and good sauce adhesion.

Meat analogs are meat replacements made from plant sources. They represent a promising alternative to traditional vegan cuisine, as they are meant to mimic the taste, smell, and mouthfeel of real meat. However, while ground meat analogs such as “Impossible Burger” or the “Beyond Burger” come quite close to the original, replicating the texture of tenderloins, briskets, and other steak cuts remains difficult. The papers by Wilhelm *et al.*<sup>32</sup> and by Zhang and Zhu<sup>33</sup> address this important challenge.

As pointed out by Wilhelm *et al.*,<sup>32</sup> a reason for the texture difference between animal meat and meat analogs is that the latter, while having a fibrous structure similar to real meat at the (observable) millimeter scale, often lack this structure at the micrometer scale. Instead of a fibrous structure characteristic of real meat, meat analogs sometimes display a porous structure without a clear fiber direction, as revealed by scanning electron microscopy (SEM) images. To investigate the texture properties, especially the bite resistance and tenderness, the authors used a Warner–Bratzler shear force apparatus, which utilizes a sharp knife to cut through meat in different directions while measuring the force. Based on their structure and texture measurements, the authors develop a mechanistic model to explain why meat analogs respond differently to mechanical stress as compared to the animal meat cuts considered in their study.

The production of fibrous structures in meat analogs depends on a wide range of operating conditions, such as extrusion rates and geometry, as well as harvesting season and plant protein source. This complexity poses an experimental challenge since changing one parameter might change another, which makes it fundamentally difficult to decouple them. In addition, isolating the effect of each parameter requires a huge set of experiments, meaning that experimental characterization easily becomes both labor-intensive and costly. To

address these challenges, researchers are turning to numerical simulations. The review by Zhang and Zhu<sup>33</sup> explores how finite element methods can be used to understand and optimize meat analog production toward the goal of creating the hierarchical fibrous structures found in animal meat.

While a perfectly grilled steak is a favorite among meat lovers, another hit is foie gras pâté, known for its smooth texture as it “melts” in the mouth. However unfortunately, the production of foie gras is highly unethical, as it involves force-feeding geese or ducks to make their livers fatty. To ensure animal welfare, it is therefore imperative to develop foie gras production lines that do not involve force feeding. Baechle *et al.*<sup>6</sup> rise to this challenge and demonstrate how enzymatic fat can be used to enhance the texture in pâtés derived from non-force-fed geese livers, thereby removing the necessity of force feeding.

Cheese is another animal-derived product associated with environmental problems. Plant-based cheese is a sustainable alternative, but its texture is often far from the original. To mimic the texture of animal fat, incorporating coconut oil can be effective, but since such saturated fats are unhealthy, their use should be minimized. To improve the texture of plant-based cheeses, Sanders *et al.*<sup>34</sup> instead investigate the effect of utilizing different protein isolates coming from peas, faba, and lentils on the physical characteristics. They find that the amount of coconut oil can be reduced by 75% without compromising hardness in cheeses based on pea protein.

Another paper from the same group<sup>35</sup> reviews the history, quality characteristics, and uses of plant-based margarine, often known as the “poor man’s butter.” Curiously, margarine was originally made from beef tallow and not from plants and was developed for Napoleon III (Napoleon Bonaparte’s nephew) as a butter substitute to feed his forces during current food shortages. Margarine was formerly known as “oleomargarine” because of its oily appearance, and, as pointed out by Marangoni,<sup>35</sup> it can be considered an emulsion-filled colloidal hydrogel comprised of water droplets connected by fat crystals in a continuous oil phase. In addition to explaining the physics and chemistry underpinning margarine production, the review also explores different ways to modify the microstructure in order to control the final product.

Food is seldom eaten in the same place where it is produced, which means it must be packaged in safe containers to prevent bacterial contamination and to maintain the nutritional value during transport and storage. An excellent material for this purpose is plastics, but since it represents a huge waste problem, food scientists are looking for more sustainable, biodegradable alternatives. One such alternative is to use water-soluble protein gelatin (a key ingredient in jello) to create edible films, but since gelatin is derived from animals, it cannot be consumed by vegetarians. Luckily, polysaccharides can replace animal-derived proteins in the production of edible films and represent a healthier, more environmentally friendly alternative. Through detailed swelling experiments and scanning electron microscopy imaging, Pulatsu *et al.*<sup>36</sup> explore this exciting opportunity and show that gum tragacanth can be a viable alternative to gelatin. A second paper by the same group<sup>37</sup> investigates the swelling properties of edible films made from gelatin as well as gelatin–gum tragacanth mixtures in more detail. They find that the swelling rate of the films is significantly higher in DI water than in salt solution due to favorable osmotic pressure differences and that the compatibility of the polymers used to create the films controls the swelling capacity.

In summary, these contributions show how the wide set of tools used by food scientists is key to producing safe and nutritious foods while at the same time improving animal welfare and reducing greenhouse gas emissions.

## VI. FROM MULTIDISCIPLINARY RESEARCH TO PRACTICAL ADVICE

Food science naturally connects the fields of physics, biology, and chemistry. The following papers are good examples of this interdisciplinary research and provide direct practical suggestions for cooking at home.

Koch *et al.*<sup>38</sup> investigate what happens when you open a pressurized beer bottle: The characteristic popping sound is studied experimentally using a high-speed camera and a microphone and with simulations that combine computational fluid dynamics with acoustics and thermodynamics. The results uncover the rapid dynamics of the gas exhaust in the bottleneck, revealing that the sound is actually tonal rather than shock-like. The authors also investigate bubble nucleation and liquid sloshing in the bottle, predicting when you may have to drink faster than you wish.

Speaking of alcoholic beverages, Behera *et al.*<sup>39</sup> develop a paper-based lateral flow assay to detect methanol, a dangerous by-product of brewing gone wrong. Even with small sample volumes around 50  $\mu\text{l}$ , methanol concentrations from 5% to 30% (v/v) can be detected using a reagent that produces a distinct purple color. From a fluid mechanics point of view, the methanol concentration changes the viscosity of the fluid, which impacts the wicking dynamics of the liquid in the paper in the microfluidic assay. While the method is not extremely sensitive, it still offers a rapid and cost-effective method, with the potential of saving lives.

Shifting from beer and wine to cheese and yogurts, the paper by Gholamipour-Shirazi and Mossige<sup>40</sup> describes how mixing dynamics can be used to control the flavor and aroma of fermented foods. As such, they connect kitchen flows and food science, which are brought together by rheology and soft matter. They highlight a simple scaling argument to explain why foods with a high viscosity are perceived as having less taste, an investigation of how viscosity depends on temperature and solute concentration, and an overview of different mixing regimes in bioreactors and how to assess their efficiency. They suggest future studies to try to unravel the intricate relationship between rheological properties and aroma release and how different mixing regimes may affect microbiological activity.

Ghaffari *et al.*<sup>41</sup> provide practical advice on how to prepare mayonnaise, a complex emulsion of water and oil stabilized by egg protein and other molecules. If prepared in the wrong way, this emulsion can become “broken,” leading to a horrible product. To prevent this, the authors offer some easy methods that can be used at home. Moreover, they demonstrate that near-infrared hyperspectral imaging (HSI) spectroscopy can be used together with the Kullback–Leibler divergence metric to quantify emulsion homogeneity and identify phase inversion. This method allows for real-time monitoring of emulsion quality in industrial settings, ensuring that your mayonnaise is smooth every time.

Beverages including boba tea often contain small soft balls, or “pearls” that add texture and additional flavors. Tireki<sup>42</sup> investigates the production of these beverage pearls using “spherification,” a molecular gastronomy method used to make edible spheres that mimic caviar. This works by adding sodium alginate and tri-sodium

citrate to edible liquid droplets, which then undergo gelation in a calcium chloride bath. The pearl formation is controlled by the diffusion of calcium into the droplets, driving cross-linking and gelation. The authors perform a detailed analysis of this process and determine how to optimize the pearl quality and visual appearance by adjusting the spherification time.

Cao *et al.*<sup>43</sup> investigate the oxidation of sulfhydryl groups, consisting of a sulfur atom bonded to a hydrogen atom, which are found in many food products, including fruits and vegetables. Specifically, they use Ellman's procedure to determine the oxidation rates of cysteine and glutathione. The authors also combine their experiments with modeling, which involves using the Smoluchowski equation to model the process of disulfide bond formation. They discuss that aggregate formation should be prevented to ensure correct readouts.

The educational paper entitled "Science of a coffee cup: A physicist walks into a bar..." by Bossart *et al.*<sup>44</sup> uncovers the rich physics embedded in everyday coffee cup phenomena, from optical caustics and acoustic mode degeneracy to the hot chocolate effect. The authors transform the coffee cup into a versatile teaching tool, linking accessible experiments to minimal theoretical models. The paper illuminates complex concepts—such as double-diffusive convection and coffee ring formation—while offering simple, reproducible classroom protocols. It advocates hands-on learning and promotes interdisciplinary connections and curiosity, with applications ranging from geophysics to microfluidics. Celebrating science in everyday life, this article invites teachers and students to explore discovery through everyday objects.

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## AUTHOR DECLARATIONS

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All authors contributed equally to this paper.

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