On the Optimal Immersion Time of a Biscuit in Hot Tea

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Annotations

This is a *fictional* manuscript in revision before submission: every coloured mark is a live annotation produced by the **Quarto Proofread Comments** extension. Render it to HTML and PDF to see margin callouts, flowing highlights, and inline badges in context. For a feature-by-feature reference, see `docs.qmd`.

Abstract

We investigate the structural failure of a biscuit[1] subjected to prolonged immersion in hot tea, and derive a closed-form estimate of the *critical dunk time* beyond which catastrophic structural collapse becomes all but certain. Our model rests on capillary uptake and predicts an optimum that matches informal observation . The result is a single dimensionless group that collapses measurements taken across biscuit thicknesses, tea temperatures, and pore geometries onto one master curve. We further argue that the longstanding folk wisdom — that a biscuit should be withdrawn just before it *feels* too soft — is, to first order, quantitatively correct, and that the margin for error is far smaller than most tea-drinkers suppose.

John Chief: "Catastrophic" is doing a lot of work here. Define the failure criterion operationally.

Copy-editor: Hedge or quantify — "all but certain" is not a probability.

Prof. Halvorsen: Nice hook. Could you foreground the broader impact — why dunking matters — one sentence earlier?

Introduction

The dunking of a biscuit is among the most widely performed yet least formally studied operations in applied gastrophysics. Estimates place the number of dunks performed worldwide each morning in the billions, yet the operation is governed almost entirely by intuition and inherited habit. A misjudged dunk has only two

[1] This manuscript is fictional — its narrative, data, authors and reviewer annotations are invented purely to demonstrate the extension. Several physical details (the Washburn model, the pore-radius ordering of Rich Tea, Hobnob and Digestive, the capillary uptake rates, and the dunking angle) and the references above are adapted from K. Nomerotski, *Biscuit Dunking Analysis* (2024), and the works it cites.

outcomes, both painfully familiar: a biscuit withdrawn too dry to yield any comfort, or one fragment lost irretrievably to the silt at the bottom of the cup.

Prior work has treated the biscuit as a rigid body, an assumption we relax below. Our contribution is threefold: we formalise the failure criterion in mechanical terms, we derive the critical immersion time in closed form, and we test the prediction against a controlled three-point bending experiment. Throughout, we treat the biscuit not as a monolith but as a saturable porous solid whose stiffness degrades continuously as tea advances through it.

Dr. Marchetti: Should we cite Fisher (1999) here, or is that section mine to expand?

The central trade-off is intuitive: dunk too briefly and the biscuit stays dry and brittle; dunk too long **John Chief:** An inline aside: the failure mode here is governed by the saturation fraction $\phi = V_{\text{tea}}/V_{\text{pore}}$, which the authors never define. and it disintegrates into the cup. Between these regimes lies a narrow window of *optimal compliance*. It is the width of that window — not merely its location in time — that decides whether a given biscuit is forgiving or treacherous to dunk, and it is precisely this width that the existing folklore leaves unquantified.

Theory

We model the biscuit as a porous medium of mean pore diameter D. Capillary uptake follows the Washburn relation $L(t) = \sqrt{\frac{\gamma D t}{4\eta}}$, linking the wetted depth L to immersion time t, surface tension γ, and viscosity η, from which the wetted depth grows as the square root of time. Two features of this relation deserve emphasis. First, uptake is rapid at the outset and decelerates thereafter, so the biscuit spends most of any realistic dunk close to saturation rather than far from it. Second, because L depends on the square root of time, halving the immersion does far less than halve the wetted depth — a property that makes precise timing simultaneously important and unforgiving.

Dr. Marchetti: This is my derivation — please don't retune the constants without asking. The 1/4 factor assumes a cylindrical pore.

A subtlety we at first neglected is the *angle* at which the biscuit meets the liquid surface. A biscuit held obliquely presents its pores at an angle φ to the rising column, so the uptake law strictly carries a factor of $\cos\varphi$ and the governing grouping is really $L^2/\cos\varphi$. We initially set $\varphi \approx 0$, but this seemingly cosmetic term proves to carry more weight than its appearance suggests, and we return to it below.

The biscuit fails when the wetted depth reaches the neutral axis, giving the boundary conditions $\begin{cases} L(t^*) = h/2 \\ \sigma(t^*) = \sigma_c \end{cases}$ where h is the biscuit thickness and σ_c the critical stress. Solving for the critical dunk time yields a standalone result worth stating on its

Prof. Halvorsen: Does this system need an existence-and-uniqueness note, or is the monotonicity of L enough to make t^* well defined?

Prof. Halvorsen: Lovely — this closed form is the paper's headline. Consider boxing it in the final layout.

own: $t^* = \frac{\eta h^2}{\gamma E}$. The scaling $t^* \propto h^2$ is the practical heart of the result: a biscuit twice as thick tolerates roughly four times the immersion before it yields. Thickness, not surface area, is the lever the dunker actually controls, and it is the variable a thoughtful biscuit-maker might wish to specify on the packet.

Method

Three commercial varieties spanning the porosity range were studied — Rich Tea, Hobnob, and Digestive — each sourced from a single batch to control for within-type variation and stored in a sealed container at constant humidity so that their dry stiffness did not drift between trials. Each specimen was immersed for a fixed interval and then subjected to a three-point bending test . The interval was varied in fine increments around the predicted optimum, with several specimens tested at each setting to average over the small differences that survive even a carefully selected batch.

Copy-editor: "A fixed interval" needs a number and a unit — state it in seconds, and mind the non-breaking space when you do (write "7 s", not "7s").

Dr. Marchetti: The full apparatus schematic lives in my supplementary file — link it here before submission.

Temperature was held at 85 °C throughout, since viscosity — and hence the uptake rate — varies sharply with it; between trials the cup was refreshed to prevent dissolved solids from accumulating and quietly altering the surface tension over the course of a session. We repeated each measurement, though the sample size was modest, and we report the mean response together with its standard error.

John Chief: "Modest" is an understatement. n must be reported, and frankly the authors should replicate across at least three biscuit varieties before I can recommend acceptance for submission.

Results

The measured critical times cluster tightly around the predicted optimum. The agreement is striking , and the residuals show no systematic trend with thickness, temperature, or batch. Across the central range of thicknesses the predicted and observed critical times agree to within experimental error, and the dimensionless collapse holds remarkably well: rescaling each specimen's response by its own t^* brings the whole dataset onto a single trajectory, just as the theory anticipates.

Janet: Janet is not declared in the reviewers map, so a colour is auto-assigned from the palette — no crash, no fallback to grey.

Pore radius proved the sharpest discriminator between varieties. Microscopy placed the coarse-pored Digestive at one extreme and the fine-pored Rich Tea at the other, with the Hobnob between them, and a single-parameter Washburn fit reproduced the measured radii with a coefficient of determination of $R^2 = 0.99738$ — close enough that, for routine work, the model can stand in for the microscope. The fitted radii order the capillary uptake rates exactly as the theory demands (Table 1).

Table 1: Fitted pore radius and capillary uptake rate for the three varieties. Values adapted from Nomerotski (2024).

Variety	Mean pore radius (µm)	Capillary uptake rate ($\times 10$ m^2 s^{1})
Rich Tea	0.30	1.1
Hobnob	0.52	2.1
Digestive	0.80	4.2

A deviation appears only for the thickest specimens, where the rigid-body assumption breaks down and the biscuit begins to sag under its own absorbed mass before the bending test can be applied. In that regime the failure is no longer a clean fracture but a slow droop, and the bending test — which presumes a beam stiff enough to span its supports — ceases to measure what we intend; we therefore exclude the three thickest specimens from the fit and flag them for separate treatment.

John Chief: This is exactly the regime I worried about. Add a figure, or this claim is unsupported.

No author given: the label is suppressed and the mark is rendered in neutral grey, whatever its type. Useful for anonymous shared drafts.

Conclusion

A biscuit has an optimal dunk time, it is short, and it scales with the square of its thickness. The window of safety around that optimum is narrow, which explains both the universality of the dunking mishap and the quiet expertise of those who never seem to suffer one. We commend moderation in all dunking. More constructively, the square-thickness law suggests a simple operational rule: when in doubt, prefer a thicker biscuit dunked briefly to a thin one dunked in hope. Future work should extend the model to non-cylindrical pore networks, to the softening of the matrix as it warms, and to the richer problem of a biscuit dunked, withdrawn to drain, and then dunked once more. Two empirical loose ends deserve particular attention. The first is the dunking angle φ: our data suggest that the wetted depth falls as φ grows, so a biscuit dunked beyond the conventional 1.1 rad may buy the drinker a little extra time — a prediction worth testing directly. The second is the moment of failure itself: where the present optimum is *inferred* from a loss of stiffness, the biscuit is in practice observed to crumble in under a minute, and folding that measured time-to-collapse into the model would close the gap between theory and the breakfast table.

Prof. Halvorsen: End on the broader point — link back to the abstract's "why it matters".

Beyond the teacup, the same square-root kinetics govern any thin porous solid brought into contact with a wetting fluid — blotting paper, a sugar cube, the wick of an oil lamp — so the biscuit is less a curiosity than a convenient model system for a broad class of everyday capillary failures. That a problem so humble should yield so clean a law is, we think, reason enough to take it seriously. We therefore leave the reader with a single practical injunction, supported by our data at the 95% level: dunk with conviction, but dunk briefly.

Copy-editor: Cross-check every reference and unit before the final pass.

References

1. E. W. Washburn. *The dynamics of capillary flow.* **Physical Review** 17 (3): 273–283 (1921).
2. L. Fisher. *Physics takes the biscuit.* **Nature** 397: 469 (1999).
3. L. Fisher. *How to Dunk a Doughnut: The Science of Everyday Life.* Penguin (2004).
4. K. Nomerotski. *Biscuit Dunking Analysis.* (2024). Available at k-nom.com/assets/biscuit_report.pdf.