What Sets Cooking Time Is Not Heat but Water, and the Ratio of the Two Clocks Does Not Depend on Thickness

— The dimensionless time for **90** % to reach the centre of a cylinder is **0.479635** by Bessel series and **0.479611** by finite differences — the separator is whether what one waits for to reach the inside is thermal diffusivity or water diffusivity — [Paper 776]

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— From thinking to syncing. —

Abstract

The time to boil pasta is readily taken as the time for heat to get inside. But heat is not the only thing entering the pasta; water does too.The times for heat and for water to reach the centre, and their ratio, are counted.No new theorem or law is claimed. First, the time to reach the centre is proportional to one number set by shape——the dimensionless time for 90 % at the centre of a cylinder is 0.479635 (0.479611 by finite differences) (Section 2). **Second, heat arrives at once——2.361279 s at radius 0.8 mm** (Section 3). **Third, water is far slower——1705.368250 s at the same radius** (Section 3). **Fourth, and this is the core. The ratio of the two clocks does not depend on thickness——722.222222 at radii 0.6, 0.8 and 1.0 mm alike** (Section 3). **Fifth, mid-boil, heat has fully arrived while water has not——after 600 s, heat remaining at the centre is 1.267×10^{-306} and water remaining 0.597480** (Section 3). **Sixth, the separator is whether what one waits for to reach the inside is thermal diffusivity or water diffusivity——"cooking time is the time for heat to get through" has no truth value until one says which diffusion is awaited** (Section 4). **Keywords**: pasta, thermal diffusivity, water diffusion, two clocks, diffusion in a cylinder, Bessel functions.

Scope of this paper (scope note): **No new theorem or law is claimed——the series solution of diffusion in a cylinder, the zeros of Bessel functions, heat conduction and mass diffusion obeying equations of the same form, and cooking time being set by moisture transport are all known (Crank 1975, Carslaw and Jaeger 1959).Values are representative——thermal diffusivity 1.3×10^{-7} m²/s and water diffusivity 1.8×10^{-10} m²/s are for comparison and vary with the pasta and temperature.Constant coefficients——changes in the coefficients from starch gelatinisation or swelling are not included.Fixed surface——the surface is taken to reach the temperature and moisture of boiling water at the moment boiling starts.No real cooking time is claimed——cooking times and textures of particular pasta are not treated.Relation to earlier papers**: **Paper 445 showed that what the waiting is for is diffusion, not reaction——its scope note fixed the geometry to one dimension, stating that spheres and cylinders change the coefficients but not the square law. There reaction and diffusion were separated. Here, on a cylinder, heat diffusion and water diffusion are separated, and their ratio is counted as independent of thickness. Reaction or diffusion, and which diffusion.**What is added is **deriving the dimensionless time to reach the centre in two ways, by series and by finite differences**, **tabulating the heat and water clocks at three radii and showing the ratio 722.222222 unchanged**, **deriving what remains at the centre after 600 s for heat and for water**, and **placing the separator on which diffusion is awaited**.

1. Notation and the Question

Setting: **holding the surface of a cylinder of radius R fixed, the fraction not yet arrived at the centre is a series in the dimensionless time Fo. For heat use diffusivity α; for water, diffusivity D.**

$$\theta_c(\mathrm{Fo}) = \sum_n \frac{2}{\lambda_n J_1(\lambda_n)} e^{-\lambda_n^2 \mathrm{Fo}}, \qquad J_0(\lambda_n) = 0, \qquad t_{\text{heat}} = \frac{\mathrm{Fo}\, R^2}{\alpha}, \quad t_{\text{water}} = \frac{\mathrm{Fo}\, R^2}{D}$$

For the same criterion of arrival, the ratio of the two times is set by α/D alone.

Question: **is the wait for pasta to cook a wait for heat or for water?**

2. The Dimensionless Time to Reach the Centre

Computation 2.1: **six zeros of J_0 were found to build the series, and the Fo for 90 % at the centre derived; the same value was derived by finite differences.**

quantity	value
zeros of J_0	2.404826, 5.520078, 8.653728, 11.791534, 14.930918, 18.071064
Fo for 90 % at the centre (series)	0.479635
same (finite differences)	0.479611
relative difference	0.000049

Observation 2.2

the time to reach the centre is proportional to one number set by shape, $\mathrm{Fo} = 0.479635$.Series and finite differences agreed to a relative difference of 0.000049——this number is shared by heat and water; only the coefficient dividing R^2 differs.

3. Two Clocks

Computation 3.1: **at three radii, the times for heat and for water to reach 90 % at the centre were derived, along with what remains at the centre after 600 s at radius 0.8 mm.**

radius	heat	water	ratio
0.6 mm	1.328220 s	959.269641 s	722.222222
0.8 mm	2.361279 s	1705.368250 s	722.222222
1.0 mm	3.689499 s	2664.637891 s	722.222222

0.8 mm, 600 s	dimensionless time	remaining at the centre
heat	121.875000	1.267×10^{-306}
water	0.168750	0.597480

Observation 3.2

heat arrives at once, water far later.At radius 0.8 mm heat takes 2.361279 s and water 1705.368250 s (28.422804 minutes)——the order of magnitude of cooking time is set on the water side.

Observation 3.3

this is the core: the ratio of the two clocks does not depend on thickness.Changing the radius to 0.6, 0.8 and 1.0 mm, the ratio stays 722.222222, equal to α/D——thicker pasta takes longer, but the ratio of the heat and water delays stays the same.

Observation 3.4

mid-boil, heat has fully arrived while water has not.After 600 s, the heat remaining at the centre is 1.267×10^{-306} and the water remaining is 0.597480——a firm core is not a shortage of heat but water not yet at the centre.

4. The Separator

Observation 4.1

the separator is whether what one waits for to reach the inside is thermal diffusivity or water diffusivity.Heat takes seconds and water tens of minutes: the same form of equation keeps clocks 722.222222 times apart——“cooking time is the time for heat to get through” has no truth value until one says which diffusion is awaited.

Observation 4.2

beside Paper 445.Paper 445 showed that what the waiting is for is diffusion, not reaction, fixing the geometry to one dimension——here, on a cylinder, heat and water are separated within diffusion, and their ratio counted as independent of thickness.

Observation 4.3

what is not said.Coefficients are representative, and gelatinisation, swelling and real cooking times are not treated——what is shown is that the wait is for water, and that the ratio of the two clocks does not depend on the shape number.

5. Roll Call and Closing

1. $\mathrm{Fo} = 0.479635$ (Computation 2.1): **a number set by shape.**
2. **finite differences** 0.479611 (Observation 2.2): **agreeing.**
3. **heat** 2.361279 **s** (Computation 3.1): **arrives at once.**
4. **water** 1705.368250 **s** (Observation 3.2): **far slower.**
5. **ratio** 722.222222 (Observation 3.3): **the core.**
6. 722.222222 **at 0.6 mm too** (Computation 3.1): **thickness does not matter.**
7. **heat remaining after 600 s** 1.267×10^{-306} (Computation 3.1): **fully arrived.**
8. **water remaining** 0.597480 (Observation 3.4): **not yet arrived.**
9. **first zero of** J_0**,** 2.404826 (Computation 2.1): **the base of the series.**
10. **thermal or water diffusivity** (Observation 4.1): **the separator; Paper 445.**

Closing: **What sets cooking time is not heat but water, and the ratio of the two clocks does not depend on thickness.The dimensionless time for 90 % at the centre of a cylinder is 0.479635 by Bessel series and 0.479611 by finite differences, shared by heat and water——only the coefficient dividing R^2 differs.With thermal diffusivity 1.3×10^{-7} m²/s and water diffusivity 1.8×10^{-10} m²/s, heat reaches the centre of a 0.8 mm radius in 2.361279 s and water in 1705.368250 s, and the ratio is 722.222222 at radii 0.6, 0.8 and 1.0 mm alike——changing thickness leaves the ratio of the delays unchanged.After 600 s of boiling, heat remaining at the centre is 1.267×10^{-306} while water remaining is 0.597480: a firm core is water not yet arrived.The separator is whether what one waits for to reach the inside is thermal diffusivity or water diffusivity.Placed among the earlier papers——Paper 445 showed the wait to be for diffusion, not reaction; this separates heat and water within diffusion.To be honest——coefficients are representative, and gelatinisation, swelling and real cooking times are not treated.**

References

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