The Ranking of Pot Materials Reverses Between Spreading Heat and Storing It

— conductivity differs **26.912752**-fold between copper and stainless steel, but heat capacity per volume only **1.544445**-fold between aluminium and stainless steel, with the order reversed — material matters for the question in which temperature differs within the base of the pot — [Paper 589]

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— *From thinking to syncing.* —

Abstract

A pot of high thermal conductivity is said to be a good pot.What this paper shows is that a pot is asked for two properties, spreading heat (thermal conductivity k) and storing it (heat capacity per volume ρc), that the ranking of metals reverses between the two, and that material matters greatly only for spreading.No new theorem or law is claimed. First, the ranking reverses——the order in spreading heat is copper, aluminium, iron, stainless steel; in storing it, stainless steel, iron, copper, aluminium. Stainless steel is last among the metals in spreading and first in storing (Section 2). **Second, the spreads differ by an order of magnitude——across the four metals, thermal conductivity spans 26.912752-fold and heat capacity per volume 1.544445-fold** (Section 2). **Third, the distance heat spreads goes as the square root of thermal conductivity——the length $\sqrt{kd/h}$ over which a base 3 mm thick spreads heat from where the flame strikes is 3.4684 cm for copper and 0.6686 cm for stainless steel, 5.187750 times apart; solving for the temperature in the base by finite differences agrees to a relative 1.0×10^{-6}** (Section 3). **Fourth, and this is the core.A difference in storing is made up by thickness; a difference in spreading is not——aluminium 4.6333 mm thick stores as much heat as stainless steel 3 mm thick, but to spread heat as far as copper 3 mm thick, stainless steel must be 80.7383 mm thick** (Section 4). **Fifth, the storing side agrees with Paper 465——465 showed that the rate of cooling differs only 1.3081-fold with material; the 1.544445-fold spread of the metals' heat capacity per volume is the same story. What is new is the side of "the temperature distribution inside", which 465 left open in its scope note, and there material matters 26.912752-fold** (Section 5). **Sixth, the separator is whether the question involves temperature differences within the base——if it does, thermal conductivity decides; if not, heat capacity per volume decides. The two are different quantities with different roots** (Section 5). **Keywords**: cookware, thermal conductivity, heat capacity, fin equation, cooking.

Scope of this paper (scope note): **No new theorem or law is claimed——heat conduction, the equation for heat spreading while escaping from a thin plate (the fin equation), and heat capacity are all standard.No pot is designed or recommended.The properties are representative——copper, aluminium, iron and stainless steel 304 take the values listed in heat-transfer textbooks for the pure metals and the steel near room temperature, and the earthenware pot a representative value for ceramic.The heat-transfer coefficient is representative——1000 W/(m^2 K) from the base to the contents; the ratio of spreading lengths does not depend on it.The base is one plate——multi-layer pots with copper or aluminium clad in stainless steel, the sides and the handle are not treated.Sticking, weight, price and reactions with food are not treated.Relation to earlier papers**: **Paper 465 showed that the rate of cooling differs only 1.3081-fold with material and is set by shape, and stated in its scope note that it does not treat the temperature distribution inside: "when the Biot number is large, the internal gradient matters and this treatment fails"——the storing side of this paper agrees with 465, and this paper takes the seat left open there, the temperature gradient within the base.Paper 451 showed that what insulates is not the snow but the air it holds——there too, the name of the material did not decide how heat passed.Paper 300 showed that sharing a root is decidable——spreading (thermal conductivity) and storing (heat capacity per volume) are different quantities with different roots.**What is added is **setting out the two rankings for five materials, finding the spreading length by two routes, closed form and finite differences, giving the thickness ratios needed to make up each difference (1.544445 and 26.912752)**, and **placing the separator on whether the question involves temperature differences inside**.

1. Notation and the Question

Setting: **take the base of a pot as one plate of thickness d, with thermal conductivity k, density ρ, specific heat c and thermal diffusivity $\alpha = k/(\rho c)$.When heat spreads sideways from where the flame strikes while escaping to the contents with a heat-transfer coefficient h, the temperature of the base spreads over a length given by**

$$\frac{d^2T}{dx^2} = \frac{h}{kd}\,T, \qquad T \propto e^{-x/\lambda}, \qquad \lambda = \sqrt{\frac{kd}{h}}.$$

The heat the base stores per area is proportional to $\rho c d$.

> **Observation 1.1**
>
> **a pot of high thermal conductivity is said to be a good pot.An iron pot is also said to be good because it does not cool quickly——the two say different things. Whether one "goodness" ranks the materials is another question.**

Question: **is there one ranking of pot materials?**

2. Two Rankings

Computation 2.1: representative values for five materials, with the time d^2/α for heat to cross a base 3 mm thick.

material	k (W/(m K))	ρc (MJ/(m^3 K))	α (m^2/s)	d^2/α (s)
copper	401.0	3.4392	1.1660×10^{-4}	0.0772
aluminium	237.0	2.4399	9.7135×10^{-5}	0.0927
iron	80.2	3.5179	2.2798×10^{-5}	0.3948
stainless steel (304)	14.9	3.7683	3.9540×10^{-6}	2.2762
earthenware (representative)	1.5	1.8400	8.1522×10^{-7}	11.0400

> **Observation 2.2**
>
> the ranking reverses.In spreading heat (k) the order is copper, aluminium, iron, stainless steel, earthenware; in storing it (ρc), stainless steel, iron, copper, aluminium, earthenware——among the metals, stainless steel is the worst at spreading heat and the best at storing it.

> **Observation 2.3**
>
> the spreads differ by an order of magnitude.Across the four metals, thermal conductivity spans **26.912752**-fold and heat capacity per volume **1.544445**-fold——the metals' heat capacity per volume is nearly the same, and the difference between them is concentrated in thermal conductivity.

3. Spreading Heat

Computation 3.1: for a base 3 mm thick and a heat-transfer coefficient of 1000 W/(m^2 K) to the contents, the spreading length $\sqrt{kd/h}$ is **3.4684** cm for copper, 2.6665 cm for aluminium, 1.5511 cm for iron, **0.6686** cm for stainless steel and 0.2121 cm for earthenware.The ratio of copper to stainless steel is **5.187750**, the square root of the ratio of conductivities.

Computation 3.2: as a route separate from the closed form, the equation for the temperature of the base was solved by finite differences and the position at which the temperature falls to e^{-1} was read.It is 3.468433 cm for copper

(closed form 3.468429 cm) and 0.668581 cm for stainless steel (closed form 0.668581 cm), a relative difference of 1.0×10^{-6}.

> **Observation 3.3**
>
> the ratio of spreading lengths is the square root of the ratio of conductivities, whatever the heat-transfer coefficient.In a stainless-steel base, heat from where the flame strikes escapes to the contents before it has spread even 1 cm sideways——this is a question in which temperature differs within the base, and thermal conductivity decides it.

4. Can Thickness Make It Up?

Computation 4.1: the heat stored per area by a base 3 mm thick, $\rho c d$, is 10.3176 for copper, 7.3197 for aluminium, 10.5537 for iron, 11.3049 for stainless steel and 5.5200 kJ/(m^2 K) for earthenware.To store as much as stainless steel 3 mm thick, aluminium must be **4.6333** mm (1.544445 times), copper 3.2871 mm and iron 3.2135 mm.

Computation 4.2: to spread heat as far as copper 3 mm thick, stainless steel must be **80.7383** mm (26.912752 times), iron 15.0000 mm and aluminium 5.0759 mm.Solving by finite differences with stainless steel 80.7383 mm thick gives a spreading length of 3.468433 cm, level with copper at 3 mm.

> **Observation 4.3**
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> this is the core.A difference in storing is made up by making the base about 1.5 times thicker. At the same thickness, iron stores less than stainless steel (10.5537 against 11.3049)——if an iron pot feels slow to cool, that is its thickness, not its material. To make up a difference in spreading by thickness, however, takes 26.9 times the thickness, and a base 8 cm thick is not a pot. Material matters greatly only for spreading.

5. The Separator

Observation 5.1

the separator is whether the question involves temperature differences within the base.Spreading heat sideways, or the base keeping up when the flame is turned up, involves differences inside and is decided by thermal conductivity. Storing heat looks only at the temperature of the whole and is decided by heat capacity per volume——a “good material” is not decided until the question is written down.

Observation 5.2

taking the seat left open by Paper 465.It showed that the rate of cooling differs only 1.3081-fold with material and is set by shape, and set aside the temperature distribution inside, noting that the internal gradient matters when the Biot number is large——the storing side of this paper agrees with 465; on the side it left open, the gradient within the base, material matters 26.912752-fold.

Observation 5.3

beside Paper 451.It showed that what insulates is not the snow but the air the snow holds——there too the name of the material did not decide how heat passed; here too “a material good with heat” means nothing until one says whether it is to spread heat or to store it.

Observation 5.4

different roots, under Paper 300.Thermal conductivity and heat capacity per volume are different quantities, and neither follows from the other——the ranking reverses because two different quantities were being called by one “goodness”.

Observation 5.5

what is not said.No pot is designed or recommended, and multi-layer pots, sticking, weight, price and reactions with food are not treated——what is shown is that the ranking of materials changes with the question, and that material matters greatly only for questions involving temperature differences inside.

6. Roll Call and Closing

1. **the rankings in spreading and storing reverse** (Observation 2.2): **stainless steel last and first.**
2. **thermal conductivity spans 26.912752-fold** (Observation 2.3): **four metals.**
3. **heat capacity per volume spans 1.544445-fold** (Observation 2.3): **nearly the same.**
4. **spreading lengths: copper 3.4684 cm, stainless steel 0.6686 cm** (Computation 3.1): **a ratio of 5.187750.**
5. **finite differences and closed form agree to 1.0×10^{-6}** (Computation 3.2): **two routes.**
6. **the storing difference is made up by aluminium 4.6333 mm thick** (Computation 4.1): **by thickness.**
7. **the spreading difference needs stainless steel 80.7383 mm thick** (Computation 4.2): **the core.**
8. **at the same thickness iron stores less than stainless steel** (Observation 4.3): **slow cooling is thickness.**
9. **taking the seat left open by Paper 465** (Observation 5.2): **the side of the internal gradient.**
10. **the separator is whether the question involves differences inside** (Observation 5.1): **spreading and storing have different roots.**

Closing: **A pot of high thermal conductivity is said to be a good pot, and an iron pot is said to be good because it does not cool quickly.These are two questions, and the ranking of materials reverses between them——the order in spreading heat is copper, aluminium, iron, stainless steel, and in storing it stainless steel, iron, copper, aluminium, so stainless steel is last among the metals in spreading and first in storing. Across the four metals, thermal conductivity spans 26.912752-fold, heat capacity per volume only 1.544445-fold.A difference in storing is made up by thickness; a difference in spreading is not——aluminium 4.6333 mm thick stores as much as stainless steel 3 mm thick, but to spread heat as far as copper 3 mm thick, stainless steel must be 80.7383 mm thick. The spreading lengths are 3.4684 cm for copper and 0.6686 cm for stainless steel, agreeing with the temperature solved by finite differences to a relative 1.0×10^{-6}.The separator is whether the question involves temperature differences within the base——if it does, thermal conductivity decides; if not, heat capacity per volume. Under Paper 300 the two have different roots.Placed among the earlier papers——the storing side agrees with Paper 465, which found that cooling barely changes with material, and this paper takes the seat for the internal gradient that 465 left open in its scope note. As in Paper 451, the name of a material does not decide how heat passes until the question is written down.To be honest——the properties and the heat-transfer coefficient are representative, the base is one plate, and multi-layer pots, the sides, sticking, weight, price and reactions with food are not treated. No pot is designed or recommended.**

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