# An Intro to Coffee Extraction Theory

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# What is coffee?

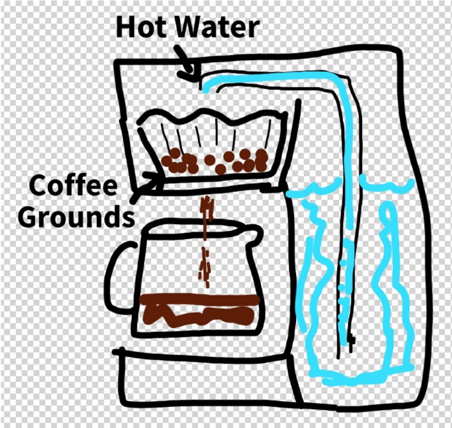
Coffee bean cells contain particles that end up in our cup of coffee.

… obvious

https://coffeeaffection.com/how-to-make-green-coffee/

Our goal as coffee makers is to

1. Extract these particles as quick as possible (most people)
2. Extract the good tasting particles while keeping the bad ones out of our cup (nerds, also this is hard)



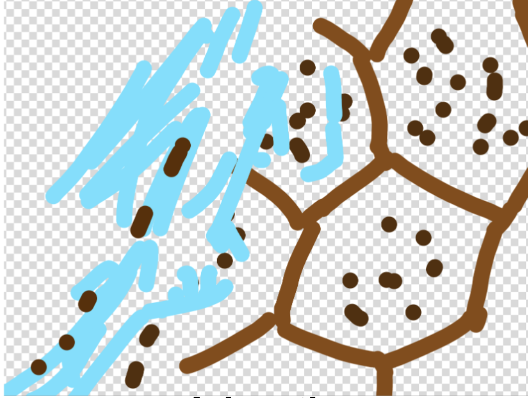
# Methods of extraction

Average Extraction Yield: % of coffee by weight that ends up in your cup.

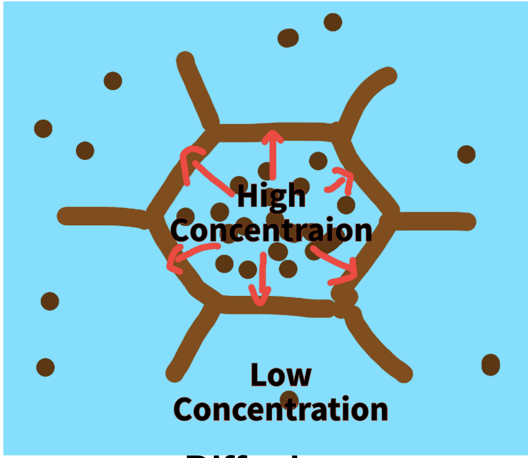
- with traditional filtered brew methods, upper limit is 30-32% [1]

At a microscopic level[1]:

- Advection: particles washed away
- Diffusion: particles diffuse through cell wall



Advection




Diffusion

[1] Ellero, M., and L. Navarini. 2019. “Mesoscopic Modelling and Simulation of Espresso Coffee Extraction.” *Journal of Food Engineering* 263 (December): 181-94. https://doi.org/10.1016/j.jfoodeng.2019.05.038

# Building a model for extraction[1]

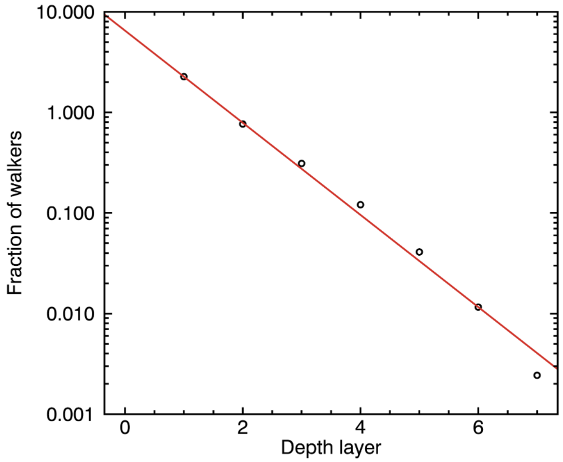
During extraction, for intact coffee cells, assume that the mass of the ‘i’th extractable chemical compound decreases exponentially like

$$\frac{\partial m_i}{\partial t} = e^{-t/\tau_i} \quad \Longrightarrow \quad m_i(t) = M_i\left(1 - e^{-t/\tau_i}\right)$$

But what about the intact coffee cells deeper in the coffee ground?

Also exponential (good assumption based on simulation).

$$\tau_i\left(x\right) = \tau_i' e^{x/\lambda}$$




[1] Gagné, J. “The Dynamics of Coffee Extraction.” Blog, January 30, 2019. https://coffeeadastra.com/2019/01/29/the-dynamics-of-coffee-extraction/

# Assume a spherical coffee ground

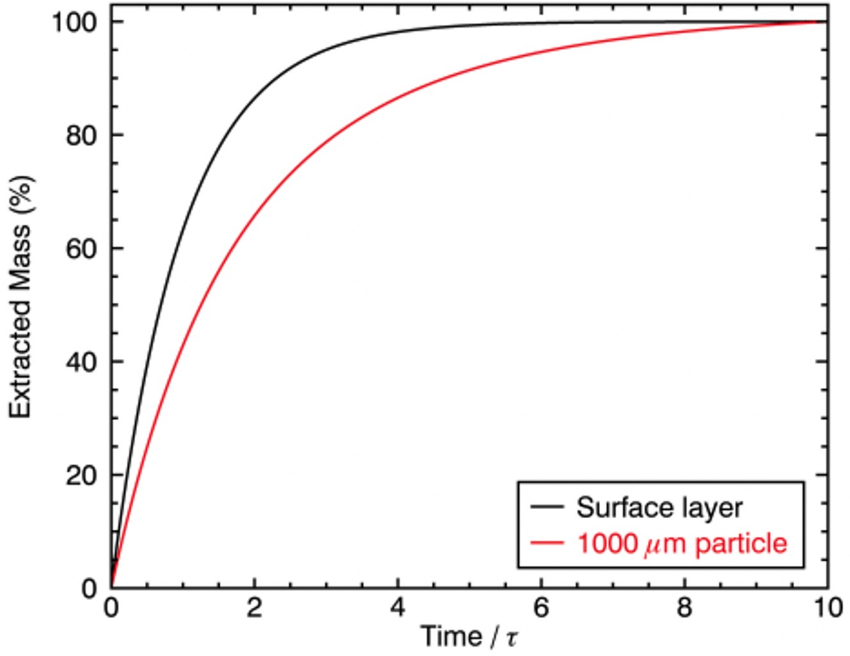
Many spherical shells of cells

$$\frac{m_i(t)}{M_i} = \sum_k 4\pi(R - ks)^2 \left(1 - \exp\left(-\frac{t}{\tau_i'} e^{-ks/\lambda}\right)\right)$$

Assume cell layers continuous (not true but maybe better at capturing irregularity (and easier to code up))

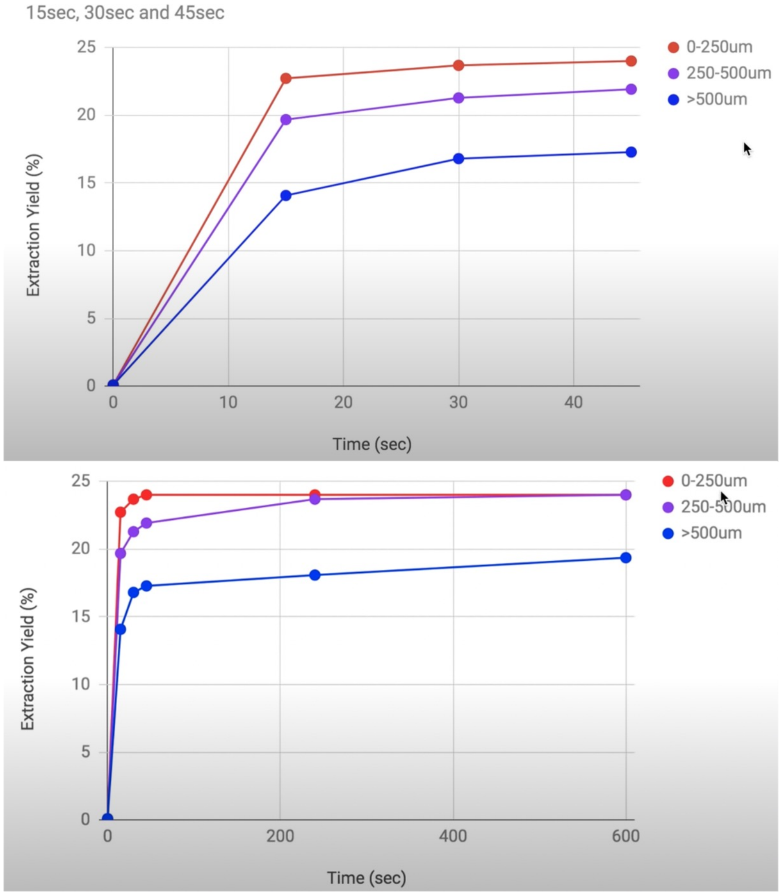
$$\frac{m_i(t)}{M_i} = \int_0^R 4\pi(R - r)^2 \left(1 - \exp\left(-\frac{t}{\tau_i'} e^{-r/\lambda}\right)\right) dr$$

# Comparison to experiment




Gagné's model

λ = 100 μm, R = 1000 μm




Experiment

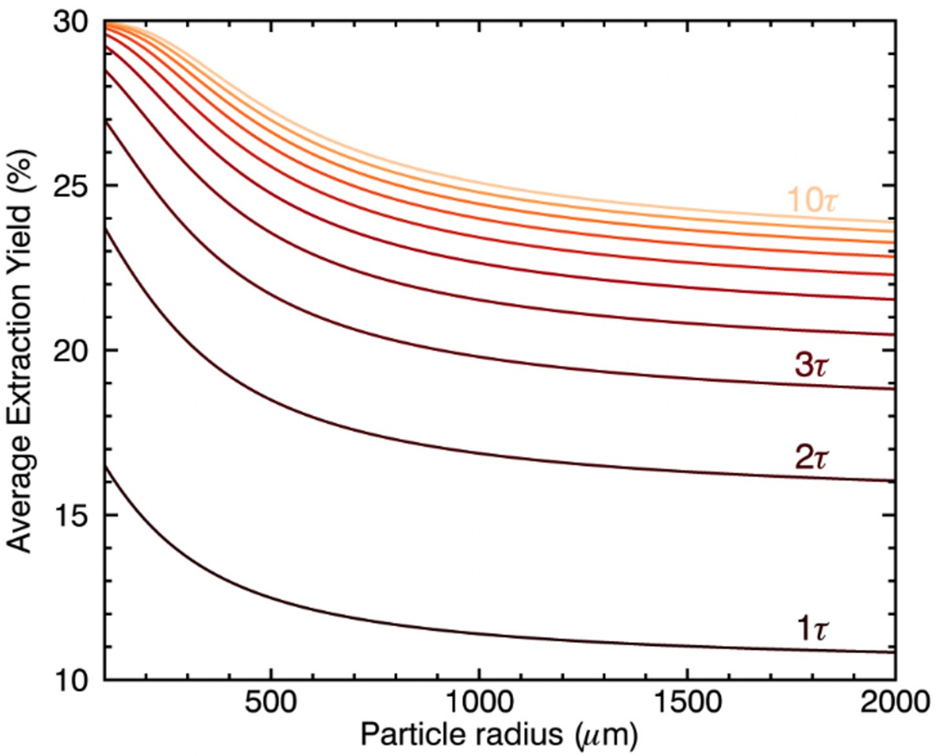
Barista Hustle. "Sifting Coffee Grinds - An Experiment." Youtube Video, https://www.youtube.com/watch?v=kI3zOwFG9mg

# More results with Gagné's model

Matches with expectations

- Smaller grounds extract faster
- Extraction increases with time

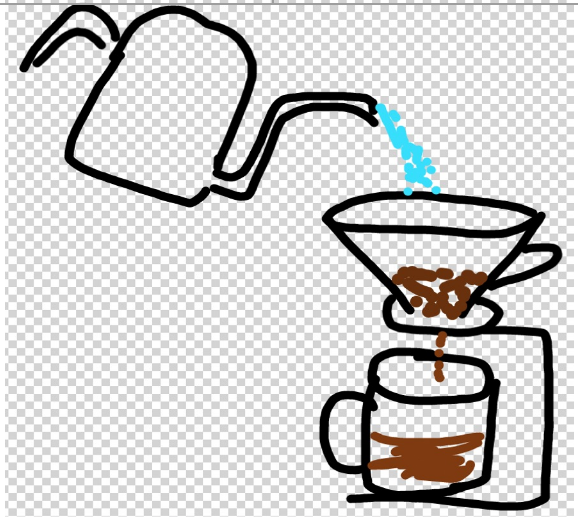
Also, for larger grounds, it is harder extract the entire ground in a reasonable amount of time.



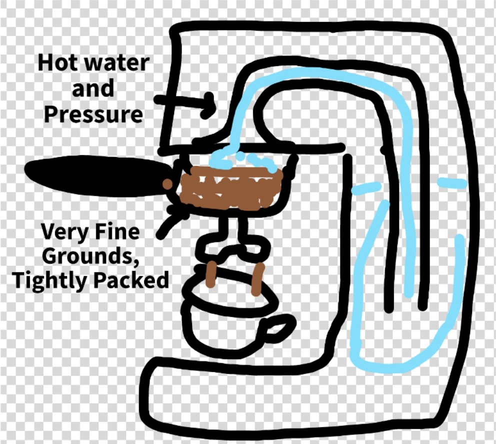
# Applications

| Method | French Press | Pour Over | Espresso |
|---|---|---|---|
| Grind Size | Coarse | Medium | Fine |
| Brew Time | 4-5 minutes | 2-4 minutes | 30 sec |
| Coffee:Water Ratio | 1:12 | 1:15 | 1:2 |

**French Press**



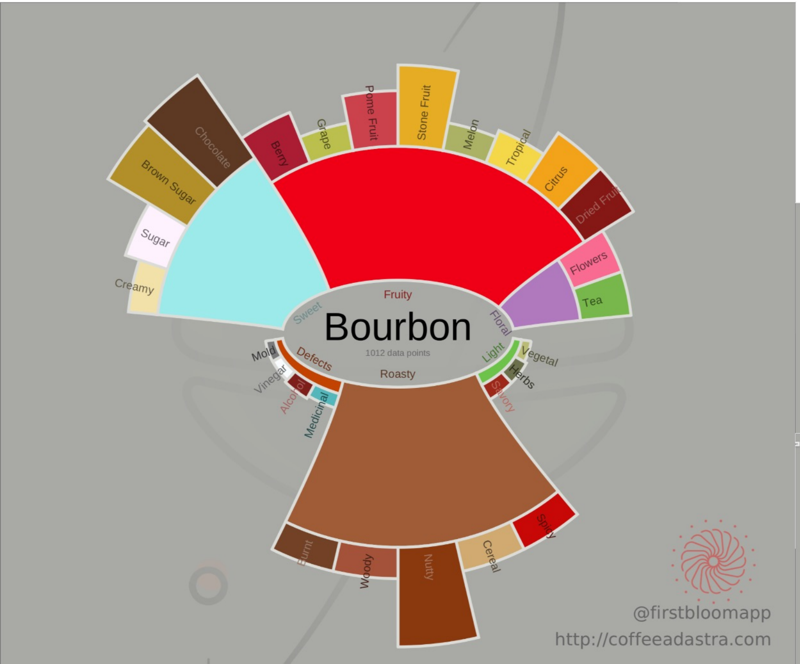
**Pour Over**

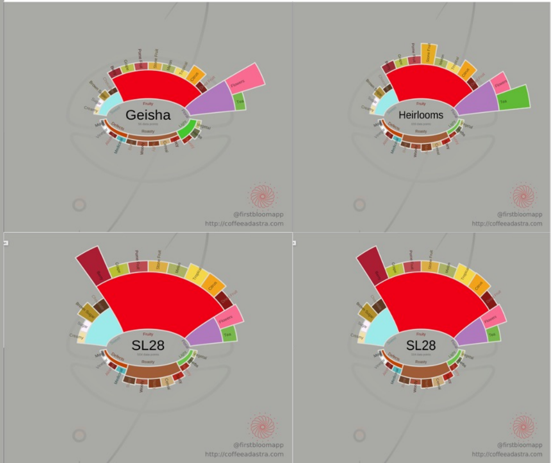



**Espresso**

# Removing bitterness from your cup

Because coffee can be so much more than hot bitter caffeine (i.e. hot not-bitter caffeine)





Vendor's Description
violet, rose, purple grape, and pluot, with a juicy grape acidity and a floral honey viscosity: a beautifully structured coffee with a chocolate and cotton candy fragrance

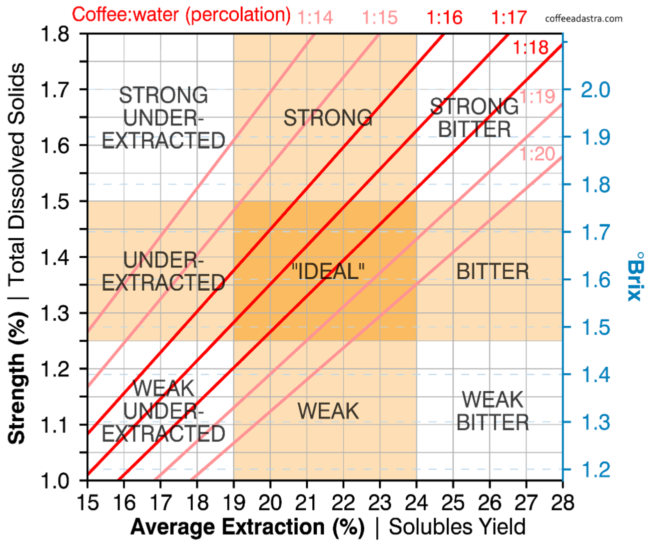
# The mechanism behind astringency/bitterness

Often associated with over-extraction

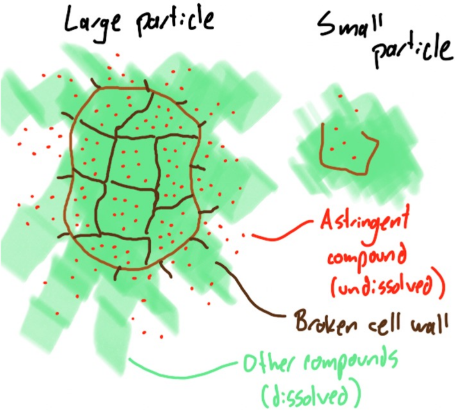
- So grind coarser to decrease avg extraction?

Not so simple:

- Grinders produce a distribution of grind sizes.
- Not all grounds of the same size may not extract the same.




https://coffeeadastra.com/2019/02/17/measuring-and-reporting-extraction-yields/




Ongoing Study (Samo Smrke)

- Chemical compounds responsible for astringency require a very high temperature to dissolve efficiently in water

https://coffeeadastra.com/2022/08/01/the-mechanism-behind-astringency-in-coffee/

# So what can we do?

Ideally: Achieve an optimal average extraction (~22%) with a tight distribution of coffee grounds that are evenly extracted (bonus: keep undissolved astringent compounds out of cup), then maybe you brew a good cup every now and then.

Optimal extraction: tune grind size, brew time, temperature; agitation (like swirling)

Tight distribution of grounds: good grinder + burr set ($$$), sifter

Evenness of extraction: better technique (pourover), immersion

Bonus: favor coarser grind size

Realistically: Settle for bitter bean water with caffeine.

Weber EG-1: $4300

# Sources

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Ellero, M., and L. Navarini. 2019. “Mesoscopic Modelling and Simulation of Espresso Coffee Extraction.” Journal of Food Engineering 263 (December): 181-94. https://doi.org/10.1016/j.jfoodeng.2019.05.038