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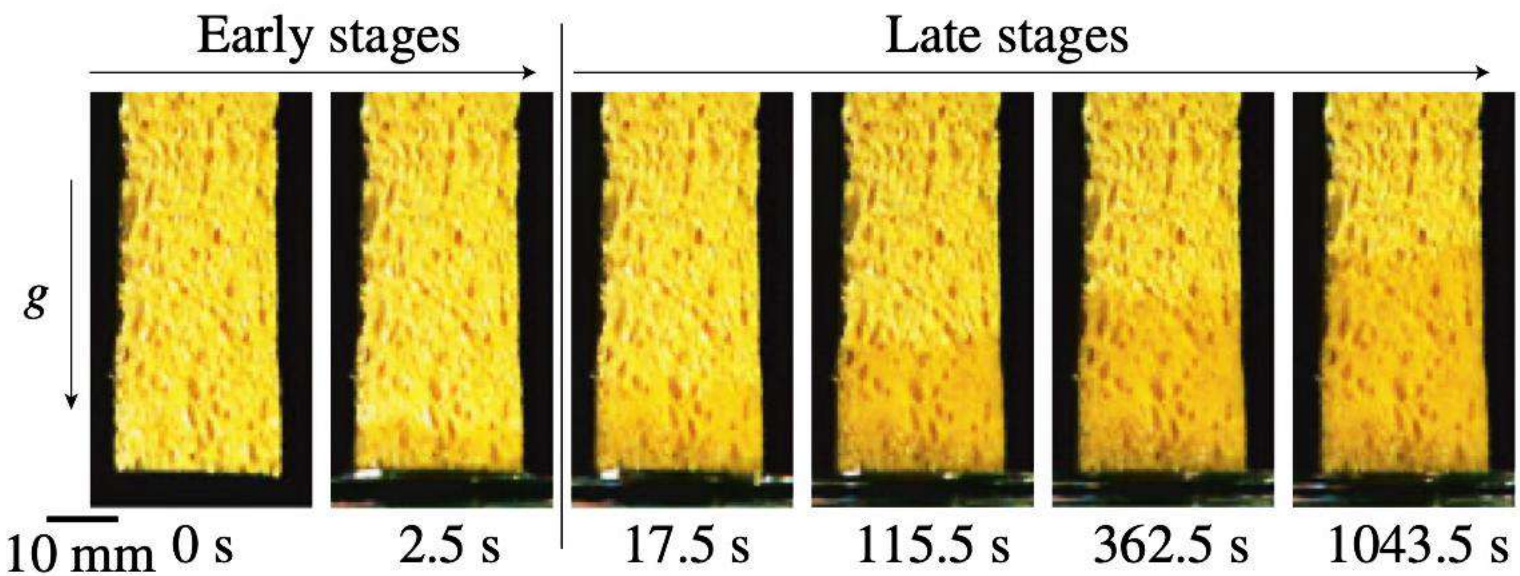
International Young Physicists' Tournament

13

Sponge

A sponge will soak up water at a rate and in a quantity determined by various parameters. Investigate how effective a sponge is at drying a wet surface.



Kim, J., Ha, J., & Kim, H. (2017). Capillary rise of non-aqueous liquids in cellulose sponges. *Journal of Fluid Mechanics, 818*, R2. doi:10.1017/jfm.2017.165

A sponge will soak up water at a rate and in a quantity determined by various parameters.

1. Why does a sponge soak up water?
2. What parameters affect the phenomenon?

Investigate how effective a sponge is at drying a wet surface.

3. Experimental investigation of the effectiveness.

Capillary explanation

The sponge is made out of a net of capillaries soaking up liquid due to capillary action.

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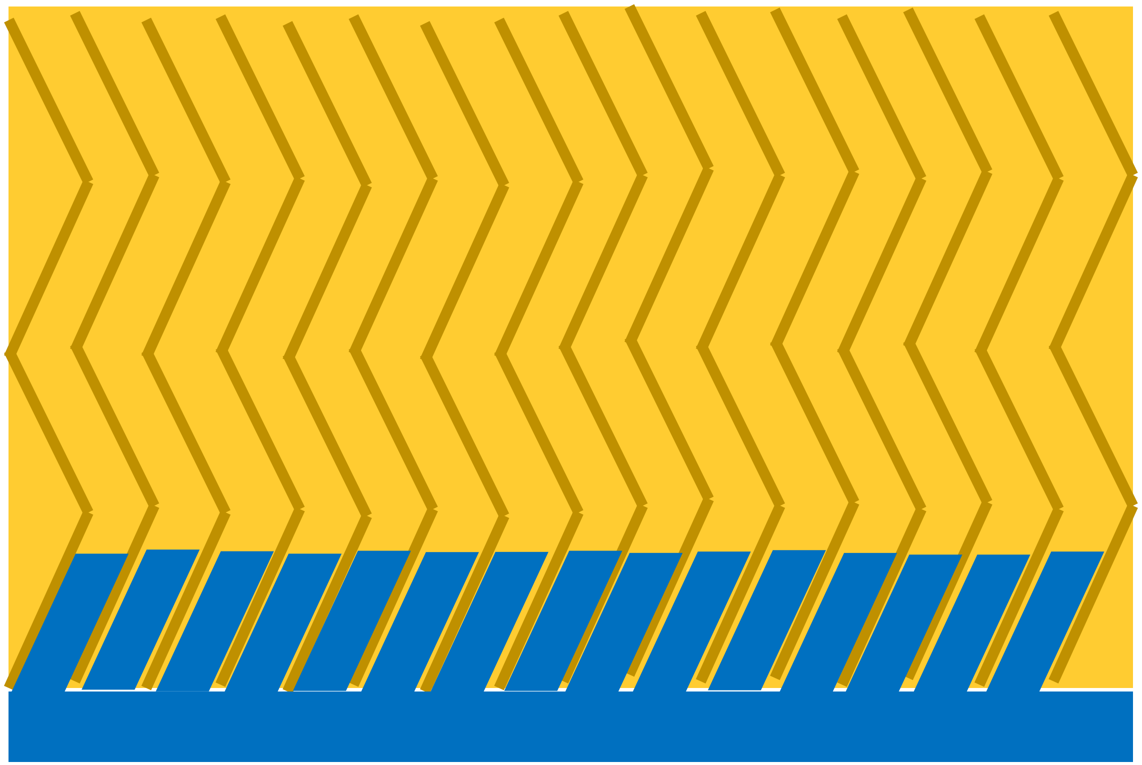
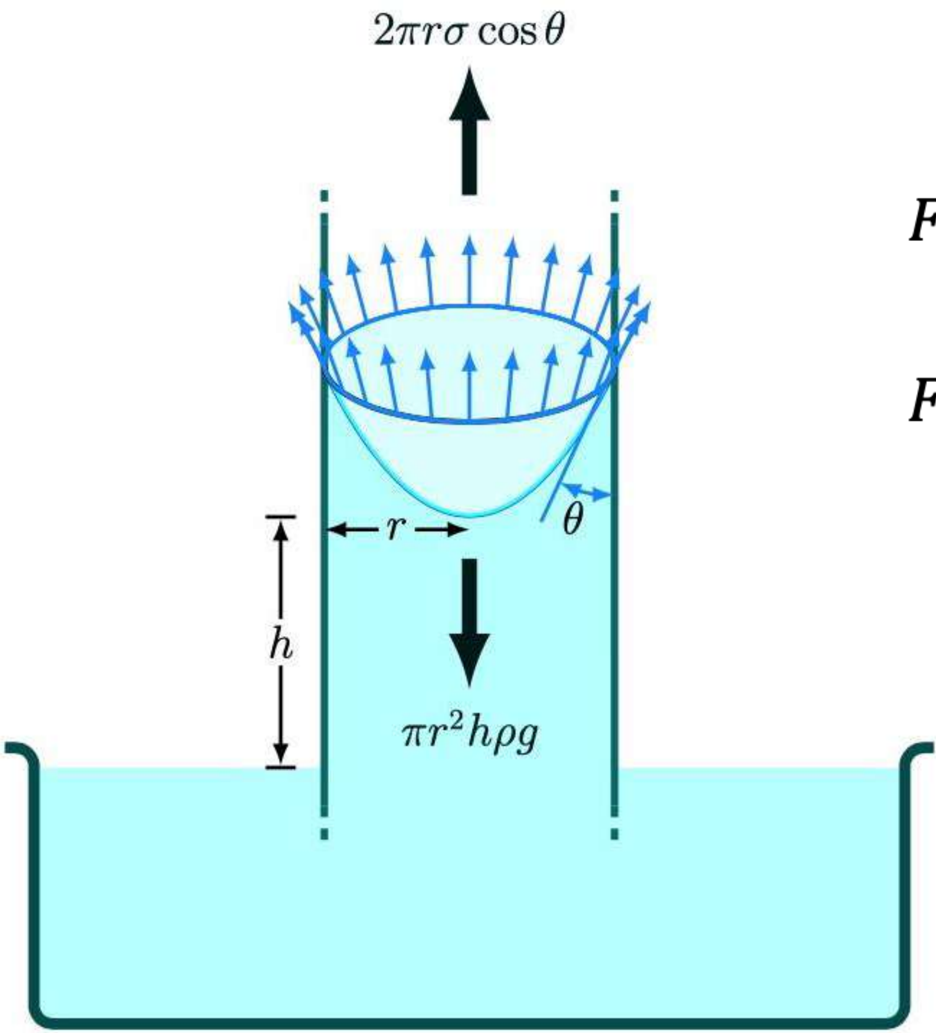


Capillary action in a tube



$$F_{total} = Force_{up} - Force_{down}$$

$$F_{total} = 2\pi r\sigma\cos\theta - \pi r^2 h\rho g$$

Soaked up volume V

Taking out πr and dividing by m

$$\ddot{h} = \frac{\pi r}{m}(2\sigma\cos\theta - rh\rho g)$$

Capillary action in a tube

We can now compare the two terms

$$\ddot{h} = \frac{\pi r}{m}(2\sigma\cos\theta - rh\rho g)$$

The liquid with higher surface tension rises faster

With increasing height, the soaking up slows down

This simple example can give us an intuition about how the sponge will behave

In practice, flow through porous media is a complicated problem.

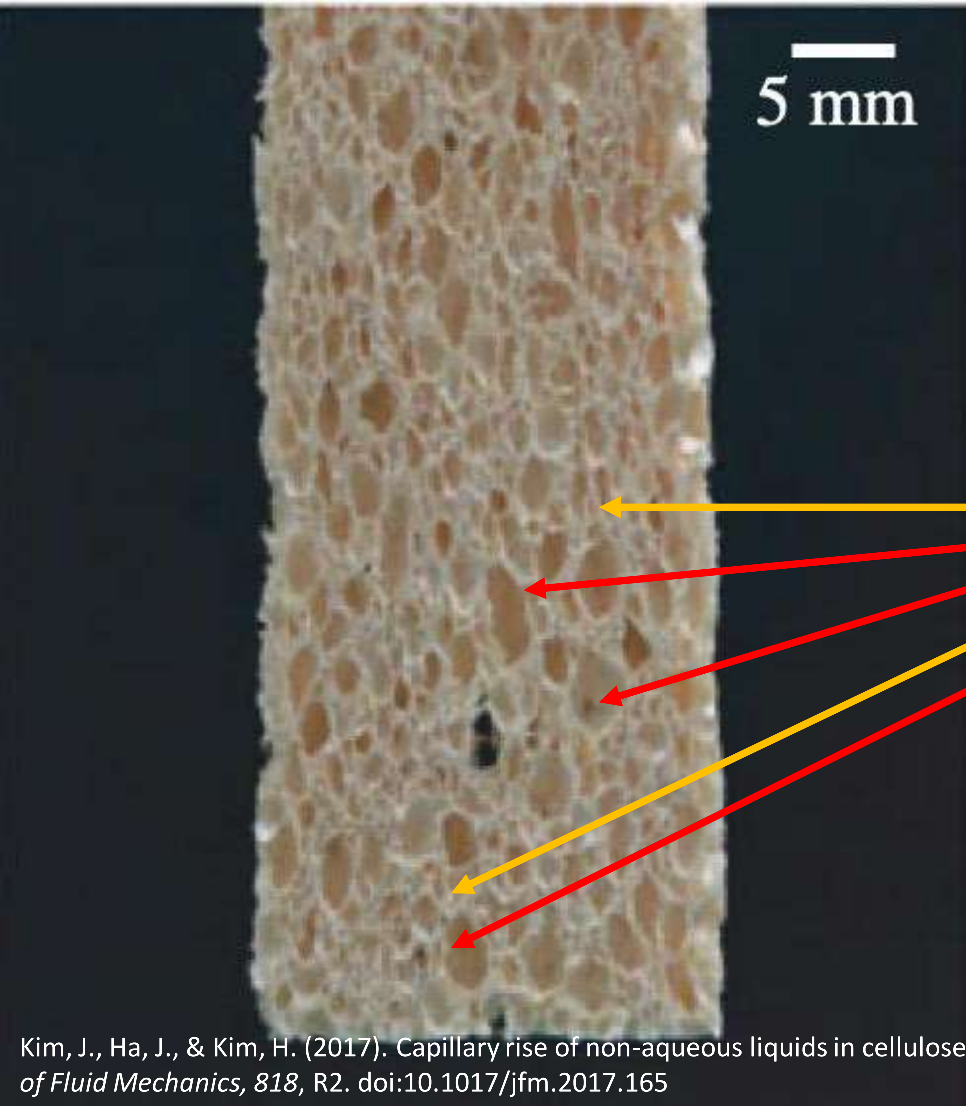
Theory to look up:

Darcy's law – describes flow of a liquid through porous medium

Washburn equation – describes the penetration length of a liquid into capillary pore or a tube

Though bear in mind that fully theoretical description of the phenomenon may not be feasible. !

Real sponge



Pores of various sizes that need to be filled with liquid

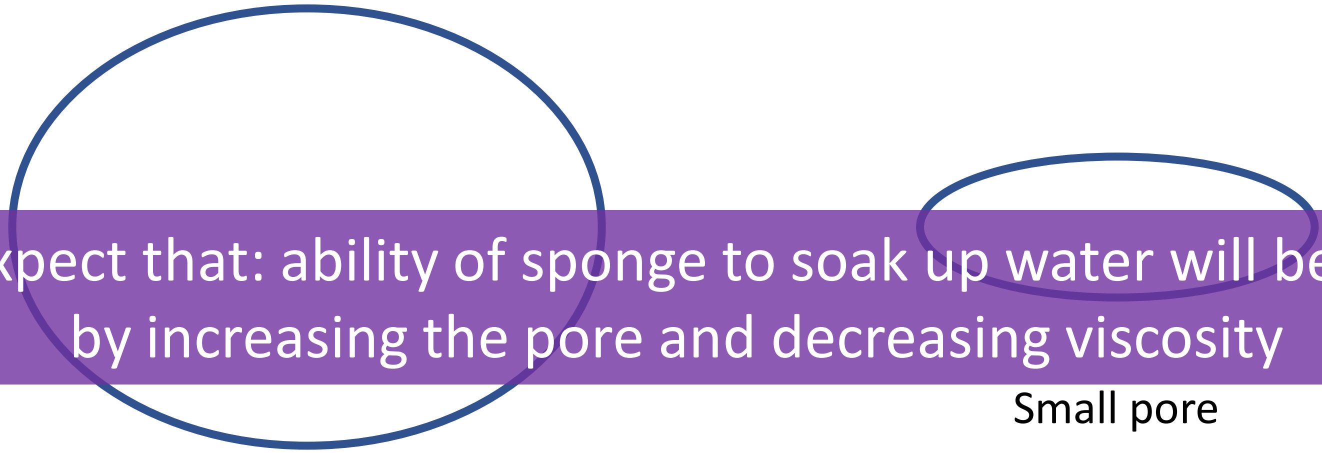
Kim, J., Ha, J., & Kim, H. (2017). Capillary rise of non-aqueous liquids in cellulose
of Fluid Mechanics, 818, R2. doi:10.1017/jfm.2017.165

Real sponge

Because real fluids have viscosity, we need to take it into account.

It is easier for the fluid to flow into a large pore than a smaller one

Note that capillary action occurs in the weaves of the sponge not the pores



We can expect that: ability of sponge to soak up water will be increased by increasing the pore and decreasing viscosity

Real sponge - research

Kim, J., Ha, J., & Kim, H. (2017). Capillary rise of non-aqueous liquids in cellulose sponges. *Journal of Fluid Mechanics, 818,* R2. doi:10.1017/jfm.2017.165

In the limit that only large pores are being filled (early stages):

$$h \sim \left(\frac{\sigma R t}{\mu}\right)^{1/2}$$

Identical to Washburn equation

R – Characteristic size of the pores

$\sigma - surface\ tension$

$\mu\ - viscosity$

$t - time$

$h - height\ of\ the\ liquid$

Real sponge - research

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In the late stages, unfilled pores are being compressed by the filled ones:

$$h \sim \left[\frac{\sigma^3}{\mu(\rho g)^2 \epsilon r_0}\right]^{1/4} t^{1/4}$$

$\epsilon - pore\ compression\ ration$

r_0 – radius of curvature responsible for driving force

$h - height\ of\ the\ liquid$

$\sigma - surface\ tension$

$\mu\ - viscosity$

$\rho\ and\ g\ - density\ and\ grav.acceleration$

$t - time$

Real sponge - research

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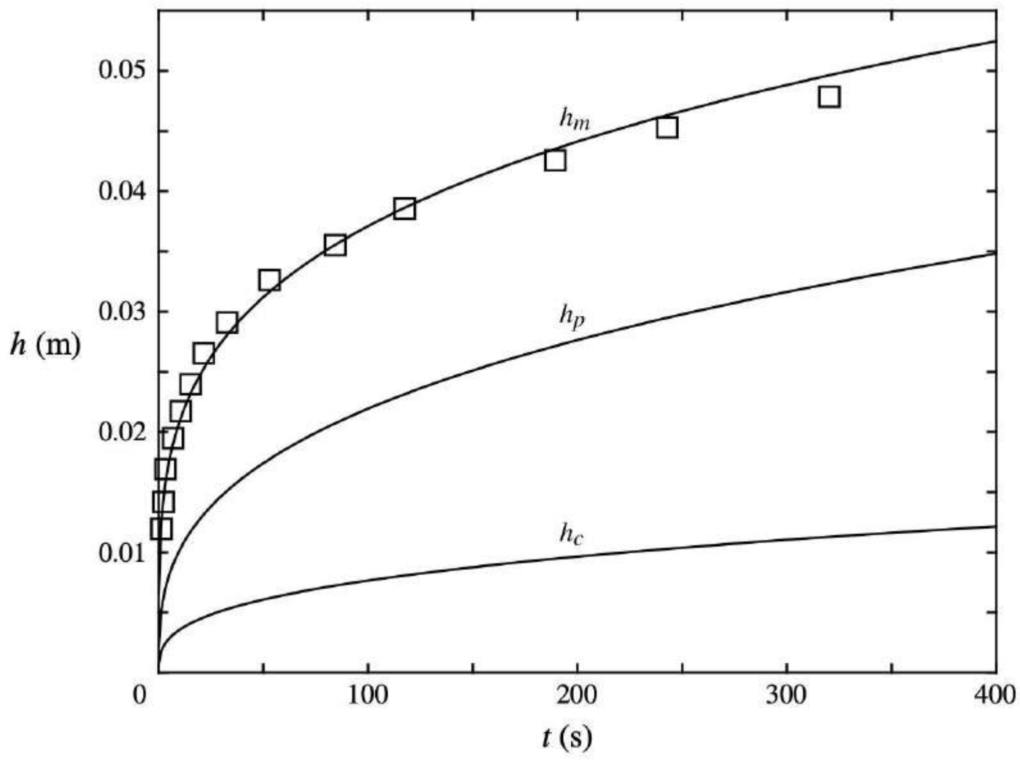
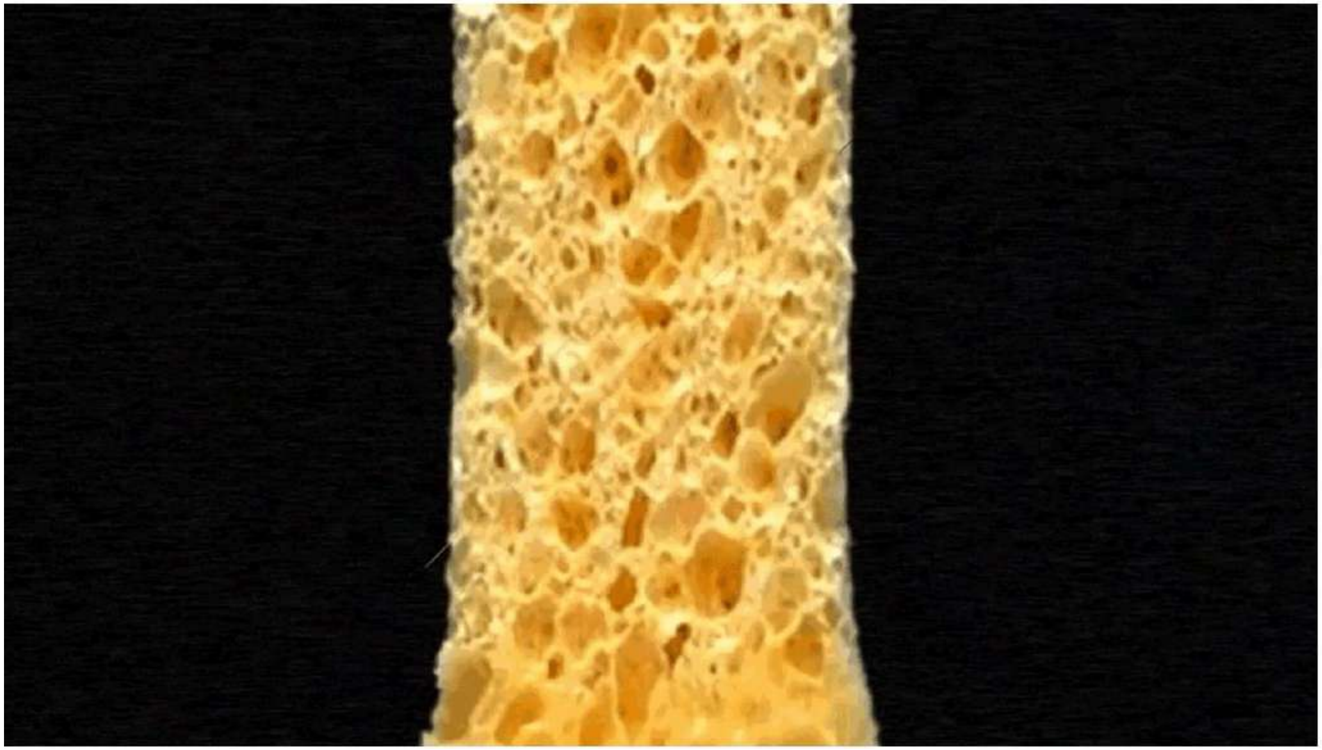


Real sponge - research

More complicated model – sponge is expanding when wetted

Ha, J., Kim, J., Jung, Y., Yun, G., Kim, D. N., & Kim, H. Y. (2018). Poro-elasto-capillary wicking of cellulose sponges. Science advances, 4(3), eaao7051



Additional resources

https://stemfellowship.org/iypt-2021-references/sponge/

A sponge will soak up water at a rate and in a quantity determined by various parameters.

① Why does a sponge soaks up water?

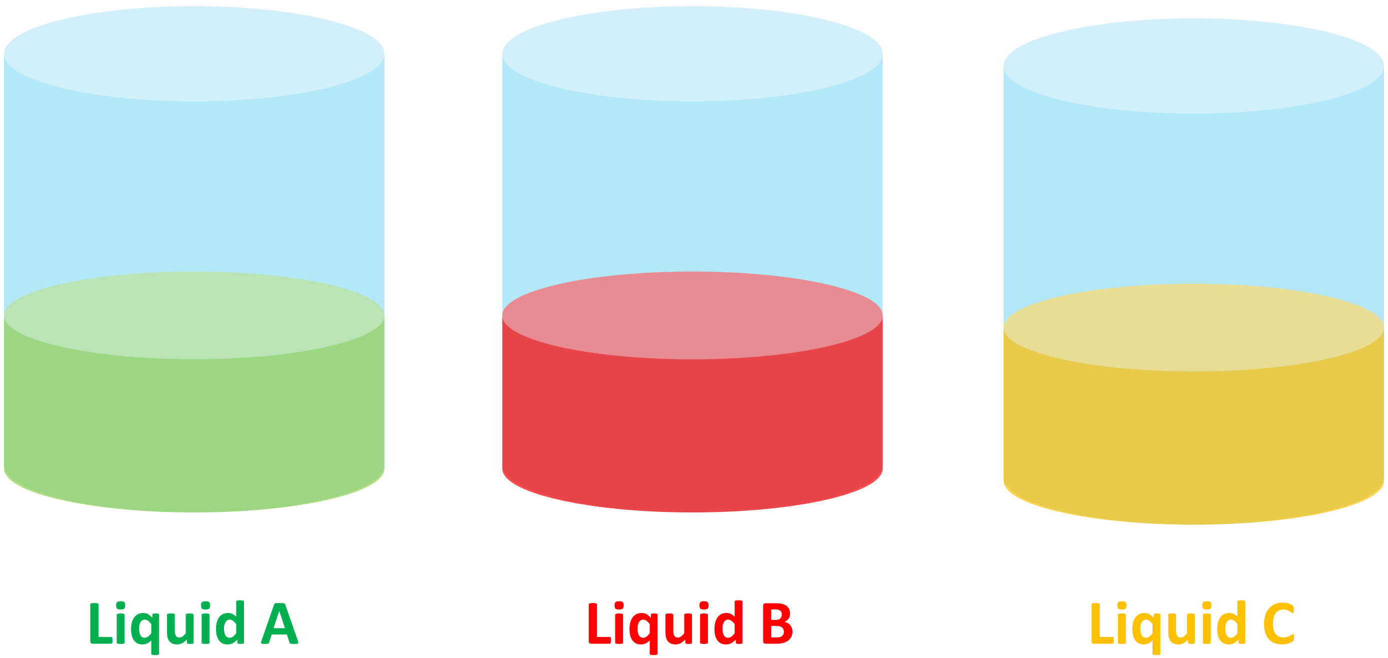
Most likely it’s capillary action.

② What parameters affect the phenomenon?

Parameters of the fluid: <u>surface tension, viscosity</u>, in later stages density

Parameters of the sponge: <u>size of the pores</u>,
in later stages compression ratio etc…

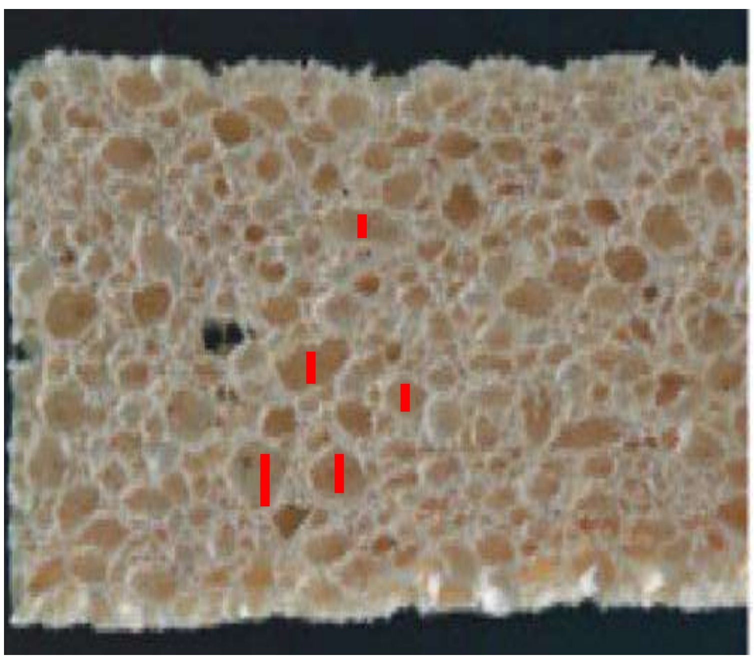
Fluid parameters

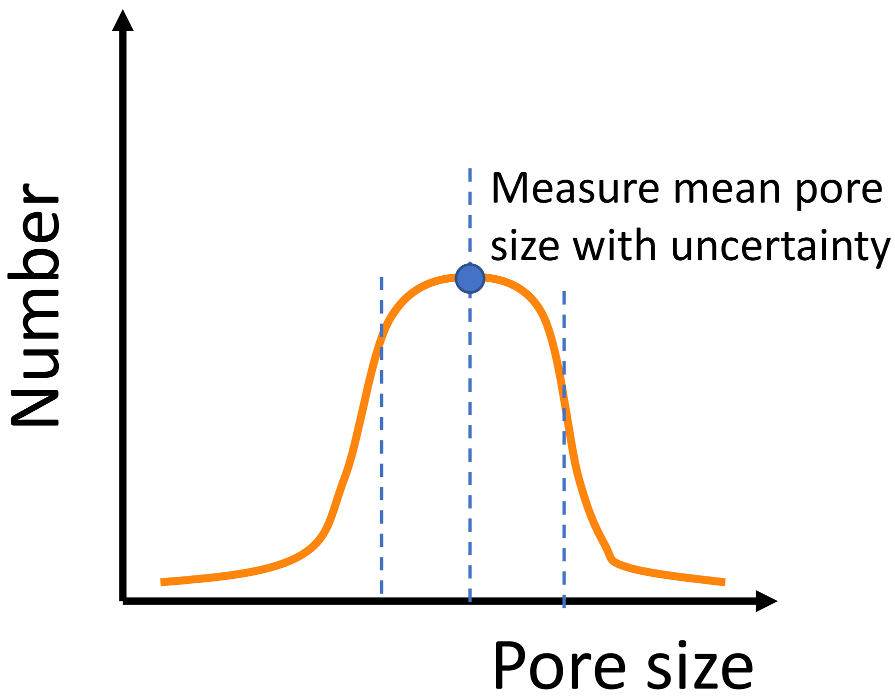


You can create solutions where you vary just viscosity or surface tension while keeping the other constant by combining 3 liquids e.g. water, glycerol, ethanol, sulfuric acid etc.

Size of the pores

Can be measured by taking a photo of a sponge under a microscope/very zoomed in and measuring a lot of pores in Tracker.



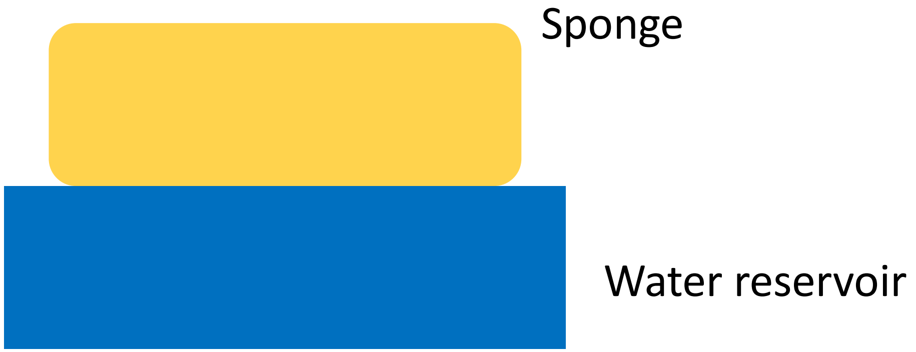


Investigate how effective a sponge is at drying a wet surface.

③ Experimental investigation of the effectiveness.

Experiments

First, verify the relationships from the papers

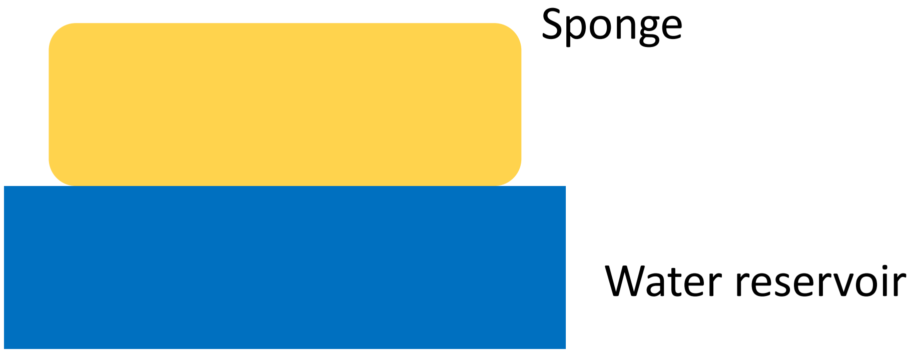


Measure the height of liquid in the sponge against time, take photos at various times.

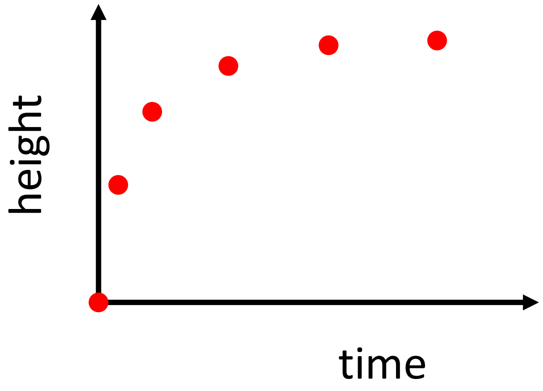
Note: to avoid experimental complications, measure it with a thin slice of a sponge.

Experiments

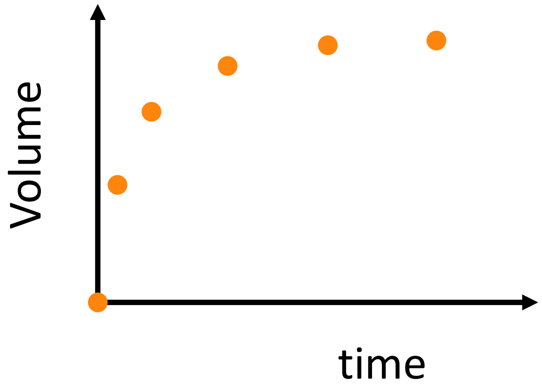
First, verify the relationships from the papers



Desired output for different fluids:



or



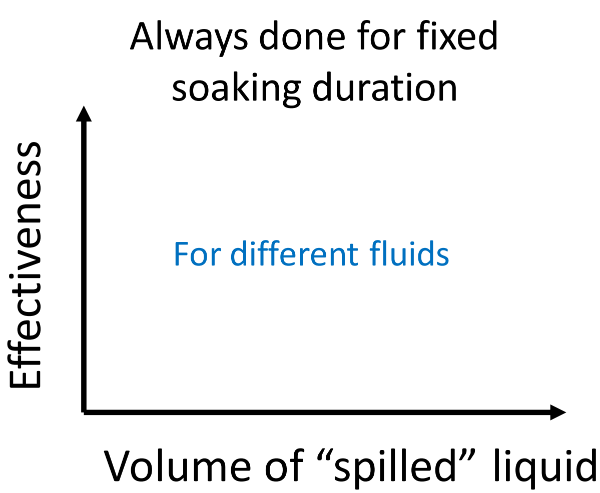
Experiments - Effectiveness

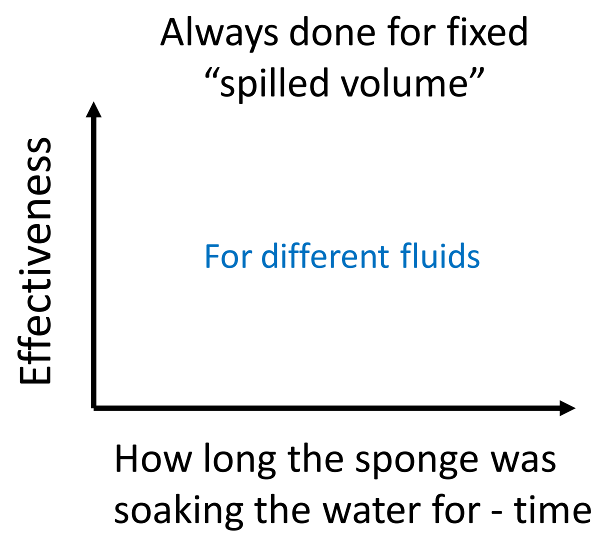
Optimisation problem

① Define Effectiveness for example: $\zeta = \frac{\text{Volume soaked by a sponge}}{\text{Total "spilled" volume}}$

② Perform quantitative experiments

measure each point multiple times and take mean and standard deviation, always label the data so it can be reused afterwards

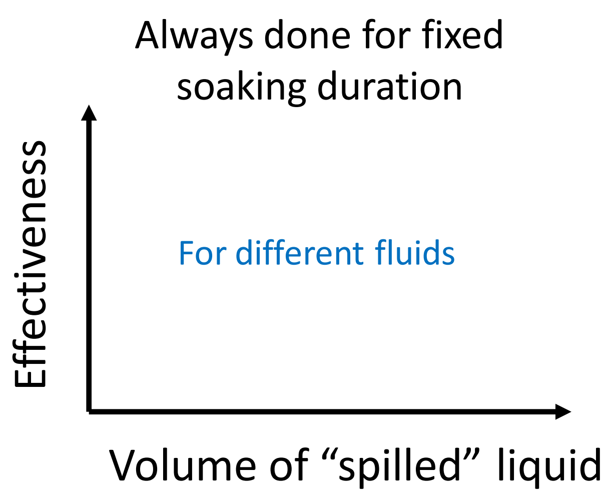


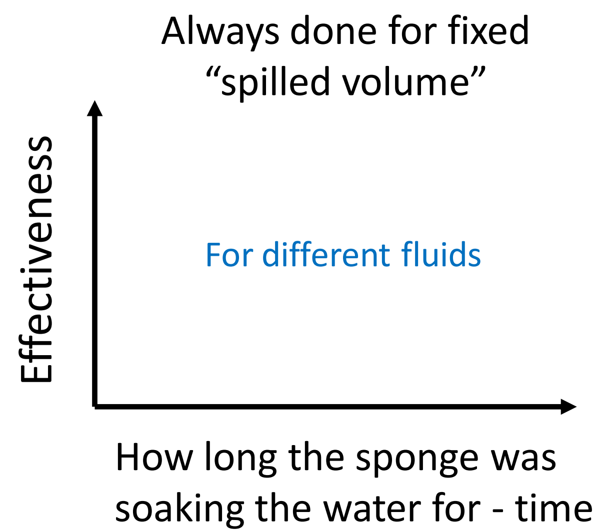


Experiments - Effectiveness

2 Perform quantitative experiments

measure each point multiple times and take mean and standard deviation, always label the data so it can be reused afterwards





Be careful to make the experiments repeatable → always do them the same way

If you have small amounts of spilled liquid → do the experiments quickly so evaporation has little effect

Something different?

First make sure you have done the basics and have a proper understanding of them

Additional experiments

Interesting to see what happens with different sponge. It can be expanding while soaking or not…see what happens. You can follow the Science Advances paper .

Expanded theoretical model

You can try to obtain a sophisticated theoretical predictions than just proportionalities. By modelling the flow in COMSOL or creating your own more advanced capillary model, though it can be difficult.

Summary

- Read papers mentioned in this presentation and on stemfellowship website, read the papers that these papers are citing
- Verify the results obtained by Kim et. al.
- Build a setup for repeatable effectiveness experiments: control amount of spilled liquid, measure volume of soaked up water.
- Modify the theory in the papers/make your own and compare it with your experiments.

Most important: label your data, save it, keep organised!