2023/24
Science Society
Newsletter
November 2023

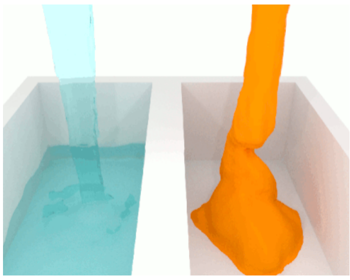
Rat's Monthly Science Quest - November (Field: General Science)
Is philosophy a science? *(1997 International Philosophy Olympiad)* Write an essay or share your thoughts to s201901056@ccchwc.edu.hk. Lucky participants can get a small gift from the Science Society!

Toothpaste Rheology and Fluid Dynamics

「蓋將自其變者而觀之，則天地曾不能以一瞬。自其不變者而觀之，則物與我皆無盡也，而又何羨乎？」《前赤壁賦》蘇軾

Fluid dynamics and specifically viscosity is an interesting topic. One can research how to make a perfect Takoyaki (https://www.shueisha-int.co.jp/pdf/takoyaki.pdf) or how to design a container to allow people to drink yogurt cleanly by considering dead zones in chemical engineering. One can also research **toothpaste**.

When we pinch the toothpaste and squeeze it, the toothpaste is still stripe. This is due to the fact that toothpaste is Bingham fluid. What do the properties come from? We will discuss it today. When we squeeze toothpaste, the content flows as a whole and is extracted from the nozzle, which offers the stripes we see. Here comes the problem: Toothpaste is soft as the fluid, right? Thern why is it not mixed in the tube? We need to consider the nature of fluid.



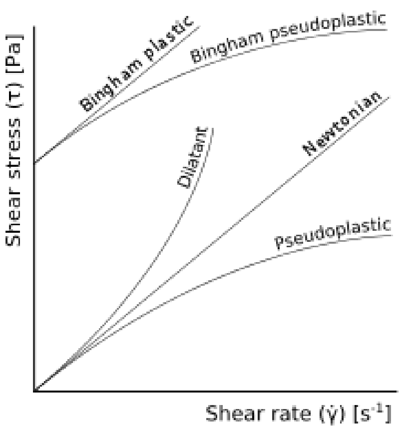
We know that matters exist in three states: Gas, liquid and solid. Liquids and gasses are categorized as fluid. Solid can hold their shape but fluids change shapes and flow.

The viscosity of a fluid is a measure of its resistance to deformation at a given rate. All fluids can be broken down into Newtonian and non-Newtonian fluids. The viscosity follows **Newton's law of viscosity**. To keep it simple, the viscosity is independent of external force. Do you know which fluid has higher viscosity in the bottom image in the previous page??

The viscosity of non-Newtonian fluid changes with shear rate. Shear (**剪切**) in liquids is not what it seems. It is neither cutting with shears, nor is Ctrl+X. For example, if you cut a paper with a pair of scissors, the scissors blade exerted on the paper with two forces which are in opposite directions (by Newton's third law).

When we stir a fluid with a glass. The fluid layer adjacent to the glass rod moves forward. The nearby fluid layers slide relatively to it producing backward resistive forces due to viscosity, which is exactly similar to cutting paper with scissors.

Therefore, stirring and squeezing toothpaste, which make the fluid layers slide relatively, are called shearing. Non-newtonian fluid can be categorized as follows:

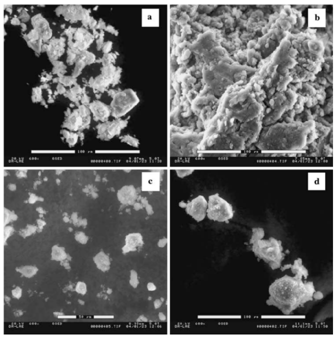


For example, do you know which kinds of non-newtonian fluid oobleck and ketchup are? Toothpaste is the most special Bingham fluid, which has a critical shear stress. If you squeeze it with a force less than the critical value, it is solid. When the force exceeds the yield stress, it suddenly becomes fluid, which can be explained by the Bingham-Papanastasiou model or Herschel-Bulkley model (Check them by yourself if you are interested).

In recent years, some researchers classified toothpaste as Casson fluid. To put it simply, a shear thinning Bingham fluid. Feel free to research it if you are interested.

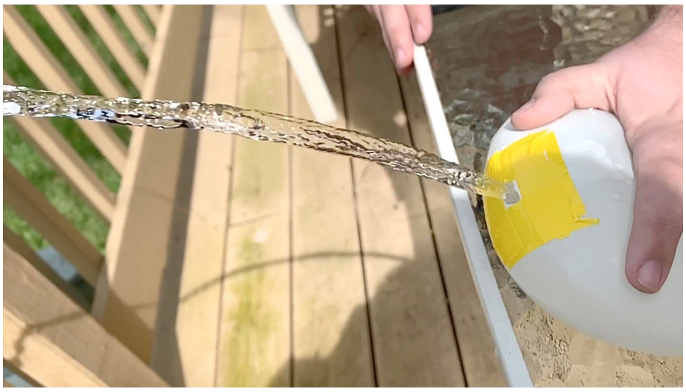
Why do Bingham fluids have this suspicious characteristic? Back in 1916, Bingham himself explained this in his ground-breaking work. The solid particles in the suspension, which create a network structure that gives it solid-like yield stress at rest. When the external force exceeds the critical value, the particle network breaks into smaller structures, which begin to flow and viscosity decreases.

Toothpaste contains inorganic abrasive particles suspended (as shown as right) with water, humectants like sorbitol, glycerin and thickeners such that HEC and carrageenan, behave magically as Bingham fluid. So if you leave it alone, it is nothing but a solid and it won't mix for a year.



After you squeeze it wildly, the content flows, but the stripes still won't mix. Why is that? We have to study the nature of flow. There are few types of flow, like brooks, cascading into pools and whirlpools. Then how does toothpaste flow? In science, what is used to describe a fluid flow situation? The answer is Reynolds number, which is a dimensionless quantity defined as $Re = \frac{\rho u L}{\mu}$.

If $Re < 2000$, the fluid is laminar flow, the layers do not interfere with each other (as shown in the figure) and flow forward smoothly and regularly. When $Re > 4000$, it is a turbulent flow, with irregular changes in pressure and speed. Layers diffuse and mix and are often accompanied by eddies (as shown below, which is Jupiter's Great Red Spot)



There is the transition between laminar flow and turbulent flow. For example, after a candle is extinguished, we can see the transition from laminar to turbulent. Reynolds number shows us a simple yet magical law: *Flow speed can actually determine the properties of fluids.* There is an essential difference between fast and slow water. It will go from regularity to chaos, from calm to restless, from axial movement to radial propagation and even the equations will go from easily being solved to having no solutions.

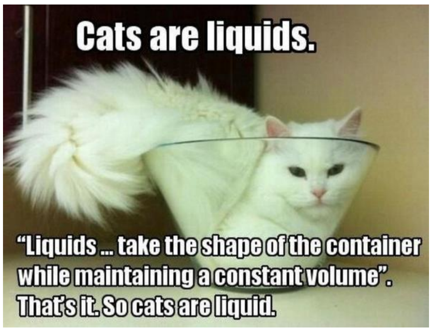
What is the situation of the toothpaste when squeezing it? In toothpaste, we have $\mu = 300\, Pa \cdot s,\ \rho = 2g/cm^3,\ d = 8mm,\ u = 1cm/s.\ Re = 0.0005$. This laminar flow cannot be more laminar. Therefore, toothpaste is a laminar flow when squeezed. All layers of toothpaste do not interfere with each other, flow independently and parallelly forward. So color stripes will not be mixed.

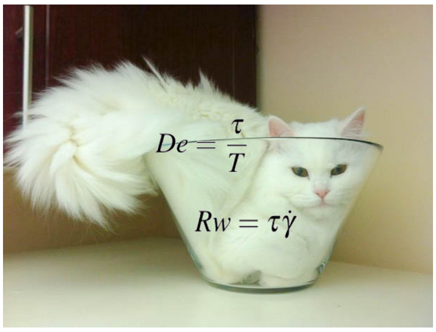
If you really want to squeeze toothpaste into a turbulent flow and mix it, just spray the toothpaste at a speed of $75000\, m/s$, which is just 4.5 times the third cosmic velocity.

Whether a matter changes or not depends on the time scale on which you observe. If there exists a creature who can observe the Earth on the scale of tens of thousands of years, the growth of mountains and the movement of the land become constant flows.

Reiner defined a dimensionless number called **Deborah number**, $De = \frac{t_c}{t_p}$. The boundary between solids and fluids have since been blurred, mainly depending on the time scale of your observation. On a long time scale, solids also seem to be flowing. In an instant, fluid seems to be solid hard. This thought process has gone beyond science and entered the field of Philosophy. It went back to the quote at the beginning of this newsletter.

Relaxing Zone





5				9	2			8
				4			7	
4			5				6	9
								6
			7					
	8				3			2
				3		6		
	3	5		6	7			1
				8				

Solutions will be uploaded to Science Society Instagram account @ccchwc_science_society

2023-2024 Science Society
TIC: Mr. Lau CK
Chairperson: 5D Lee Yiu Sing
Vice Chairperson: 5C Lee Tsoi Ying, 4D Chan Ho Ming, 4D Wong Ho Yin
Committee Members: 2E To Chi Hon, 3A Mak Ho Long, Joshua, 3A Man Hoi Ching, Ruby, 3A Wong Tsz Wai, 3B Lee Kwan Ho, 3C Au Man Hin, 3C Wong Chiu Chung, 4B Wong Ho Yin, 4B Yiu Cheuk Wang, 4C Law Ka Yan