The Unexpected Physics of Ketchup

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You are seated at a table in a diner. The chips arrive and you eye the glass Heinz bottle before you. You reach out and flip the bottle upside down, watching apprehensively as the thick tomato paste slides down at a snail's pace. It stops at the neck, its descent suspended by some invisible force. You thump the base of the bottle. Nothing. Try again. Disappointment. Against your better judgement and past experience, perhaps a violent shake will do the trick. A hungry creature lives dangerously – there's a fine line between a successful dollop and a fateful wallop. A brief thought, a momentary action and an everlasting aftermath. History repeats itself; the Great Ketchup Disaster strikes yet again as you become another victim of self-sabotage and a ruined meal. Maybe you were just unlucky today. After all, it might be better next time. Or will it?

The ketchup user experience of all-or-nothing is a frustration which resonates globally. Surely, failing to get those last dribs and drabs out, or worse, the embarrassment of flooding your plate, is enough to put people off such a catastrophe. However, the fact that we keep reaching for our favourite utterly destroyed tomatoes really shouldn't be a surprise. After all, we have the existence of Christmas ice-skating, a prime opportunity for public humiliation during the festive season.

Despite the shared struggle against ketchup, we often overlook how weird its behaviour is. We are so used to pouring this troublesome condiment that we simply accept its stubbornness without question and hope for the best. Ketchup presents a mystery which can only be answered by science: *why is it so incredibly difficult to pour?*

Why is Ketchup So Hard to Pour?

The distinctive behaviour of ketchup is seen when you shake or tilt a bottle – it seems to be neither solid nor liquid, but rather a sort of in-between substance. This quirk can be explained with rheology, the study of fluid flow behaviour (and the field of ketchup scientists).

The viscosity of a fluid describes its internal resistance to flow as the ratio of the shear stress (F/A) to the velocity gradient (dv_x/dz). Newton's law of viscosity states that the shear stress between adjacent fluid layers is proportional to the velocity gradient between them. In other words, the viscosity law states that a fluid's shear and therefore flow speed is directly proportional to the applied force, where the viscosity is the constant of proportionality η [1]. This is similar to Newton's second law of motion ($F=ma$):

$$\frac{F}{A} = \eta \frac{dv_x}{dz} \quad \Leftrightarrow \quad F = m\frac{dv}{dt}$$

Water, oils and alcohols are Newtonian fluids – they have constant viscosity and respond to force linearly so they pour like a dream. Ketchup, on the other hand, pours like an absolute nightmare; as a non-Newtonian fluid, it rebels against Newton's law of viscosity with messy consequences. Non-Newtonian fluids become thinner or thicker in viscosity as their behaviour depends on shear rate (force) or time. There are 4 types of non-Newtonian fluids and ketchup is classified as a "shear thinning fluid".

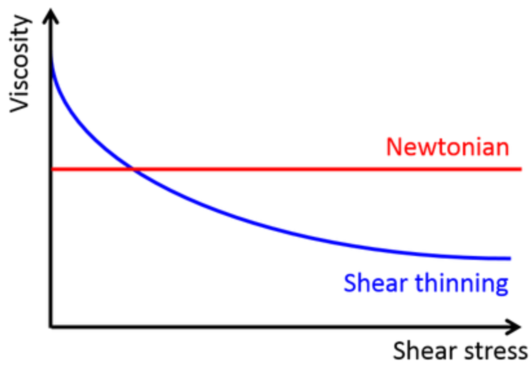

Fig. 1. A graph of viscosity against shear stress for Newtonian and non-Newtonian shear thinning fluids like ketchup [2].

As a shear thinning fluid, ketchup exhibits two 2 non-Newtonian characteristics:

1) Sudden thinning at a threshold force:

The greater the force you apply, the thinner ketchup becomes (Fig. 2). Ketchup acts like a solid until the applied force exceeds a certain threshold point, where its viscosity suddenly decreases, resulting in a drastically thinner substance than before. This is why moderate violence is often used to release ketchup from its glassy prison – the force from a hard hit to the bottle overcomes the critical stress point. However, this method can be fatal as it causes the ketchup to flow very quickly, triggering an uncontrollable cascade of sauce.

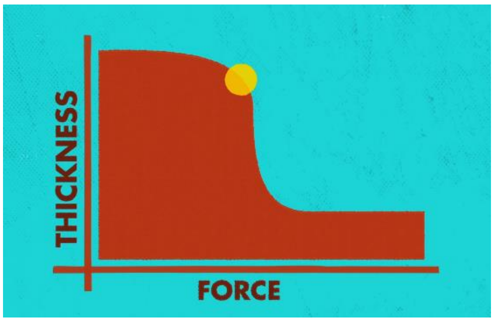

Fig. 2. A graph of thickness against force for non-Newtonian fluids like ketchup. The yellow circle marks the threshold point, at which sudden thinning occurs [3].

2) More gradual thinning after a small force is applied for a long time: Even if the applied force is below the threshold force, the ketchup will eventually start to flow after a while. In this case, time, rather than force, is the factor which determines the pouring of ketchup from the bottle.

Fig. 3. Over time, the applied force causes the ketchup to flow even if the threshold point is not reached [3].

How to Actually Pour Ketchup

Although an almighty whack is not the only method, the gentle approach is a test of patience, usually the last thing a person who wants their ketchup has. Thankfully, scientists have investigated the dilemma of pouring ketchup out of glass bottles, and the best techniques to do so. Not all heroes wear capes.

All approved methods begin with a good shake of the bottle. Not only does it add the necessary force, it also re-homogenises (mixes) all the suspended particles evenly so that no watery mixture, or “serum” as it is known in the industry, can thwart your meal.

The Heinz Secret

As the brand which rules over all in the ketchup kingdom, Heinz designs glass bottles with user efficiency in mind. Who would have thought? It turns out that the official pouring method is to shake the bottle and then tap the sweet spot on the neck, where the number 57 is embossed (Fig. 4). From personal experience, this approach has been confirmed to be effective.

Although this is not exactly a secret per se, the Heinz trick might as well be one since it is so unknown – only 11% of people are aware of it [4]. Heinz scientists have discovered that the iconic ketchup flows at 0.045 km per hour, and any ketchup which exceeds the standard viscosity is rejected for sale [4].

Fig. 4. The sweet spot of a Heinz glass bottle [5].

The Best Scientific Solution

Dr Antony Stickland of the Melbourne School of Engineering drew upon his expertise in rheology to present the ideal solution to the sticky situation in three key steps:

1. "Briefly invoke your inner paint shaker" by shaking the bottle with the cap on.

2. Turn the bottle upside down (still with the cap on) and "thrust downward at high speeds, accelerating both the ketchup and the bottle". Stopping the bottle quickly should cause the ketchup to collect in the neck. A single "strong whack" may be needed to dislodge the ketchup from the bottom.

3. This is where things get tricky. In summary, one should remove the cap, tilt and pour. In more detail, the amount of force required depends on how full the bottle is. Tilting a full bottle is an easy path to success as the weight of the ketchup pushes down due to gravity. A nearly empty bottle poses a risk as it involves more effort. To tackle this, hold the bottle by the neck with one hand at a 45 degree angle, tapping the bottom firmly with the other hand. Be warned that only the brave can do it entirely upside down.

It must be noted that the above method was only devised using the knowledge of physics, without experimental proof [6]. Although this may be good enough for theoretical physicists, it is a given that the ultimate solution to the condiment conundrum should tested experimentally for real life applications. An official experiment in ketchup decantation has not yet been conducted so only methods developed through trial and error, or theoretically, shall suffice in the absence of data.

The Physics Department of the University of Illinois at Urbana-Champaign suggest another pouring method which was technically proven by trial and error. The order of the tilt and shake is different to that of Stickland's theoretical solution. Instead, they propose that for optimal results, one should "tip the ketchup bottle at about a 30-degree angle with respect to the horizontal" with the neck aimed at the target. This should then be followed by a shake in a "mostly vertical direction", or rotations about its centre of mass. Like the previous approach, this ensures that swiftly halting the bottle's downward motion creates an upward acceleration large enough to free the ketchup. The specified order of action allows air to enter the bottle, past the plug the ketchup forms in the neck [7].

Fig. 5. A Heinz advert depicting the angle of the perfect pour with an off-angle label [8].

The inhibition of ketchup to flow through the narrow bottle neck is due to both high static shear strength and air blockage. The first goal is to induce shear thinning, giving the ketchup a sort of solid-to-liquid makeover. Sideways forces are more likely to induce shear thinning. During the pouring process, the ketchup in the bottle is displaced by air. This means that holding the bottle vertically upside down squeezes air up one side of the neck and ketchup down the other. Which side of the neck is chosen is a matter of spontaneous symmetry breaking; the ketchup will not have a smooth exit if the choice of which side to flow down awaits it. The second goal is therefore to "break the symmetry deliberately, allowing both gravity and the external acceleration to force the ketchup in the plug down one side of the bottle's neck in preference to the other" – this explains why the angle between the shaking direction and the bottle is necessary [7] .

The Evolution of Ketchup Containers

The Past

The classic Heinz bottle is an iconic design which debuted on the global stage in 1876. During this time, other manufacturers packaged their product in barrels to conceal the use of cheap fillers, of which turnips were a popular choice. With a sleek glass figure, the Heinz ketchup bottle flaunted the purity and quality of its contents, inadvertently dooming millions to public humiliation. Ironically, the narrow neck was designed for ease of pouring, and also minimised oxidation of the ketchup to maintain its crimson hue [9].

The frustrating ketchup user experience of all-or-nothing presented a critical problem, prompting innovation in container design. Ketchup packets were introduced in 1968 but failed to become popular at the kitchen table, with fast-food chains remaining their dominion to this day. Plastic squeeze bottles joined the competition in 1983. Despite releasing ketchup much more efficiently than their glass counterparts, they tended to make amusing noises when squeezed and created unappetising, watery squirts when nearly empty. Plastic squeeze bottles were just as unpredictable as glass ones, with users facing the same issues of lack of control [9].

The glass bottle design reigned until the plastic squeeze bottle problem was solved with the invention of a silicone valve in 1991. The valve design was originally used for shampoo and was sold to ketchup companies later on. This valve was cut with right-angled slits which opened when the plastic bottle was squeezed, enabling a neat flow of ketchup. The slits closed back up afterwards to seal the condiment within the container. As a result, the plastic squeeze bottles with valves became much more convenient and soon outsold the glass bottles. Heinz's main rival, Hunt's, incorporated this valve when they brought upside-down bottles to the world in 2002. Their ketchup caps featured "a new grooved section that trapped ketchup juice and mixed it back in with the ketchup" [9].

Fig. 6. An explanation of the difference between UI design (User Interface) vs. UX design (User Experience) with ketchup [10].

The Present

Although the squeeze bottle is a popular choice of ketchup packaging for good reason, glass bottles which offer inferior user experience are still common and often feature at restaurants today. This beckons the question: *Why do glass bottles still exist in this day and age?*

There are a few reasons why glass bottles are still spotted in restaurants, even though they generally prioritise customer service and experience. Firstly, Heinz usually sells ketchup bottled in glass to foodservice establishments. Aesthetics is a key factor; glass looks classier than seemingly cheap plastic. After all, most restaurants besides fast-food places opt for glass cups over plastic or waxed paper ones although they would all do the job just fine.

Glass ketchup bottles are also more economical as they can be easily refilled from a larger container and washed in a commercial kitchen. Even the labels on glass bottles are heavy duty as they are made to withstand the cleaning process. Purchasing disposable plastic bottles is more expensive, and packets are the most wasteful as people only use a couple of the handful they are given before throwing the rest away. Fancier restaurants tend to avoid glass bottles altogether by serving sauces in small pots, sparing you any shame other than having to ask for ketchup in the first place.

As humans, we have an instinctual preference for glass over plastic as we subconsciously perceive the contents of a glass bottle to be of higher quality, for the same reason we value aged alcohol. Our instinct equates slow with better, which is why we tend to choose things which take longer to prepare if given a choice, such as picking a meal which took all day to cook over one that was made in minutes [11].

Subsequently, the commercial industry exploits the idea that glass containers are superior – the sales of glass coke bottles skyrocketed when they were reintroduced as a premium product, with 41% of people believing that the product tasted better in glass than plastic [11]. For this reason, much of Heinz's advertising costs have gone into convincing consumers to use glass over the past few decades. An iconic 1970s Heinz advert focusing on the agonising wait for ketchup to emerge from the bottle even featured Carly Simon's song "Anticipation", later dubbed "The Ketchup Song". Whilst it seems bizarre to promote a product as a source of frustration, it seems that Heinz did indeed know what they were talking about by applying human psychology [11].

The Future

Despite the progress which has been made in the ketchup field, one drawback remains: You can never squeeze all the ketchup out of the bottle. This also happens with other non-Newtonian fluids, including toothpaste and shampoo. Luckily, an answer to this issue has been found, and will hopefully become commonplace in the future. A team of ketchup-loving scientists at MIT have made the non-stick bottle a reality. The inside walls of the vessel are lined with LiquiGlide, a highly slippery coating which makes every last drop of ketchup attainable. By enabling viscous products to flow smoothly, LiquiGlide optimises flow efficiency, and could cut down huge losses across industries, saving tonnes of product from wastage [12].

Fig. 7. A demonstration of LiquiGlide, an invention which makes non-stick bottles a reality [12].

The Takeaway

Viscosity is a crucial characteristic in food production; it is essential for not only consistent product quality, but also for understanding the behaviour of fluids during the processes of pumping and mixing [13]. Foods like ketchup often have particular rheology to achieve the right texture so concentrated suspensions do not obey Newton's law of viscosity.

The next time you encounter a glass bottle of ketchup, do not fear. Remember that to get that shear-thinning ketchup out neatly, you need to apply force. But don't go all out on the bottom of the bottle. The general advice is to shake, tilt, maybe hit, then pour. If all else fails, stabbing the ketchup with a knife can stir it locally and decrease the viscosity near the opening, although that is a great way to spark a red avalanche. Or you could save yourself the hassle and just use the plastic squeeze bottle.

Fig. 8. The infamous 1980s Heinz slogan shown in an advert featuring Joey from *Friends* before he became Joey from *Friends* [14].

BIBLIOGRAPHY

Cover Page: Ball. R. Still Life Link. Available: https://www.ryanballphotography.com/ Accessed on Dec. 16, 2019.

[1] G. Elert, "Viscosity", *The Physics Hypertextbook*. [Online] Available: https://physics.info/viscosity/ Accessed on Dec. 13, 2019.

[2] K. Kwon, "The Ketchup Conundrum and Molecular Dynamics: Unraveling the Mystery of Shear Thinning." [Online] Available: https://softbites.org/2018/12/05/the-ketchup-conundrum-and-molecular-dynamics-unraveling-the-mystery-of-shear-thinning/ Accessed on Dec. 13, 2019.

[3] G. Zaidan, "Why is ketchup so hard to pour?". [Online] Available: https://www.youtube.com/watch?v=KB43fM_ozKQ Accessed on Dec. 13, 2019.

[4] "Heinz Trivia: Tomato Ketchup". *Heinz*. [Online] Available: https://www.heinz.com.hk/en/trivia/tomato-ketchup Accessed on Dec. 20, 2019.

[5] N. Oakley, "There's a secret trick to get Heinz ketchup out of the bottle - but only 11% of people know about it." *Mirror*. [Online] Available: https://www.mirror.co.uk/news/weird-news/theres-secret-trick-heinz-ketchup-8441297 Accessed on Dec. 20, 2019.

[6] C. Mele, "How to Get Ketchup From a Bottle Without the Wait, Watery Goo and Splatter." *The New York Times*. [Online] Available: https://www.nytimes.com/2017/02/13/us/ketchup-bottle-pour.html Accessed on Dec. 22, 2019.

[7] "Q & A: Hitting a Bottle of Ketchup." *Department of Physics University of Illinois at Urbana-Champaign*. [Online] Available: https://van.physics.illinois.edu/qa/listing.php?id=2416&t=hitting-a-bottle-of-ketchup Accessed on Dec. 22, 2019.

[8] J. Glenday, "Heinz illustrates perfect ketchup pour with off-angle label." *The Drum*. [Online] Available: https://www.thedrum.com/news/2019/09/05/heinz-illustrates-perfect-ketchup-pour-with-angle-label Accessed on Dec. 22, 2019.

[9] M. R. McManus, "How Ketchup Works." [Online] Available: https://recipes.howstuffworks.com/ketchup2.htm Accessed on Dec. 22, 2019.

[10] P. Hansen, "UI vs UX Design Meme Problem." [Online] Available: http://www.patrickhansen.com/2017/09/01/ui-vs-ux-design-meme-problem/ Accessed on Dec. 23, 2019.

[11] M. Lindstrom, "Here for Heinz: Why The Glass Bottle Still Rules The Brand." [Online] Available: https://www.linkedin.com/pulse/here-heinz-why-glass-bottle-still-rules-brand-martin-lindstrom/ Accessed on Dec. 23, 2019.

[12] L. Kolodny, "LiquiGlide raises $16 million to get every last drop out of packages or tanks." *TechCrunch*. [Online] Available: https://techcrunch.com/2017/01/24/liquiglide-raises-16-million-to-get-every-last-drop-out-of-packages-or-tanks/ Accessed on Dec. 23, 2019.

[13] D. Bauer, "The Unexpected Physics of Ketchup: An Introduction to Non-Newtonian Fluids." [Online] Available: https://cravingsofafoodscientist.com/2019/04/17/the-unlikely-physics-of-ketchup-an-introduction-to-non-newtonian-fluids/ Accessed on Dec. 23, 2019.

[14] "Matt Le Blanc - Heinz Ketchup Commercial." *Heinz*. [Online] Available: https://www.youtube.com/watch?v=N_vssdys8lk Accessed on Jan. 2, 2019.

[15] P. J. Fellows, *Food Processing Technology: Principles and Practice*, 3rd ed. CRC Press, 2011.

[16] C.R. Daubert & E. A. Foegeding, "Rheological Principles for Food Analysis." In: S. S. Nielsen, *Food Analysis*, 4th ed. Springer, 2010. pp 541-554. DOI: 10.1007/978-1-4419-1478-1

[17] A. Tauferova, B.Tremlova, J. Bednar, J. Golian, R. Zidek &V. Vietoris, "Determination of Ketchup Sensory Texture Acceptability and Examination of Determining Factors as a Basis for Product Optimization," *International Journal of Food Properties*, vol. 18, no. 3, pp 660-669, Dec. 2014. DOI: 10.1080/10942912.2013.853186