Soft solids and the science of cake

February 24 2016, by Sarah Collins

Credit: Divulgação Petrobras, ABr - Agência Brasil

Researchers hope that working out the behaviours of soft solids, which can act like either solids or liquids, may make for tastier cakes – and safer oil wells.

What do cake batter and a massive, offshore oil drilling rig have in common? The answer lies in a type of material known as a soft solid, which can behave either like a solid or like a liquid, depending upon the stress it is subjected to. Cake batter, molten chocolate, Marmite, custard and the foamed concrete used in oil wells are all examples of these 'dual personality' materials.

Soft solids are non-Newtonian fluids, which don't adhere to the same rules as 'normal' liquids. Newtonian fluids – such as water or cooking oil – don't change their behaviour as a result of how they have been handled, such as having been mixed or being left stagnant for days. For example, if a bowl of water is mixed for an hour at high speed, it will flow in exactly the same way at the end of the hour as at the beginning.

Non-Newtonian fluids – such as custard, cake batter or foamed concrete – are different. Sometimes they behave like a solid, and sometimes they behave like a liquid. For example, move quickly and firmly enough and it's possible to walk on custard. But stop moving, and you will start to sink. This is because custard gets thicker or thinner depending on the rate at which you try to move it. This is one way in which non-Newtonian fluids differ.

However, the mechanisms that make soft solids distinctive in this way are complex and still not well understood, making it difficult for engineers to control their properties precisely. Being able to do so would open up a range of new opportunities, whether the goal is a fluffier cake or safer drilling for oil.

There are a wide range of soft solid materials, many of which are present in your kitchen. Researchers in Cambridge's Department of Chemical Engineering and Biotechnology are attempting to unravel how the structure of one type of soft solid – bubbly liquids – affects their properties, which may enable a far greater degree of control than is currently possible.

"Non-Newtonian fluids are mysterious things, and being able to accurately control their properties has all kinds of practical implications," says Professor Ian Wilson, who leads the research. "The connections between cake and concrete may not seem obvious at first, but the link is bubbles. It's amazing how widely this type of soft solid is found – we also see them in the natural world, in things like magma. What we're trying to do is to develop a simple method to describe a complex phenomenon, in order to get to the point where we can design these materials to do exactly what we want them to do."

When trying to lighten either a cake or cement, one answer is simple: fill it with air bubbles. In cake batters, this leads to a fluffier cake. In oil wells, it makes for lightweight cement which is used to fill in the gaps between the pipe and the rock to prevent oil and gas from escaping.

The fact that this approach is far from perfect was proven in disastrous terms when, in April 2010, an explosion at the giant offshore oil rig Deepwater Horizon in the Gulf of Mexico killed several workers and precipitated the largest accidental oil spill in the history of the oil industry. The subsequent enquiry highlighted that something went wrong with the foamed concrete used, and its failure was one of a series of events that led to the explosion of the rig and the massive oil spill in the Gulf of Mexico which followed.

For foamed concrete to work well, the bubbles have to be well distributed throughout the material, and they must remain stable so that they don't collapse or combine into giant holes.

Wilson and his colleague Dr Bart Hallmark have been working on a closely related, but slightly different, type of soft solid. In foamed concrete the base liquid is viscoplastic, whereas in many food products the base liquid is viscoelastic. Viscoelastic materials display both viscosity and elasticity when undergoing deformation. Adding bubbles increases the elasticity enormously – this is why cake batter climbs up your whisk when you are beating it. Much of the research in this area has focused on Newtonian base liquids, but in the food and other industries the base liquids are often viscoelastic.

Starting with honey – a viscous liquid – the researchers investigated how the amount and size of the bubbles affected its behaviour, and then attempted to model that behaviour accurately. They then moved on to gum solutions, which are used to thicken sauces. The researchers showed how the mathematical model for the base liquid behaviour – in this case, the Giesekus fluid model – responds to bubble addition.

This gives researchers a tool to understand, predict and control the properties of these soft solids. For the food industry, this may make it easier to bake moist, fluffy cakes at an industrial scale, while the approach could also be used by the huge range of industries that use bubbly liquids in their processes and products.

"By using a Giesekus model and changing the bubble size, we may be able to fine-tune the behaviours of bubbly liquids," explains Wilson. "For food production, this may help determine how a formulation or process needs to be changed to make a better cake batter: what speed to beat it at, or how best to scale the recipe up to industrial quantities so that the end product has the right structure."

However, the ramifications of this research reach far beyond the world of cakes, due to the ubiquity of bubbly liquids and related soft solids. Although foamed concrete differs from honey – it starts off as viscoplastic rather than viscoelastic – the development of models that can accurately describe these soft solids will allow engineers to design and control them, and hopefully prevent them from going wrong.

Provided by University of Cambridge