**Cellular Biophysics**
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**Department of Biology**
**Indian Institute of Science Education and Research, Pune**
**Tutorial - Part 03**

Hi, welcome back.

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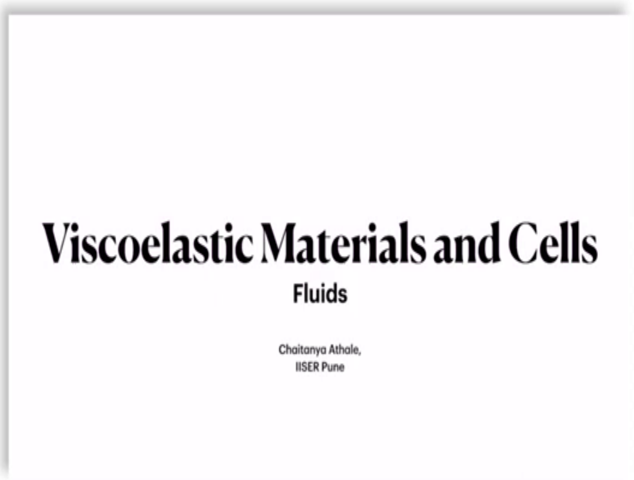


So, for the last segment of tutorial, we are going to talk about viscoelastic materials and cells. This is part of the tutorial on fluids. Now, as you recall we already spoke about Newtonians fluids, the Newton's law of viscosity, so what in some senses are viscoelastic material and we mentioned very briefly that the material, that for both solid like and liquid like properties.

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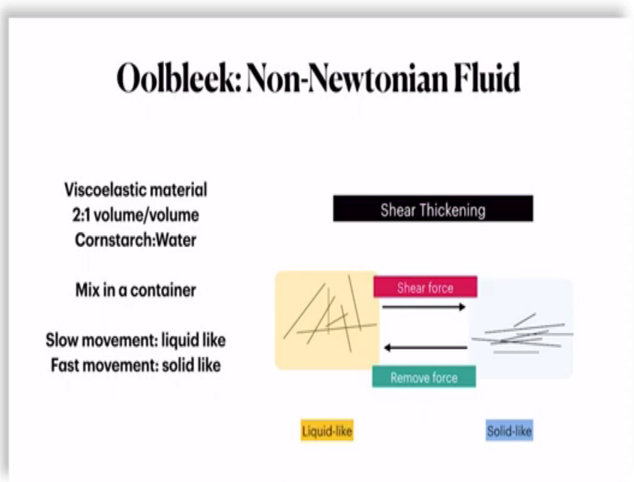

Now, Oolbleek is something that you can assemble in the kitchen, it is a viscoelastic material in the format sense. It consists of a 2 is to 1 ration volume by volume of cornstarch and water. And to do that, to prepare it you need a container to mix it, if you are in a laboratory a beaker will be fine. And a petri dish, a large petri dish in to which to pour it and demonstrate its properties. We will talk about this when this class goes live.

You can play around with this quite a bit, and you will find a lot of popular YouTube videos on this. For example, putting this Oolbleek on a plastic sheet on top of loud speaker with noise at increase frequency generates a very unusual pattern. The part that we are interested in is that when we perform slow movement, like we take a spoon and move it through the Oolbleek, it behaves like a liquid.

If we now however, try to cut it very rapidly with a high amount of force with high acceleration, you will find that the Oolbleek, this cornstarch-water mixture behaves more like a solid. And this is broadly called as shear thickening. That is to say, the shear force aligns the molecules that makeup the material creating almost a solid like geometry. When we remove the force or reduce it, then it returns to a more liquid like behavior which is disorganized and in motion.

And this can be cyclically done, you can go back and forth between solid like and liquid like, so you could argue at the nature of deformation determines what behavior you will see. A counterpart to shear thickening, shear thinning where the effect of force is the opposite instead of making of it for solid like it makes it more liquid like and instead of relieve, removed force for making it behave more liquid like, behaves more solid like. In that sense, the behavior of simple kitchen made reagents like Oolbleek maybe a bit simple.

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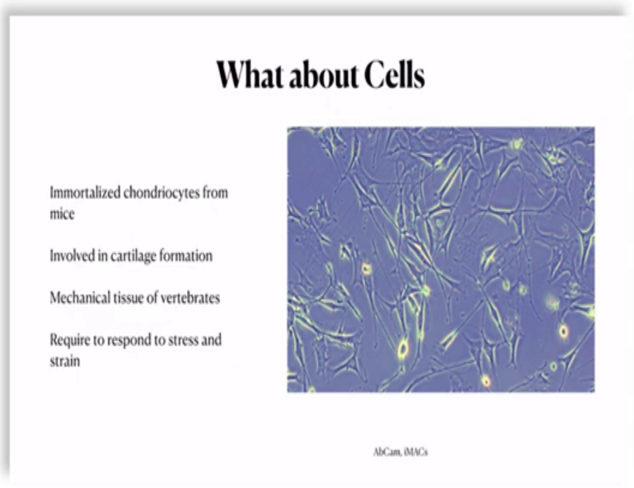


So, what about cell? Now, one of the many tissues in the human body that need to withstand stress and strain and mechanical deformation are chondrocytes, they form cartilage, and our part of the mechanical tissue in vertebrates that respond to stress and strain. Another very obvious example is muscle cells, heart muscle cells, skeletal muscle cells.

So, here you are looking at a picture of immortalized mouse artificial chondrocytes iMACs. And experiments that would done on chondrocytes in culture that demonstrate that their behavior is viscoelastic.

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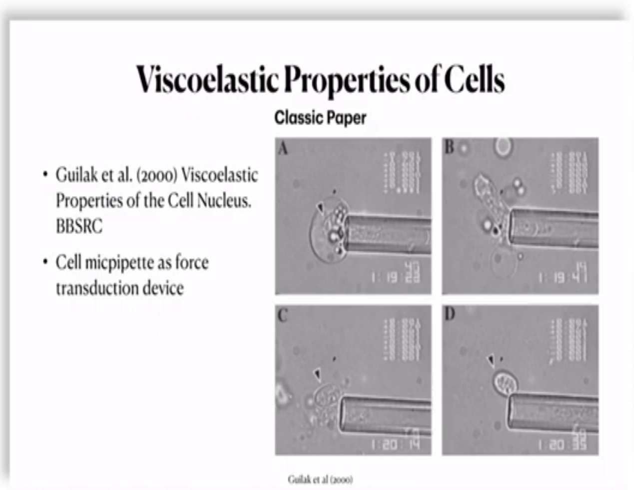


So, the experiment initially involved isolating the nucleus of a cell. So, what you are looking at in A is a whole cell, and by successive A, B, C, aspiration, expiration and aspiration,

aspiration, the workers go Guilak and company who destroy the cell body. In fact, to such a point that as you can see in D, they got a nice isolated nucleus.

The approach that they took was also compared to chemical isolation and they found very similar results in terms of morphology. How do you check that this nucleus, however, is a bona-fide nucleus, obviously you want to look whether the molecules are the correct ones inside it, the molecules inside the nucleus are nothing but DNA.

So, one straightforward way the Guilak and company team tested the validity of their method was to stain these nuclei with a DNA dye, acridine orange, today you would use Dapi or Hex. And they saw that the nuclei is bona-fine, so they went to the next step which is to modify, deform the nuclei and compare the deformation to cells, whole cells.

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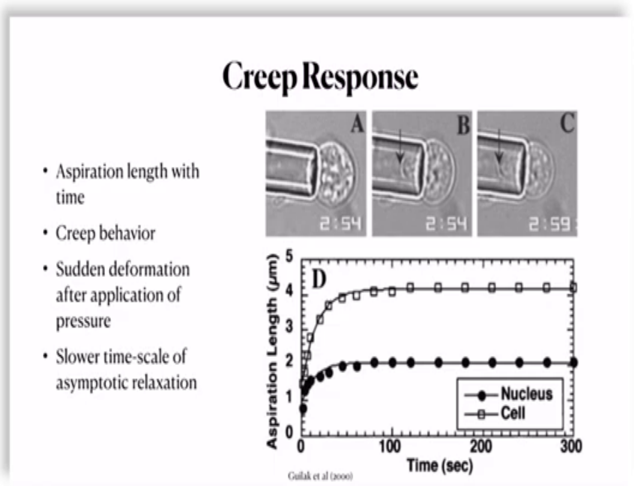


What you are looking at here is a single nucleus caught in a small 2 and 3 micron bore in a diameter micropipette chip and with a constant pressure difference applied across the micropipette. What happens as we can see that rapidly the section of the nucleus deforms where the arrow shows in D at 2.54 seconds, 2.54 minutes probably it is.

And at 2.59 minutes, 2 hours 59 minutes, in about 60 seconds, the deformation reaches the maximum and this is what they plotted in the graph below, where the aspiration length, that that is the length that enters the tubes increases initially linearly at such rates, this is true for both the nucleus and the cell. However, for the nucleus this is a far smaller range and a faster kinetic as compared to the cell.

This is initial linear deformation and slower time scale of relaxation is characteristic of viscoelastic materials and the team of Guilak and company fit a model of two elastic; constants and one dry co-efficient to estimate the modulus of elasticity of the material and the drag viscosity of the nucleus. They found that this was higher than the whole cell and it was independent, whether this nuclei were isolated or mechanically.

So, with that we end our sort of brief introduction to viscoelasticity and we will return to it at another time. With this, we end the tutorials and return to theory.

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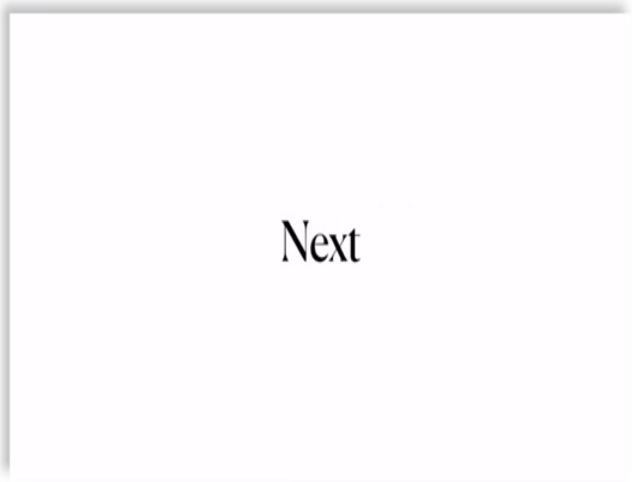


As we discussed the use of cornstarch-water mixtures can be used to demonstrate Oolbleek and Non-Newtonian viscoelasticity. So, in this following video from MIT Boston Laboratories, you will see some interesting theories that then relate to a research paper published in their lab.

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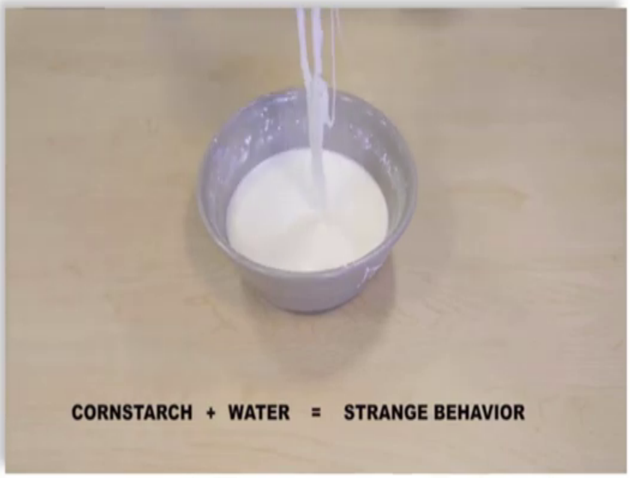
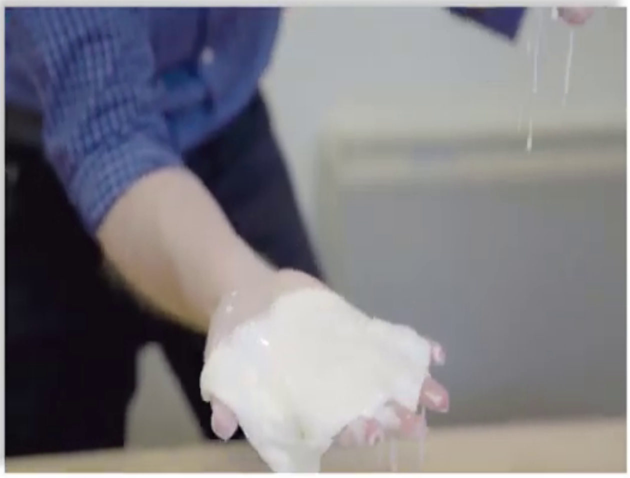
CORNSTARCH + WATER = STRANGE BEHAVIOR


CORNSTARCH + WATER = STRANGE BEHAVIOR



Video - You mix cornstarch and water, weird things happen. Swish it gently in a bowl and the mixture moves like a liquid, squeeze it and it starts to feel like paste. Roll it between your hands and it solidifies into a rubbery ball until you try to hold that ball on the palm of our hand, and it loses it structure and drip...

Professor - And this is what we referred to as shear thickening. These demonstrations are things you can do in your kitchen experiment.

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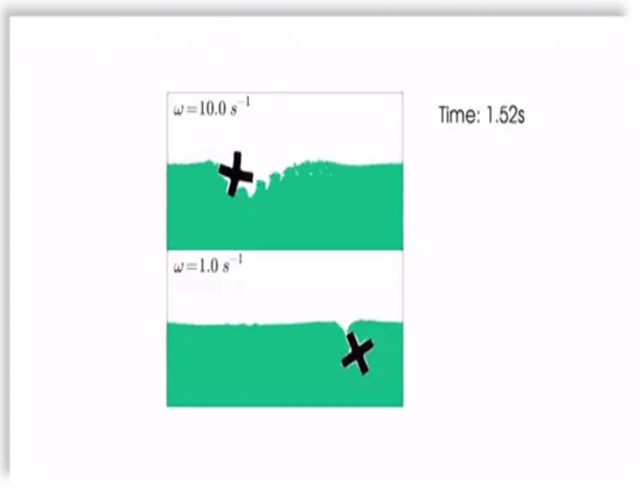


Video - dripples away. Too many who have played with this material, perhaps as children, its strange behavior is nothing new, but understanding exactly how, why and when this material will act a certain way has always been rather unpredictable, but now a team of MIT engineers have developed a mathematical model that can accurately predict this material's behavior under various conditions. A single particle of corn…

Professor - So, as you know mathematical modelling of physical system is a very common way to engineer them and this is really the crux of quantitative biology to mathematically model it using physical theory so that we can make predications and even make modification in a way that we understand them.

Now the theory that is behind this is little more complex than we have time to go into, but I recommend you to read the paper in case you are interested. This not part of your regular course work as such, but this is extra-read.

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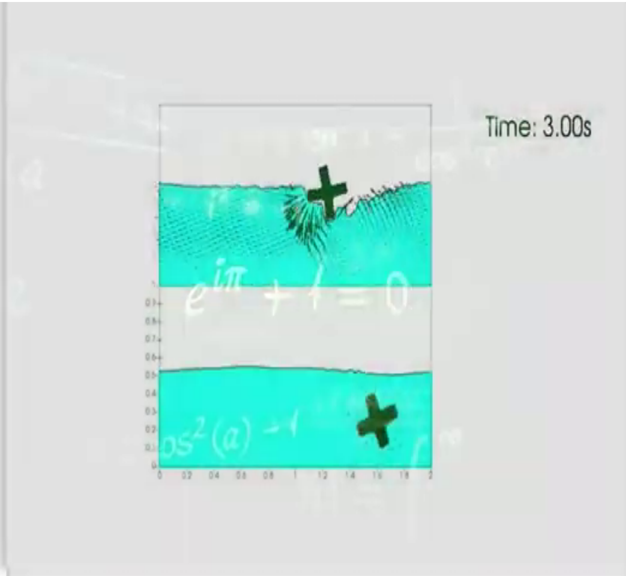
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Video: Melanie Gonick/MIT
Material simulations: Ken Kamrin and Aaron Baumgarten/MIT MechE

Video - Cornstarch is about 1 to 10 microns wide and about a 100 times smaller than a grain of sand. It turns out that particles at such a small scale experience a fix that large particles do not, because cornstarch particles are so small they are be influenced by temperature and bio-electric charges that build up between them which causes them to slightly repel against each other.

So, as long as you move slowly the grains will repel and slide past each other like a fluid, but if you do anything too fast, you will overcome that repulsion, the particles will touch, there will be friction and it will act as a solid. The researched incorporated equations into their model to describe the effects of particle repulsion and the speed it which the material is deformed.

To predict whether it would behave as a solid or a liquid under various scenarios. The researchers say the new model can be used to explore how various ultra-fine particles solution such as cornstarch model behave when put to use, as for instance, fillings for potholes or bullet proof vests.

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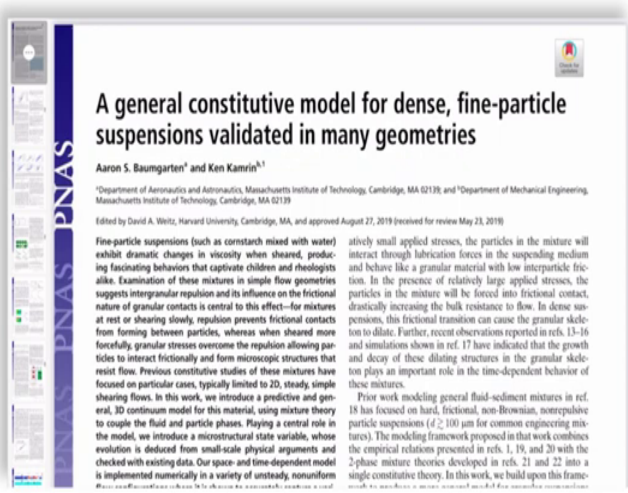

PNAS

A general constitutive model for dense, fine-particle suspensions validated in many geometries

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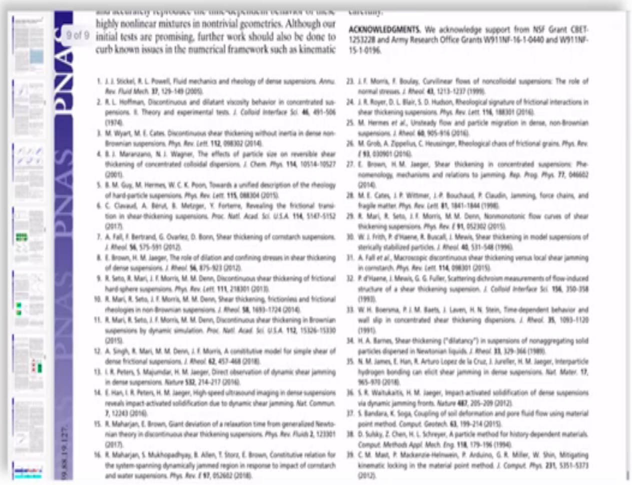
Fine-particle suspensions (such as cornstarch mixed with water) exhibit dramatic changes in viscosity when sheared, producing fascinating behaviors that captivate children and rheologists alike. Examination of these mixtures in simple flow geometries suggests intergranular repulsion and its influence on the frictional nature of granular contacts is central to this effect—for mixtures at rest or shearing slowly, repulsion prevents frictional contacts from forming between particles, whereas when sheared more forcefully, granular stresses overcome the repulsion allowing particles to interact frictionally and form microscopic structures that resist flow. Previous constitutive studies of these mixtures have focused on particular cases, typically limited to 2D, steady, simple shearing flows. In this work, we introduce a predictive and general, 3D continuum model for this material, using mixture theory to couple the fluid and particle phases. Playing a central role in the model, we introduce a microstructural state variable, whose evolution is deduced from small-scale physical arguments and checked with existing data. Our space- and time-dependent model is implemented numerically in a variety of unsteady, nonuniform

atively small applied stresses, the particles in the mixture will interact through lubrication forces in the suspending medium and behave like a granular material with low interparticle friction. In the presence of relatively large applied stresses, the particles in the mixture will be forced into frictional contact, drastically increasing the bulk resistance to flow. In dense suspensions, this frictional transition can cause the granular skeleton to dilate. Further, recent observations reported in refs. 13–16 and simulations shown in ref. 17 have indicated that the growth and decay of these dilating structures in the granular skeleton plays an important role in the time-dependent behavior of these mixtures.

Prior work modeling general fluid–sediment mixtures in ref. 18 has focused on hard, frictional, non-Brownian, nonrepulsive particle suspensions ($d \gtrsim 100$ μm for common engineering mixtures). The modeling framework proposed in that work combines the empirical relations presented in refs. 1, 19, and 20 with the 2-phase mixture theories developed in refs. 21 and 22 into a single constitutive theory. In this work, we build upon this frame-





highly nonlinear mixtures in nontrivial geometries. Although our initial tests are promising, further work should also be done to curb known issues in the numerical framework such as kinematic

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The paper relating to this study can be found in the classroom environment and it is from a journal Proceedings of the National Academy of Sciences, USA. The year of publication is 2019, the authors are Baumgarton and Kamrin. The equations as I mentioned are little complex and they go beyond the scope of this course, but you are welcome to read.