

On the Mechanical Properties of Oobleck

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Abstract

The effect of velocity on the drag force acting on a sphere moving through varying concentrations of oobleck, a suspension of cornstarch in water, was studied. A ball was pulled horizontally through the oobleck with different forces and the resulting velocity of the ball was measured. For the lowest concentration of oobleck tested, 50%, the drag force remained proportional to velocity, indicating that it acted like a Newtonian fluid. However, as concentration increased, the behavior deviated from this. For the higher concentrations, 54-56%, the velocity stayed constant no matter how great the force with which the ball was pulled through the oobleck, indicating that it had transitioned to a non-Newtonian fluid. It was also shown that drag force increases with increasing depth for the highest concentrations, likely due to the properties of the oobleck being sensitive to a small increase in pressure.

Keywords: oobleck, non-Newtonian fluid, drag force, velocity

I. INTRODUCTION

Fluids are a fundamental part of our daily lives, and their behavior has been extensively studied for centuries. Fluids are formally defined as liquids or gasses that deform continuously under shear stress. The most common category of fluids are Newtonian fluids. Newtonian fluids, aptly named after the discoverer of this physical system, Sir Isaac Newton, (not needed but leave it if you think it adds anything of value) follow a linear relationship between shear stress and shear rate. However, not all fluids behave in this manner.

Non-Newtonian fluids do not follow this linear relationship and can exhibit unique and interesting

properties.¹ One such non-Newtonian fluid is oobleck, a mixture of cornstarch and water. Oobleck can behave like either a liquid or a solid depending on the forces acting upon it.

The non-Newtonian behavior of oobleck can be attributed to its unique microstructure. As evident in figure 1, cornstarch particles are irregularly shaped and have a rough surface. When mixed with water, the cornstarch particles become suspended in the liquid creating a colloidal suspension. Under normal conditions, the mixture behaves like a Newtonian fluid, but when subjected to an external force, such as squeezing or stirring, the particles become more packed together, leading to friction between them and changing the properties of the fluid. This behavior is known as shear-thickening and is a common property of non-Newtonian fluids.¹

A study published in the Journal of Chemical Education found that the shear-thickening behavior of oobleck arises from the cooperative jamming of cornstarch particles, which form temporary frictional contacts under high shear rates.² There is a lack of understanding regarding the mechanical properties of the non-Newtonian behaviors of oobleck. This deficit in our understanding limits the application of its unique features.

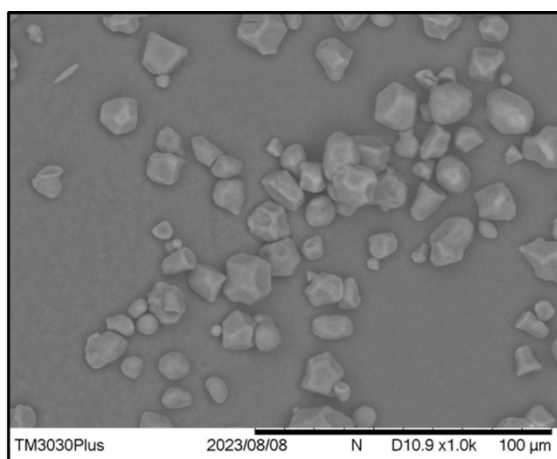


Figure 1. Cornstarch particle suspension under electron microscope.

II. METHODS

The apparatus shown in figure 2 was designed and constructed. It consisted of a rectangular container with a metal guide wire strung along the length of the container, and a pulley attached on one end. A fishing line was attached to the steel ball that was strung on the guide wire such that it was able to slide horizontally along the length of the container. The fishing line was threaded through the pulley and attached to a hanging mass. A range of hanging masses were used for the different oobleck concentrations.

Cornstarch and water were weighed using an electronic mass balance and mixed to create oobleck of five concentrations ranging from 50 to 56% mass/mass. Pre-testing of various concentrations had been done to find the range of concentrations where the oobleck transitions from

having Newtonian to non-Newtonian fluid properties. The same volume of oobleck was placed in the container for all trials.

A Vernier motion sensor was positioned below the hanging masses and the motion of the hanging mass recorded to record the motion at a rate of 30 samples a second as the ball was pulled through the oobleck. The resulting position-time graph, shown in figure 3, was then analyzed to determine the terminal velocity of the ball. as it was pulled through the oobleck. This was done for each oobleck concentration, with five to seven different hanging masses tested for each concentration and four trials for each mass.

Syrup, a Newtonian fluid, was mixed at a 3:1 sugar to water mass ratio and also tested. This was done to act as a benchmark to compare the oobleck results against the proportional relationship between drag force and velocity of a Newtonian fluid.³

III. RESULTS & DISCUSSION

The relationship between the drag force and velocity of the ball being pulled through syrup is shown in figure 4. As expected, the relationship was proportional since syrup, though very viscous, acts as a Newtonian fluid. Note the small positive x-intercept, which is likely due to friction between the ball and the guide wire.

Figure 5 shows the relationship between drag force and velocity for the five different oobleck concentrations. For the 50% concentration, it is evident from the proportional fit that at a 50% concentration, oobleck acts like a Newtonian fluid similar to the syrup. It is unknown if this trend will

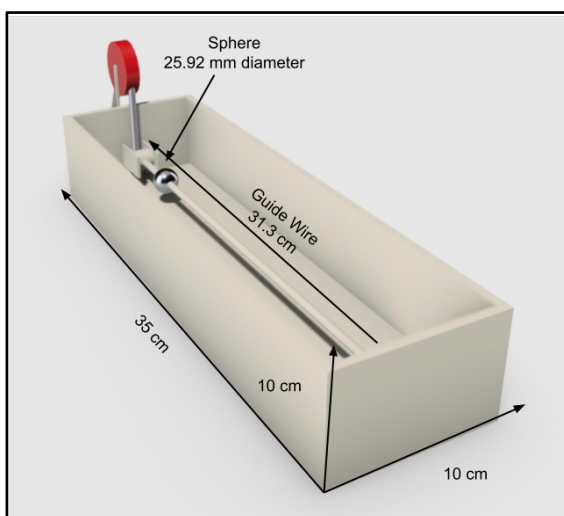
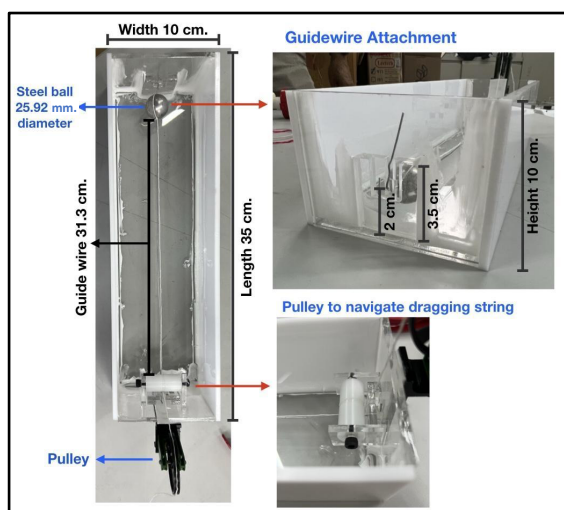


Figure 2. Details of the experimental apparatus constructed.

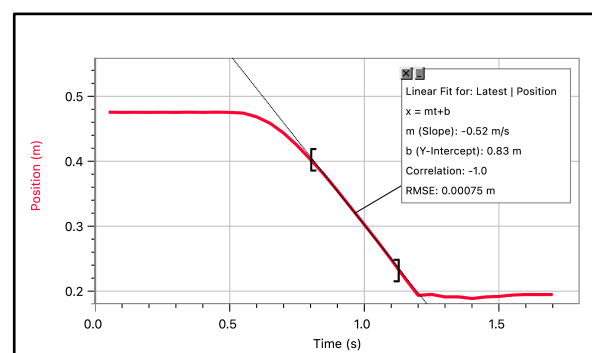


Figure 3. The terminal velocity was measured as 0.52 ms^{-1} for the ball moving through 55% concentration oobleck with a 50g pulling mass.

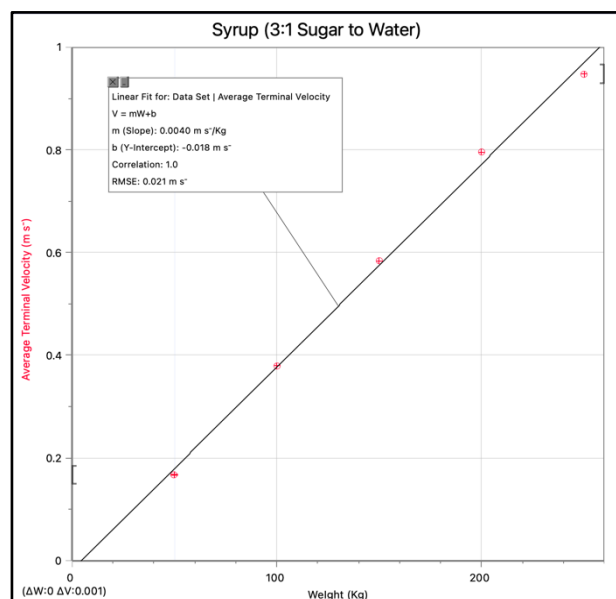


Figure 4. Relationship between velocity and drag force in syrup.

continue above the range tested. Further research is suggested to determine this.

Starting with the 52% concentration, the oobleck no longer shows a proportional relationship between drag and velocity. For the 52% concentration, the drag force increases proportionally with the velocity for low velocities. However, above 1.5 N of pulling force, the terminal velocity levels off and then actually decreases, indicating significant shear-thickening under high stress, which is a property of a non-Newtonian fluid. It appears that the transition from Newtonian to non-Newtonian behavior occurs within a narrow range of concentrations for oobleck. Further research is needed to map this transition and explain why the shift is sudden.

For concentrations above 52%, increasing pulling force had little to no effect on the velocity of the ball for the range of forces tested. The shear-thickening behavior seems to increase to match the increased stress from the pulling force, resulting in no increase in velocity. Further research is suggested with larger pulling forces for the 50% oobleck, and with pulling forces approaching zero for the concentrations above 52% to see if all of the oobleck concentrations matches the transition behavior of the 52%, just at different pulling forces.

It is interesting to note the dramatic decrease in the maximum velocity of the ball could achieve in moving through the oobleck for the different

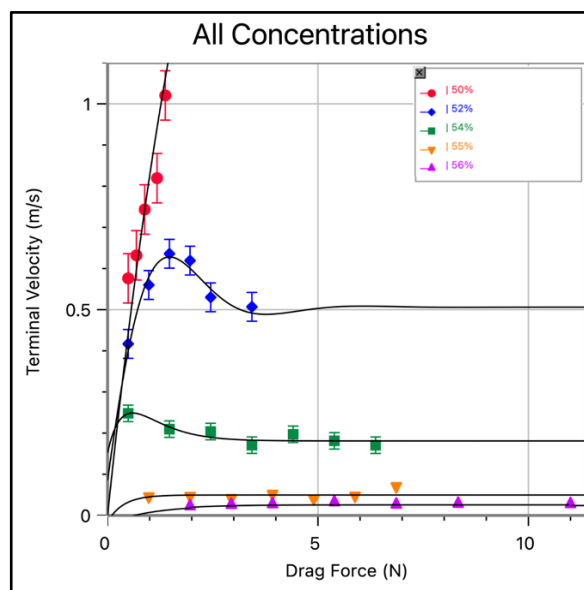


Figure 5. Relationship between velocity and drag force of the various oobleck concentrations.

concentrations. For the 52% concentration, the ball seems to have (has) a maximum velocity of $0.5\text{--}0.6\text{ ms}^{-1}$. For 54% oobleck, the maximum velocity dropped to around 0.2 ms^{-1} . Then for 55% and 56% oobleck, only a very small increase in cornstarch concentration, the maximum velocities were only 0.05 and 0.02 ms^{-1} , respectively. An 8% increase in concentration led to a 96% drop in the maximum velocity at which the ball could be pulled through the oobleck. The reasons for this decrease are not clear. Further research is needed to better understand and explain this behavior.

The position-time graphs for a trial of the 54% and 56% oobleck are shown in figure 6. It can be

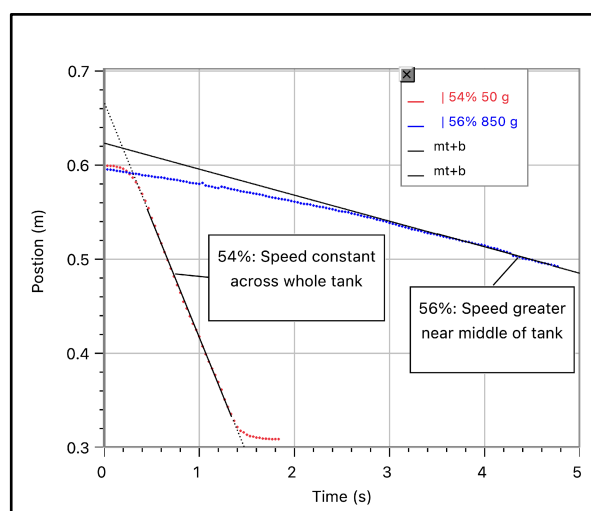


Figure 6. Position-time graph for 54% and 56% concentration trials.

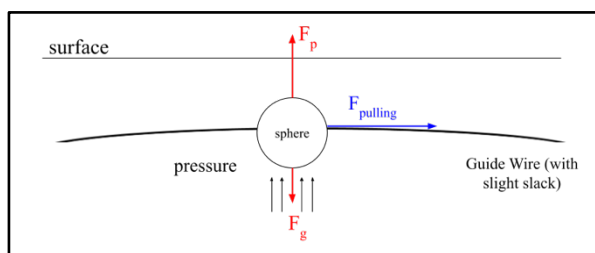


Figure 7. Forces acting on the ball in high concentration oobleck.

clearly seen that the speed for the 54% oobleck is constant across the whole tank, while the speed increases smoothly to a maximum near the middle of the tank for the 56% oobleck, as evidenced by the observed curve in the graph. It was observed during trials with higher concentration oobleck, such as 56%, the slight slack in the guidewire allowed the ball to rise to the surface of the oobleck in the middle of the container and then dive back down near the end.

Since fluid pressure increases with increasing depth, and pressure is expected to have a significant effect on the drag force for the non-Newtonian fluid oobleck, the drag force on the bottom of the ball would be significantly greater than that on the top, leading to a significant net upward force on the ball in the 56% oobleck, causing the ball to rise to the surface where the slackness of the guide wire allowed it to, as illustrated in figure 7. As the ball rose towards the middle of the container, it was traveling nearer the surface of the oobleck, where the pressure, and hence drag force, was less, which led to the increased speed seen in figure 6.

For the 54% oobleck concentration, the drag force differential due to pressure might have been less, so the phenomenon observed in 56% concentration was not observed, as the ball was observed to stay at the same depth all the way across the tank. Further research is suggested to determine how the drag force varies as a function of depth for oobleck of different concentrations,

and to determine if this is due to the increasing pressure at greater depths.

IV. CONCLUSION

Oobleck was shown to exhibit a transition from Newtonian to non-Newtonian behavior in the range of 50-52% cornstarch concentration, as evident from the shift from a linear to non-linear trend between pulling force and velocity for a ball being dragged through the oobleck. Tests of higher concentrations of 54-56% showed the purely non-Newtonian behavior of oobleck as terminal velocity remained constant as the pulling force was increased. The maximum velocity of the ball moving through oobleck was also shown to drop dramatically for the higher concentrations. Finally, there is evidence that increased pressure due to depth has a significant effect on the shear-thickening characteristic of high concentration oobleck.

V. REFERENCES

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