CREW (Climate Restorative Edible Water): Saving the planet 1 plastic bottle at a time

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Abstract:

Bill Gates is the author of the book "*How to Avoid a Climate Disaster"* which really shows the urgency of an innovative methods to reduce our carbon footprint. We may face severe consequences due to climate change by 2050, including massive animal and human casualties (Wikipedia contributors, 2022). One of the main contributors to the warming of the climate is the manufacturing of plastic, specifically plastic bottles. The necessity for plastic bottles is due to their sturdiness, temperature resistance, and their capacity to hold a liquid. Liquid encapsulation, using the process of spherification, has been adopted by high end restaurants, as a way to deliver liquid to imitate caviar, but there is a larger outlook for liquid encapsulation. This project investigates whether spherification and reverse spherification can be applied to encapsulate beverages instead of using plastic bottles. Two methods for spherification, reverse and direct, which use the same 2 chemicals – sodium alginate and calcium lactate but reverses the order were applied. The optimal size and stability of the encapsulated water and juice 'containers' was tested for their sturdiness and integrity at different temperatures. The optimal size" for direct spherification was 25 grams, for a drop height of 47 centimeters and for reverse, it was 25 grams, for a drop height of 26 centimeters. Refrigeration of the encapsulated liquid for 60 hours for direct spherification and 54 hours for reverse spherification was found to be the most effective for maintaining the integrity of the encapsulated liquid. In conclusion, the process of spherification has the potential to eradicate the usage of plastic bottles thereby preventing the release of 17 million metric tons of carbon dioxide.

Researching the Topic/ Rationale:

Climate Restorative Edible Water (CREW) is a method that this proposal accomplished to encapsulate a liquid in a clear gel also called '*spherification'*. Originally in 1940's, William J.S. Peschardt invented the technique but as more time progresses, there was a greater divergence in the methods to achieve spherification (Halford, n.d.). This idea became more prominent when a restaurant called Gaggan in Bangkok adopted the encapsulation in its menu which was part of the inspiration for this project (*Gaggan Anand Menu*, n.d.). Liquid encapsulation can have huge implications, but the most substantial cause is eliminating plastic bottles; encapsulation itself could eradicate the usage of any container for any liquid. In terms of the climate, considering that 583.3 billion plastic bottles are projected to be manufactured by 2021, and each of those bottles emits 82.2 grams of carbon dioxide (Blue, 2019). This would allow for 1,749.9 kilotons (17 million metric tons) of carbon dioxide to be pumped in the atmosphere. This proposal could prevent this massive amount of carbon dioxide from getting pumped in the first place. This project is essentially, an edible water bottle. This project addresses both the necessity for liquid encapsulation and some other creative way of replacing plastic, but also, there has been lots of chemical speculation, in terms of the ingredients necessary in obtaining spherification. This project debunks some of the theory's by creating its own method and testing some of the other methods that exist. In terms of the ingredients and quantity, Logsdon (n.d.) used a calcium chloride bath, whereas the YouTube channel Molecular Gastronomy (2013) called for calcium lactate gluconate. Also, Youssef (2019) called for a certain pH level that the liquid must be, whereas the YouTube channel Science Buddies (2021) called for a ratio of calcium to be 1:500, or 0.2%. This uncertainty was clarified in this presentation, but that was not the entire goal. This proposal also focused on measuring the different aspects of the encapsulated liquid (i.e., largest size, sturdiness, stability) and comparing these attributes to reverse spherification which uses the same methodology except switching the order in which 2 ingredients are mixed. Reverse spherification by most organizations is considered more versatile, being able to encapsulate a liquid without the pH or calcium content restriction, therefore allowing a broader range of liquids. All this data will take around two days to collect, the first day will be dedicated to finding the right ingredients to form the encapsulated 'water bottles', and the second day will be when the actual data is collected involving the two different spherification and the stability, sturdiness, and largest size.

Research Question:

The main objective of this project is to investigate if **liquid encapsulation can replace plastic bottles?** Our proposal aimed at identifying the best encapsulated ball in terms of testing different independent variables like sturdiness and maximum size. The testing was conducted by using different sized balls, and dropping them from different heights, to find the highest point in which the ball of different diameters can get dropped to remain intact. Stability was tested in different temperature conditions i.e., fridge (3°C), freezer (-14°C), room temperature (15°C), warmth (35°C). The experiment will be done by taking the ball from each of these temperature conditions and dropping from the optimal height (above) and testing whether the ball stays intact. These results will then be compared to reverse spherification. This will allow a comparative analysis of reverse spherification and direct spherification. If successful even at a small scale, the replacement of plastic bottles with environmentally friendly encapsulated water will have a dramatic impact on climate restoration. For example, the marathon runners are handed plastic bottles at certain checkpoints while running, and instead they could be handed encapsulated liquid. In one marathon in London, they used 700,000 bottles, which could have been easily saved (Nace, 2019).

Hypothesis:

The overall hypothesis is that the process of spherification and reverse spherification using two chemicals sodium alginate and calcium lactate in the appropriate quantities allows creation of edible gels to encapsulate water. Based on certain preliminary tests that were conducted before this experiment, it is hypothesized that the optimal size for sturdiness is 25 grams, and its drop height would be 40 centimeters. I also hypothesize that the sturdiest encapsulated liquid would be frozen, as it would be more resistant to a drop (*Frozen Spherification*, n.d.).. This hypothesis has two parts, the first is sturdiness and optimal size, which in terms of graph theory, I hypothesize would create a graph that would travel upward, till a point, where the balls would pop and become unusable. This project would make a graph for reverse spherification and direct spherification to find the best fit.

Independent, Dependent and Controlled Variables:

As we are conducting 2 experiments, all the variables are accumulated in this chart:

Independent Variables		
Sturdiness and Maximum Size	**Temperature**	**What?**
The encapsulated liquid ball size by using various size spoons during the encapsulation process	The temperature the ball is stored	The independent variable is the variable that is changing

Dependent Variables		
Sturdiness and Maximum Size	**Temperature**	**What?**
The sturdiness of the ball by dropping it at different heights, to deduce the maximum drop point	After obtaining results from the Sturdiness and Maximum size, I would drop the ball (which had been stored at different temperatures) at the appropriate height until it no longer remains intact	The dependent variable is the variable that is measured

Control Variables	
Sturdiness and Maximum Size	**How?**
The room temperature that the encapsulated liquid is placed in	It is important to keep the encapsulated liquids in the appropriate temperatures, because that might have an effect on the overall sturdiness of the encapsulated liquid
The increments in which the encapsulated liquid is dropped from	This is crucial, considering that if these increments are changed, you might not get an accurate result
The increments in the creation of the encapsulated liquid size	This would affect the overall shape of the encapsulated liquid, and affect
The chemicals that are used and their quantity during encapsulation	This would allow the encapsulated liquids to develop properly, and thus affecting the maximum size and sturdiness
The purity of the reagents and supplies used	If the reagents weren't clean, it would affect the chemical process, and thus

	affecting the sturdiness and maximum size

Control Variables	
Temperature	**How?**
Prevention of temperatures fluctuation	A temperature fluctuation would result in the under-development of the encapsulated liquids, and thus affecting the sturdiness
The surface the encapsulate liquid is placed on	If the surface is hard, or spikey, it might affect its intactness
The chemicals that are used and their quantity	This would allow the encapsulated liquids to develop properly, and thus affecting the maximum size and sturdiness
The timing for the reaction to occur	The timing that is given, will allow the chemicals to either over-develop or under-develop, affecting the sturdiness and maximum size
The purity of the reagents and supplies used	If the reagents weren't clean, it would affect the chemical process, and thus affecting the sturdiness and maximum size

Procedure/Methodology: Direct and Reverse Spherification

In this method, the objective is to obtain encapsulated liquid. For spherification, water mainly works, but as mentioned before, reverse spherification is more versatile, and can be used by more liquids. This experiment can be done in any ordinary science room because it requires minimal chemicals (which are safe) and doesn't require any other hazardous materials. The material list and their cost include:

Equipment	Quantity	Cost	Uncertainty
Sodium alginate	(Quantity: 1)	($9.99)	None
Calcium lactate	(Quantity 1)	($14.96)	None
Distilled water	(Quantity 2)	($28.00)	None
Safety goggles	(Quantity 1)	($9.59)	None
Weighing boats	(Quantity 1)	($15.95)	None
Weighing scale	(Quantity 1)	($14.97)	(±0.05)
250 mL beaker	(Quantity 1)	($10.59)	(±0.5)
2000 mL beaker	(Quantity 1)	($10.59)	(±0.5)
Blender	(Quantity 1)	($23.99)	None
Strainer	(Quantity 1)	($13.99)	None

Total: $173.72

In the preliminary tests, this project tried out numerous chemicals (i.e., agar, xanthan gum, sodium alginate, calcium lactate) and concluded that the mixture with sodium alginate and calcium lactate is the most feasible. Also, in preliminary tests, this project tried numerous quantities of the chemicals (i.e., 0.2% solution till 7% solution) to create the best possible outcome.

Method for Direct Spherification

1. Wear the safety goggles
2. Make a 0.5% solution with Sodium alginate and distilled water (ratio of 1: 200)
    a. Keep in mind that to make 10-15 balls, you only need 1 gram of sodium alginate

    b. Use the weighing scale and the weighing boats, to get an accurate measurement
    c. Make this solution in a 250 mL beaker
    d. Use the blender to mix well, until the sodium alginate is dissolved
3. Let this sit for 12 hours, until there are no bubbles in the solution
4. Make a 3% solution with Calcium lactate and distilled water (ratio of 1: $33\frac{1}{3}$)
    a. Keep in mind that you will need more of this solution because this is a bath. To make 10-15 balls, you need 9-12 grams of calcium lactate.
    b. Use the weighing scale and the weighing boats, to get an accurate measurement
    c. Make this solution in a 500 mL beaker
    d. Use the blender to mix well, until the calcium lactate is dissolved
5. Take 5 grams of the sodium alginate solution, place it in a spoon, and put the spoon into the calcium lactate bath. It might be hard to see the encapsulated ball.
6. Let this sit for 5-10 minutes
7. Use the strainer, and go through the calcium lactate bath, until you have found the encapsulated ball.

Method for Reverse Spherification

Reverse spherification is mostly the same, with a few minor changes:

1. Wear the safety goggles
2. Make a 3% solution with calcium lactate and distilled water or any other thick liquid (i.e., smoothie, yogurt) (ratio of 1: $33\frac{1}{3}$)
    a. Keep in mind that to make 10-15 balls, you only need 5 grams of calcium lactate
    b. Use the weighing scale and the weighing boats, to get an accurate measurement
    c. Make this solution in a 250 mL beaker
    d. Use the blender to mix well, until the calcium lactate is dissolved
3. Make a 0.5% solution with sodium alginate and distilled water (ratio of 1: 200)
    a. Keep in mind that you will need more of this solution because this is a bath. To make 10-15 balls, you need 2-4 grams of sodium alginate.
    b. Use the weighing scale and the weighing boats, to get an accurate measurement
    c. Make this solution in a bowl
    d. Use the blender to mix well, until the sodium alginate is dissolved

4. Let this sit for 12 hours, until there are no bubbles in the solution
5. Take 5 grams of the calcium lactate solution, place it in a spoon, and put the spoon into the sodium alginate bath. It might be hard to see the encapsulated ball.
6. Let this sit for 5-10 minutes
7. Use the strainer, and go through the sodium alginate bath, until you have found the encapsulated ball.

Sturdiness & Maximum Size: measured in the height dropped, and in centimeters. The independent variable would be the diameter of the liquid balls whereas the dependent variable would be the maximum height in which the encapsulated ball stays intact (whether it pops or not).

Procedure/Methodology: Testing Research Question

Equipment	Quantity	Cost	Uncertainty
Yard stick	(Quantity: 1)	($4.65)	(±0.5)
Encapsulated liquid	20-30 encapsulated liquid	None	None

Method:

1. Hold the yard stick perpendicular to the surface that the encapsulated liquid is being dropped
2. Start dropping the encapsulated liquid from 1 centimeter, and keep increasing this until the encapsulated liquid pops
3. Take notice of this "maximum height" and repeat steps 2 and 3, changing the size of the encapsulated liquid

Stability: measured in the duration the encapsulated liquid stays in a certain condition while it maintains integrity (doesn't pop or leak). The independent variable would be the hours in which the liquid sustains integrity within a specific temperature, while the dependent variable would be integrity of the ball by dropping the ball from the optimal height.

Equipment	Quantity	Cost	Uncertainty
Freezer	(Quantity 1)	($180.98)	None

Fridge	(Quantity 1)	($110.00)	None
Water bath	(Quantity 1)	($55.00)	None
Bottles	(Quantity 2)	($25.98)	None
Weighing boats	(Quantity 1)	($15.95)	None
Encapsulated liquid	20-30 encapsulated liquid	None	None
Thermometer	(Quantity 1)	($9.98)	(±0.05)

Method:

1. Testing extreme cold environment (-14 degrees Celsius)
    a. Find the optimal or usable height from the data collected for sturdiness
        i. This can be found by finding the midpoint on the x axis of the graph
    b. Use this size and create encapsulated liquid based on this measurement
    c. Make 2 encapsulated liquids and put them in a weighing boat
    d. Put the weighing boat in the freezer
    e. **For the next sequential days, test the integrity of the balls by dropping them from the "optimal point" as calculated above**
2. Testing cold environment (3 degrees Celsius)
    a. The above protocol will apply for this test, but instead of putting the encapsulated liquid in a freezer, it will be put in a fridge
3. Testing room temperature environment (15 degrees Celsius)
    a. The above protocol will also apply for this test, but instead of putting the encapsulated liquid in a fridge, it will be put in at room temperature
4. Testing warm environment (35 degrees Celsius)

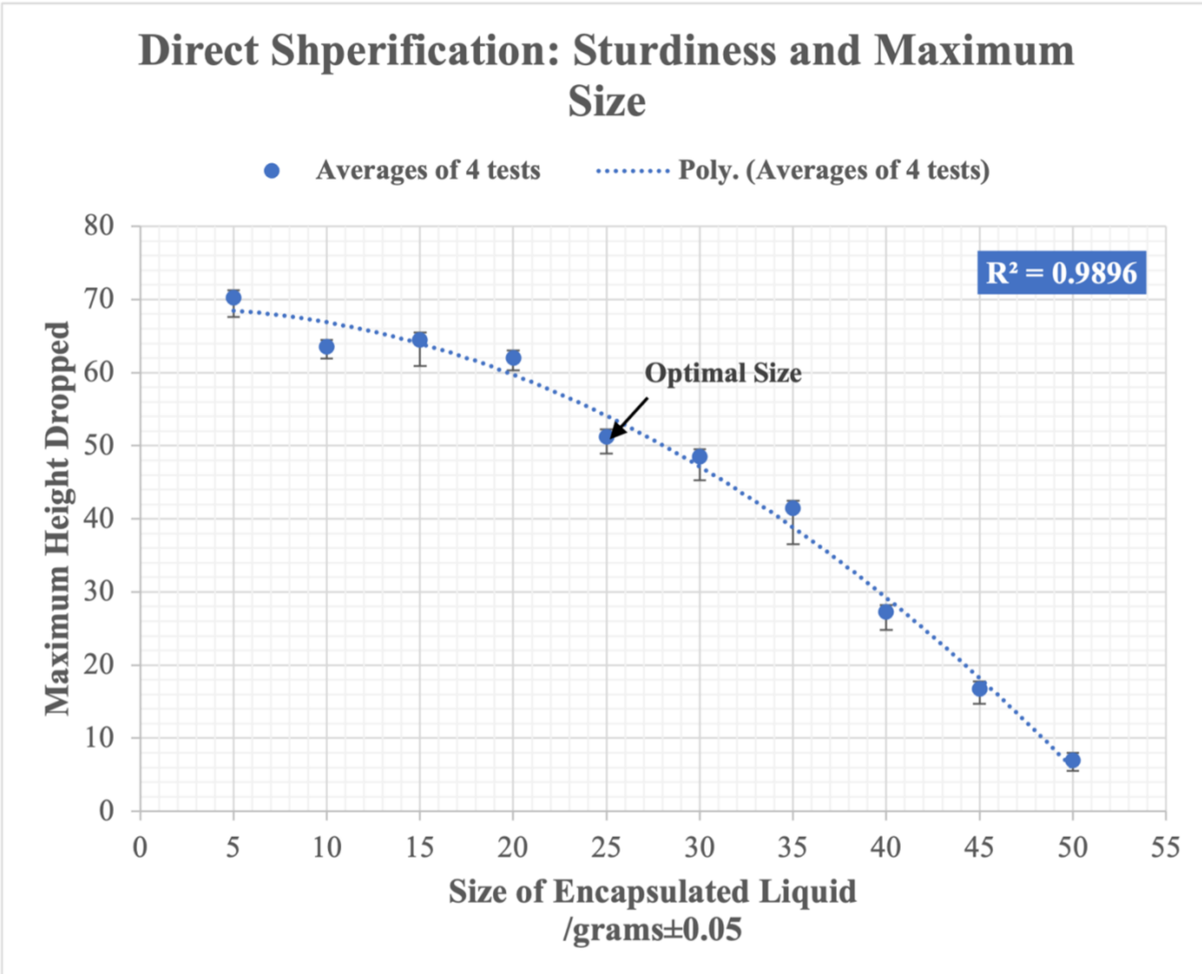
a. As keeping a consistent warm temperature is not only a technical hurdle, but it is also an engineering problem, therefore, to create a warm environment, this project decided to use a water bath
b. Fill water bath with 1.5 liters of water
c. Use same methodology as previously stated, but instead of putting the encapsulated liquid in a weighing boat, it is placed in a bottle which is sealed afterward.
d. This bottle is then placed in the water bath, set to 35 degrees Celsius.

Safety and Risk:

This project is safe. This proposal uses two chemicals being calcium lactate and sodium alginate. Sodium alginate is a safe ingredient and is used in many food products and is completely edible (Yerramathi et al., 2021). Also, calcium lactate is considered by the Food and Drug Administration (FDA) as safe and can be used as a calcium supplement as well (Petre, 2020). Since a handheld mixer is used, some of the solution might go in the users' eyes, therefore, the user will be wearing safety goggles, but also safety mixers can be dangerous if they aren't used properly, therefore this project will need adult supervision.

Results (Sturdiness and Maximum Size) Spherification:

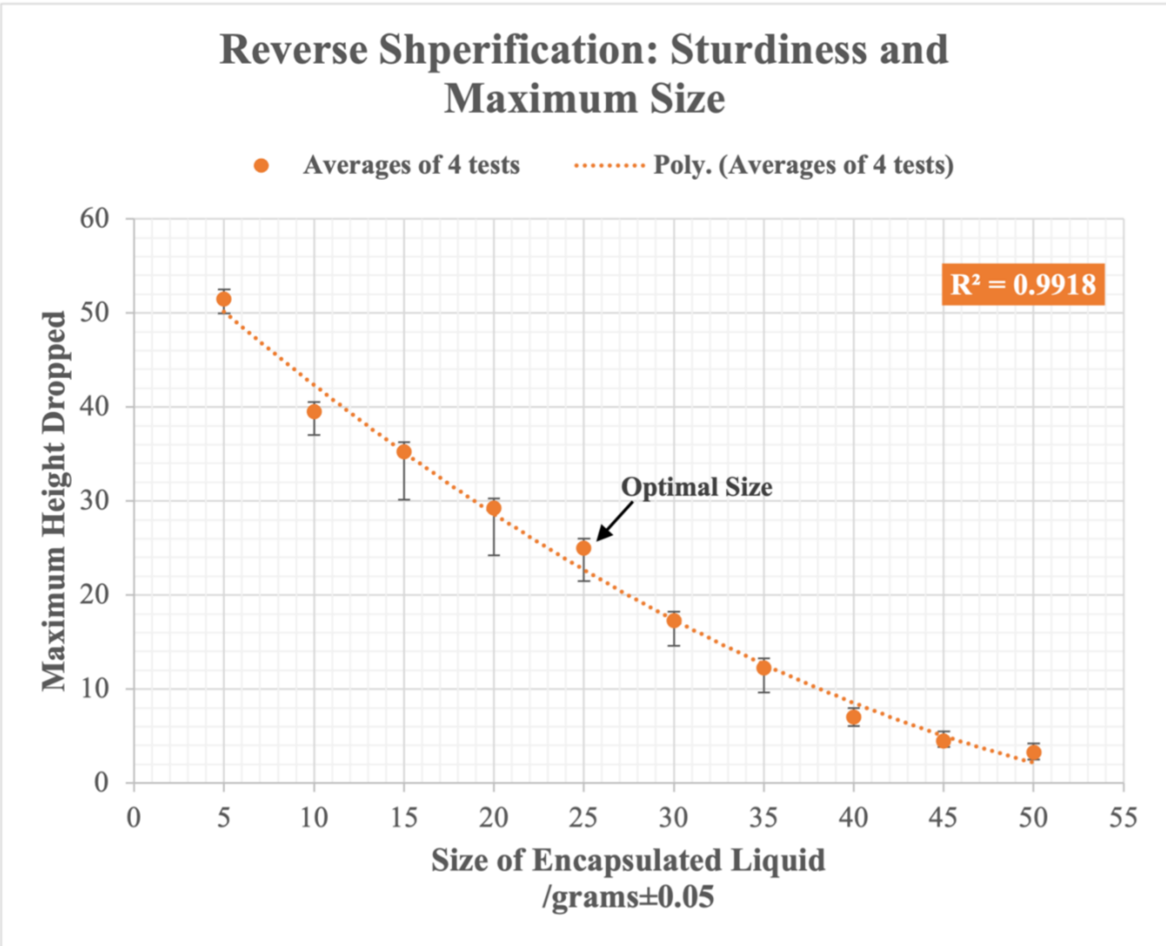
Size of balls /±0.5 grams	**Max Height Dropped/unit±0.5 meters**					
	Test 1	Test 2	Test 3	Test 4	Average	Standard of Error
5	70	63	73	75	70.25	2.62599188
10	65	62	67	60	63.5	1.55456318
15	67	67	70	54	64.5	3.57071421
20	60	60	67	61	62	1.68325082
25	50	58	50	47	51.25	2.35849528
30	47	40	53	54	48.5	3.22748612
35	54	30	40	42	41.5	4.9244289
40	30	29	20	30	27.25	2.42813371



The error bars are the standard error of the mean (shown in the table above). It is apparent that size of 30 grams and 35 grams had the most variation.

Results (Sturdiness and Maximum Size) Reverse Spherification:

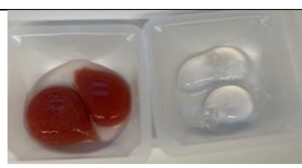
Size of balls /±0.5 grams	Max Height Dropped/unit±0.5 meters					
	Test 1	Test 2	Test 3	Test 4	Average	Standard of Error
5	50	53	48	55	51.5	1.55456318
10	33	40	45	40	39.5	2.46644143
15	20	39	40	42	35.25	5.12144185
20	21	20	38	38	29.25	5.0559371
25	18	20	30	32	25	3.51188458
30	13	16	15	25	17.25	2.65753645
35	10	10	9	20	12.25	2.59406374
40	6	5	8	9	7	0.91287093



The error bars are the standard error of the mean (shown in the table above). It is apparent that size of 15 grams and 20 grams had the most variation.

Results (Temperature):

	Duration of Stability /hours					
	Spherification			Reverse spherification		
Temperature	Test 1	Test 2	Average	Test 1	Test 2	Average
-14°C	∞	∞	∞ (As it was frozen)	∞	∞	∞ (As it was frozen)
3°C	60	60	60	48	60	54
15°C	24	36	32	24	12	24
35°C	24	12	18	36	24	30

	Spherification Day 1	**Spherification Day 2**	**Spherification Day 3**
Freezer (-14°C)			
Fridge (3°C)			
Room Temperature (-15°C)			
Warmth (35°C)			

Freezer:

The encapsulated liquid was frozen

Fridge:

The encapsulated liquid looked bright and edible

Room Temperature:

Most of the liquid was drained out of the encapsulated liquids

Warmth:

There was fungus growing on the reverse spherification encapsulated liquid

Conclusion:

As we can conclude from the data the size of the encapsulated liquid has an effect on the maximum height dropped. Generally speaking, the more grams the encapsulated liquid would weight, the less of a drop height it would maintain and the correlation on each of the trend lines was above 0.98, which means it is a really strong positive correlation as well. In terms of mechanics and physics, this makes sense. A smaller object would have a smaller surface area, and therefore result in a less of an impact. As you make the encapsulated liquid larger, it tends to become more of a spheroid rather than a sphere. This is due to the increasing pressure that gravity puts on this object. As this project is encapsulating a liquid, it tends to easily be influenced by the gravity. In nature, a sphere is the strongest shape because the stress from a drop would be distributed throughout the same, rather than a specific point. This is proven by the formula:

$$\boldsymbol{P = \frac{F}{A}}$$

This principle states that as the surface area of an object increases, the pressure being applied will also distribute resulting in a lower impact of pressure (and vice versa for an object that has a smaller surface area). Not only would gravity act on the object, but also human error would cause a more oblong shape as well. Comparatively speaking with direct and reverse spherification, we can see that the reverse spherification was more variable and had a greater range of data. The optimal point in my hypothesis was accurate for direct spherification, 25-gram ball; 48 centimeters, whereas for reverse spherification, it was only a 26 centimeter drop height. Not only this, but direct spherification was able to a 70 centimeter drop height, whereas the maximum for reverse spherification was 50 centimeters. Based on optimal drop height, direct spherification was sturdier, and had a greater capacity in terms of its size. This same notion was continued in the next study, regarding temperature.

Firstly, looking at the quantitative data, we can see that the fridge had the longest longevity, excluding the freezer, where the encapsulated liquid had frozen. Also, the warmth had the least sturdy encapsulated liquid, and as looking at the qualitative data (provided above) the warmth, was quickly a breeding ground for bacteria and fungus. This lowered the integrity of the balls, which also caused the decrease in the integrity for room temperature. You can also see the color of the fridge encapsulated liquid, as it is bright and prominent. The encapsulated liquids that were kept in a environment of 3 degrees Celsius was the most optimal for the longevity of the encapsulated liquids, considering it maintained its sturdiness for more than 5 days, and just based on the qualitative data, it looked edible.

Evaluation:

The key strength of this project is the simplicity in the method to encapsulate water or strawberry juice using only 2 chemicals. The durability of the encapsulated balls was tested based on temperature changes and sturdiness from fall. What remains to be tested is the consistency and reproducibility in the manufacturing, scalability, packaging, and distribution process. The use of direct vs reverse specification for water vs juice encapsulation also cannot be generalized because we are changing 2 variables. We cannot fully make a conclusion based on the methods, considering that we are not only changing the method, but also the different liquids we are using. Not only this, but some parts of our method were slightly limited. Firstly, we only had five days to measure the sturdiness of the encapsulated liquids, thus not allowing any more data points past 60 hours. But overall, I think that this is a very applicable project, and the data collection depicted the picture we wanted. This has the potential to eradicate the usage of plastic bottles in the first place, preventing the release of 17 million metric tons.

Will you be a good CREW mate, and help save the environment? The use of CREW instead of plastic bottles has the potential to change the trajectory of catastrophic disasters in the world due to climate change. Liquid encapsulation is not only the future of cleaner environment and molecular gastronomy but also our world.

Bibliography:

Blue, M. (2019, March 2). *What Is the Carbon Footprint of a Plastic Bottle?* Sciencing. Retrieved December 27, 2021, from https://sciencing.com/carbon-footprint-plastic-bottle-12307187.html

Frozen Spherification. (n.d.). ChefSteps. Retrieved December 31, 2021, from https://www.chefsteps.com/activities/frozen-reverse-spherification.com

Gaggan Anand Menu. (n.d.). Gaggan. Retrieved December 26, 2021, from https://gaggananand.com/wp-content/uploads/2021/01/A-La-Carte-Menu-final-Food-_-Bev.pdf

Halford, B. A. (n.d.). *The Science Of Spherification*. C&en Chemical and Engineering News. Retrieved December 26, 2021, from https://cen.acs.org/articles/92/i42/Science-Spherification.html

Logsdon, J. (n.d.). *What Is Spherification Molecular Gastronomy Glossary*. Amazing Food Made Easy. Retrieved December 27, 2021, from https://www.amazingfoodmadeeasy.com/define/molecular-gastronomy-glossary/what-is/spherification

Make Spheres with Liquid Inside. (2013, December 12). [Video]. YouTube. https://www.youtube.com/watch?v=JPNo79U77yI

Nace, T. (2019, April 29). *London Marathon Runners Were Handed Seaweed Pouches Instead Of Plastic Bottles*. Forbes. Retrieved December 29, 2021, from https://www.forbes.com/sites/trevornace/2019/04/29/london-marathon-runners-were-handed-seaweed-pouches-instead-of-plastic-bottles/?sh=121dabcb2ba2

Petre, M. A. S. (2020, November 4). *Calcium Lactate: Uses, Benefits, and Side Effects*. Healthline. Retrieved January 1, 2022, from https://www.healthline.com/nutrition/calcium-lactate

Science Buddies. (2021, September 3). *Make Yogurt into Spheres With Reverse Spherification* [Video]. YouTube. https://www.youtube.com/watch?v=WSRv89CiM-0

Wikipedia contributors. (2022, March 3). *Extinction risk from climate change*. Wikipedia. Retrieved March 6, 2022, from https://en.wikipedia.org/wiki/Extinction_risk_from_climate_change

Yerramathi, B. B., Kola, M., Annem Muniraj, B., Aluru, R., Thirumanyam, M., & Zyryanov, G. V. (2021). Structural studies and bioactivity of sodium alginate edible films fabricated through ferulic acid crosslinking mechanism. *Journal of Food Engineering*, *301*, 300–301. https://doi.org/10.1016/j.jfoodeng.2021.110566

Youssef, J. (2019, January 11). *Sodium Alginate & Spherification | Kitchen Theory*. Kitchen Theory. Retrieved December 27, 2021, from https://kitchen-theory.com/spherification/