PURDUE UNIVERSITY

CAPSTONE EXPERIENCE 2011

Biological and Food Process Engineering

Agricultural & Biological ENGINEERING

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Statement of Problem:

There is a need for a product that provides children with 20% of their daily fiber requirements and is aesthetically appealing while also adding flavor and sweetness to foods they are already consuming. To produce such a product, a process utilizing four separate unit operations must be designed to be implemented in industry by using or modifying existing machinery and processing techniques.

Background Review:

Based on research of previous inventions, there are currently no encapsulated soy products to provide protein and fiber in one's diet. Similar encapsulated food products are currently patented to only release flavor additives to foods. A gel forming polymer and oil were used to form a water insoluble gel matrix around the product. There is no shrinkage with the freeze-drying method, and instead provides a porous structure that allows for rehydration and increased application with little flavor and color loss.

Alternative Solutions:

Different drying methods (shown below) were explored to determine and identify potential alternative process designs based on shelf-life, aesthetics of the final product, economic impact on storage and processing conditions, cost, and time.

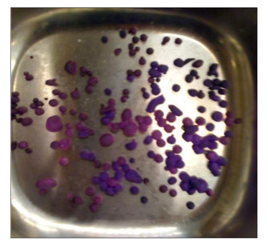
Water activity and temperature for oven-dried samples vs. freeze-dried samples

Sample	Water Activity	Temperature (degrees Celsius)
Freeze-dried	0.694	22.5
Freshly made before drying	0.990	22.1
Not fresh before drying	0.988	22.3
40 degrees Celsius for 40 min	0.987	22.0
40 degrees Celsius for 70 min	0.970	22.4
50 degrees Celsius for 80 min	0.976	22.5
50 degrees Celsius for 40 min	0.962	22.4

Summary of advantages, disadvantages, and conclusions about drying options for FIBitz

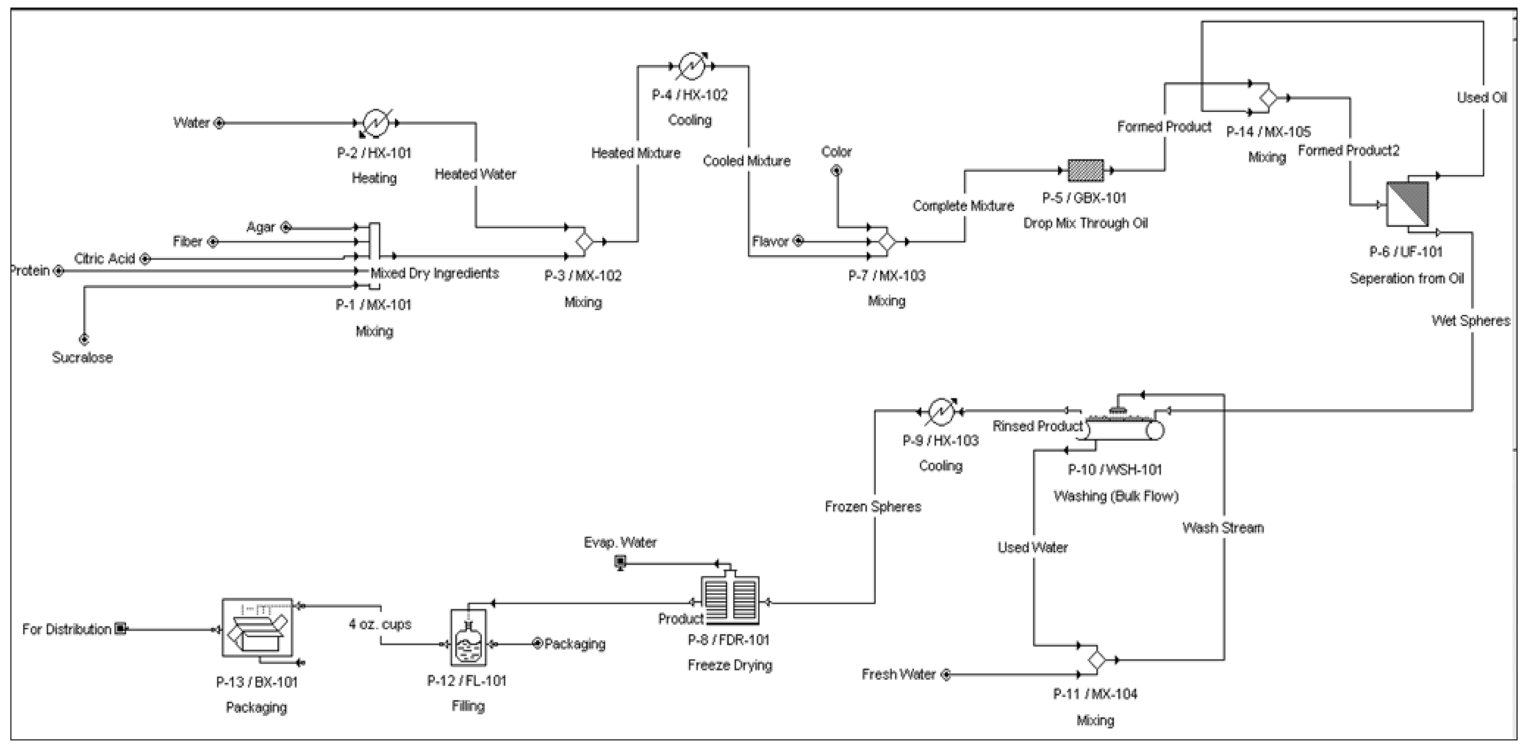
Option	Advantage	Disadvantage	Conclusion
Oven Drying	• Inexpensive • Keeps the flavoring • Gummy texture • Need less coloring (coloring became concentrated) • Easily available • Fast	• Shrinks the product • Makes product tougher • Increases microbial issues (incubates) • Large moisture content • Extremely variable based on mass	Although the texture turned our favorable the moisture and the variable processing parameters (drying time, humidity, and air circulation) made this dryer non-ideal.
Vacuum Drying	• Semi-inexpensive • Better microbially than oven drying • Fast	• Shrinks product dramatically • Product becomes hard • Discoloration (turns dark) • Loss flavoring	The texture, color, and flavoring were all changed in non-favorable directions. Even though it was fast, we did not think the speed was enough to compromise the quality of our product.
Freeze Drying	• No shrinkage • Flavor retention • Virtually no microbial issues • Extremely low water activity (which translates to shelf stability)	• Color muted • Expensive • Less available • Long drying time	The color muting was minimal and the expense is something that can be optimized in future work. Overall, we believe this was the kind of drying that would provide our product with the best texture, flavor and color while also extending shelf life and being virtually microbially clear

Results of Fibitz after drying for 40 minutes with an oven dryer (left) and a vacuum dryer (right)



Process Diagram:

Process flow diagram simulated using SuperPro Design tools



- In a large jacketed vessel, water is boiled but does not exceed 120ºC
- In a double armed mixer, mix (until homogenous) dry ingredients
- Add boiling water to dry ingredient mixture, and blend until homogenous
- Pump mixture to a counter-current tube-and-shell heat exchanger and cool to between 100ºC and 95ºC
- From the heat exchanger, pump to the double armed mixer and add coloring and flavoring; mix until homogenous
- Using an industrial dropper, drop the mixture into chilled oil bath (similar to the one employed by potato chip processes)
- Separate the oil and spheres by use of conveyer
- Using a produce washer, rinse wet spheres using cold water
- Using a tunnel freezer, freeze rinsed spheres to -20ºC
- In a continuous industrial sized freeze-dryer, freeze-dry frozen spheres
- Fill freeze-dried spheres into 4 oz cup and seal
- Store in room with humidity less than 80% to prevent water vapor absorption

Sustainability:

There are some areas for sustainability in our process involving the chilled oil unit process. Once the oil has cooled the product, it will be re-circulated to a heat exchanger to reduce its temperature and then returned to the oil bath. Other areas of reuse would include water in the heat exchangers being used in initial heating of the water, as well as using the evaporated water from the freeze-dryer.

Global Impact:

Not only does this problem help mothers provide their children with a nutritious alternative to sugar-filled breakfast foods with added fat, but Evaluation of additional target consumers could lead to the launch of FIBitz in additional markets such as: geriatric patients, who are in need of protein and fiber with the limited capability to chew vegetables or other fiber-rich foods; vegans, who are limited by their diet and must still receive adequate nutrition; 'health conscious' young adults who are looking for more variety in their diets; and soldiers, who are in need of shelf-stable, energy providing products that are low weight and therefore relatively inexpensive to ship. Additionally, our product also affects the local soybean market.

Economics:

A detailed economic evaluation of a small-scale plant is demonstrated below. Based on these calculations, recommendations for improvements can be made. The agar and oil method could be replaced by using calcium salts and alginate to reduce ingredient cost; however, this may compromise the integrity of the product. Additional research may go into additional drying methods to reduce the cost of the freeze-drying. Alternatively, the product could be made and sold as a wet, chilled product to remove the energy intensive drying steps.

Complete economic evaluation with calculated costs for ingredients, processing, and labor with assumed capital costs

Raw Ingredients	Cost	Unit	Vendor/ Source	Kg/ Year	$ / Per Year	Total
Fiber	2.15	/kg	Solae	25495000000	$54,814,250,000.00	
Protein	5.2	/kg	Solae	25495000000	$132,574,000,000.00	
Water	0.00039626	/kg	www.fcwa.org/story_of_water/html/costs.htm	3.82425E+11	$151,539,467.43	
Sucralose	90	/kg	Beijing Hezhong-Huimei International Trading Co., Ltd.	6670000000	$600,300,000,000.00	
Flavor	35.59	/kg	Firmenich	47165000000	$1,678,602,350,000.00	
Citric Acid	0.8	/kg	Dalian Chem Imp. & Exp. Group Co., Ltd.	6370000000	$5,096,000,000.00	
Agar - Agar	47.69	/kg	www.BulkFoods.com	6370000000	$303,785,300,000.00	
Coloring	2.61294584	/kg	Webstaurant Store	10000000.00	$26,129,458.39	Total for Raw Ingredients:
Operating Costs				**Amount Used/ Yr**		$ 2,775,349,568,925.82 /year
Freeze Drying:	***(One Used)***					
Refrigeration	0.65	kW/kg H2O	Handbook of Industrial Drying (Mujumdar, 2007)	426,000,000,000.00	$ 19,383,000,000.00	Total for Freeze Drying:
Vacuum Pump	0.36	kW/kg H2O	Handbook of Industrial Drying (Mujumdar, 2007)	426,000,000,000.00	$ 10,735,200,000.00	$ 30,118,410,000.00 / year
Additional Labor	$15	/hr	Handbook of Industrial Drying (Mujumdar, 2007)		$ 210,000.00	
Heat Exchanger:	***(Three Used)***					Total for Heat Exchangers:
Running Costs	3.4	kW/kg Product	Heat Exchangers: Selection, Rating, Thermal Design (Kakaç, 2002)	1.5E+12	$ 357,000,000,000.00	$ 357,000,000,000.00 /year
Desposiţing:	***(One Used)***					Total for Depositor:
Running Costs	3.8	kW/kg Product	http://www.alibaba.com/product-free/106838786/Cup_cake_depositor.html	1.9E+12	$ 133,000,000,000.00	$ 133,000,000,000.00 /year
Mixing:	***(Four Used)***					Total for Mixers:
Running Costs	3.2	kW/kg Product	http://www.mixers.com/?gclid=COTEzqOLu6cCFcbc4AodkgsKBA	6.4E+12	$ 448,000,000,000.00	$ 448,000,000,000.00 /year
Extraction:						Total for Extractors:
Running Costs	3.20	kW/kg Product	http://www.industrialfilter.com/products_processing.htm	1.6E+12	$ 112,000,000,000.00	$ 112,000,000,000.00 /year
Packaging:						Total for Packaging:
Running Costs (Cups)	$0.90	/package	www.containerandpackaging.com	See Table	$ 4,757,142,857.14	$ 5,305,535,714.29 /year
Running Costs (4-Pack)	$0.40	/package	www.containerandpackaging.com	See Table	$ 528,571,428.57	
Running Costs (Box)	$0.30	/box	http://www.packagingprice.com/	See Table	$ 19,821,428.57	
Transportation:						Total for Transportation:
Running Costs	$0.05	$ / kg Product	Food Processing Technology: Principles and Practice (Fellows, 2000)	74000000000.00	$ 3,590,184,744.64	$ 3,590,184,744.64 /year
Labor:						Total for Labor:
Assume 30 Labors	$15.00	/ laborer * hour		$450.00	$ 2,250,000.00	$ 2,250,000.00 /year
Taxes & Insurance:						Total for Tax and Insurance:
Assume 6%	$0.18	(Additional/ unit)			$ 233,100,000.00	$ 233,100,000.00 /year
				SUM:		
				Before Taxes:	**Total for 12 oz:**	
				$2.92	$3.10	
					Selling price:	
					$ 3.93	
					Profit (1st yr):	
					$ 1,043,616,800.37	

Assumptions:

1. Annual Production is 104,464 Units/Yr ≈ 5,850,000 Kgs of Final Product. This is a smaller scale production and the idea for outflow amount was derived from Food Plant Engineering Systems
2. Values based on current market price and will not change extremely during calendar year
3. Plant operates 350 days/ year, 20 hours/ day, with 4 hours/ day available for loading
4. Assumed Energy Cost of $0.07 / kWh for Indiana
5. Selling price was calculated assuming 10% markup for the plant, with an additional 10% markup for distributor, increased to the nearest tenth of a dollar
6. Assumed capital cost of 50 million dollars

A Return on Investment (ROI) is calculated to measure the performance of one investment compared to another. ROI is a percentage that is based on returns over a time period, usually one year. The formula used to calculate the ROI is:

$$ROI = \frac{(Gain\ from\ Investment - Cost\ of\ Investment)}{Cost\ of\ Investment}$$

For the dried and dehydrated fruit industry:

$$ROI = \frac{(\$26.4\ million - \$20.7\ million)}{\$20.7\ million} = 0.275 = 27.5\%$$

This industry invested $26.4 million, but after one year, it'll have a return of $5.7 million. For food supplement stores for protein and fiber:

$$ROI = \frac{(\$54.7\ million - \$48.7\ million)}{\$48.7\ million} = 0.123 = 12.3\%$$

This industry invested $26.4 million, but after one year, it'll have a return of $6.0 million. For FIBitz:

$$ROI = \frac{(\$391{,}746{,}656 - \$391{,}686{,}351)}{\$391{,}686{,}351} = 0.0002 = 0.02\%$$

The profit would be smaller than other industries' because the FIBitz industry starts as a small business with small-scale production. This industry invested $391,746,656, but after one year, it'll have a return of $60,304.99.

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