CAPSTONE/SENIOR DESIGN EXPERIENCE 2019

Spray-Dried Greek Yogurt

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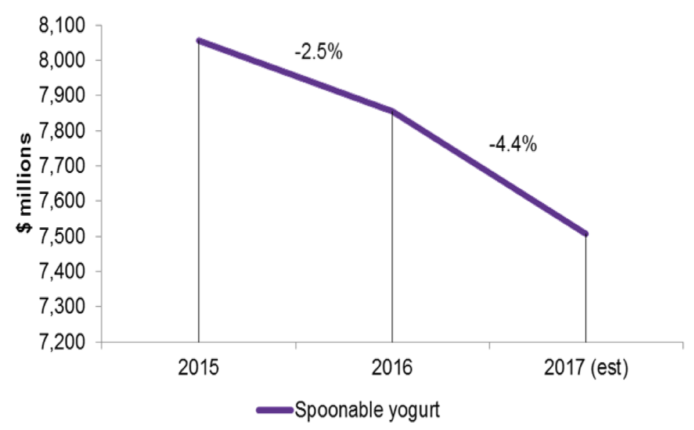
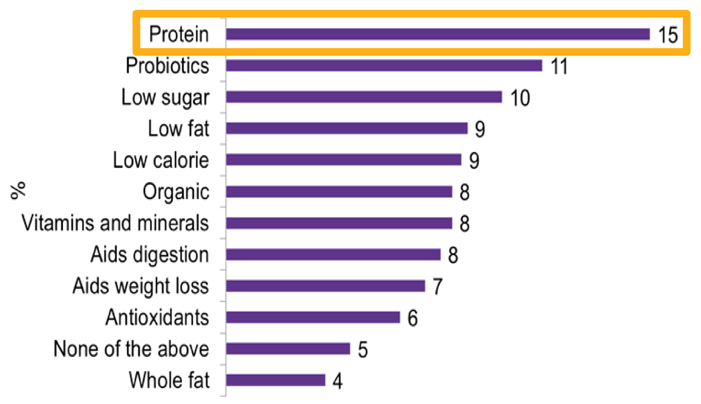
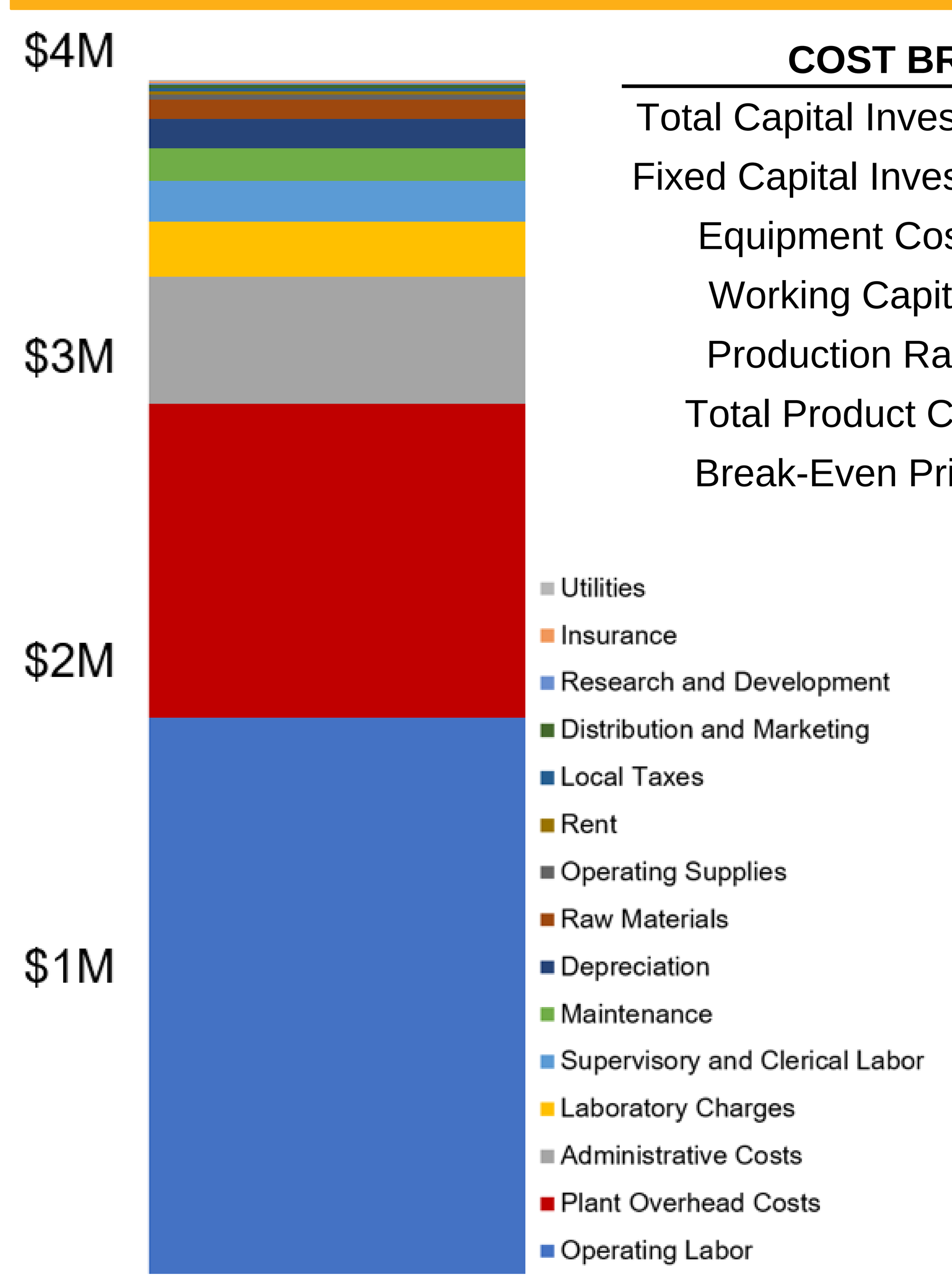
BACKGROUND

- Since 2015, the popularity of spoonable yogurt has decreased
- Consumers are looking for more portable yogurt options with a longer shelf-life
- Additionally, 15% of yogurt consumers value protein content when purchasing yogurt
- Target Market: Indiana college towns (~340K people)
- **Objective: to create a dried, high-protein yogurt product to meet the needs of the modern yogurt customer**





ECONOMICS



COST BREAKDOWN

Total Capital Investment	$1.1M
Fixed Capital Investment	$942K
Equipment Costs	$235K
Working Capital	$166K
Production Rate	14,400 kg/yr
Total Product Cost	$3.9M/yr
Break-Even Price	$271/kg

RECOMMENDATIONS

- Realistic Sales Price: $30/kg (2019 specialty yogurt market)
- Scale-up production 10X+ based on economic model
- Current labor costs are estimated for a large industrial plant, but production rate is modeled at pilot plant scale
- Individual unit operations optimized at different production rates; find an optimal rate for overall production cost

PROCESS

PASTEURIZATION

OPERATION DETAILS

- Objective: remove pathogens and enzymes that degrade product
- Method: heat treatment with 72 °C for 15 seconds
- Outcome: denatured proteins and inactivated microbes

EXPERIMENTATION

- Two heat exchangers, holding tube, centrifugal pump, and positive displacement pump in pilot plant
- Batch pasteurization in lab scale with evaluation from microbial reduction

OPTIMIZATION

- Minimized annualized cost by changing area of heat exchanger
- Improved heat transfer but higher expenses with increased area
- Balance of fixed and variable costs
- Area of 20 m² priced at $1,420/yr

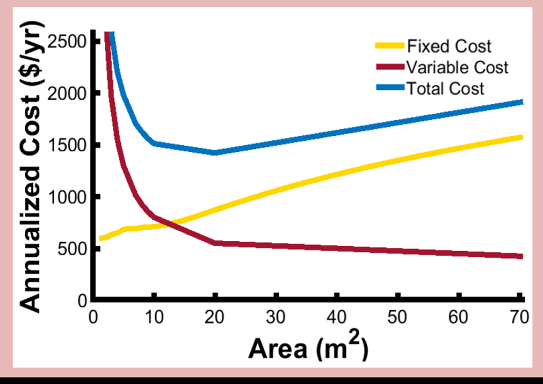
ECONOMIC/ALTERNATIVES

- Regenerative process that uses pasteurized milk to heat raw milk
- Morphological and functional analysis to select Hight Temperature Short Time over Hydrostatic Pressure Processing and Pulsed Electric Field

MODEL DESIGN

- MATLAB model to find key parameters (area, mass of steam, length of holding tube)

Parameter	*Value*
A_{HX1}	0.0771 m²
A_{HX2}	8.78 m²
m_{steam}	1850 kg/day
L_{HT}	0.0088 m



ULTRA-FILTRATION

OPERATION DETAILS

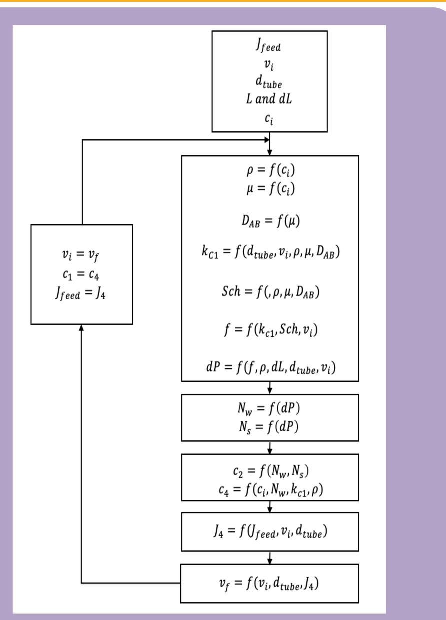
- Protein fractionation increases product casein concentration
- 30 kDa, Hollow-fiber Modules
- 4 modules in series separated by centrifugal pumps

ALTERNATIVES/ENVIRONMENTAL

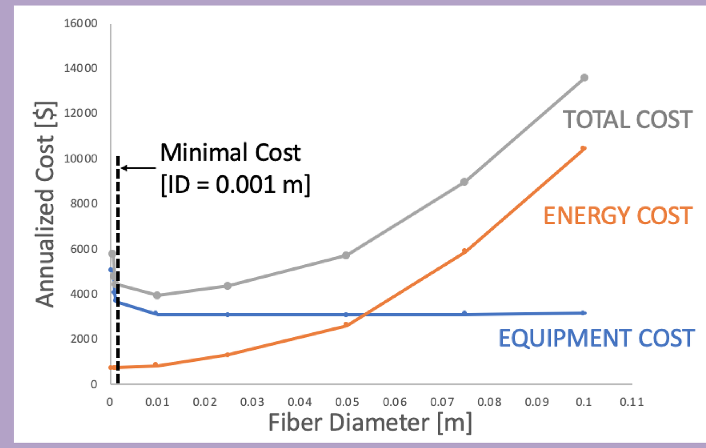
- Centrifugation
- Reverse Osmosis
- Post-Fermentation concentration

ANALYSIS/MODELING →

- Model based on literature analysis and commercial products
  - Module Dimensions/Pressure Drop
  - Flowrate



Model Constants	Value
Operation Temperature	40 C
Max. Module Pressure Drop	120 kPa
Module Length	1.014 m
Initial Fluid Velocity	5 m/s

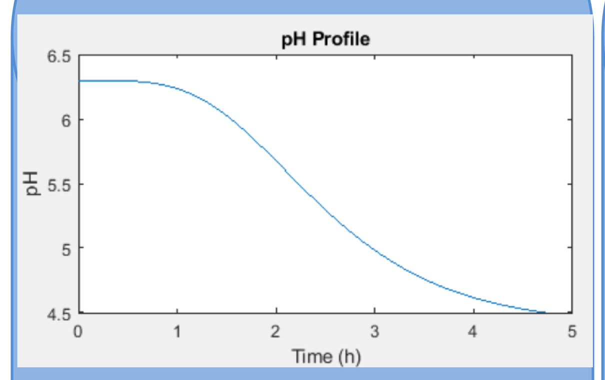


← OPTIMIZATION

- Primary Variable: Fiber Diameter
- Variable Outputs:
  - Membrane Surface Area
  - Pressure Drop
- Optimal System: 0.001 m diameter fibers
- 39 m² membrane area priced at $4435/yr

FERMENTATION

OPERATION DETAILS & DECISION RATIONALE



- 3-vessel, 5-hour, semi-continuous process chosen over fully continuous for batches being well-studied
- Lactose powder and starter culture (*Lactobacillus bulgaricus* and *Streptococcus thermophilus*) is mixed in
- 40°C regulated by water jacket, chosen based on literature testing these cultures

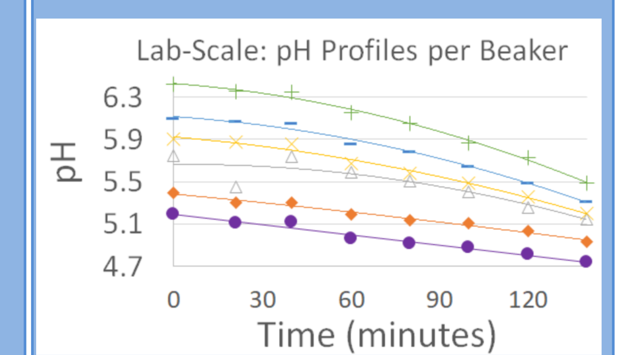
- Double-pipe countercurrent heat exchanger (A = 0.022 m²) brings yogurt to 15°C before drying
- Centrifugal pump chosen for milk and sliding vane pump chosen for yogurt based on viscosity and pressure requirements

ENVIRONMENTAL & SOCIAL IMPLICATIONS

- Utilizes recycled steam and water from throughout the plant
- No environmentally hazardous materials
- With increasing attention to probiotics, yogurt is becoming an even more desirable product to enhance health
- Dairy products are a source of bioavailable calcium

EXPERIMENTATION

Lab-scale simulations of varying extents (measured by pH) of the fermentation process formulated by mixtures of yogurt and skim milk which were heated in beakers on a hot plate



OPTIMIZATION

Fermenter height-to-diameter ratios between 2:1 and 3:1 were simulated for heat transfer and mixing time for an economic optimization.

SPRAY DRYING

OPERATION DETAILS

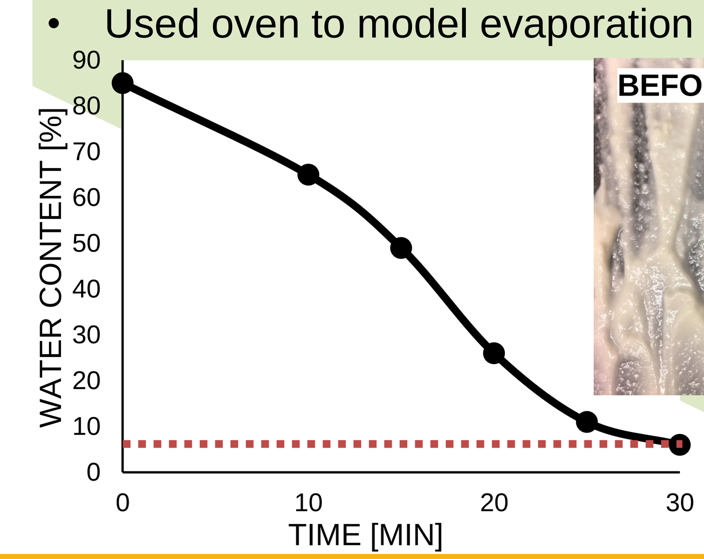
- Objective: reduce water content from ~85% to 5% to increase shelf-life
- Method: yogurt atomized to particle size 100μm and exposed to 150°C air
- Result: water removed as vapor, powdered yogurt exits

ALTERNATIVE SOLUTIONS

- Freeze drying: best microorganism retention, but expensive
- Microwave vacuum drying: poor taste retention
- Spray drying: dairy industry standard, high microorganism retention

EXPERIMENTATION

- Equipment unavailable at lab scale
- Used oven to model evaporation

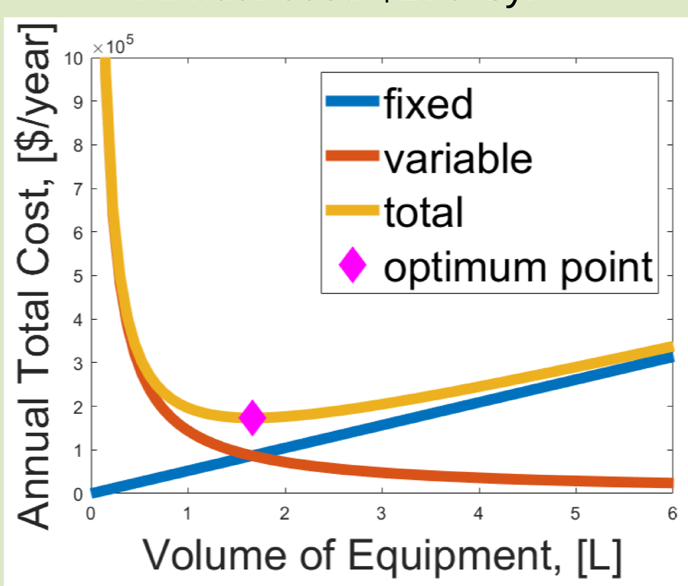


GLOBAL FACTORS

- Shelf-life of animal protein product more than doubles
- Shipment to places without refrigeration or post natural disaster

OPTIMIZATION

- Primary Variable: Yogurt Volumetric Flow Rate [kg/h]
- Variable Outputs: Dryer Volume [L], Annual Cost [$]
- Optimal System:
  - Flowrate: 16.34 kg/h
  - Volume: 1.66 L
  - Annual cost: $173K/yr



Instructors:
Thank you to Dr. Martin Okos for a wonderful two semesters of senior design. Additional thanks to Alyssa, Troy, and Joe for being helpful teaching assistants.

Acknowledgements:
To our families, thank you for sending four years of love and support from home.
To our instructors, thank you for passing on your wealth of knowledge.
To our peers, thank you for making this crazy ride so enjoyable. Congrats to the ABE Class of 2019!