Texturized Soy Protein Meat Analogs for Long-Term Space Missions

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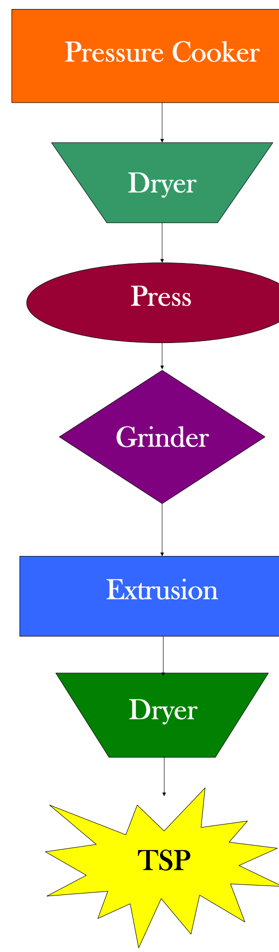
Problem:

Extended missions to Mars will require that astronauts produce their own food with limited resources. A meat substitute must be created to meet the daily protein requirement.

Objectives:

- To create a safe, highly nutritional, and palatable extruded soy product with a wide range of functionality as a meat analog
- To design a process that minimizes cost by using lightweight machinery with low space requirements and a short process time

- We will be using high protein raw soybeans in our initial process.
- Raw soybeans contain harmful trypsin inhibitors that need to be heat deactivated before consumption.
- Oil needs to be removed to ensure proper storage and minimization of fatty acid oxidation.
- Our product needs to be multifunctional and rehydrateable while keeping an appetizing texture.
- For storage our final product needs to have a low moisture content and water activity.
- The astronauts can maximize on the process by using the oil that is removed for other food purposes
- The processing equipment should also be flexible for use in other applications.



To the right are the unit operations which are used to make the final product.

Pressure Cooker

- 8qt volume Farberware FPC800
- 0.26 L of water is added to 0.25 kg of raw soybeans
- Cooked for 20 min at 250°F
- After cooking release steam and let cool for 30 minutes

Dryer

- The cooked beans should be placed in a dryer at 67 °F for 6 hrs.
- This time and temperature are necessary to reach a moisture content of 9% w.b.
- From previous experimentation we found that this moisture content is necessary to extract oil from soybeans.

Oil Press

- The dried soybeans are put through the press at the following specifications:
  - 100°C
  - 20 rpm
  - Die size 4
- Oil is collected in a beaker and weighed.
- Defatted soy product is collected & weighed.

A perforated barrel (left) is used on the press (above) to allow oil to be separated from the soybeans.

The sample as it comes out of the oil press: extrudate and oil (above left). The small grinder used to break up the extrudate (above right)

Extruder

- The extruded soy product is ground until it is a fine powder.
- Dry wheat gluten is mixed with the defatted soy product, equivalent in weight to half of the soy product weight (50 wt%).
- Water is added, equivalent in weight to the wheat gluten previously added.
- The mixture is blended with the food processor and extruded.
- The same specifications as the press are used.

Finishing

- The final extruded product is dried at 135°C for 2 hours.
- A final grinding step of the final product is used to break up the extrudate noodle into smaller pieces for rehydration.

Soy Processing Gant Chart

Process step	Duration (hrs)	Portion of a Day	Start Time	Finish Time	0:00	0:15	0:30	0:45	1:00	5:45	6:00	6:15	6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30
Creation of Meat Analog	9.42	0.39250	0:00	9:25																					
Equipment Set up	0.167	0.00694	0:00	0:10																					
Cooking	0.333	0.01389	0:10	0:30																					
Drying	6.000	0.25000	0:30	6:30																					
Pressing	0.250	0.01042	6:30	6:45																					
Grinding+Gluton Addition	0.083	0.00347	6:45	6:50																					
Repressing(extruding)	0.333	0.01389	6:50	7:10																					
Chopping + Drying	2.000	0.08333	7:10	9:10																					
Equipment Clean up	0.250	0.01042	9:10	9:25																					

(Above) Relative Processing Times for each unit operation were plotted out for our lab scale processing.

The processes in blue are variable based on the amount of product produced. They will increase when the astronauts scale up the process.

Soy consumed per person per year (kg)	# of people	Total consumption per year (kg)	Consumption per week for 6 people (kg)
85.18	6	511.08	9.83

9.83 kg of product will be consumed per week, therefore a correlation must be made to how much starting material is needed to produce 9.83 kg final product

Experiment	Initial Mass (kg)	Mass of Oil (kg)	Mass of Extruded Product	% Mass Loss
A	0.095	0.0108	0.065	31.58%
B	0.12	0.01062	0.085	29.17%
			Average	**30.37%**

The average losses are 30% therefore about 14 kg of starting material is need to produce the desired output

Equivalent System Mass

- ESM is an objective method for analyzing processes intended for space.
- The largest cost for space missions is the launch.
- All of these factors are converted to mass using equivalency factors for a Mars surface mission.
- However, this system does not take into account several important factors such as:
  - Nutrition
  - Palatability
  - Food quality
  - Food stability

Mass Equivalency Factors for a Mars Surface Habitat (Hanford et al., 2003)

Input	Factor
Volume	215.5 kg/m^3
Power	228 kg/kW
Cooling	146 kg/kW
Crew Time	1.25 kg/CM-hr

$$ESM = Mass + Volume*(\gamma_V) + Power*(\gamma_P) + Cooling*(\gamma_C) + Crew\ Time*(\gamma_{CT})$$

Results and Accomplishments

- Optimal conditions for oil extraction
  - 20 rpm
  - Die size 4
  - 9% w.b. moisture content
- Alterations of previous experimentation to include wheat gluten in order to achieve better rehydrateablity
- Creating an effective cost analysis in weight currency, since normal economics are not applicable