Freeze-Dried Tomato Paste

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April 19, 2007

Background:

After processing, tomatoes are often sent to manufacturers in the form of paste. On average, the paste consists of 30% tomato solids and 70% water. The largest of the tomato paste producers make about 1.5 billion pounds of paste a year. A conservative shipping estimate for this amount of paste is $75 million. Thus, by creating a quality product with a lower water content, millions of dollars would be saved.

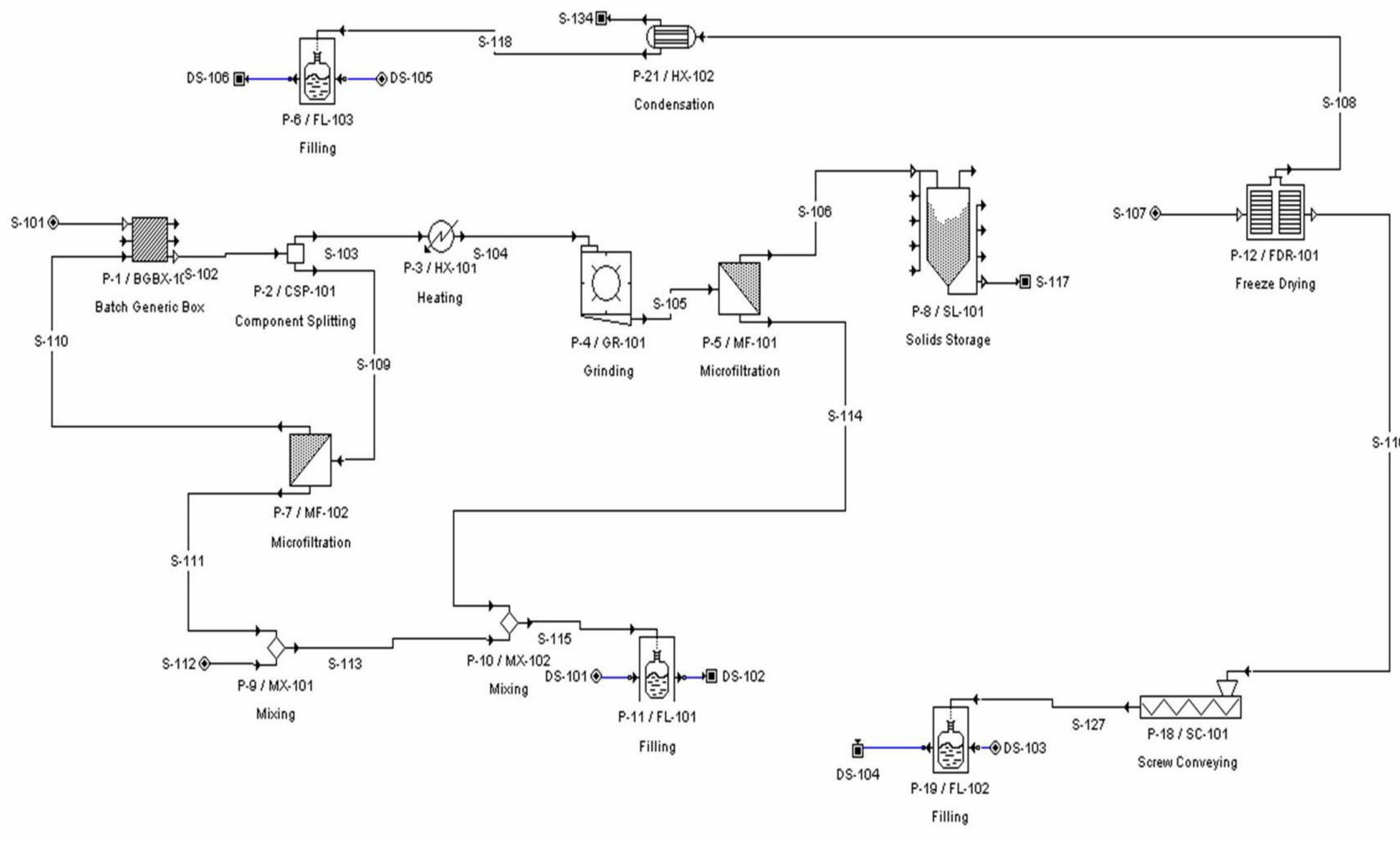
Problem Statement:

We want to develop a process that would allow the shipping of tomato paste in a more cost effective.

Objectives:

- Design a zero-discharge process.
- Develop a procedure for creating a high quality freeze-dried tomato paste.
- Optimize the process to be most profitable.

Fig. 1: Operation scheme freeze-dried tomato paste



Experimentation Objectives:

To determine if freeze dried tomatoes and/or tomato paste can be reconstituted into a product with all of the properties of typical tomato paste including taste, aromatic properties, and viscosity.

Experimentation Theories:

- According to research in order to maintain original material structural integrity one should not freeze dry above the glass transition temperature. In addition to this if one wants to increase the viscosity of the final product obtained upon reconstitution one should remain far below the glass transition state throughout the freeze drying process.[1]
- According to a group at Federal University of São Carlos, the tomato has two glass transition temperatures at -82.6 and -58.4°C.[2]
- In order to make tomato paste some thermal processing is necessary. Because of this some of the "structural integrity" of the product is lost. In order to overcome this a small amount of calcium chloride is added to the paste to add texture. "Because calcium is a divalent cation, it is able to bind free carboxyl groups on adjacent pectin polymers and bridge them, thereby creating a more stable three-dimensional network and imparting additional firmness to the tissues."[3]

Procedure:

- Roma tomatoes were chosen to be used in all instances.
- First the Roma tomatoes were washed.
- Three and half pounds of tomatoes were then weighed out and dipped in liquid nitrogen to freeze. Following this they were placed into one tray of the freeze dryer.
- Next, tomatoes were diced into cubes equivalent to three and a half pounds in weight the tomato chunks were then dipped in liquid nitrogen to freeze. Upon freezing the chunks were placed into the second tray of the freeze dryer.
- Then, tomato paste equivalent to three and a half pounds is frozen in liquid nitrogen. The paste is not made directly from the tomatoes, but is Red Gold tomato paste. The frozen paste is then placed into the third tray of the freeze dryer.

Freeze Dryer

- The remaining tray will be filled with tomato juice that has been frozen with liquid nitrogen. The tomato juice will also be a Red Gold product and not made directly from the Roma tomatoes.
- The freeze dryer then runs using the following program:
  1. Temperature of -40°F and pressure of 500 mtorr for 4 hours
  2. Temperature of -15°F and pressure of 300 mtorr for 4 hours
  3. Temperature of -10°F and pressure of 300 mtorr for 5 hours
  4. Temperature of -5°F and pressure of 300 mtorr for 5 hours
  5. Temperature of 0°F and pressure of 300 mtorr for 5 hours
  6. Temperature of 10°F and pressure of 300 mtorr for 10 hours
  7. Temperature of 20°F and pressure of 300 mtorr for 13 hours
  8. Temperature of 30°F and pressure of 0 mtorr for 2 hours
- After the freeze dryer program was complete powder was produced in each of the four trays.
- Reconstitution was then performed on the dried products which were then compared with their natural forms for quality purposes.

Mass and Energy Balances (of Freeze Drying Component):

Freeze Dryer[4]

Heat Transfer: $$\frac{L}{2}\frac{\Delta H_S}{M_A V_S}\left(\frac{-dx}{dt}\right) = \frac{1}{\frac{1}{h} + (1-x)\frac{L}{2k}}\left(T_e - T_f\right)$$

where M_A is the molecular weight of water
h is the external heat-transfer coefficient in W/m2 K
Te is the external temperature of the gas in °C
Tf is the temperature of the sublimation front or ice layer in °C
k is the thermal conductivity of the dry solid in W/m K
ΔL is the thickness of the dry layer in m
x is the fraction of the original free moisture remaining
ΔH_S is the latent heat of sublimation of ice in J/kg mol
V_S is the volume of solid material occupied by a unit kg of water initially

$$V_S = \frac{1}{X_0 \rho_S}$$

where X_0 is the free moisture content in kg H_2O/kg dry solid
ρ_S is the bulk density of dry solid in kg/m^3

Mass Transfer: $$\frac{L}{2}\frac{1}{M_A V_S}\left(\frac{-dx}{dt}\right) = \frac{1}{\frac{1}{k_g} + RT(1-x)\frac{L}{2D'}}\left(p_{fw} - p_{ew}\right)$$

where k_g is the external mass-transfer coefficient in kg mol/s m^2 atm
T is the average temperature in the dry layer
D′ is the average effective diffusivity in the dry layer in m^2/s
p_{fw} is the partial pressure of water vapor in equilibrium with the sublimation ice front in atm
p^{ew} is the partial pressure of water vapor in the external bulk gas phase in atm

Economics:

Equipment	Size	Quanity	Unit Cost	Total Cost
Washer	99538.63L	45	$ 120,000.00	$ 5,400,000.00
Heater	99.53m^2	112	$ 22,000.00	$ 2,464,000.00
Grinder	59986.87 kg/h	45	$ 256,000.00	$ 11,520,000.00
Microfilter	79.67 m^2	186	$ 107,000.00	$ 19,902,000.00
Mixer	131003.50 kg/h	1	$ 1,800.00	$ 1,800.00
Mixer	265973.96 kg/h	1	$ 1,800.00	$ 1,800.00
Filler	3533.33 entities/h	28	$ 500,000.00	$ 14,000,000.00
Freeze Dryer	1.65 tons	437	$ 2,595,000.00	$ 1,134,015,000.00
Screw Conveyor	15.00 m	1	$ 9,000.00	$ 9,000.00
Condenser	98.82 m^2	73	$ 32,000.00	$ 2,336,000.00
Splitter	668240.71 kg/h	6	$ 1,600.00	$ 9,600.00
Microfilter	78.90 m^2	70	$ 107,000.00	$ 7,490,000.00
Bin	800000L	1	$ 57,000.00	$ 57,000.00
Piping Cost				$ 5,566,000.00
			Total Inv Cost	$ 1,202,772,200.00

Capital Cost	Amount
Installation	$ 348,017,000.00
Process Piping	$ 521,508,000.00
Instrumentation	$ 596,009,000.00
Insulation	$ 44,701,000.00
Electrical	$ 149,002,000.00
Building	$ 670,510,000.00
Yard Improvements	$ 223,503,000.00
Auxiliary Facilities	$ 596,009,000.00
Engineering	$ 1,159,820,000.00
Construction	$ 1,623,748,000.00
Contractor's Fee	$ 371,142,000.00
Contingency	$ 742,285,000.00
Total Capital Cost	$ 7,046,254,000.00

Annual Cost	
Labor	$ 2,877,000.00
Raw Materials	$ 527,988,000.00
Membrane	$ 9,385,000.00
Utility	$ 12,278,704.00
Laboratory	$ 432,000.00
Facility	$ 1,613,050,000.00
Total Annual Cost	$ 2,166,010,704.00

Direct Fixed Capital Cost	$ 8,249,026,200.00
Working Capital	$ 153,149,000.00
Startup Cost	$ 426,814,000.00
Total Investment	$ 8,828,989,200.00

Revenues	# of entities	Cost/entity	Profit
Waste product	703652	$ 10.00	$ 7,036,520.00
Dried Powder	1492421	$ 1,050.00	$ 1,567,042,050.00
Bottle water	734083018	$ 2.00	$ 1,468,166,036.00
		Total Profit	$ 3,042,244,606.00

Gross Profit	$ 876,233,902.00
Tax Rate	0.35
Taxes	$ 306,681,865.70
Net Profit/Year	$ 689,829,256.30
Rate of Return	7.813230265
Pay back Period(year)	12.79880365

Conclusions:

Based upon the economics analysis performed on the freeze drying tomato process we determined that it is not feasible as a competitor in the tomato paste industry. This conclusion was based on the fact that the decreased shipping cost for the powdered product is unable to overcome the astronomical cost of the energy used to run the freeze driers.

[1] B.R. Bhandari and T. Howes, Implication of glass transition for the drying and stability of dried foods, *Journal of Food Engineering* **40** (1999) (1–2), pp. 71–79

[2] L.G. Marques, M.C. Ferreira, and J.T. Freire, Freeze-drying of acerola, *Chemical Engineering and Processing* **In Press, Corrected Proof**, Available online 17 September 2006

[3] Barret, DM., Garcia, E., and Jo Ellen Wayne, "Textural Modification of Processing Tomatoes," *Critical Reviews in Food Science and Nutrition*, 38(3):173-258 (1998).

[4] Geankoplis, C.J. (2003). Transport Processes and Separation Process Principles, Prentice Hall, 4th ed., pp. 607-610.

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