Waste Optimization of Cheese Processing

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Objective:

To design a mozzarella cheese plant which will:

- Optimize the process of making mozzarella cheese
- Produce zero waste from the process

Market Size:

- In 2001, Americans consumed around 30 pounds of cheese per capita
- In 2015, the projected cheese consumption is 34lbs per capita

Plant Size:

Production line:

1,640,000 kg of Mozzarella/year
1,529,224 kg of Ricotta/year

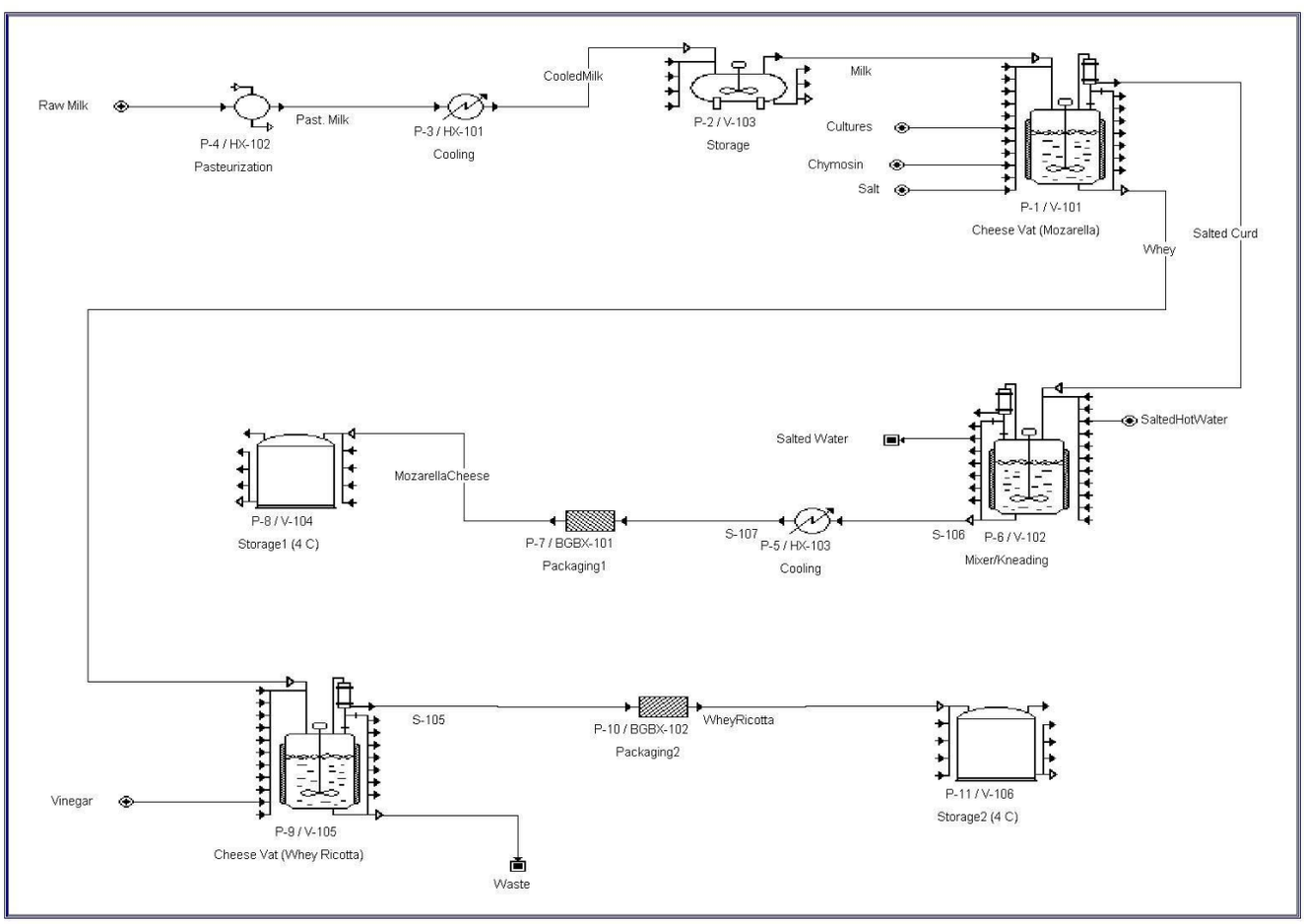
- Operating hours:
  - Pasteurization line: 24 hours for 5 days/week
  - Cheese processing line: 24 hours for 360 days/year

Background:

There are hundreds of types of cheeses produced around the world, each with different characteristics and compositions. However, in general, cheese has the same basic manufacturing process. The basic steps in process cheese are selecting and blending the raw material (crucial part is stabilizing proteins with emulsifying salts), heat processing, forming, and packaging.

- Milk pretreatment
  - Standardization/Homogenization
  - Pasteurization
- Coagulation
  - Milk undergoes physical and rheological change
  - Usually enzyme dependent
- Syneresis (formation of whey)
  - Draining of whey controls moisture content of cheese
  - Accelerated by
    - Increased surface area (from cutting of curds)
      Timing of curd cutting is critical to prevent loss of milk solids (too soon) or high moisture product (too late)
    - Decreased pH
    - Increased temperature of coagulum
      Heating, or cooking, facilitates contraction of protein matrix
- Shaping and salting
  Salt changes texture, flavor, inhibits harmful microbial growth in cheese, dissolves casein, and slows enzyme activity
- Ripening (aging)

Process Diagram:



Experimental Design

Mozzarella Cheese

Materials:
Pasteurized whole milk, bacterial starter cultures, Chymosin, Salt

Methods:
1. Heat the whole milk to 38C.
2. Mix the heated milk with frozen starter cultures (thermococcus and thermorod), 0.50 mL mixture / kg milk. Leave the milk mixture to ripen for 60 min, keep at 38C.
3. Add chymosin, 0.10 mL / kg milk. Let coagulate for 30 min. cut the coagulum with 1.2 cm wire knife. And allow the coagulum to heal for 5 min.
4. Stir the curd at 38C for 10 min then drain the whey. After the draining, add salt in 3 equal applications with 5 min intervals between applications. Allow the curd to mellow for 5 min after the last salt application. Stir continuously during salt application and mellowing process. Maintain at 38C all times.
5. Mold/stretch the salted cheese in hot circulating water(57C) contains 6% salt (wt/wt).
6. Place cheese into stainless steel container and cool it in cold water for 60 min or until the internal temperature reaches 20C.
7. Package the cheese in vacuum container.

Whey Ricotta Cheese

Materials:
2 gal of fresh whey (no more than 3hrs old) from mozzarella cheese
¼ cup cider vinegar
(performed on lab scale using less whey and vinegar)

Methods:
1. Pour the whey into a large pot, heat to 200 F.
2. While stirring, turn off the heat and add the vinegar.
3. Carefully ladle the curds into a colander lined with cheese cloth.
4. Allow to drain
5. Cover and refrigerate for up to 1 week

Challenges with Experiments:

- pH remained too high after whey separation for mozzarella production
- Formation crumbly mozzarella curd occurred instead of curd with smooth texture
- Temperature control during experimental process

Plackett-Burman Design for Five Variables and Two Estimates of Error

Run	Variable						
	A	B	C	D	(E)	F	(G)
1	+	+	+	-	+	-	-
2	-	+	+	+	-	+	-
3	-	-	+	+	+	-	+
4	+	-	-	+	+	+	-
5	-	+	-	-	+	+	+
6	+	-	+	-	-	+	+
7	+	+	-	+	-	-	+
8	-	-	-	-	-	-	-

Code	Variable
A	Amount of bacterial cultures (+ 0.7 mL/kg, -0.5 mL/kg
B	Amount of fat in milk (+ whole, - skim)
C	Agitation time (+20 min, -10 min)
D	Temperature of Stretching (+ 57C, - 50C)
E	Dummy
F	Amount of rennet (+0.15 mL/kg, -0.1 mL/kg)
G	Dummy

Composition (% weight) of Mozzarella and Whey Ricotta Cheese

Component	Mozzarella Cheese	Whey Ricotta Cheese
Moisture	54.1	82.5
Protein	19.4	11.3
Fat	21.6	0.5
Ash	2.6	-
Carbohydrate	2.2	1.5
pH	5.3	5.8

Rheology:

- Depends on cheese composition and maturity
- One of the properties: firmness
  - Protein content (the stress carrying component)
  - Linear correlation : as protein content increases, firmer.
  - Moisture content (m.c.)
    - Increase in Moisture Content
      - Resistance of cheese deform
      - Stress of fracture decreases
      - Fracture increases
      - Low protein content
      - Good lubricant due to space occupation between fat and protein
      - Less resistance to deformation due to swollen protein particles
  - Fat content
    - Affects microstructure
    - Less fat globules mean more protein matrix and firmer texture
    - Low fat cheese are firmer and more rubbery in texture

Zero Discharge and Minimum Energy Design:

•Use whey from Mozzarella production to produce Ricotta cheese

•Removal of nutrients from Ricotta cheese discharge and purification of remaining water to use in cleaning and as recycle water for heat exchanger

•Regeneration section in pasteurization process reduces energy required to heat milk

•Countercurrent flow in pasteurization process reduces energy required to heat and cool milk

•Heating and Cooling sections of heat exchanger recycle water

Mass and Energy Balance:

- Cheese Vat (Mozzarella)
  - Whey produced: 24,700,000 kg/year
  - Curd produced: 1,640,000 kg/year
  - Hot water needed: 11,800,000 kg/year
  - Heat loss: 1,590,000 kJ/year
- Cheese Vat (Whey Ricotta)
  - Whey produced: 22,561,107 kg/year
  - Curd produced: 1,529,224 kg/year
  - Energy: 6,081,000,000 kJ/year
- Mixer/Stretcher/Kneader
  - Salt Water: 88,200 kg/year
  - Energy: 153,000 kJ/year
- Cooling of product
  - Energy: 55,100,000 kJ/year

Scheduling:

- Pasteurization – continuous process (milk goes to cold storage until needed)
- Cheese Vat – 245 minutes/batch
- Mixer – 20 minutes/batch
- Cooling – 60 minutes/batch
- Packaging – 15 minutes/batch

Future Work:

- Recycling more process streams to make completely zero discharge
- Reduction of energy used to make ricotta cheese
- Alternative uses for drainage from ricotta cheese
- Reduction of energy lost through steam using cheese vat
- Possibilities for use of continuous process instead of batch
- Lactose utilization from ricotta drainage: possibility for crystallization and sale

Heat Exchanger Sizing:

Total Area: 57.5 m^2
Hold tube: 12.4 m
Heat exchanger sections:
- Heating/Pasteurization- 20 plates, 0.15 m x 0.43 m
- Regeneration- 40plates, 0.76 m x 1.2 m
- Cooling- 10 plates, 0.76 m x 1.2 m

Mixer/Kneader

Vacuum Packaged

Cheese Vat

Cost Analysis

Direct Costs:	
Purchased Equipment Cost (EC)	282,712
Installation (40% of EC)	113,085
Instrumentation and Controls (30% of EC)	84,814
Piping System (40% of EC)	113,085
Electrical System (30% of EC)	84,814
Building (50% of EC)	141,356
Service Facilities (55% of EC)	155,492
Land (6% of EC)	16,963
Total Direct Cost (TDC)	**992,319**
Indirect Costs:	
Engineering and Supervision (20% of EC)	56,542
Legal Expenses (3% of EC)	8,481
Construction Expenses (30% of EC)	84,814
Contingency (35% of EC)	98,949
Total Indirect Cost (TIC)	**248,787**
Fixed Capital Investment (FCI): (TDC + TIC)	**1,241,106**
Working Capital (WC): (75% of EC)	**212,034**
Total Capital Investment (TCI): (FCI + WC)	**1,453,140**

Equipment Cost and Sizing:	
Pasteurizer (60 m^2)	25,000
Holding tube (12.4 m)	3,712
Pump (for Pasteurizer)	15,000
Additional Pumps	20,000
Cheese vats (Mozzarella)	40,000
Cheese vats (Ricotta)	30,000
Mixer/Stretcher/Kneader	50,000
Packaging Equipment	30,000
Cooler	23,000
Storage tank (Pasteurized milk)	30,000
Water purifier (waste water)	16,000
Total Equipment Cost	282,712

Selling Price = $63/kg

Total Sales = $199,661,112

ROI = 50%

Gross Profit = $867,112

ANNUAL NET PROFIT: $784,736.36

Manufacturing Costs:	
Direct Production Costs (60% TPC)	119,276,400
Raw Materials (50% TPC)	99,397,000
Operating Labor, OL (10% TPC)	19,879,400
Supervisory and clerical labor, SCL (10% TPC)	1,987,940
Utilities (15% TPC)	29,819,100
Maintenance and Repairs, MR (5% FCI)	62,055
Operating Supplies (1% FCI)	12,411
Laboratory Charges (10% OL)	1,987,940
Patents and Royalties (2% TPC)	3,975,880
Fixed Charges: (15% TPC)	**29,819,100**
Local Taxes (3% FCI)	37,233
Insurance (1% FCI)	12,411
Rent (8% value of land/buildings)	12,665
Financing (4% TCI)	58,126
Plant Overhead Costs (5% TPC)	9,939,700
General Expenses:	**28,241,159**
Administrative Costs (20% of OL+SCL+MR)	4,385,879
Distribution and Marketing (7% TPC)	13,915,580
Research and Development (5% TPC)	9,939,700
Total Product Cost:	**198,794,000**

PURDUE UNIVERSITY Optimization of Cheese Process. Dolly Mok, Elizabeth Hooper, Frisca Tandean. FBPE
April, 2007