DAIRY PROCESSING PLANT

PRODUCTION By

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A Thesis Submitted to The Honors College

In Partial Fulfillment of the Bachelors degree
With Honors in

Chemical and
Environmental
Engineering

THE UNIVERSITY OF ARIZONA

M A Y 2 0 11

Approved by:

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Summary of Roles:

Although this document was prepared in partial fulfillment of requirements for an honors degree at the University of Arizona it was also made in fulfillment of the requirements of the design aspect of an engineering degree. As such, this honors thesis was the result of a collaborative effort including other students in the department of chemical engineering. The other students who contributed their work to this team effort were Michelle Frandsen, Alyssa Garcia, and Justin Dinh. The components in which I had a major role included the mass and energy balance calculation, the design of the process , the block flow diagrams, the economic analysis, and the written report. The project itself was chosen by the team as a whole and there was a significant amount of collaboration among the various parts. For the equipment design(one of the more important sections) I focused on the the calculations and costing of the most difficult pieces of equipment, such as the heat exchanger network and the cheese vat. Of course, certain pieces of equipment were so specialized that it was determined that the most accurate way to obtain pricing and sizing was to contact an industry representative and obtain a quote. Most of this work was done by Michelle and Alyssa, who had connections with people who had worked in this industry. With respect to the written part of the report I wrote a number of sections, like the environmental section and several appendicies. However, most of this work was split up and finished collaboratively. As a result  each section of the report was influenced by each team member.

# CHEE 443

# Senior Project

# Dairy Processing Plant Production

*Holstein Engineering*

Justin Dinh

Michelle Frandsen

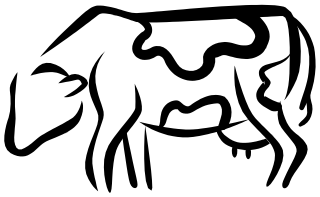
Alyssa Garcia

Marco Ravaglia

Department of Chemical and Environmental Engineering

University of Arizona

April 29, 2011



## Summary

The project premise of this report was to design a dairy processing facility in Oahu, Hawaii. This was decided due to the strong demand for fresh dairy by the local populace. This has traditionally been a problem stemming from the high manufacturing costs and the price fixture of milk put forth by the state government of Hawaii. Many milk processing plants went out of business due to the high cost of importing materials and shipping. Since the majority of the milk in Oahu is re-pasteurized and not fresh, many consumers often complain about the quality of milk. Holstein Engineering considered these complications and devised a plan to make fresh milk and cheese for the denizens of Oahu. An integrated complex method was used by purchasing a preexisting dairy facility.

One design parameter was the creation of a zero waste facility. The undesired byproducts of this plant were whey and cream. The whey was planned to be sold to animal feed providers, while the cream was to be sold to various other dairy companies. This would allow an extra source of revenue as well as supporting local sustainability.

Using statistical data, Holstein Engineering determined the amount of milk to be produced by considering how many people would drink milk and how much milk each person would consume. A contracted co-op with milk farmers to purchase raw milk was also used. The final products produced were 44.5 kg/hr of cheese and a total of 32,450 kg/hr of liquid milk.

One important consideration was the material of construction for the equipment, regulations from the Food and Drug Administration mandate that it would be stainless steel. There were no major safety elements associated with the plant precluding the minor, expected

leak or spill. However, extra precautions were used when dealing with ethylene glycol for the coolant.

This design assumed that all raw milk used as an input was obtained from local farmers and that all milk processed was sold at all Oahu locations. Using these assumptions the net present value of the plant was estimated at $61.5 million over thirty years, providing that the milk demand and price of milk stay fixed. As long as the selling price of milk to retailers is over $3.57 per gallon, this plant would continue to project profitable earnings. Overall this facility would provide new jobs and be sustainable.

## Table of Contents

## ***I. Introduction***

### *I.1. Overall Goal*

The overall goal of this project was to construct and design a food processing plant that makes milk and cheese products in Oahu, Hawaii. The Holstein Engineering company consists of four members who designed the plant with the constraints of having a fixed price of milk, not relying on imported products or resources, and having a zero-waste and a sustainable facility. The Holstein Engineering company plans to sell its products entirely within Oahu at competitive prices.

### *I.2. Current Market Value*

Oahu is the third largest island in Hawaii with 597 square miles with more than 75% of the state's total population in Oahu (http://oahu.aloha-hawaii.com/Hawaii/oahu/, 2011). In 2008, the last dairy facility on Oahu shut down leaving 875,000 residents dependent on imported milk. This is a huge concern for the people of Oahu because they become more vulnerable in an emergency to be dependent on the Continental United States. (Hao, 2008). It has been more than a decade since Oahu or the other islands have enjoyed locally produced milk. In recent years, 80% of the supply of milk is imported from the Continental U.S. (Hillyer, 2011). It is estimated that 61% of the population in Oahu drink milk (http://quickfacts.census.gov/qfd/states/15/15003.html, 2011), and the price of a gallon of milk is $8.99 and eight ounces of cheese cost $5.99 (Hillyer, 2011). The Holstein Engineering uses the U.S. Census Bureau and the demand for milk to estimate how much milk and cheese to produce. The design of the plant has a basis of making 44.5 kg/hr of cheese and a total of 32,450 kg/hr of skim, 2%, and whole milk.

*I.3. Project Premises and Assumptions*

As recently as 1980, Hawaii's dairy industry supplied the state with all its milk (Gomes et al., 2010). Since then, the economic value for Hawaii's milk industry dropped from $33.3 million in 1998 to $21.5 million in 2003. During that time, small and medium-sized operations shut down, leaving only two milk processors left—Meadow Gold Dairies Hawaii and Foremost Dairies, which exist only on the main island of Hawaii (Natarajan, 2004). The reason for many plants closing their businesses was due to economic struggles with manufacturing price of milk, mainland competition, and high shipping and land costs. Six months ago, the price of raw milk was $13.00 per every 100 pounds of milk, and now it is more than $23.00 dollars (Hillyer, 2011). The state of Hawaii regulates the price of milk paid to dairy farmers but the state cannot control the retail price. The reason why milk prices are so high is due to the price paid to farmers in Northern California; it is also based on the price of milk in Northern California, plus a $12.00 dollar differential for transportation cost (Hillyer, 2011). The Continental U.S. ships the milk eight to ten days old, and when it gets to the island it has to be re-pasteurized or reprocessed, which causes the milk to spoil faster (Gomes, 2010). The reprocessed milk was coinciding with milk that was aged to 25 to 30 days and many consumers complain that it often goes bad before the printed expiration date (Gomes, 2010).

## ***II. Process Description, Rationale and Optimization***

### *II.1. Block Flow Diagrams*

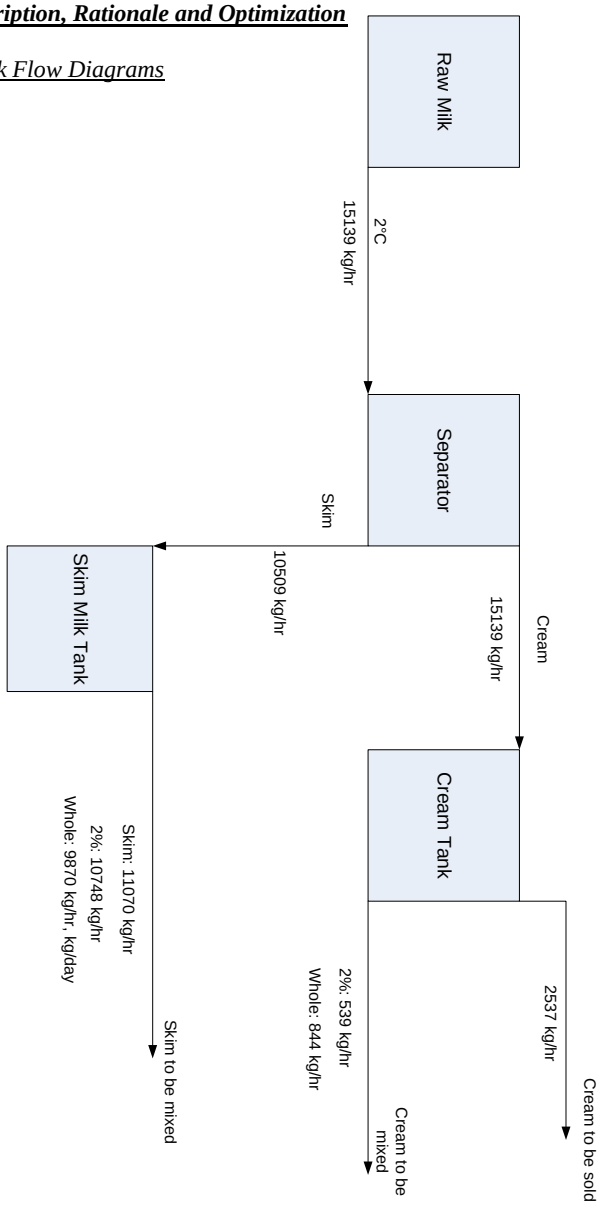



*Figure II.1.1: Block flow diagram of Unit 100, the separation of raw milk into cream and skim.*

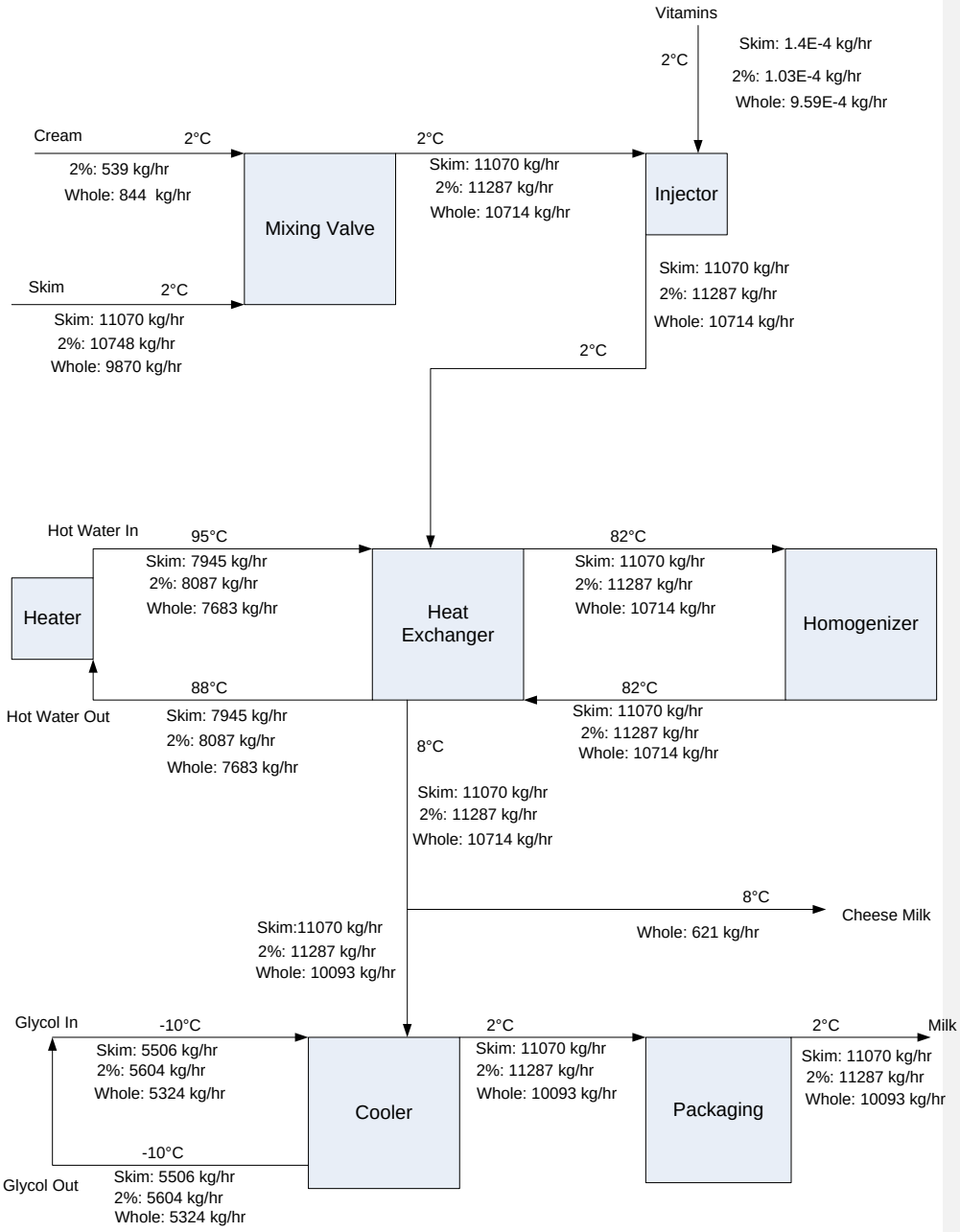



*Figure II.1.2: Block flow diagram of Unit 200, the mixing and processing of milk.*

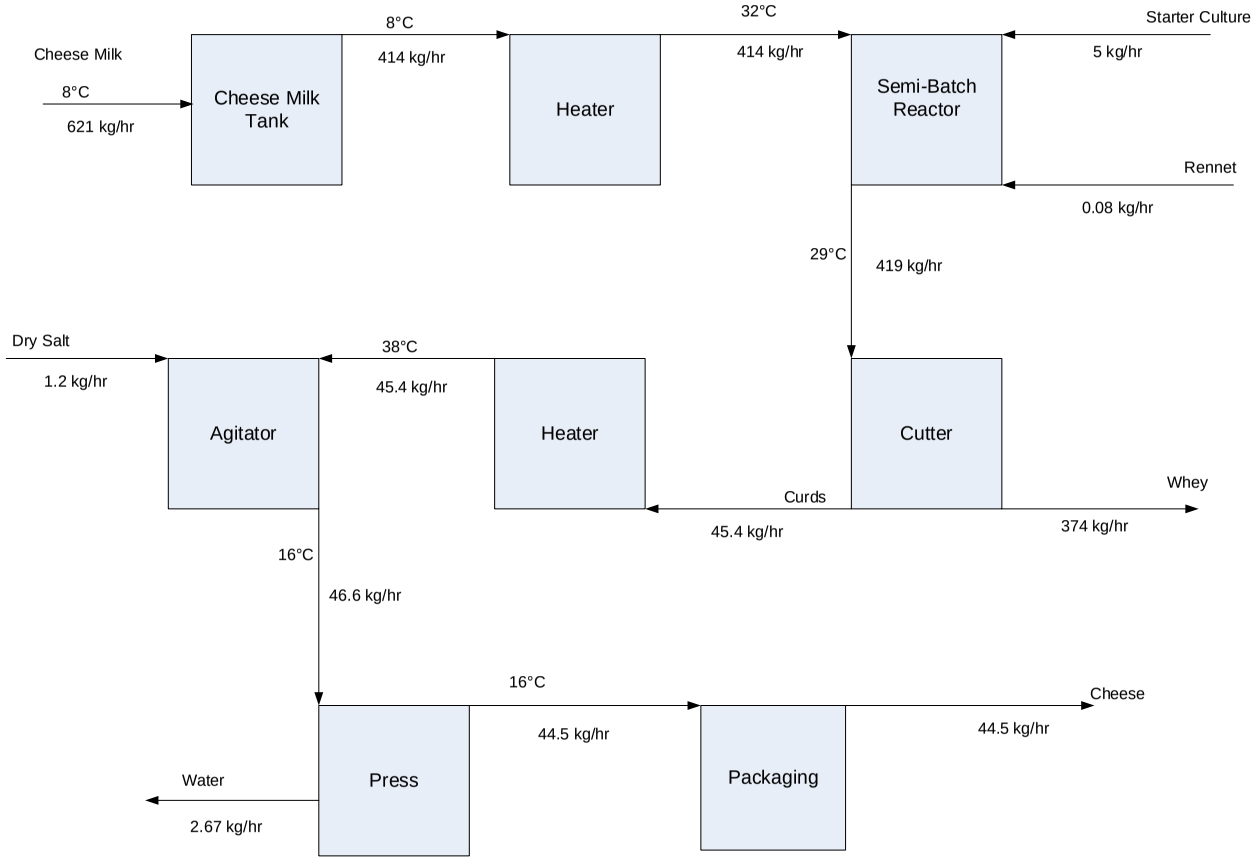



*Figure II.1.3: Block flow diagrams of Unit 300, the processing of cheese.*

## *II.2 Process Flow Diagrams*

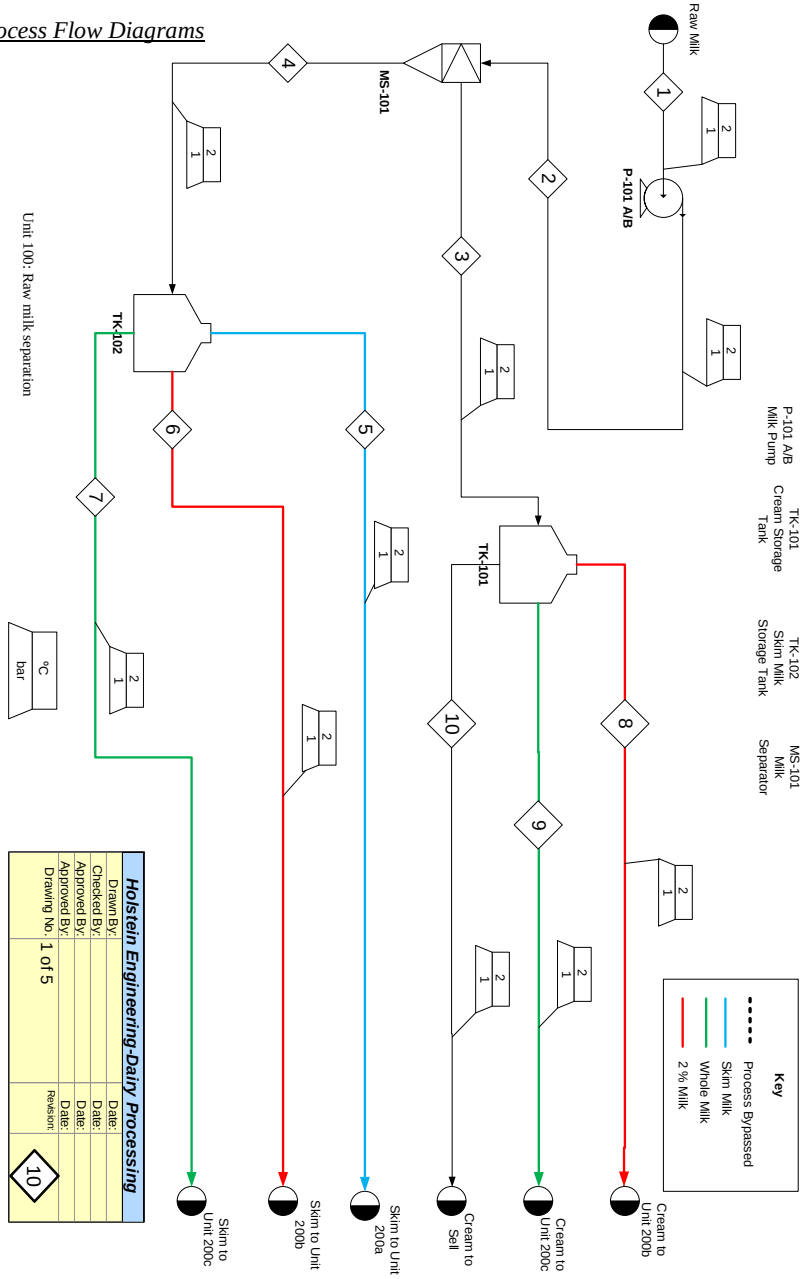



*Figure II.2. 1: Process flow diagram of Unit 100, the separation of cream and skim*

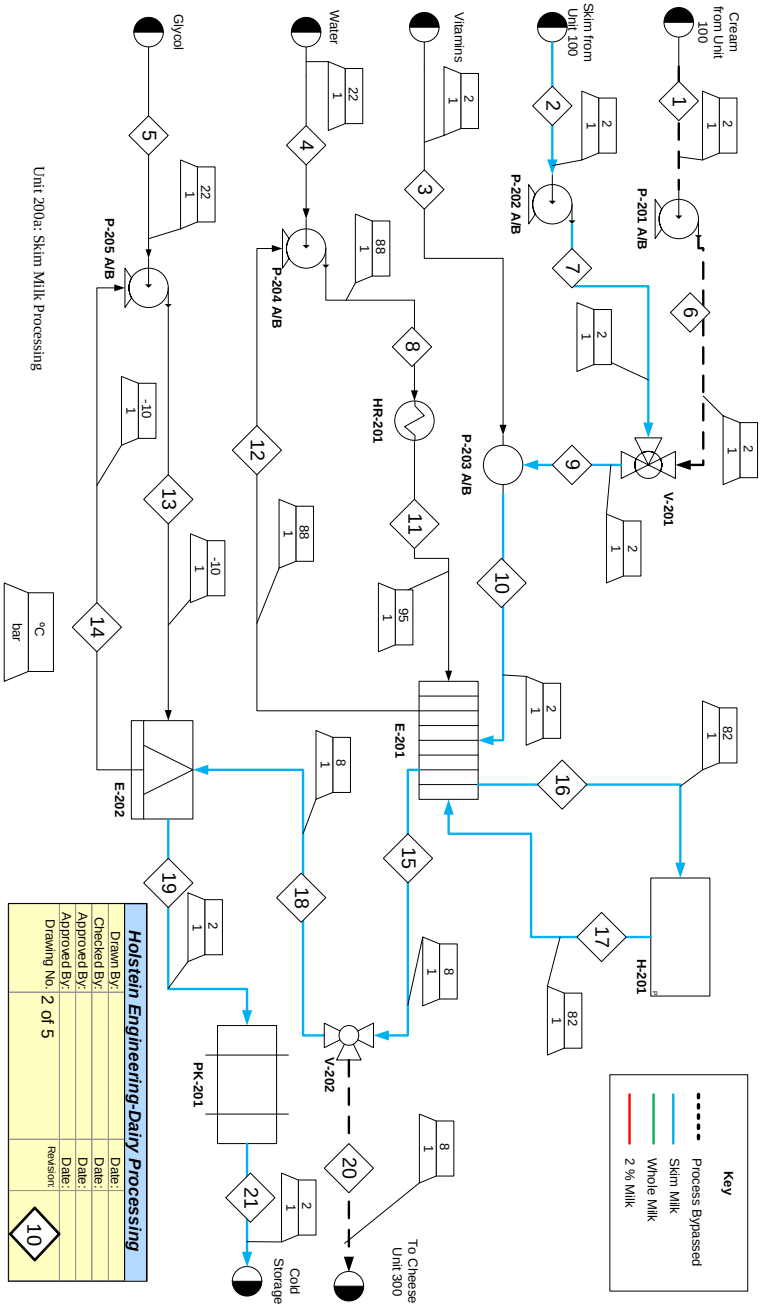



*Figure II.2. 2: Process flow diagram of Unit 200(a), processing skim milk*

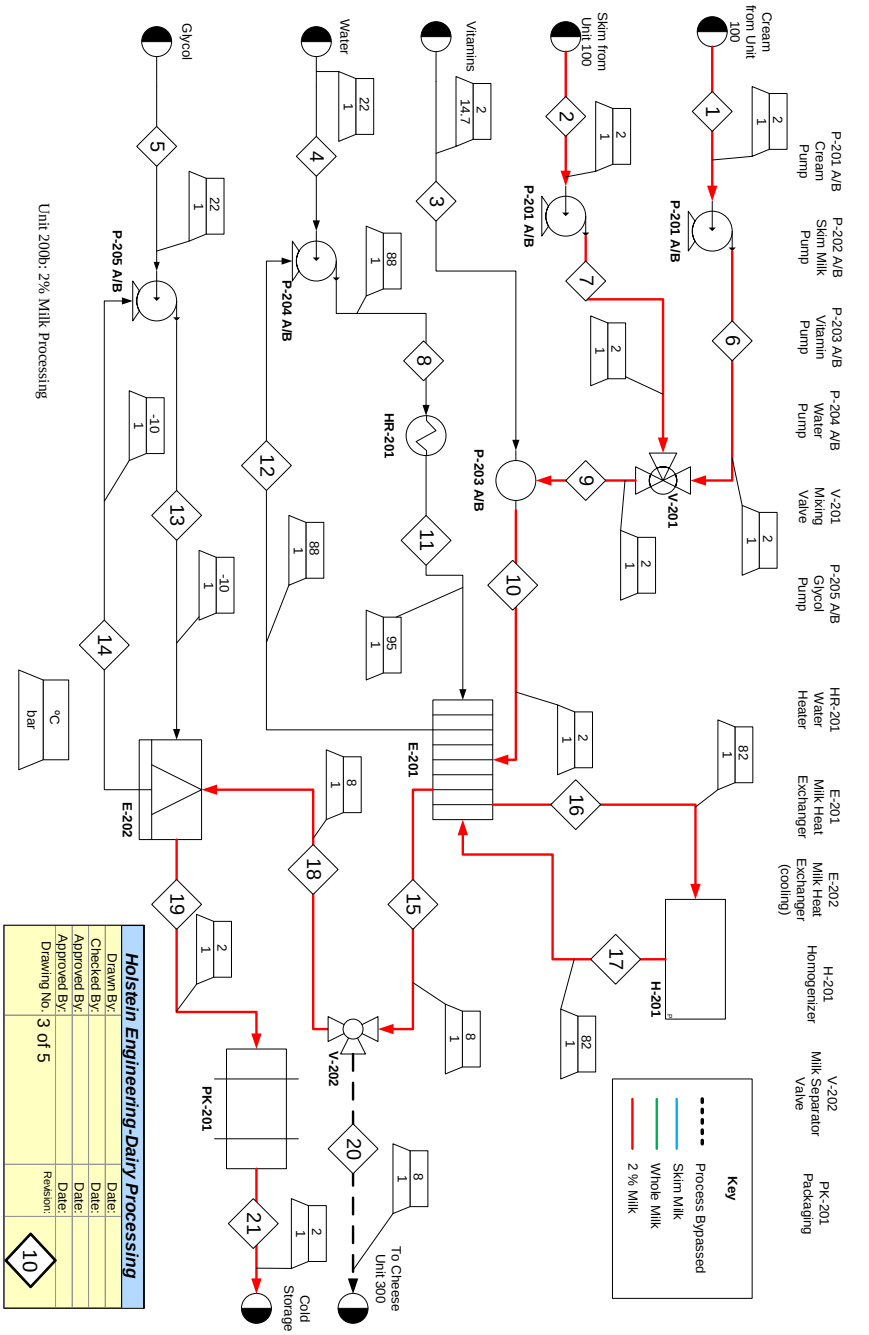



*Figure II.2. 3: Process flow diagram of Unit 200(b), processing 2% milk*

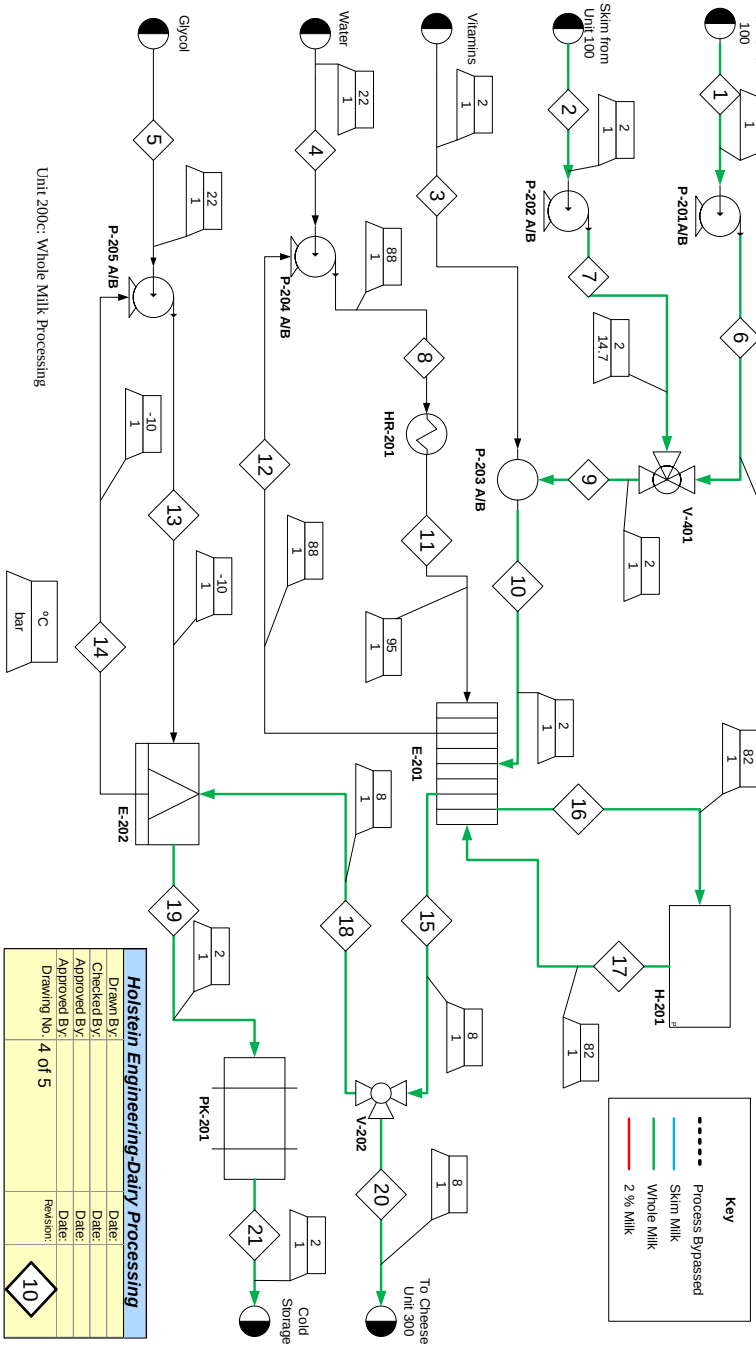



*Figure II.2. 4: Process flow diagram for Unit 200(c), processing whole milk*

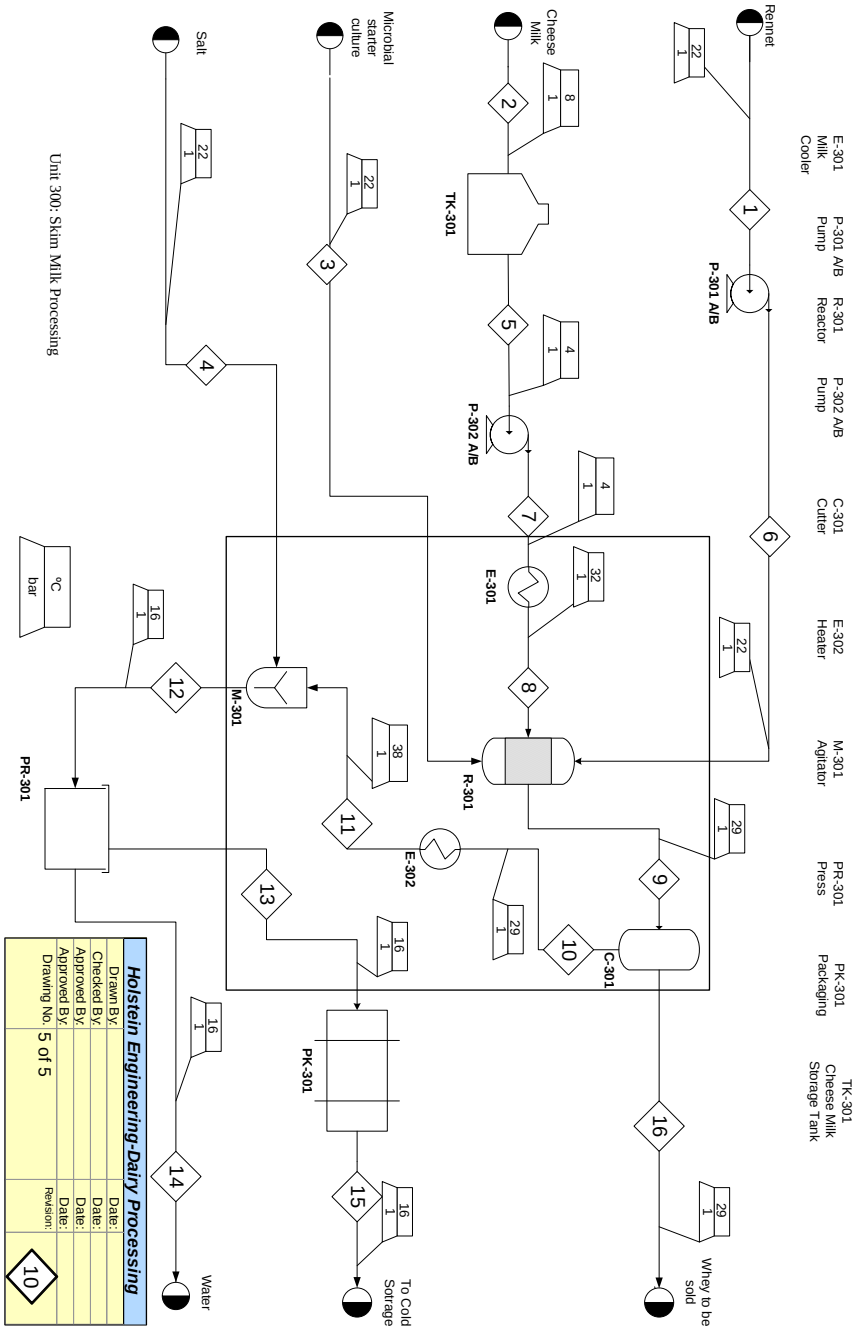



*Figure II.2. 5: Process flow diagram of Unit 300, processing cheddar cheese*

*II.3 Stream Tables*

*Table II.3. 1:Stream table for Unit 100*

| **Stream** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Stream Description | *Raw Milk* | *Raw Milk* | *Cream* | *Skim* | *Skim to 200a* |
| Temperature [C] | 2 | 2 | 2 | 2 | 2 |
| Pressure [bar] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total Mass Flow [kg/hr] | 15,000[tf] | 15,000[tf] | 3,100[tf] | 10,500[tf] | 11,000[f] |
| Mass Fraction | | | | | |
| Fat | 0.04 | 0.04 | 0.4 | 0.01 | 0.01 |
| Water | 0.88 | 0.88 | 0.54 | 0.90 | 0.90 |
| Proteins | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 |
| Carbohydrates | 0.04 | 0.04 | 0.03 | 0.05 | 0.05 |
| Minerals | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

| **Stream** | **6** | **7** | **8** | **10** | **11** |
|---|---|---|---|---|---|
| Stream Description | *Skim to 200b* | *Skim to 200c* | *Cream to 200b* | *Cream to 200c* | *Cream to sell* |
| Temperature [C] | 2 | 2 | 2 | 2 | 2 |
| Pressure [bar] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total Mass Flow [kg/hr] | 10,700[t] | 10,000[e] | 500[t] | 800[e] | 2,500[tf] |
| Mass Fraction | | | | | |
| Fat | 0.01 | 0.01 | 0.4 | 0.4 | |
| Water | 0.90 | 0.90 | 0.54 | 0.54 | 0.54 |
| Proteins | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 |
| Carbohydrates | 0.05 | 0.05 | 0.03 | 0.03 | 0.03 |
| Minerals | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

[tf] Based on a 24 hour production time
[f] Based on a 4 hour production time
[t] Based on a 12 hour production time
[e] Based on an 8 hour production time

*Table II.3. 2: Stream Table for Unit 200, Skim Milk (Unit 200a)*

| **Stream** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream Description | *N/A* | *Skim* | *Vitamin D* | *HE Water* | *Glycol* | *N/A* | *Skim* | *HE Water* | *Skim* | *Skim* | *HE Water* |
| Temperature [C] | N/A | 2 | 2 | 22 | 22 | N/A | 2 | 88 | 2 | 2 | 95 |
| Pressure [bar] | N/A | 1.00 | 1.00 | 1.00 | 1.00 | N/A | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total Mass Flow[f] [kg/hr] | N/A | 11,000 | 1.4E-4 | 7,900 | 5,500 | N/A | 11,000 | 7,900 | 11,000 | 11,000 | 7,900 |
| Mass Fraction | | | | | | | | | | | |
| Fat | N/A | 0.01 | 0.00 | 0.00 | 0.00 | N/A | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 |
| Water | N/A | 0.90 | 0.00 | 0.00 | 0.00 | N/A | 0.90 | 0.00 | 0.90 | 0.90 | 0.00 |
| Proteins | N/A | 0.03 | 0.00 | 0.00 | 0.00 | N/A | 0.03 | 0.00 | 0.03 | 0.03 | 0.00 |
| Carbohydrates | N/A | 0.05 | 0.00 | 0.00 | 0.00 | N/A | 0.05 | 0.00 | 0.05 | 0.05 | 0.00 |
| Minerals | N/A | 0.01 | 0.00 | 0.00 | 0.00 | N/A | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 |
| Vitamins | N/A | 0.00 | 1.00 | 0.00 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | Trace | 0.00 |
| Water[*] | N/A | 0.00 | 0.00 | 1.00 | 0.00 | N/A | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 |
| Glycol | N/A | 0.00 | 0.00 | 0.00 | 1.00 | N/A | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| **Stream** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** |
|---|---|---|---|---|---|---|---|---|---|---|
| Stream Description | *HE Water* | *Glycol* | *Glycol* | *Skim* | *Skim* | *Skim* | *Skim* | *Skim* | *N/A* | *Skim* |
| Temperature [C] | 88 | -10 | -10 | 8 | 82 | 82 | 8 | 2 | N/A | 2 |
| Pressure [bar] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | 1 |
| Total Mass Flow[f] [kg/hr] | 7,900 | 5,500 | 5,500 | 11,000 | 11,000 | 11,000 | 11,000 | 11,000 | N/A | 11,000 |
| Mass Fraction | | | | | | | | | | |
| Fat | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | N/A | 0.01 |
| Water | 0.00 | 0.00 | 0.00 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | N/A | 0.90 |
| Proteins | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | N/A | 0.03 |
| Carbohydrates | 0.00 | 0.00 | 0.00 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | N/A | 0.05 |
| Minerals | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | N/A | 0.01 |
| Vitamins | 0.00 | 0.00 | 0.00 | Trace | Trace | Trace | Trace | Trace | N/A | Trace |
| Water[*] | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A | 0.00 |
| Glycol | 0.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A | 0.00 |

[f] Based on a 4 hour production time

[*] Water used in heat exchanger, not the water present in milk

*Table II.3. 3: Stream Table for Unit 200, 2% Milk (Unit 200b)*

| **Stream** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream Description | *Cream* | *Skim* | *Vitamin D* | *HE Water* | *Glycol* | *Cream* | *Skim* | *HE Water* | *2%* | *2%* | *HE Water* |
| Temperature [C] | 2 | 2 | 2 | 22 | 22 | 2 | 2 | 88 | 2 | 2 | 95 |
| Pressure [bar] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total Mass Flow[t] [kg/hr] | 500 | 10,700 | 1.03E-4 | 8,100 | 5,600 | 500 | 10,700 | 8,100 | 11,200 | 11,200 | 8,100 |
| Mass Fraction | | | | | | | | | | | |
| Fat | 0.4 | 0.01 | 0.00 | 0.00 | 0.00 | 0.4 | 0.01 | 0.00 | 0.02 | 0.02 | 0.00 |
| Water[*] | 0.54 | 0.90 | 0.00 | 0.00 | 0.00 | 0.54 | 0.90 | 0.00 | 0.89 | 0.89 | 0.00 |
| Proteins | 0.02 | 0.03 | 0.00 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.03 | 0.03 | 0.00 |
| Carbohydrates | 0.03 | 0.05 | 0.00 | 0.00 | 0.00 | 0.03 | 0.05 | 0.00 | 0.05 | 0.05 | 0.00 |
| Minerals | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 |
| Vitamins | Trace | 0.00 | 1.00 | 0.00 | 0.00 | Trace | 0.00 | 0.00 | Trace | Trace | 0.00 |
| Water | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 |
| Glycol | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| **Stream** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** |
|---|---|---|---|---|---|---|---|---|---|---|
| Stream Description | *HE Water* | *Glycol* | *Glycol* | *2%* | *2%* | *2%* | *2%* | *2%* | *N/A* | *2%* |
| Temperature [C] | 88 | -10 | -10 | 8 | 82 | 82 | 8 | 2 | N/A | 2 |
| Pressure [bar] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | N/A | 1.00 |
| Total Mass Flow[1] [kg/hr] | 8,100 | 5,600 | 5,600 | 11,200 | 11,200 | 11,200 | 11,200 | 11,200 | N/A | 11,200 |
| Mass Fraction | | | | | | | | | | |
| Fat | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | N/A | 0.02 |
| Water | 0.00 | 0.00 | 0.00 | 0.89 | 0.89 | 0.89 | 0.89 | 0.89 | N/A | 0.89 |
| Proteins | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | N/A | 0.03 |
| Carbohydrates | 0.00 | 0.00 | 0.00 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | N/A | 0.05 |
| Minerals | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | N/A | 0.01 |
| Vitamins | 0.00 | 0.00 | 0.00 | Trace | Trace | Trace | Trace | Trace | N/A | Trace |
| Water[*] | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A | 0.00 |
| Glycol | 0.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A | 0.00 |

[t] Based on a 12 hour production time
[*] Water used in heat exchanger, not the water present in milk

*Table II.3. 4: Stream Table for Unit 200, Whole Milk (Unit 200c)*

| **Stream** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream Description | *Cream* | *Skim* | *Vitamin D* | *HE Water* | *Glycol* | *Cream* | *Skim* | *HE Water* | *Whole* | *Whole* | *HE Water* |
| Temperature [C] | 88 | -10 | -10 | 8 | 82 | 82 | 8 | 2 | N/A | 2 | 95 |
| Pressure [bar] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total Mass Flow[e] [kg/hr] | 800 | 10,000 | 9.59E-4 | 7,700 | 5,300 | 800 | 10,000 | 7,700 | 10,800 | 10,800 | 7,700 |
| Mass Fraction | | | | | | | | | | | |
| Fat | 0.4 | 0.01 | 0.00 | 0.00 | 0.00 | 0.4 | 0.01 | 0.00 | 0.03 | 0.03 | 0.00 |
| Water | 0.54 | 0.90 | 0.00 | 0.00 | 0.00 | 0.54 | 0.90 | 0.00 | 0.88 | 0.88 | 0.00 |
| Proteins | 0.02 | 0.03 | 0.00 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.03 | 0.03 | 0.00 |
| Carbohydrates | 0.03 | 0.05 | 0.00 | 0.00 | 0.00 | 0.03 | 0.05 | 0.00 | 0.05 | 0.05 | 0.00 |
| Minerals | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 |
| Vitamins | Trace | 0.00 | 1.00 | 0.00 | 0.00 | Trace | 0.00 | 0.00 | Trace | Trace | 0.00 |
| Water [*] | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 |
| Glycol | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| **Stream** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** |
|---|---|---|---|---|---|---|---|---|---|---|
| Stream Description | *HE Water* | *Glycol* | *Glycol* | *Whole* | *Whole* | *Whole* | *Whole* | *Whole* | *Cheese Milk* | *Whole* |
| Temperature [C] | 88 | -10 | -10 | 8 | 82 | 82 | 8 | 2 | 8 | 2 |
| Pressure [bar] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total Mass Flow [kg/hr] | 7,700 | 5,300 | 5,300 | 10,800 | 10,800 | 10,800 | 10,200 | 10,200 | 600 | 10,200 |
| Mass Fraction | | | | | | | | | | |
| Fat | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Water | 0.00 | 0.00 | 0.00 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 |
| Proteins | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Carbohydrates | 0.00 | 0.00 | 0.00 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Minerals | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Vitamins | 0.00 | 0.00 | 0.00 | Trace | Trace | Trace | Trace | Trace | Trace | Trace |
| Water | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Glycol | 0.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

[e] Based on an 8 hour production time
[*] Water used in heat exchanger, not the water present in milk

*Table II.3. 5: Stream Table for Unit 300, Cheese*

| **Stream** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| Stream Description | *Rennet* | *Cheese Milk* | *Starter Culture* | *Salt* | *Cheese Milk* | *Rennet* | *Cheese Milk* | *Cheese Milk* |
| Temperature [C] | 22 | 8 | 22 | 22 | 4 | 8 | 4 | 32 |
| Pressure [bar] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total Mass Flow[b] [kg/hr] | 0.08 | 600[e] | 5 | 1.2 | 400 | 0.08 | 400 | 400 |
| Mass Fraction | | | | | | | | |
| Cheese Milk | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 |
| Starter Culture | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Rennet | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 |
| Salt | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Curds | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Whey | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Water[*] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| **Stream** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
|---|---|---|---|---|---|---|---|---|
| Stream Description | *Curd & Whey* | *Curds* | *Curds* | *Salted Curds* | *Cheese* | *Water* | *Cheese* | *Whey* |
| Temperature [C] | 31 | 29 | 38 | 16 | 16 | 16 | 16 | 29 |
| Pressure [bar] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total Mass Flow[b] [kg/hr] | 400 | 45 | 45 | 46 | 45 | 2.2 | 45 | 40 |
| Mass Fraction | | | | | | | | |
| Cheese Milk | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Starter Culture | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Rennet | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Salt | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.02 | 0.00 |
| Curds | 0.13 | 0.59 | 0.59 | 0.58 | 0.61 | 0.00 | 0.61 | 0.00 |
| Whey | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 |
| Water* | 0.87 | 0.41 | 0.41 | 0.4 | 0.37 | 1.00 | 0.37 | 0.00 |

[b] Based on a 2 hour production time per batch, throughout a 24 hour day
[e] Based on an 8 hour production time
[*] Water not extracted with the whey

*II.4 Equipment Tables*

*Table II.4 1:Equipment table for pumps in Unit 100, Unit 200 & Unit 300.*

| **Pump** | **P-101 A/B** | **P-201 A/B** | **P-202 A/B** | **P-203 A/B** | **P-204 A/B** | **P-205 A/B** | **P-301 A/B** | **P-302 A/B** |
|---|---|---|---|---|---|---|---|---|
| Component | Raw milk | Cream | Skim Milk | Vitamin | HE Water | Glycol | Rennet | Cheese Milk |
| Flow[1] [kg/hr] | 13,600 | 3,000 | 11,000 | 1.04E-4 | 8,100 | 5,600 | 0.08 | 600 |
| Efficiency | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| Pressure, Inlet [bar] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Pressure, outlet [bar] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Total Expansion Ratio | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Temperature, inlet [C] | 2 | 2 | 2 | 2 | 88 | -10 | 22 | 4 |
| Temperature, outlet [C] | 2 | 2 | 2 | 2 | 88 | -10 | 22 | 4 |
| MOC | S.S. | S.S. | S.S. | S.S. | S.S. | S.S. | S.S. | S.S. |
| Power [kW] | 2.1[1] | 0.37[b] | 2.6[a] | 0.04[c] | 2.4[a] | 2.23[a] | 0.06[e] | 0.3[b] |

*Table II.4 2: Equipment table for the milk separator in Unit 100*

| **Milk Separator** | **MS-101** |
|---|---|
| Component | Raw Milk |
| Flow [kg/hr][1] | 11768 |
| Efficiency | 0.90 |
| Pressure, Inlet [bar] | 1 |
| Pressure, outlet [bar] | 1 |
| Total Expansion Ratio | 1 |
| Temperature, inlet [C] | 2 |
| Temperature, outlet [C] | 2 |
| MOC | S.S. |
| Power [kW] | 18.64[d] |

[1] The largest flow rate of the milk production was used.
[1] http://solutionsforagriculture.com/?post_type=product&p=180
[b] http://ittflowcontrol.com/files/43000_0549_09_04.pdf
[c]http://ittflowcontrol.com/food-and-beverage-processing/chemical-dispensing/oscillating-pumps/et508-series-fnb.htm
[e] http://ittflowcontrol.com/files/81000_379.pdf
[d] http://www.westfalia-separator.com/fileadmin/Media/PDFs/Brochures/Westfalia-Separator-procool-cold-milk-separation-9997-1109-020.pdf

*Table II.4 3: Equipment table for the storage tanks in Unit 100 & Unit 300*

| **Cool Storage Tank** | **TK-101** | **TK-102** | **TK-301** |
|---|---|---|---|
| Component | Cream | Skim Milk | Cheese Milk |
| Flow, Inlet [kg/hr][1] | 3,100 | 10,500 | 600 |
| Flow, Outlet[1] [kg/hr] | 800 | 11,000 | 400 |
| Pressure, Inlet [bar] | 1 | 1 | 1 |
| Pressure, outlet [bar] | 1 | 1 | 1 |
| Total Expansion Ratio | 1 | 1 | 1 |
| Temperature, inlet [F] | 2 | 2 | 8 |
| Temperature, outlet [F] | 2 | 2 | 4 |
| MOC | S.S. | S.S. | S.S. |
| Power [kW][2] | 2.2[a] | 7.4[b] | 13[c] |

*Table II.4 4: Equipment table for the heat exchangers in Unit 200*

| **Heat Exchanger** | **E-201** | **E-202** |
|---|---|---|
| Type | Plate & Fin | Cooler |
| Flow, Milk[1] [kg/hr] | 11287 | 11287 |
| Flow,Water[1] [kg/hr] | 245833 | 0 |
| Flow,Water[1] [kg/hr] | 0 | 5604 |
| Total Area [$m^2$] | 5.4 | 5.9 |
| Duty [kW] | 67 | 67 |
| Pressure, Inlet [bar] | 1 | 1 |
| Pressure, outlet [bar] | 1 | 1 |
| Total Expansion Ratio | 1 | 1 |
| Temperature, inlet [C] | 2 | 8 |
| Temperature, outlet [C] | 8 | 2 |
| MOC | S.S. | S.S. |

[1] The largest flow rate of the milk production was used.
[2] Equipment was sized based on the kilograms stored per day, power is for the aggregate
[a] Based off of one insulated tank with a capacity of 35,000 kg/day of storage (http://www.skylarkpune.com/milk-processing-equipments.html)
[b] Based off of two insulated storage tanks with a capacity of 130,000 kg/day of storage (http://www.skylarkpune.com/milk-processing-equipments.html)
[c] Based off of one cooling storage tank with a capacity of 5200 kg/day of storage (http://www.bimalindia.net/bulk-milk-coolers.html)

*Table II.4 5: Equipment table for the homogenizer in Unit 200*

| **Homogenizer Pump** | **H-201** |
|---|---|
| Component | Milk |
| Flow [1][kg/hr] | 11287 |
| Efficiency | 0.90 |
| Pressure, Inlet [bar] | 1 |
| Pressure, outlet [bar] | 1 |
| Total Expansion Ratio | 1 |
| Temperature, inlet [C] | 82 |
| Temperature, outlet [C] | 82 |
| MOC | S.S. |
| Power [kW] | 30[a] |

*Table II.4 6: Equipment table for heater in Unit 200*

| **Heater** | **HR-201** |
|---|---|
| Component | Water |
| Flow[1] [kg/hr] | 8087 |
| Efficiency | 0.80 |
| Pressure, Inlet [bar] | 1 |
| Pressure, outlet [bar] | 1 |
| Total Expansion Ratio | 1 |
| Temperature, inlet [C] | 88 |
| Temperature, outlet [C] | 95 |
| MOC | Carbon Steel |
| Power [kW] | 65 |

*Table II.4 7: Equipment table for packaging unit in Unit 200 & Unit 300*

| **Packaging** | **PK-201** | **PK-301** |
|---|---|---|
| Type | Milk | Cheese |
| Flow [kg/hr][1] | 10093 | 52 |
| MOC | C.S. & S.S | C.S. & S.S |
| Power [kW] | 23[b] | 20[c] |

[1] The largest flow rate of the milk production was used.
[a] http://www.alibaba.com/product-gs/283663194/Homogenization_pump_creamy_milkiness_raw_liquid.html
[b] http://www.alibaba.com/product-gs/425595692/SF_M1000_Liquid_Milk_Packing_Machine.html
[c] http://www.alibaba.com/product-gs/335935523/automatic_cheese_packing_machine_47.html

*Table II.4 8: Equipment table for cheese vat in Unit 300*

| **Cheese Vat** | |
|---|---|
| Component | Cheese Milk |
| Flow [kg/hr] | 600 |
| Temperature, inlet [C] | 4 |
| Temperature, outlet [C] | 16 |
| MOC | S.S. |
| Power [kW] | 5[c] |

*Table II.4. 9: Equipment Table for cheese press in Unit 300*

| **Press** | **PR-301** |
|---|---|
| Component | Cheese |
| Flow [kg/hr] | 45 |
| Temperature, inlet [C] | 16 |
| Temperature, outlet [C] | 16 |
| MOC | S.S. |
| Power [kW] | 4.4[d] |

*Table II.4. 10: Equipment table for valves in Unit 200*

| **Valve** | **V-201** | **V-202** |
|---|---|---|
| Type | Mixing | Separating |
| Component | Milk | Milk |
| Flow [kg/hr][1] | 11,200 | 600 |
| Pressure, Inlet [bar] | 1 | 1 |
| Pressure, outlet [bar] | 1 | 1 |
| Total Expansion Ratio | 1 | 1 |
| Temperature, inlet [C] | 2 | 2 |
| Temperature, outlet [C] | 2 | 2 |
| MOC | S.S | S.S |

[c] http://www.discoverarmfield.co.uk/data/ft20/?js=enabled
[d] http://www.vikingmachine.com/cmm.html
[1] The largest flow rate of the milk production was used.

*II.5. Raw Material Requirements*

*Table II.5 1: Raw material costs*

| Materials | Amounts kg per Day | Unit Cost per Kilogram | Cost per Day |
|---|---|---|---|
| Raw Milk | 326333 | $0.38[a] | $124007 |
| Rennet | 0.05 | $439.4[b] | $21.97 |
| Starter Culture | 59.6 | $0.59[b] | $32.99 |
| Salt | 14.9 | $0.62[c] | $9.24 |
| Resin | 1128 | $1.56[d] | $1759.68 |
| Glycol | 22022 | $1.15[e] | $25325.3[*] |

*II.6. Utility Requirements*

*Table II.6.1: Utility table for entire plant*

| Unit | Utility | Amounts | Units per day | Unit Cost $ | Cost per Day $ |
|---|---|---|---|---|---|
| All | Water[1] | 277445 | kg | 2.59E-4[f] | 71.86 |
| All | Steam[1] | 149394 | kg | 2.59E-4 | 38.70 |
| 200 | Water | 190291 | kg | 2.59E-4 | 49.29[g] |
| All | Electricity | 4770 | kWh | 0.17[h] | 810 |

[a] Wise, W. et al 2011
[b] http://www.thecheesemaker.com/cultures.htm
[c] http://www.webstaurantstore.com/non-iodized-table-salt-25-lb-bag/
[d] Personal Communication, Troy Hancock (2011)
[e] http://www.icis.com/V2/chemicals/9075765/ethylene-glycol-mono/pricing.html
[*] Assumed the glycol is recycled, so this is considered a one time cost
[1] Personal Communication, Troy Hancock (2011); 1 gallon of milk uses 2 gallons of water.
[f] http://www.hawaiidws.org/4%20your%20water%20bill/waterrates11%2003-11.pdf
[g] Assumed the water is recycled, so this is considered a one time cost
[h] http://www.heco.com/portal/site/heco/menuitem.508576f8baal4340b4c0610c510b1ca/?vgnexto.html

## *II.7 Process Description*

### II.7.1 Process Overview

The raw milk is separated into the cream and skim milk and placed into separate holding tanks, the cream holding tank and the skim milk holding tank. Although there are three streams depicted in Unit 100 on the process flow diagram (PFD) (see Figure II.2.1) coming out of the cream tank, there are only two finite pipelines. The first is for the excess cream that is to be sold. The second is for the cream being mixed into the skim to make the desired composition of milk.

This similar situation is shown on the skim milk storage tank. Depicted on the PFD are three separate streams when only one major pipeline leads to Unit 200. Each composition of milk is made one after the other, but has differing flows. These processes are shown on separate process flow diagrams labeled Unit 200a, 200b and 200c (See Figure II.2.2 through Figure II.2.4). This depicts that while only one unit is present, the flow rates are different depending on the type of milk being made. The cream and skim are then mixed back together, pasteurized, homogenized then cooled and sent to packaging.

Unit 300 is the unit used to make cheese; this process is based on a 24 hour day running separate batches at 2 hours each. The whole production of milk is based off of a 24 hour day, but the different types of milk were separated into different time slots of 4, 8 and 12 hours. The original calculations (see Appendix IX.A.1.6) were based off of kilograms per day then split into kilograms per hour based on the milk and cheese production time. Below are the details of the processes.

II.7.2 Raw Milk Processing: Unit 100[a]

Raw milk is delivered at 2ºC from a cold tank truck, because this milk will be separated and stored, the flow rates for the incoming raw milk to the storage tanks are based on 24 hours. All flow rates and temperatures can be found in Table II.3.1.

The raw milk in stream 2 is pumped into a milk separator where it is separated into two streams, the cream, stream 3 and the skim milk, stream 4. The cream in stream 3 is pumped into the cream holding tank. The skim in stream 4 is pumped into the skim milk holding tank. The holding tanks keep the milk at 2ºC and all the milk is transported through stainless steel pipes.

The holding tanks will then dispense the right amount of cream and skim milk depending on the composition and production time of the milk. In Unit 100 (see Figure II.2.1) the skim milk streams are shown as stream 5 (skim milk), 6 (2% milk), 7 (whole milk), and the cream streams are shown as stream 8 (2% milk) and 9 (whole milk). These streams flow through one pipeline and happen at separate times.

II.7.3 Milk Processing: Unit 200

This starts by drawing skim milk from the skim milk storage tank and cream from the cream storage tank, and sending it to Unit 200 to be processed. The composition and production time determines the amount that comes out of the tanks, see Figure II.7.3.1 for a graph of how production time is split up.

[a] Please refer to Figure II.2.1 for process flow diagram

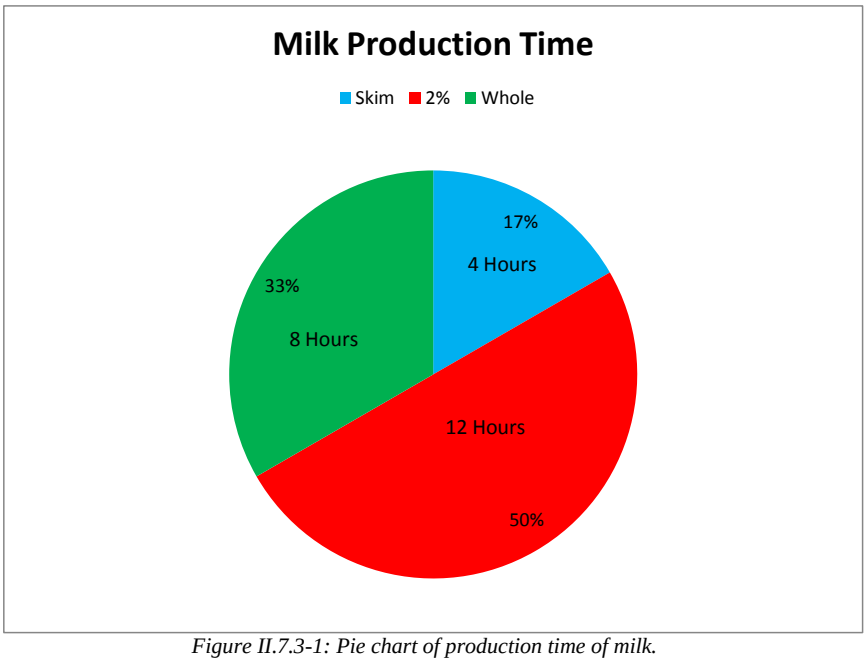



*Figure II.7.3-1: Pie chart of production time of milk.*

The skim and cream are then mixed back together based on composition needed through a mixing valve. The milk in stream 9 is then injected with vitamin D via stream 3[a]. Stream 10 is then pasteurized by sending it through a heat exchanger where it is brought up to 82°C. Stream 16 is then homogenized, and then the homogenized milk, still at 82°C, in stream 17 is sent back through the heat exchanger to be cooled and help heat incoming non-homogenized milk. Stream 15 is now sent to a separating valve. The separating valve separates some of the milk out to be made into cheese; stream 20 is bypassed for skim and 2% milk (Unit 200a and 200b respectively). Stream 18 is now sent through a cooling heat exchanger where is it cooled to 2°C. Stream 19 is then sent to packaging, after packaging stream 21 is then sent to cold storage.

*II.7.3.1 Skim Milk Processing: Unit 200a*[1]

This process is based off of 4 hours because it is the smallest flow produced, see Table II.3.2. This starts with stream 2 (stream 1 is bypassed for the production of skim milk) by drawing skim milk from the skim milk storage tank. This stream is shown as stream 5 on Unit 100 going to Unit 200a where it is labeled as stream 2. The skim milk is then injected with vitamin D, pasteurized, homogenized, cooled, packaged, and stored as previously explained.

[a] All stream numbers mentioned in this section are the same for all milk compositions, see Figure II.2.2 through Figure II.2.4.
[1] See Figure II.2.2 for process flow diagram

*II.7.3.2 2% Milk Processing: Unit 200b*[2]

This process is based on 12 hours because it is the biggest flow produced, see Table II.3.3. This starts with stream 1, the cream and stream 2, the skim passing through a mixing valve to create a 2% milk composition in stream 9. Stream 2 in Unit 200b comes from stream 6 in Unit 100. Stream 1 in Unit 200b comes from stream 8 in Unit 100. The 2% milk is then injected with vitamin D, pasteurized, homogenized, cooled, packaged, and stored as previously explained.

*II.7.3.4 Whole Milk Processing: Unit 200c*

This process is based on 8 hours because it is the second largest flow produced, see Table II.3.4. This starts with stream 1, the cream and stream 2, the skim passing through a mixing valve to create the whole milk composition in stream 9. Stream 2 in Unit 200b comes from stream 7 on Unit 100. Stream 1 in Unit 200b comes from stream 9 in Unit 100. The whole milk is then injected with vitamin D, pasteurized and homogenized. Stream 20 is now utilized, the separating valve takes a portion of the whole milk and sends it to Unit 300 to be processed for cheese, the rest in stream 18 is sent to be cooled, packaged and stored as previously explained.

[2] See Figure II.2.3 for process flow diagram

II.7.4 Cheese Processing: Unit 300[1]

This process is done in a cheese vat; the vat is shown on Figure II.2.5 as the dotted line. This process is based on 24 hours but because each batch takes about 2 hours to make (Schwartz, 1973), the hourly flow rate is based off of 12. See Figure II.7.4-1 to see how each batch is split up.

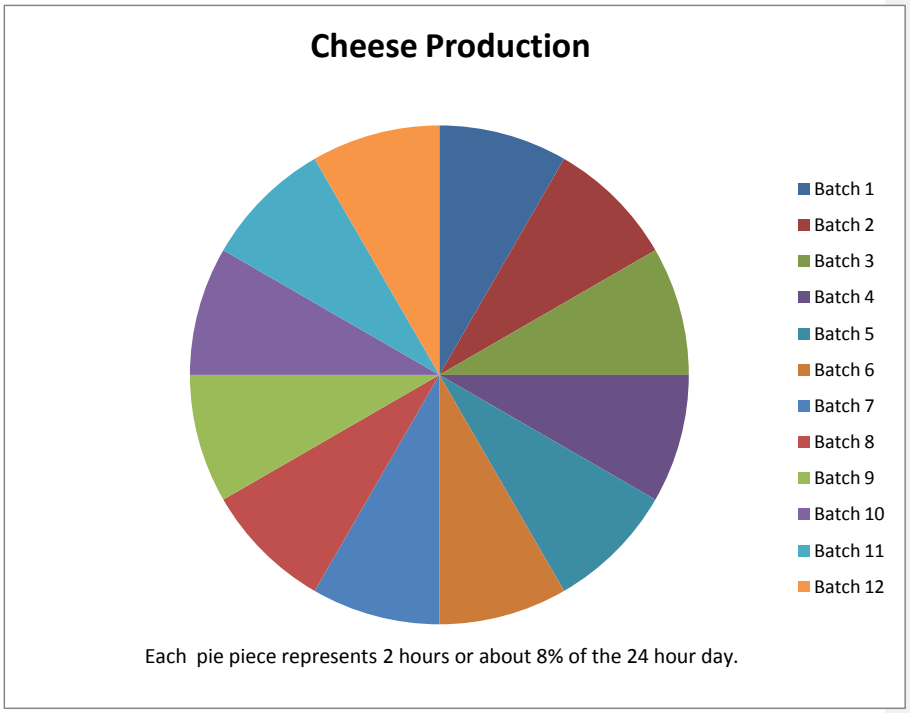



*Figure II.7.4-1: Pie chart of production time for each batch of cheese made.*

Each 2 hour interval proceeds as follows; whole milk (stream 2) from Unit 200 is put into a cooled storage tank, and then stream 5 is taken from the storage tank and pumped into the cheese vat. The cheese milk will then be heated to 32°C. Next, stream 3 introduces the

[1] See Table II.3.5 for stream information

starter culture to the vat; the vat will then be slowly mixed for 5 minutes to make sure the starter culture is uniformly mixed. The mixture will then sit for 30 minutes. After 30 minutes stream 1 introduces a rennet solution to the vat, the vat will again agitate the mixture to assure uniformity. This will sit for another 30 minutes. During these waiting periods the vat will keep the mixture at a temperature of 29°C. After the curds have formed the whey will be separated out. This is done by allowing the whey to drain from the vat through the bottom out to stream 16, during this time the vat will agitate the curds and heat the mixture to 38°C. The curds are then cut and stream 4 introduces the dry salt to stream 11, this is continuously mixed and cooled by natural air convection to 16°C. The curds are then placed into a cheese press via stream 12 where the remaining moisture is removed from the curds and the cheese is shaped. The shaped cheese is then sent to a packing unit and then stored in a cooler to bring the cheese temperature down to 2°C.

*II.8 Rationale for Process Choice*[1]

The original design for this plant was to separate just enough cream to produce the desired compositions (see Appendix IX.F). This resulted is an excess cream of 30,000 kg per day. This was mainly in part because whole milk was assumed to need no cream removal. The optimized design of separating all the cream from the skim in the beginning, resulted in an excess of 61,000 kg per day of cream. This extra cream could then be sold to various markets.

The choice to include storage tanks for the cream, skim and cheese come from the fact that the flow rates out of the tanks are different. Because all three milk compositions were being made in one 24-hour period, the time it takes to make each type of milk had to be split up between the 24 hours.

[1] Further explanation can be found in Appendix IX.A with the calculations

The amount of each milk composition produced was based on the statistical amount of people whom consume milk, then on the statistical amount of how much milk people consume followed lastly by the percentage of each different type of milk purchased.

The amount of cheese produced was again based on the statistical amount of people who eat cheese followed by the amount of cheddar cheese consumed by each person (See Appendix IX.A.1.1)

The choice to keep the milk at 2°C was due to a regulation put forth by the USDA (United States Department of Agriculture). The regulation states that the milk can be no higher than 4°C (Frandsen, J., 1958). After a tour of Shamrock Farms it was found that 2°C was the optimum temperature to keep milk to inhibit bacteria growth and keep cream from separating out (Personal Communication, Troy Hancock).

The milk being injected with vitamin D is essential even though this flow was negligible to the overall flow. Most of the vitamin D resided in the cream because it dissolves in fat. Therefore most of the vitamin D was taken out when the cream was separated from the skim and the vitamin D count still needed to be brought up to USDA standards (http://www.madehow.com/volume-4/milk.html, 2011).

The pasteurization of milk happened because all remaining bacteria in milk must be killed in order to keep milk fresh. The FDA (Food and Drug Administration) states that the milk must be heated to a minimum of 72°C (Frandsen, J., 1958). After touring Shamrock Farms it was found that 82°C was the preferred standard to ensure a good shelf life. The homogenization of milk is done to ensure the milk does not separate from the cream. This results in a longer shelf life and a more uniform distribution of the fat in milk (Personal Communication, Troy Hancock).

The entire cheese process[2] was based on  research. After entering the vat, the cheese milk was heated to 32°C to ensure the proper growth of bacteria needed to create curds. The starter culture was added to allow fermentation; this developed the flavor of the cheese. Rennet solution was added to allow formation curds, the rennet solution contained enzymes that act on the milk protein (http://www.milkfacts.info/Milk%20Processing/Cheese%20production.htm, 2011). During these waiting periods the vat kept the mixture at a temperature of 29°C, to ensure the bacteria created the cruds properly (Schwartz, 1973).

The curds were then cut from the whey and heated to 38°C. After most of the whey was drained the curds were salted while the rest of the whey drained out (http://www.milkfacts.info/Milk%20Processing/Cheese%20production.htm, 2011). It was assumed that no salt left with the whey. This whole process was continuously mixed to ensure the curds did not prematurely set up. After salting and mixing the natural air convection brought the temperature down.

At this point the salted curds were about 41% moisture, to ensure proper moisture content and firmness the salted curds were placed into a cheese press. The press applies the right amount of pressure to remove water and bring the moisture content to 38% and properly form the cheese into a firm shape (Schwartz, 1973).

[2] See Appendix IX.A.1.5 for Cheese Ingredient calculations

## ***III. Equipment Description, Rationale, and Optimization***

Modern design is aimed at developing dairy equipment to be more compact, more nearly automatic, more economical, and maintaining the quality of the products (Baldwin et al., 1949). Processing equipment is constructed with stainless steel because of the requirements for strength, function, durability, and sanitation as required by the regulations of the U.S. Food and Drug Administration (FDA) and the 3-A Sanitary Standards (Baldwin et al., 1949). Stainless steel processing equipment provides a high degree of corrosion resistance, and used for almost all product-contact surfaces (Baldwin et al., 1949).

### *III.1. P-101 A/B, P-201 A/B, P-202 A/B, P-203 A/B, P-204 A/B, P-205 A/B*

All the pumps used are reciprocating pumps, which are most common for milk production because the pump can handle a wide range of flow rates. JABSCO Company sells the most common pumps that are specific for industry use (http://ittflowcontrol.com/files/43000_0549_09_04.pdf, 2011).

### *III.2. TK-101, TK-102 and TK-301*

Three storage tanks are used when separating raw milk and cream; they are used to keep the cream and skim milk cool at 2°C; the skim milk and cream can be stored in the tanks up to 72 hours (Personal Hancock, 2011). The tanks consist of a stainless steel inner shell, a layer of insulation, an outer jacket, and necessary fittings for control, inspection, and cleaning (Baldwin et al., 1949). These tanks are capable of storing 100,000 kg to 160,600 kg and are durable and easy to install (http://www.rozienggpune.com/milk-storage-tank.htm, 2011). Another tank is used to store milk for the cheese process; a cooling tank is used since it is required that the milk must be kept at 4°C and can store up to 62,000 kg of milk. Also, storage tanks are used because of the varying flow rates in making different types of milk.

*III.3. MS-101*

To achieve standardization, milk is processed through a milk separator, which is similar to a centrifuge—this creates a skim and cream portion of the milk. The separation produces a skim portion less than 0.01% fat and cream portion that is 40% fat (milkfacts.info, 2011). The cream portion is then added back to the skim to yield the desired fat content for the product such as whole, 2% and skim. Air-tight separators such as Procool are purchased from Westfalia Separator because of the reduction in maintenance time due to low-maintenance belt drive. Also, this unit increases the availability of high separation performance (http://www.westfalia-separator.com/fileadmin/Media/PDFs/Brochures/Westfalia-Separator-procool-cold-milk-separation-9997-1109-020.pdf, 2011). Air-tight separators keep the milk cool at 2°C and can handle capacities up to 9,600 kg per hour (Baldwin et al., 1949). Figure III.3 shows a technical drawing of the inside of an air-tight separator.

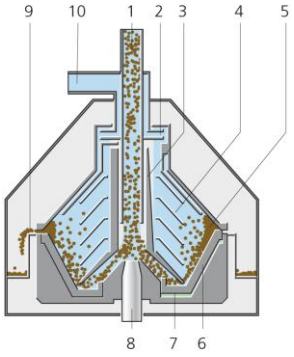



*Figure III.3. Technical drawing of an air-tight separator. 1: Product feed, 2: Centripetal pump, 3: Distributor, 4: Disk stack, 5: Solids holding space, 6: Sliding piston, 7: Closing chamber, 8: Spindle, drive, 9: Solids ejection port, 10: Discharge, clarified phase.* [3]

[3] GEA Westfalia Separator Group <http://www.westfalia-separator.com/products/product-finder/product-finder-detail/product/separator-mse-100-01-177.html, 2011>.

*III.4. V-201 and V-202*

Since the valves are part of the piping system design, there is no specific type of valve nor a specific price since the cost is included in the installation economic factors. A mixing valve and a milk separator valve are the only valves used in this operation.

III.4.1. V-201

Once the milk separator separates skim milk and cream, a mixing valve is used. Depending on the composition needed, a mixing valve is used to mix a portion of cream and skim together to make 2% and whole.

III.4.2. V-202

For the whole milk process, a milk separator valve causes the whole milk to have two different flow rates: one for the milk, which is sent to packaging and another one that is used to make cheese.

*III.5. HR-201*

Water is heated electrically to 95°C to be used in the heat exchanger network. The water coming in to the heater is at 88°C recycled from the outlet of the heat exchanger network. An electric heater is used because only water near boiling is required for the heat exchanger and not steam.

*III.6. Heat Exchanger Network*

This heat exchanger network heats the milk up to 82°C then cools it back down to 2°C. This is done by passing hot water counter current to the cool milk, as well as passing already heated milk counter current to the cool milk. The heated milk is then passed through another heat exchanger where is it cooled. See Figure III.6.1 for the overall view of the heat exchanger network.

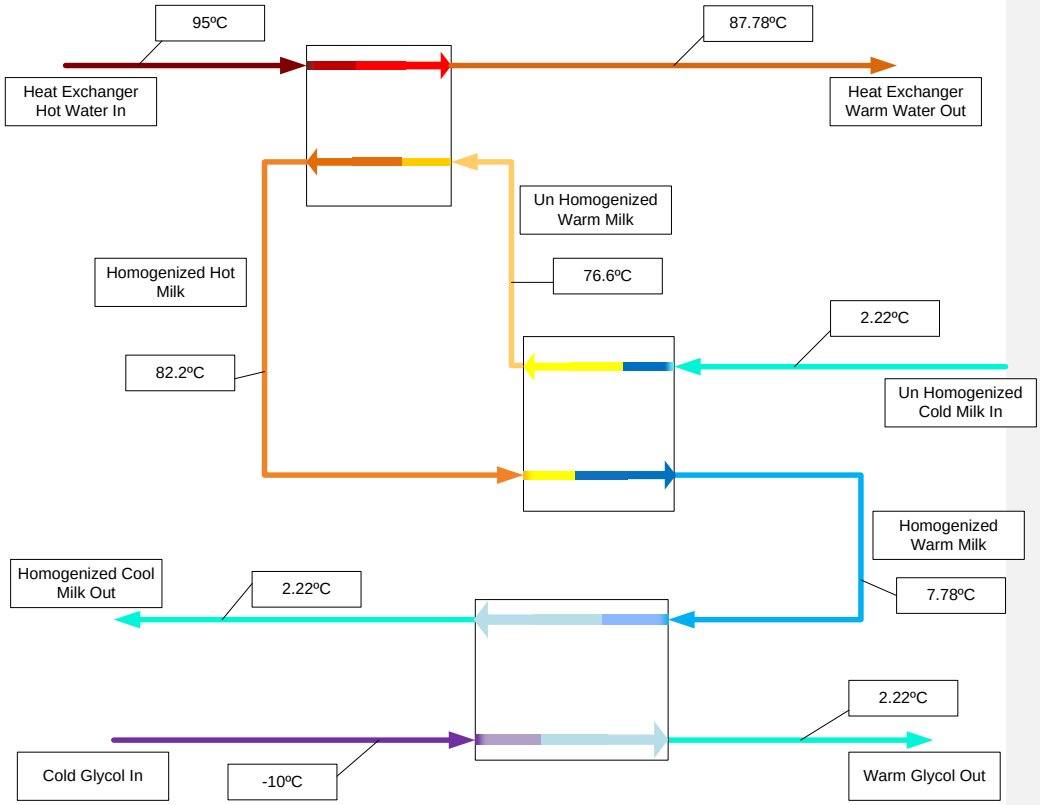



*Figure III.6.1: Overall heat exchanger network*

III.6.1 E-201: Pasteurizer

If looking at this as a continuous process the milk starts at 2°C. It is pumped into the heat exchanger where it is heated to 82°C by heated water and previously homogenized milk. This stream simultaneously cools the heated water and the previously homogenized milk. The water used is heated to 95°C and is passed counter current by the cool milk. The water then cools to 88°C after heating the milk and is sent through a heater to be heated back to 95°C. The milk, now pasteurized to 82°C is sent to the homogenizer. To save energy, after being homogenized this stream is sent back to the heat exchanger to help heat the incoming non-homogenized cold milk and be cooled by it at the same time. After passing by the non-homogenized milk it comes out of the heat exchanger at 8°C. See Figure III.6.1.1 for a diagram of the heat exchanger.

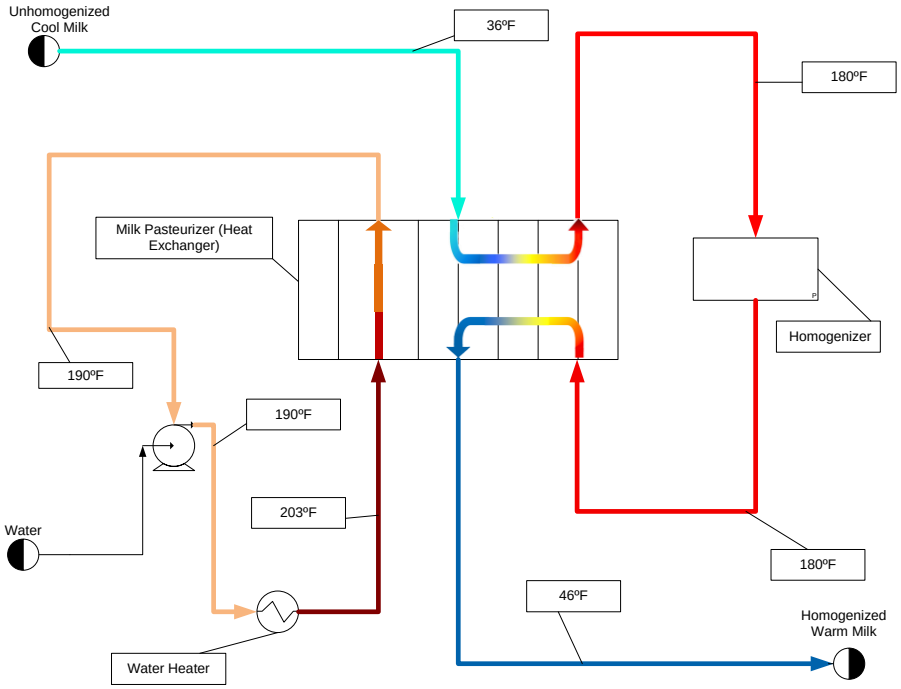



*Figure III.6.1.1: Diagram of heat exchanger that pasteurizes milk*

III.6.2 E-202: Cooler

The 8°C homogenized milk is passed counter current by a glycol solution at -10°C, this cools the homogenized milk to 2°C and warms the glycol solution to 2°C. The glycol solution is then re-cooled to -10°C through a cooler built into the heat exchanger, much like a refrigerator. See Figure III.6.2.1 for a diagram of the heat exchanger. Our specific cooler can be bought from Wales Products Inc. (http://www.dairychiller.com, 2011).

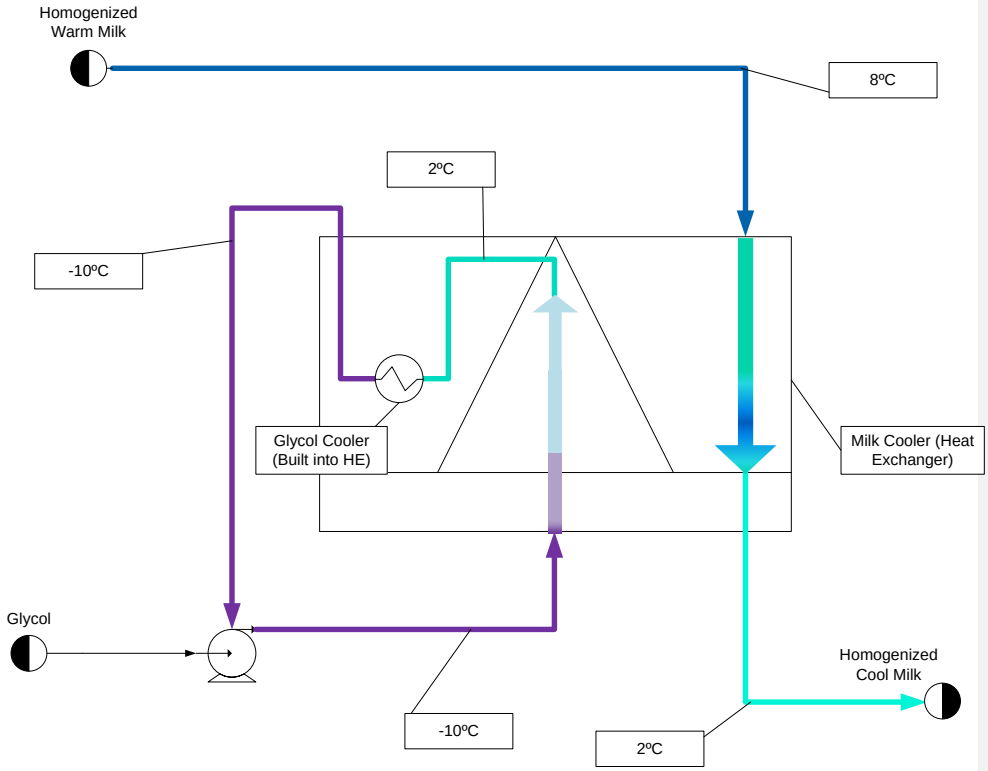



*Figure III.6.2.1: Diagram of heat exchanger that cool the milk*

*III.7. H-201*

Homogenization is used to reduce the size of the remaining fat particles in the skim milk after separation of the cream, which prevents the milk fat from separating and floating to the surface. The homogenizer also distributes the milk fat evenly (www.madehow.com/Volume-4/Milk.html, 2011). Homogenization follows pasteurization to inactivate native enzymes that deteriorate fat (lipases) and cause rancidity, which results in off-flavors and reduces shelf life of the milk (Milkfacts.info, 2011). Homogenization is a high-pressure process and typical pressures are as high as 2,500 psi. The homogenizer forces the milk through a small valve to break up the fat globules. This piece of equipment used for this dairy facility is a seven-piston homogenizer because it is able to meet the demand of large flow rates and has a capacity of 13,400 kg per hour (Baldwin et al., 1949). Selection of a seven-piston homogenizer is due to its capacity, ease of cleaning, maintenance, and durability (Baldwin et al., 1949). Figure III.7 shows how effective the homogenizer works for the milk process.

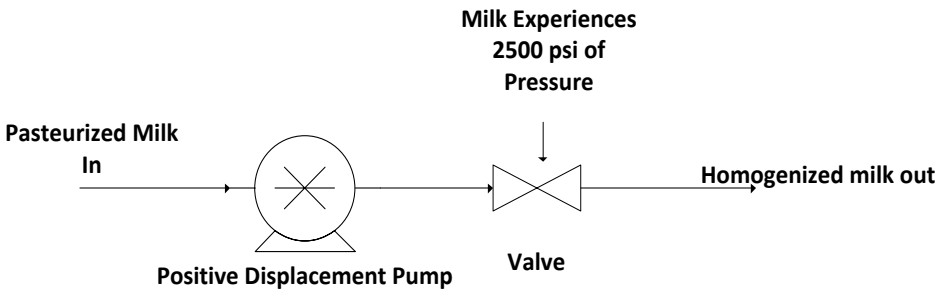



*Figure 111.7. Homogenization of milk.*

*III.8. PK-201 and PK-301*

III.8.1. PK-201

All packaging of milk is done at the place of pasteurization as well as capping and closure of the plastic container in a sanitary manner (Phillips et al., 2003). The milk is pumped into one-gallon plastic bottle and sealed. The containers stamped with a "sell-by" date to ensure that the retailers do not allow the milk to stay on their shelves longer than that date (www.madehow.com/Volume-4/Milk.html, 2011). The labeling is also done at this time and done so in accordance with the Federal Food, Drug, and Cosmetic Act, the Nutrition Labeling and Education Act of 1990 (NLEA), the Code of Federal Regulations (CFR), and the applicable Grade A Pasteurized Milk Ordinance (PMO) (Phillips et al., 2003). The milk bottles are placed into protective milk crates and kept in cold storage at 2°C, and then sent to individual markets, where they are kept in refrigerated display cases (www.madehow.com/Volume-4/Milk.html). Attached in Appendix IX.D is a block flow diagram for the packaging unit and Figure III.8.1 shows a schematic overview of the unit.

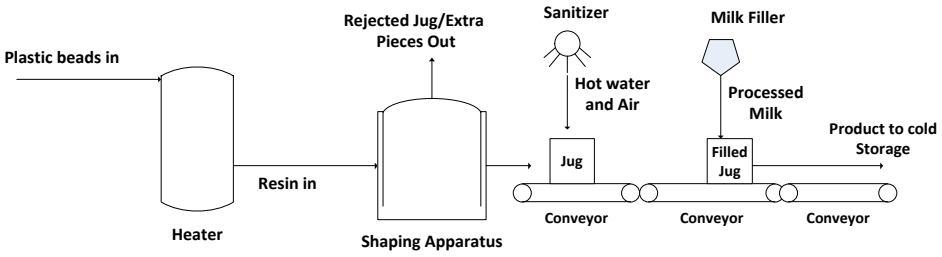



*Figure III.8.1. Milk packaging unit.*

III.8.2. PK-301

There are two types of cheese packaging: wrapping of cheese blocks or slices and re-sealable bags of cheese, which range from 1.5 kg to 4.5 kg (Scott et al., 1981). Holstein Engineering uses both types of packaging with the most effective packaging materials. The packaging materials depend on the required storage life, effectiveness of sealing, the moisture barrier, and the material strength. Vacuum packing is also essential to obtain a close bond between film and rind. Holstein Engineering uses Pukka-film (DRG Flexible Packaging) for both types of cheese packaging (Scott et al., 1981). Figure III.8.2 shows a schematic of the automatic cheese packaging unit.

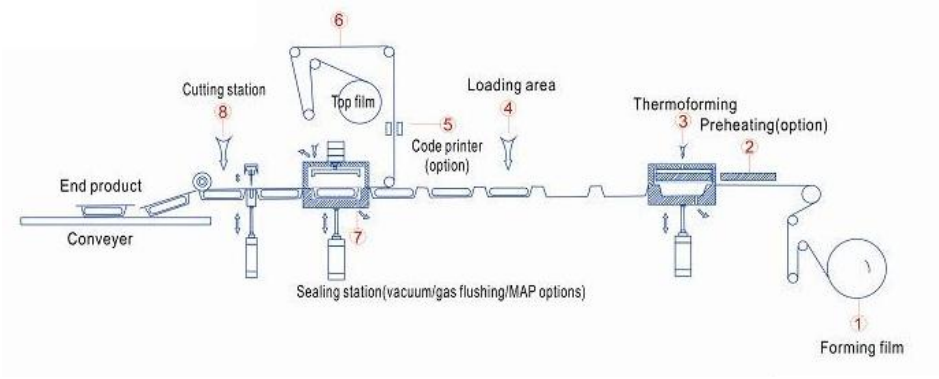



*Figure III.8.2. Automatic cheese packaging unit.*[4]

[4] Alibaba <http://www.alibaba.com/product-gs/335935523/automatic_cheese_packing_machine_47.html, 2011>.

*III.9. Cheese Vat*

Since the cheese vat is one whole unit, the following equipment will be discussed together: P-301, P-302, E-301, E-302, R-301, C-301, and M-301. The cheese vat in this process starts with milk, which processes the milk into curds and whey. The next step is to isolate the curds, which are the desired products in the first step to making cheese. It includes many parts because cheese making is mostly a batch process. Since culture and rennet must react with the milk for a long time, it is efficient in making the most cheese out of milk. The vat is purchased as a whole unit to save on installation costs and on extra equipment. There are no drawbacks in buying this piece of equipment, therefore, a vat was chosen for the cheese-making process (http://www.discoverarmfield.co.uk/data/ft20/?js=enabled, 2011).

*III.10. PR-301*

The cheese press is used in order to compact the curd particles more closely as well as remove the residual moisture and whey after the process of the cutter (V-301). Since curds hold air before being pressed, the cheddar cheese that this process is making must be pressed in a vacuum of 85-95 $kN/m^2$ to let the curds compress to the standards of cheddar cheese (Scott et al., 1981). The cheese also must be molded while being pressed so that air does not re-enter the curds. The pressure of the press that must apply to the curds is dependent on the type of cheese being produced. In this plant, a pressure of 2.7 bar must be applied in order to press and mold cheddar cheese.

***IV. Safety Statement***

There are many special considerations that need to be evaluated for this plant. Food processing plants requires special equipment to insure food safety and prevent unwanted components inside the process streams. Safety also needs to be considered, because of hazards associated with chemicals in the plant and hazards based on the equipment in the process.

Special equipment must be worn in order to minimize the contamination potential of the milk and cheese. Personnel must wear hairnets, safety gowns and gloves so that worker contact with the milk and cheese products is minimized. This keeps the process as sanitary as possible (http://www.fsis.usda.gov/Food_Safety_Education/index.asp, 2011) and complies with food safety laws. The production storage must be maintained at 2°C to keep the milk fresh, so workers may need to change into winter clothing in order to work in the storage facility without being affected by the cold.

Raw milk can possibly spread disease if raw milk is taken from a sick cow; therefore the milk that the plant buys for its stock must be checked. The milk is also tested regularly for antibiotics and sanitation. In antibiotic testing, the standard test for raw milk is the bacillus stearothermophilus disc assay method (Rushing, J.E., et al., 2011). This test detects penicillin levels in the milk, since penicillin is the most common antibiotic used. This is not the only antibiotic used in cows, since veterinarians can prescribe different antibiotics to cows (Rushing, J.E., et al. 2011). For these antibiotics, times before cows can be milked again for sale are not established. Therefore, random testing must be done to detect if antibiotic levels are above FDA safe levels for other antibiotics (Rushing, J.E., et al., 2011).

The dairy process also uses chemicals that may be hazardous to people working in the plant, therefore a list of hazardous materials and the necessary response to contact with the hazardous materials are listed on Table IV. Most of the chemicals listed are not very hazardous

unless contact in copious amounts occurs, which is not very likely. One chemical, ethylene glycol, is the exception in this plant. Ethylene glycol is toxic, where the average lethal dose in a human would be 100 mL by ingestion. Contact by other means is not as hazardous and standard safety measures are used as shown in Table IV.

*Table IV: Exposure Hazards and Response for Process Chemicals*

| | Hazard | | | | Response | | | |
|---|---|---|---|---|---|---|---|---|
| Chemical | Skin | Eyes | Ingestion | Inhalation | Skin | Eyes | Ingestion | Inhalation |
| Ethylene Glycol[5] | Minor skin irritation | Irritation, pain, eye damage | Toxic. Lethal dose: 100 mL | Nausea, vomiting | Remove contaminated clothing. Wash hands with soap and water 15 minutes | Flush eyes 15 minutes | | Remove to fresh air |
| Milk | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Polyethylene[6] | Irritation. Molten plastic may cause burns | Mechanical irritation | N/A | N/A | Solid: Wash with soap and water Molten: Put hands in cold water | Flush eyes | N/A | Remove to fresh air |
| Rennet[7] | Irritation | Irritation | Gastrointestinal discomfort | Irritation | Remove contaminated clothing. Wash affected area with water 15 minutes | Flush eyes 15 minutes | Medical attention | Remove to fresh air |
| Salt[8] | Irritation damaged skin | Irritation, redness, pain | Very large dose can cause vomiting, diarrhea | Irritation | Wash with soap and water | Flush eyes 15 minutes | Drink water and get medical advice for large dose | Remove to fresh air |
| Starter Culture[9] | Dryness, irritation | Irritation. Avoid contact with contact lenses | Nausea | N/A | Wash with water | Flush eyes 15 minutes | Drink water and get medical attention | N/A |
| Vitamin D[10] | Irritation and acne-form eruptions | Temporary blurred vision | Not significant route of overexposure | Irritation | Wash with water. Discontinue use/exposure if adverse skin effects occur. | Flush eyes 15 minutes | Medical attention or call poison control center | Remove to fresh air |
| Water[11] | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[5] Obtained from <http://www.jtbaker.com/msds/englishhtml/e5125.htm, 2011>.
[6] Obtained from <http://www.jgspetrochem.com/Evalene%20Polyethylene%20-%20MSDS.pdf, 2006>
[7] Obtained from <http://www.carolina.com/category/teacher%20resources/material%20data%20safety%20sheets%20(msds)/msds-%20d-f/emporase%20microbial%20rennet.do, 2011>.
[8] Obtained from <http://www.jtbaker.com/msds/englishhtml/w0600.htm, 2011>.
[9] Obtained from <http://www.vrm.com.au/MSDS%20Pdfs/MSDS%20%20Starter%20Culture.pdf, 2011>.

[10] Obtained from <http://www.esainc.com/docs/spool/MSDS-059_Vitamin_D_Reagent_A.pdf, 2011>.
[11] Obtained from <http://www.jtbaker.com/msds/englishhtml/w0600.htm, 2011>.

Equipment needs to be stainless steel as is mentioned in the rationale for the equipment in Section III since the materials of all wetted parts must be food grade. The main pieces of equipment with safety hazards are the heat exchanger network (E-201), homogenizer (H-201), and cheese-making unit (P-301, P-302, V-301, R-301, PR-301, TK-301). The heat exchanger in this plant contains a hot water stream that operates at temperatures up to 95°C as well as ethylene glycol for cooling at subzero temperatures. A leak in streams 8, 11 and 12 of Unit 200 could cause burns; leaks in streams 13 and 14 of Unit 200 can cause frostbite, so pressures of these streams must be monitored in case a leak occurs. The homogenizer is a high-pressure pump, so high pressure fluids can spray out if a leak occurs on that piece of equipment. The cheese-making unit is large and people can fall into the apparatus. Modifications have been made in order to minimize hazardous operations from these pieces of equipment as shown in the hazards and operability forms in the emailed HAZOP forms.

## ***V. Environmental Impact Statement***

The process being designed has minimal toxicity as it deals almost entirely with food production. Leaks and spills of only a few of the substances used at this facility would merit environmental concern. Large losses of containment of milk and the milk products produced are also capable of causing problems. The energy and water consumed by this process is also worthy of attention, especially since the plant will be situated in an island.

### *V.1. Effluent Streams*

There are few effluent streams leaving this plant, as most everything is recycled or turned into a product. The only effluent stream that is leaving the plant and not entering a product is the water stream that is removed from the cheese by the press. This stream may contain a small amount of bacteria from the starter culture and will also contain some salt. This water

will be disposed by sending it to sewage as it is almost negligible in terms of volume (26kg per day) and danger to the environment. Sewage treatment will nullify any potential effects to biodiversity.

Waste produced in terms of farming activities will have to be discharged in a manner which is consistent with the environmental laws of Hawaii. A National Pollutant Discharge Elimination System (NPDES) permit will have to be obtained for this purpose.

*V.2. Leaks and Spills*

Another way in which this facility could impact the environment is through loss of containment from any of the pieces of equipment or the streams. Although glycol is the most toxic substance handled on site, it is not terribly dangerous for the environment. When released into the soil or bodies of water, it is expected to biodegrade rapidly through bacterial metabolization (http://www.jtbaker.com/msds/englishhtml/e5125.htm, 2011). Glycol will not bio-accumulate in organisms. As a result of these properties spills involving this substance will pose no long term dangers. However, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandate the spills involving ethylene glycol be reported (http://www.jtbaker.com/msds/englishhtml/e5125.htm 2011). Although milk and other milk products are not inherently toxic, large losses of containment may cause problems to aquatic organisms as a result of increased chemical oxygen demand (COD).This is because an increase in COD is equivalent to reducing the concentrations of oxygen, which fish and other aquatic organisms require for respiration, in a particular body of water.

*V.3. Water and Electrical*

As a result of recycle streams, major water consumption by the plant will be limited to the startup of the heat exchanger, where an amount of water will need to be added to the hot water stream. No additional water will be required except in the case of spills. However, farming activities will require significant amounts of water both to produce the feed and to maintain the livestock.

Among all of the environmental concerns power consumption of this facility is the single largest environmental impact of the plant. The plant consumes roughly 5000 kWh per day. This would result in rough 1800 metric tons of carbon dioxide per year (see Appendix IX.A.2 for calculations). When compared to the amount of power necessary to ship the milk from California by sea, however, the plant presents a significant reduction in terms of metric tons of carbon dioxide emitted. Shipping would produce an additional 12,000 (see Appendix IX.A.2 for calculations) metric tons per year on top of the energy usage necessary to produce the milk on the mainland.

In terms of a life cycle analysis of the product, the largest concerns would be in the packaging materials and production of the raw milk. There exists the possibility to use emerging technologies to drastically reduce the amount of plastic and increase the amount of recyclable material in the packaging of our products. As stated in the report "Life Cycle Assessment of Example Packaging Systems for Milk" the best way to improve the result of the LCA is to reduce the quantity of materials used, followed by reusing materials and recycling them (http://www.wrap.org.uk/downloads/Final_Report_Doorstep_29_01_10_2_.2f8e0cd1.8403.pdf_2011). Efforts to improve on the kind of packaging used should reflect this.

***VI. Economic Analysis and Economic Hazards***

The economic integrity of this design was based off of its ability to be a profitable plant. Feasibility of this plant was determined by the cost analysis of the plant and net present value for the plant was determined. Preliminary calculations have determined this plant to be a successful investment, however, economic hazards exist that can change the profitability of the plant. These hazards were weighed with the net present value to determine how much risk was involved with the running of this plant. Integrating complex method was used to determine the service building ($C_{serv}$) and site preparation ($C_{site}$) since Holstein Engineering would purchase an existing dairy facility.

Cost analysis for this plant can be seen in the Appendix IX.B of this report. Costs of equipment were determined and multiplied by a bare module factor ($F_{BM}$) to find the bare module costs ($C_{BM}$) for each piece of equipment. Some of the costs were found using Shamrock Farms equipment prices as a source. Equations and calculations can be found in Appendix IX.B for all of the bare module costs. These costs were summed up in order to find the total bare module cost ($C_{TBM}$). The $C_{TBM}$ of this plant was projected to be $11.9 million.

The utilities used for this plant were electricity and process water. The utilities calculations are in Appendix IX.B.9. The electricity price was determined using the current prices of electricity in Hawaii at $0.1636 per kWh (http://www.heco.com/portal/site/heco/menuitem.508576f8baal4340b4c0610c510b1ca/?vgnexto.html, 2011). The price of water was determined using a basis of $2.02 per 748 gallons. Since the plant plans on recycling a water/ethylene glycol mixture for cooling in stream 13 and 14 of Unit 200 in the plant, the amount of water only needs to be priced once. Ethylene glycol helps prevent corrosion as well as microbial growth so the recycled coolant does not need to be changed often. Total cost for utilities are calculated to be $300,000 per year. Feedstock costs were included in

section IX.B.8 of the report. The cost of raw milk, rennet, salt, culture, and packaging costs were calculated to be $117,600.

Net present value (NPV) for the plant was calculated in order to determine the profitability of the plant. The calculations in Table IX.B.14 show that this plant will be profitable with a NPV of $61.5 million over 30 years. This was assuming that the sales prices of all of the products (cream, milk, cheese, whey) were fixed for the 30 years this plant is planned to run. The calculations also assume a 40% tax rate and a 20% interest rate for the plant, which could be different in actuality.

Since the plant is profitable, some of the money will be reinvested in the plant. Future work on the plant will include making half pint milk cartons targeted toward public school cafeterias. Expanding benefits aimed towards all shift workers including quarterly bonuses and insurance policies is also planned.

Economic hazards would affect the profitability of the plant and therefore must be considered determining the feasibility of the plant. One economic hazard for this process was the selling price of the commodities. Since the Hawaiian government regulated the prices of the commodities of this plant, competition between dairy companies does not affect the cost of these commodities. The laws can be changed in the future so these prices must be monitored. Another economic hazard to this plant was the demand of the milk. In order to calculate the flows of each type of milk being processed in the plant, current demands were used in order to determine how much 2%, skim and whole milks are being made, when in actuality plants pay very close attention to these demands and change these values slightly. Since the demands could change at any time during this process, this could affect the profitability of the plant. Another economic hazard was the food safety regulations that were imposed on milk. The USDA and FDA control

the amount of chemicals and type antibiotics that were regulated, which could affect the price of raw milk and the cost to process milk.

The economic analysis of this plant was determined to be feasible. In order for the plant to be profitable after 10 years of running until the plant closes, the sales for milk must be sold for more than $3.84 per gallon average. Since the current planned sale price of the milk is $4.99 per gallon, the plant was determined to be profitable with a large margin for fluctuation in price.

## ***VII. Conclusions and Recommendations***

Holstein Engineering concludes that this plant is economically feasible, profitable and recommends building this plant. Since the demand is high, the milk supply will be guaranteed to be sold without surplus. This milk facility will be beneficial for locals because of the jobs created and the products sold will be fresh. Even though the retail price of milk cannot change, this plant is more profitable than imported milk due to low production cost and low transportation cost. The cheese from this plant will also become profitable since the majority of cheese consumed in Hawaii is goat milk cheese (http://www.surfinggoatdairy.com/about/html, 2011). The undesired products of cream and whey are also being sold, eliminating these wastes and creating a zero waste facility to minimize the environmental impact of this plant.

Recommendations include production of additional milk products, utilization the some of the waste streams, and lowering the energy consumption. One recommendation is to sell half-pint milk cartons to local public schools, sell half-gallons of milk and flavored milk such as chocolate, strawberry, and tropical flavors. The cream waste stream can be used to make products such as heavy whipping cream, cream cheese, sour cream, ice cream, and half-half. Also, the whey can be utilized by making whey protein powder drinks. Solar panels and energy saving pieces of equipment can also be used to lower the amount of energy consumed. Another recommendation is an alternative type of packaging in order to minimize the environmental impact of the bottles of milk when discarded. Currently being tested in England are new gallon milk containers with cardboard casing that is recyclable up to eight times, and the milk is held in a plastic bag (http://www.bbc.co.uk/news/uk-12335042, 2011).

To further investigate this process of design, Holstein Engineering should consider purchasing a farm instead of purchasing raw milk from the contracted co-op. It is more likely

that milk producing facilities tend their own farm and cows due to the large amount of raw milk necessary to run the plant.

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## ***IX. Appendices***

### *IX.A. Calculations*

#### IX.A.1. Dairy Calculations

***IX.A.1.1 Finding out how much cheese to produce***

According to Wisconsin Milk Marketing Board 5% of the population consumes cheddar cheese. (http://media.eatwisconsincheese.com/retail/statistics/dairyStatistics.aspx, 2011)

In order to find out how many people consumed cheese in Oahu, Hawaii 5% of 875,000 was found.

$$875000 \times 0.05 = 43750 \quad (1)$$

It was found that 43,750 people should presumably consume cheese.

According to Amber Waves, an average person consumes 9.9 pounds of cheddar cheese per year (http://www.ers.usda.gov/AmberWaves/February05/Findings/CheeseConsumption.htm,2011).

Using the conversion of 0.45 kg is equal to 1 pound the kilograms of cheese consumed per year per person was found.

$$9.90\ pounds\ \times 0.45\ = 4.453\ kg \tag{2}$$

It was found that each person would consume about 4.453kg per year of cheese this was then divided by 365 days per year to find the amount of cheese consumed per day per person.

$$4.453 \frac{kg}{year} \frac{1\ year}{365\ days} = 0.011\ kg \tag{3}$$

It was found each person consumes about 0.011 kg of cheese per day.

To find out how much cheese would be consumed by the whole population per day 43,750 was multiplied by 0.0122.

$$43750\ people \times 0.0122 \frac{kg}{day} = 533.75\ \frac{kg}{day} \tag{4}$$

533.75 kg of cheese would need to be made each day.

***IX.A.1.2 Finding out how much milk to produce***

In order to find out how much milk would be needed to produce 489 kg of cheese per day the conversion of 1 gallon of milk produced 1.1 pound of cheese was used (http://library.thinkquest.org/CR0215162/dairy.html,2011).

533.75 kg is equivalent to 1176 pounds this approximates to 1076 gallons of milk needed to produce cheese. In order to find out how many kilograms that is we use the density of milk, 4.62 kg/gallon.

$$1076 \frac{gal}{day} \times 4.62 \frac{kg}{gal} = 4970\ \frac{kg}{day} \tag{5}$$

According to Emax Health, 61% of the population consumes milk (http://www.emaxhealth.com/77/2621.html, 2011).

According to US Census Bureau, there are 875,000 people residing in Oahu, Hawaii (quickfacts.cencsus.gov/qfd/states/15000.html, 2011).

In order to find out how many people consumed milk in Oahu, Hawaii 61% of 875,000 was found.

$$875000 \times 0.61 = 533750 \quad (6)$$

It was found that 793,000 people should presumably consume milk.

According to Nutrition Insights, an average person drinks two 8 ounce glasses of milk per day (http://www.cnpp.usda.gov/Publications/NutritionInsights/Insight20.pdf, 2011).

According to Cornell University, there are 244 g of milk per 8 ounces of milk or 488 g per two glasses of milk (http://www.milkfacts.info/Milk%20Composition/Milk%20Composition%20Page.htm, 2011).

To find out how much milk would be consumed by the whole population per day 533,750 was multiplied by 488.

$$533{,}750\ people \times 488 \frac{g}{day} = 260470000\ \frac{g}{day} \quad (7)$$

260,470,000 g per day or 260,470 kg per day of milk would need to be made each day.

Now the amount of milk dedicated to each composition needed to be found.

According to the Wisconsin Milk Marketing Board people purchase 31% whole milk, 52% 2% milk and 17% skim milk (http://media.eatwisconsincheese.com/retail/statistics/dairyStatistics.aspx, 2011). These percentages were used to find to find out how much milk needed to be produced for each composition.

$$\text{Skim: } 2640470\ \frac{kg}{day} \times 0.17 = 44279.9\ \frac{kg}{day} \quad (8)$$

$$\text{2\%: } 2640470\ \frac{kg}{day} \times 0.52 = 135444.4\ \frac{kg}{day} \quad (9)$$

$$\text{Whole: } 2640470\ \frac{kg}{day} \times 0.31 = 80745.7\ \frac{kg}{day} \quad (10)$$

For the final total of whole milk needed the amount of milk needed to make cheese was added to the whole milk

$$\text{Total Whole: } 80745.7 + 4970 = 85715.7\ \frac{kg}{day} \quad (11)$$

In order to find out how much milk will be produced the milk needed for the liquid milk production was added to the milk needed for cheese production.

$$2640470 + 4970 = 265440 \quad (12)$$

It was found that 265,440 kg of liquid milk would need to be processed.

***IX.A.1.3 Mixing cream and skim to get 2% and whole milk***

Because the amount of product out is known, the raw milk in was calculated by finding out how much skim and cream is needed to produce the 3 different compositions of milk.

For this the compositions of skim[1], 2%[121] and whole[1] milk (see Table IX.A.1.3.1 through Table IX.A.1.3.3) were needed. The tables below show the composition and mass of the separate materials in 2% and whole milk. The mass of each material was found by multiplying the mass fraction by the total amount of milk calculated previously. This was 135,444.4 kg for 2% and 85,715.7 kg for whole.

*Table IX.A.1.3.1: Skim Milk composition*

| Material | Percentage |
|---|---|
| Fat | 0.08% |
| Water | 90.84% |

[1] http://www.milkfacts.info/Milk%20Composition/Milk%20Composition%20Page.htm

| | |
|---|---|
| Proteins | 3.37% |
| Carbohydrates | 4.96% |
| Minerals | 0.75% |

*Table IX.A.1.3.2: 2% milk composition*

| Materials | Mass Fraction | Mass [kg] |
|---|---|---|
| Fat | 0.02 | 2708.89 |
| Water | 0.894 | 121087.29 |
| Proteins | 0.032 | 4334.22 |
| Carbohydrates | 0.046 | 6230.44 |
| Minerals | 0.0069 | 934.57 |

*Table IX.A.1.3.3: Whole milk composition*

| Materials | Mass Fraction | Mass [kg] |
|---|---|---|
| Fat | 0.0325 | 2785.76 |
| Water | 0.8832 | 75704.11 |
| Proteins | 0.0322 | 2760.05 |
| Carbohydrates | 0.0452 | 3874.35 |
| Minerals | 0.0069 | 591.44 |

In order to find out how much cream and skim goes into 2% milk a system of equations was used using the fat content and total milk produced.

$$0.0008x + 0.403y = 2708.89 \quad (13)$$

$$x + y = 135444.4 \quad (14)$$

Where x is the amount of skim and y is the amount of cream. By solving this system of equations it was found that 128,979 kg per day of skim milk and 6,465 kg per day of cream were needed to make 2% milk.

In order to find out how much cream and skim goes into whole milk, a system of equations was used using the fat content and total milk produced.

$$0.0008x + 0.403y = 27585.76 \quad (15)$$

$$x + y = 85715.7 \quad (16)$$

Where x is the amount of skim and y is the amount of cream. By solving this system of equations, it was found that 78,959.9 kg per day of skim milk and 6,755.82 kg per day of cream were needed to make whole milk.

To find the total amount of skim milk need to produce the 3 compositions the skim milk was added to the amount of skim milk that 2% and whole milk needed.

$$44279.9\ \frac{kg\ skim}{day} + 128979\frac{kg\ skim\ in\ 2\%}{day} + 78959.9\frac{kg\ skim\ in\ whole}{day} = 252219\frac{kg\ skim\ total}{day} \quad (17)$$

With the total amount of skim needed to produce 265,440 kg of milk, the amount of raw milk needed can be calculated using a system of equations and the composition of raw milk, skim milk and cream (see Table IX.A.1.3.4, Table IX.A.1.3.1 & Table IX.A.1.3.5).

*Table IX.A.1.3.4: Raw milk composition*

| Materials[1] | Mass Fraction | Mass [kg] |
|---|---|---|
| Fat | 0.039 | 10352.16 |
| Water | 0.875 | 232260 |
| Proteins | 0.033 | 8759.52 |
| Carbohydrates | 0.046 | 12210.24 |
| Minerals | 0.007 | 1858.08 |

*Table IX.A.1.3.5: Cream composition*

| Material[2] | Percentage |
|---|---|
| Fat | 40.3% |
| Water | 54.4% |

[1] http://www.milkfacts.info/Milk%20Composition/Milk%20Composition%20Page.htm
[2] http://www.milk.co.uk/page.aspx?intPageID=197

| | |
|---|---|
| Proteins | 2.0% |
| Carbohydrates | 2.7% |
| Minerals | 0.60% |

Using the fat content of each in the system of equations will give:

$$0.039m_r = 0.008m_s + 0.403m_c \quad (18)$$

$$m_r = m_s + m_c \quad (19)$$

Where $m_r$ is the mass of raw milk, $m_s$ is the mass of skim milk and $m_c$ is the mass of the cream.

Plugging in the known value of the mass of skim milk; 252,219 kg per day of skim milk:

$$0.039m_r = 201.775 + 0.403m_c \quad (20)$$

$$m_r = 252219 + m_c \quad (21)$$

By solving this system of equations, it was found that the mass of raw milk was 326,333 kg per day and the amount of cream that will result from that amount of raw milk was 74,113.6 kg per day.

So overall placing 326,333 kg per day of raw milk into a milk separator will result in 252,219 kg per day of skim milk and 74,113.6 kg per day of cream.

The amount of cream left over can now be calculated. This was done by adding the amount of cream needed to make the 2% and whole milk then subtracting that from the amount of cream that was separated out of the raw milk.

$$74{,}113.6\frac{kg\ cream}{day} - \left(6465\frac{kg\ cream\ in\ 2\%}{day} + 6755.82\frac{kg\ cream\ in\ whole}{day}\right) = 60892.8\frac{kg\ cream\ to\ sell}{day} \quad (22)$$

$$10352.2\frac{kg\ fat}{day} - x = 0.0008\left(265440\frac{kg\ raw}{day} - \frac{x}{0.403}\right) \quad (23)$$

Where x is the amount of fat in cream that must be removed to make skim 0.8%. Solving for x leads to 10,147.9 kg of fat needs to be removed. Since all of this fat will come out in the cream how much cream results in a 40.3% fat content of 10,147.9 kg needed to be found.

$$10147.9\frac{kg\ fat}{day} = 0.403x \tag{24}$$

Where x is the amount of cream. Solving for x gave the amount of 25,180.9 kg of cream. How much skim came out after separation was found by subtracting the amount of cream from the raw.

$$265440\frac{kg}{day} - 25180.9\frac{kg}{day} = 240259\frac{kg}{day} \tag{25}$$

Now that it was know that after putting 265,440 kg per day of raw milk through a separator, 240,259 kg per day of skim comes out and 25,180.9 kg per day of cream comes out.

***IX.A.1.4 Finding the amount of Vitamin D***

The amount of vitamin D that has to be added to each composition of milk can now be calculated. This is done by using the amount of vitamin D in cream. According to The Dairy Council there is 0.3µg of vitamin D per 100 g of cream (http://www.madehow.com/volume-4/milk.html, 2011). Because vitamin is fat soluble it is assumed that all the vitamin D present in the cream. According to Cornell University milk should be fortified at minimum to 100 IU (2.5 µg) for whole milk, 2.26 µg for 2% milk and 3.175 µg for skim milk, per 244 g of milk (http://www.milkfacts.info/Milk%20Composition/Milk%20Composition%20Page.htm , 2011).

*Skim*

It was assumed skim had no vitamin D, to find out how much needed to be added it was found out how many times 244 g went into 44,279.9 kg.

$$\frac{44279.9\ kg\ milk}{0.244\ kg\ milk} = 181475 \quad (26)$$

This was then multiplied by 3.175 to find out how many micrograms of vitamin D needed to be added

$$181475 \times 3.175 = 576183 \mu g = 0.000576\ \frac{kg}{day} \quad (27)$$

*2%*

To find out how much vitamin D was in 2% it was found out how many times 100 g went into 6,465 kg

$$\frac{6465\ kg\ cream}{.100\ kg\ cream} = 64650 \quad (28)$$

This was multiplied by 0.3 to find out how many micrograms are already in 2% milk

$$64650 \times 0.3 = 19395\ \frac{\mu g}{day} = 0.000019\ \frac{kg}{day} \quad (29)$$

To find out how much needed to be in 2% milk, the amount of milk was divided by 0.244 kg

$$\frac{135444.4\ kg\ of\ milk}{0.244\ kg\ of\ milk} = 555100 \quad (30)$$

This was then multiplied by 2.26 µg.

$$555100 \times 2.26 = 1.254\ \times 10^6\ \frac{\mu g}{day} = 0.00125\ \frac{kg}{day} \quad (31)$$

To find out how much vitamin D needed to be added the amount already in 2% milk was subtracted from the amount needed in 2% milk

$$0.00125\ \frac{kg}{day} - 0.000019\ \frac{kg}{day} = 0.00123\ \frac{kg}{day} \quad (32)$$

*Whole*

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To find out how much vitamin D was in whole milk it was found out how many times 100 g went into 6,756 kg

$$\frac{6756\ kg\ cream}{.100\ kg\ cream} = 67560 \tag{33}$$

This was multiplied by 0.3 to find out how many micrograms are already in whole milk

$$67560 \times 0.3 = 20268 \frac{\mu g}{day} = 0.00002 \frac{kg}{day} \tag{34}$$

To find out how much needed to be in whole milk the amount of milk was divided by 0.244 kg

$$\frac{85715.7\ kg\ of\ milk}{0.244\ kg\ of\ milk} = 351294 \tag{35}$$

This was then multiplied by 2.5 µg.

$$351294 \times 2.5 = 878235 \frac{\mu g}{day} = 0.000878\ \frac{kg}{day} \tag{36}$$

To find out how much vitamin D needed to be added the amount already in whole milk was subtracted from the amount needed in whole milk

$$0.000878 \frac{kg}{day} - 0.00002 \frac{kg}{day} = 0.00767\ \frac{kg}{day} \tag{37}$$

***IX.A.1.5 Cheese Ingredients***

*Starter Culture*

To find out how much starter culture needed to be introduced to make 489 kg of cheese per day, Cheese-Making Technology (Schwartz, 1973) was used.

According to this book for every 25,000 pound of milk used, 300 pounds of starter culture are needed.

A conversion of pounds to kilograms are needed, 0.45 kilograms is equal to 1 pound

$$25{,}000\ lbs = 1139.8\ kg \tag{38}$$

$$300\ lbs = 136.1\ kg \tag{39}$$

Using the fact that 4,970 kg of milk was used to make the cheese, a ratio was used to determine how much starter culture was needed.

$$\frac{1139.8\ kg\ milk}{136.1\ kg\ starter\ culture} = \frac{4970\ kg\ milk}{X\ kg\ starter\ culture} \tag{40}$$

After solving this ratio it was found that 59.64 kg per day are needed of starter culture.

*Rennet*

To find out how much rennet needed to be introduced to make 489 kg of cheese per day, Cheese-Making Technology (Schwartz,1973) was used.

According to this book for every 25,000 pound of milk used, 3.57 ounces of rennet was needed.

Using the same ratio as above the amount of rennet needed was found

$$\frac{1139.8\ kg\ milk}{3.57\ oz\ of\ rennet} = \frac{4970\ kg\ milk}{X\ oz\ of\ rennet} \tag{41}$$

After solving this ratio it was found that 1.56 ounces of rennet was needed.

According to Cheese-Making Technology the rennet needed to be added in a water solution, the solution should be a 20 to 1 solution, meaning for every 1 part rennet 20 parts of water was used.

$$\frac{1.56\ oz\ rennet}{x\ oz\ solution} = \frac{1\ oz}{21\ oz\ solution} \tag{42}$$

After solving this ratio it was found that 32.76 ounces of solution were needed.

Assuming the solution was mostly water therefore the density of rennet would be negligible, the density of water was used to determine the mass of the solution.

$$997\frac{kg}{m^3}\frac{1\ m^3}{33814\ oz}32.76\ oz = 0.966\ \frac{kg}{day}solution \tag{43}$$

This was also used to find the mass of rennet

$$\frac{X\ kg\ rennet}{0.966\ kg\ solution} = \frac{1\ kg}{21\ kg\ solution} \quad (44)$$

Solving this ratio it was found that 0.046 kg of rennet is needed per day.

*Salt*

According to Cheese-Making Technology ( Schwartz,1973), for every 1,000 pounds of milk used, 3 pounds of dry salt was needed.

$$1000\ lbs = 453.59\ kg \quad (45)$$

$$3\ lbs = 1.36\ kg \quad (46)$$

Using a ratio the amount of salt needed to make cheese from 4,970 kg of milk was found.

$$\frac{1.36\ kg\ salt}{453.59\ kg\ milk} = \frac{x\ kg\ salt}{4970\ kg\ milk} \quad (47)$$

After solving this ratio it was found that 14.9 kg of salt per day were needed.

*Whey*

According to Whey Processing and Utilization (Gillies, 1974) for every gallon of milk used 9.2 pounds of whey was produced as a byproduct.

$$9.2\ lbs = 4.17\ kg \quad (48)$$

$$1\ gallon\ milk = 4.62\ kg\ of\ milk \quad (49)$$

Again a ratio was used to determine the amount of whey that was produced

$$\frac{4.62\ kg\ milk}{4.17\ kg\ whey} = \frac{4970\ kg\ milk}{X\ kg\ whey} \quad (50)$$

After solving this ratio it was found that 4,485.91 kg per day of whey was produced as a by product

*Water*

According to Cheese-Making Technology (Schwartz, 1973), the cheese curds before going into the press was 41% moisture after the press it was 38% moisture.

In order to find out how much water needs to be removed a system of equations was used using the amount of water and total:

$$0.62m_{ch} = 0.59m_c \tag{51}$$

Where $m_{ch}$ is the mass of the pressed cheese solid and $m_c$ is the mass of the curds before pressing. Plugging in the known

$$0.62m_{ch} = 0.59 \times 545kg \tag{52}$$

After solving this equation, it was found that the mass of the cheese after the press should be 518.62 kg per day.

To find out how much water comes out of the curds the mass of the pressed cheese was subtracted from the mass of the curds.

$$545\,\frac{kg\ curds}{day} - 518.62\,\frac{kg\ cheese}{day} = 26.38\ \frac{kg\ water}{day} \tag{53}$$

### *IX.A.1.6 Converting from kilograms per day to kilograms per hour*

*Table IX.A.1. 6.1: Table for converting kilogram per day to kilograms per hour for a 24 hour basis*

| | Raw Milk Requirements | | | |
|---|---|---|---|---|
| **Mass** | *Raw Milk* | *Cream* | *Skim* | *Cream to sell* |
| kg/day | 363,333 | 74,114 | 252,219 | 60,893 |
| divide by 24 | | | | |
| kg/hour | 15138.875 | 3088.0667 | 10509.125 | 2537.216667 |

*Table IX.A.1.6.2: Table for converting kilogram per day to kilograms per hour for a 4 hour basis*

| | Skim Milk Production Requirements | | | |
|---|---|---|---|---|
| **Mass** | *Skim* | *Vitamin* | *HE* | *Glycol* |

| | | *D* | *Water* | |
|---|---|---|---|---|
| kg/day | 44279.9 | 5.76E-04 | 31778.6 | 22,022 |
| divide by 4 | | | | |
| kg/hour | 11069.975 | 1.44E-04 | 7944.65 | 5505.375 |

*Table IX.A.1.6.3: Table for converting kilogram per day to kilograms per hour for a 12 hour basis*

| | 2% Milk Production Requirements | | | | | |
|---|---|---|---|---|---|---|
| **Mass** | *Cream* | *Skim* | *Vitamin D* | *HE Water* | *Glycol* | *2%* |
| kg/day | 6,465 | 128,979 | 1.23E-03 | 97,048 | 67,251 | 135,444 |
| divide by 12 | | | | | | |
| kg/hour | 538.75 | 10748.25 | 1.03E-04 | 8087.366667 | 5604.2625 | 11287.03 |

*Table IX.A.1.6.4: Table for converting kilogram per day to kilograms per hour for an 8 hour basis*

| | Whole Milk Production Requirements | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Mass** | *Cream* | *Skim* | *Vitamin D* | *HE Water* | *Glycol* | *Whole* | *Whole* | *Cheese Milk* |
| kg/day | 6755.82 | 78959.9 | 7.67E-03 | 61463.99 | 42592.395 | 85715.7 | 80745.7 | 4970 |
| divide by 8 | | | | | | | | |
| kg/hour | 844.4775 | 9869.988 | 9.59E-04 | 7682.99875 | 5324.049375 | 10714.463 | 10093.21 | 621.25 |

*Table IX.A.1.6.5: Table for converting kilogram per day to kilograms per hour for a 24 hour basis with a 2 hour batch time*

| | Cheddar Cheese Production Requirements | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Mass** | *Rennet* | *Cheese Milk* | *Starter Culture* | *Salt* | *Curds & Whey* | *Whey* | *Salted Curds* | *Water* | *Cheese* |
| kg/day | 0.966 | 4970 | 59.64 | 14.9 | 5030.91 | 4485.91 | 545 | 26.38 | 533 |
| divide by 12 (based on 24 hours, with each batch taking 2 hours to complete) | | | | | | | | | |
| kg/hour | 8.05E-02 | 414.17 | 4.97 | 1.24 | 419.24 | 373.83 | 45.42 | 2.20 | 44.42 |

IX.A.2 Environmental Calculations[13]

Metric tons $CO_2$ emitted per year to ship milk from California to Hawaii

$$0.0887\frac{lbs\ CO_2}{ton\ mile}\times\frac{1\ ton}{2204\ lbs}\times 2500\ miles\times 326\ ton = 32\frac{metric\ ton}{day} = 12000\frac{metric\ ton}{year} \quad (54)$$

Metric ton of $CO_2$ produced at the dairy plant

$$2.117\frac{lbs}{kWh}\times 5009\frac{kWh}{day}\times\frac{365\ day}{year}\times\frac{ton}{2204\ lbs} = 1800\frac{metric\ ton}{year} \quad (55)$$

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*IX.B. Economics*

IX.B.1. Spreadsheets

*Table IX.B.1.1: Bare Module Costs for each piece of equipment used in the process.*

[13] http://www.carbonfund.org/site/pages/carbon_calculators/category/Assumptions ~~ADD REFERNCE FOR THIS INFORMATION~~

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| Equipment piece | PFD Label | FP | FM | Costs of Equipment CB | cost - CP | FBM | CBM | CBM at 5SO |
|---|---|---|---|---|---|---|---|---|
| Homogenizer | H-201 | | | | $220,000.00 | 3.3 | $726,000.00 | $798,600.00 |
| Milk Separator | MS-101 | | | | $450,000.00 | 2.03 | $913,500.00 | $1,004,850.00 |
| Tanks | TK-101, TK-102, TK-301 | | | | $800,000.00 | 3.05 | $2,440,000.00 | $2,684,000.00 |
| Vitamin Injector | P-203 A/B | | | | $2,000.00 | 3.3 | $6,600.00 | $7,260.00 |
| Vat | | | | | $12,000.00 | 3.05 | $36,600.00 | $40,260.00 |
| Milk Pump | P-101 A/B | 1 | 2.2 | 382.7910213 | $842.14 | 3.3 | $2,779.06 | $3,056.97 |
| Cream pump | P-201 A/B | 1 | 2.2 | 1.553514332 | $3.42 | 3.3 | $11.28 | $12.41 |
| Skim milk pump | P-202 A/B | 1 | 2.2 | 326.4873349 | $718.27 | 3.3 | $2,370.30 | $2,607.33 |
| Water pump | P-204 A/B | 1 | 2.2 | 21727.3676 | $47,800.21 | 3.3 | $157,740.69 | $173,514.76 |
| Ethylene Glycol pump | P-205 A/B | 1 | 2.2 | 49.33177083 | $108.53 | 3.3 | $358.15 | $393.96 |
| Water Heater | HR-201 | | | | $109,797.80 | 2.19 | $240,457.19 | $264,502.91 |
| Milk heat exchanger | E-201 | 1 | 3 | 2649.044939 | $7,947.13 | 3.17 | $25,192.42 | $27,711.66 |
| Milk Heat exchanger | E-202 | 1 | 3 | 2465.60275 | $7,396.81 | 3.17 | $23,447.88 | $25,792.67 |
| Milk Packaging unit | PK-201 | | | | $6,000,000.00 | 1 | $6,000,000.00 | $6,600,000.00 |
| Cheese packaging unit | PK-301 | | | | $82,000.00 | 1 | $82,000.00 | $90,200.00 |
| Cheese Press | PR-301 | | | | $50,000.00 | 4.16 | $208,000.00 | $228,800.00 |
| Total Costs | | | | | | | $10,865,056.97 | $11,951,562.67 |

*Table IX.B.1.2: Total bare-module cost, direct permanent investment, total permanent investment, and total capital investment.*

| $C_{FE}$ | $C_{PM}$ | $C_{spare}$ | $C_{storage}$ | $C_{catalyst}$ | $C_{comp}$ | $C_{TBM}$ |
|---|---|---|---|---|---|---|
| $1,385,667.24 | $1,191,695.42 | $186,845.42 | $9,374,200.00 | $0.00 | $1,000,000.00 | $13,138,408.09 |
| | | $C_{serv}$ | $C_{site}$ | $C_{building}$ | $C_{offsite}$ | $C_{DPI}$ |
| | | $656,920.40 | $656,920.40 | $1,313,840.81 | $16,177,644.36 | $18,805,325.97 |
| | | | | | $C_{cont}$ | $C_{TDC}$ |
| | | | | | $3,384,958.68 | $22,190,284.65 |
| | | | $C_{land}$ | $C_{royal}$ | $C_{startup}$ | $C_{TPI}$ |
| | | | $0.00 | $443,805.69 | $2,219,028.46 | $24,853,118.81 |
| | | | | | $F_{ISF}$ | Corrected $C_{TPI}$ |
| | | | | | 1.25 | $31,066,398.51 |
| | | | $C_{alloc}$ | $C_{WC}$ | $C_{TCI}$ | New $C_{TCI}$ |
| | | | $16,177,644.36 | $447,474.24 | $24,856,787.35 | $31,066,398.51 |

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*Table IX.B.1.3: Cost of labor related operations.*

| Labor Related Operations | | | |
|---|---|---|---|
| **Operators/Shift** | 5 | **DW&B** | $1,820,000.00 |
| **Operator wages, $/hr** | 35 | **Direct Salaries and Benefits** | $273,000.00 |
| **# of Shifts** | 5 | **Operating supplies and services** | $109,200.00 |
| | | **Technical assistance to manufacturing** | $300,000.00 |
| | | **Control laboratory** | $325,000.00 |
| | | **Total labor-related operations annual cost** | $2,827,200.00 |

*Table IX.B.1.4: Maintenance costs.*

| Maintenance | |
|---|---|
| **MW&B** | $776,659.96 |
| **Salaries & benefits** | $194,164.99 |
| **Materials and services** | $776,659.96 |
| **Maintenance Overhead** | $38,833.00 |
| **Total maintenance, per year** | $1,786,317.91 |

*Table IX.B.1.5: Operating overhead.*

| Operating Overhead | |
|---|---|
| **DW&B** | $1,820,000.00 |
| **MW&B** | $776,659.96 |
| **Direct Salaries and Benefits** | $273,000.00 |
| **Maintenance Salaries and benefits** | $194,164.99 |
| **Total** | $3,063,824.95 |
| **Annual Operating Overhead** | $698,552.09 |

*Table IX.B.1.6: Property tax and annual depreciation.*

| Property Taxes and Insurance | |
|---|---|
| **Taxes and Insurance** | **Depreciation - Direct plant** |
| $443,805.7 | $248,053.1 |

*Table IX.B.1.7: Cost of manufacturing (COM) and work and capital.*

| Cost of Manufacturing, Work and Capital | |
|---|---|
| **$C_{com}$** | $60,456,921.92 |
| **Cash reserves** | $5,036,061.60 |
| **Inventories** | $2,285,677.06 |
| **Accounts Receivable** | $9,916,505.18 |
| **Accounts Payable** | $4,511,018.67 |
| **$C_{wc}$** | $12,727,225.16 |

*Table IX.B.1.8: Cost of all the utilities used for the process.*

| Feedstocks/Utilities | | Amount Used per Day | Cost of Utilities |
|---|---|---|---|
| **Continuous plant operation** | 7920 hr/yr | | |
| **Electricity** | $.1636kW-hr | 5009 | $299,107.43 |
| **Cooling water** | $2.02/748 gal | 0 | $0.00 |
| | | | |
| **Total utilities, $/yr** | | | $299,107.43 |

*Table IX.B.1.9: Cost of all the utilities allocated.*

| Utilities | Size Factor | Unit | $C_{alloc}$ |
|---|---|---|---|
| **Water** | 532 | gpm | $71,387.13 |
| **Electricity** | 9 | MW | $16,106,257.23 |
| | | | |
| **Total** | | | $16,177,644.36 |

*Table IX.B.1.10: Cost of the feedstock, unit cost.*

| Unit costs | | |
|---|---|---|
| **Packaging** | $0.17 | per unit |
| **Raw milk** | $0.38 | per kg |
| **Salt** | $0.60 | per kg |
| **Rennet** | $32.99 | per day |
| **Culture** | $50.00 | per day |

*Table IX.B.1.11: Cost of the feedstock used for the process.*

| Feedstock | | |
|---|---|---|
| | kg/day | Cost per Day |
| **Raw Milk** | 363333.00 | $138,066.54 |
| **Rennet** | | $32.99 |
| **Culture** | | $50.00 |
| **Salt** | 28.80 | $17.28 |
| **Packaging** | | $10,200.00 |
| **Total** | | $148,366.81 |

*Table IX.B.1.12: Cost and sales[14].*

| | cost/unit | unit | units/day | Sales |
|---|---|---|---|---|
| **Milk** | 4.99 | gal | 56000 | $279,440.00 |
| **Cream** | 0.04 | kg | 60893 | $2,435.72 |
| **Cheese** | 20 | kg | 454.5454545 | $9,090.91 |
| **Whey** | 3.92 | kg | 8976 | $35,185.92 |
| **Total** | | | | $326,152.55 |

*Table IX.B.1.13: General cost and expenses of the production system.*

| General Expenses, GE | |
|---|---|
| **Selling** | $3,571,370.41 |
| **Direct Research** | $5,714,192.66 |
| **Allocated Research** | $595,228.40 |
| **Administration** | $2,380,913.61 |
| **Management Incentive Compensation** | $1,488,071.01 |
| **Total** | $13,749,776.09 |
| **Total Production Cost, C** | $74,206,698.01 |

[14] Holstein Engineering is selling milk wholesale at $4.99 and the retailers are selling milk at $8.99.

*Table IX.B.1.14: Tabulates the overall finances of the process for a thirty year period (continued on next page)*[15].

| End of Year | $fC_{TDC}$ | $C_{WC}$ | D | C excl D | S | Net Earning | Undisc. Cash Flow | Disc. Cash Flow (PV) | Cumulative PV |
|---|---|---|---|---|---|---|---|---|---|
| **0** | (22,190,284.65) | | | | | 0.00 | (22,190,284.65) | (22,190,284.65) | (22,190,284.65) |
| **1** | (22,190,284.65) | (12,727,225.16) | | | | 0.00 | (34,917,509.81) | (29,097,924.84) | (51,288,209.49) |
| **2** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 18,888,374.94 | (32,399,834.56) |
| **3** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 15,740,312.45 | (16,659,522.11) |
| **4** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 13,116,927.04 | (3,542,595.07) |
| **5** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 10,930,772.53 | 7,388,177.46 |
| **6** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 9,108,977.11 | 16,497,154.57 |
| **7** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 7,590,814.26 | 24,087,968.83 |
| **8** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 6,325,678.55 | 30,413,647.38 |
| **9** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 5,271,398.79 | 35,685,046.17 |
| **10** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 4,392,832.33 | 40,077,878.50 |
| **11** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 3,660,693.60 | 43,738,572.10 |
| **12** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 3,050,578.00 | 46,789,150.11 |
| **13** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 2,542,148.34 | 49,331,298.44 |
| **14** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 2,118,456.95 | 51,449,755.39 |
| **15** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 1,765,380.79 | 53,215,136.18 |

[15] all numbers are in dollars, where () denotes a negative number. i=20%(annual interest), t=40%(annual tax rate), Straight line depreciation used.

*Table IX.B.1.14: Tabulates the overall finances of the process for a thirty year period (continued from previous page)[16].*

| End of Year | $fC_{TDC}$ | $C_{WC}$ | D | C excl D | S | Net Earning | Undisc. Cash Flow | Disc. Cash Flow (PV) | Cumulative PV |
|---|---|---|---|---|---|---|---|---|---|
| **16** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 1,471,150.66 | 54,686,286.84 |
| **17** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 1,225,958.88 | 55,912,245.72 |
| **18** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 1,021,632.40 | 56,933,878.12 |
| **19** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 851,360.33 | 57,785,238.46 |
| **20** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 709,466.95 | 58,494,705.40 |
| **21** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 591,222.45 | 59,085,927.86 |
| **22** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 492,685.38 | 59,578,613.23 |
| **23** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 410,571.15 | 59,989,184.38 |
| **24** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 342,142.62 | 60,331,327.01 |
| **25** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 285,118.85 | 60,616,445.86 |
| **26** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 237,599.04 | 60,854,044.91 |
| **27** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 197,999.20 | 61,052,044.11 |
| **28** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 164,999.34 | 61,217,043.45 |
| **29** | | | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 27,199,259.91 | 137,499.45 | 61,354,542.89 |
| **30** | | 12,727,225.16 | 739,676.15 | (74,206,698.01) | 119,045,680.42 | 26,459,583.75 | 39,926,485.07 | 168,199.11 | 61,522,742.00 |

[16] all numbers are in dollars, where () denotes a negative number. i=20%(annual interest), t=40%(annual tax rate), Straight line depreciation used.

IX.B.2. Economic Handwritten Calculations

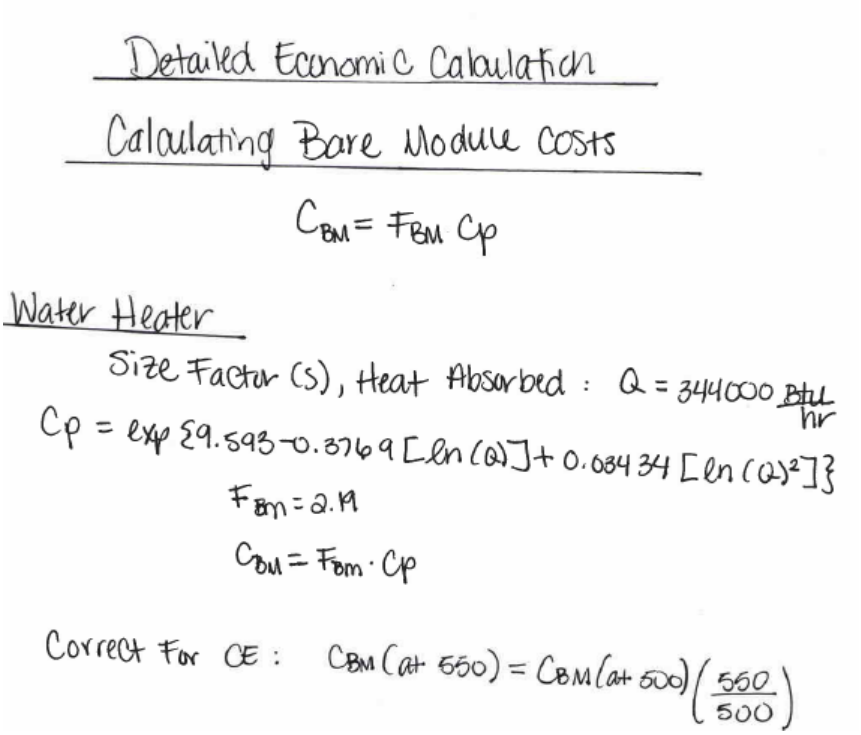


*Figure IX.B.2.1: Handwritten calculations.*

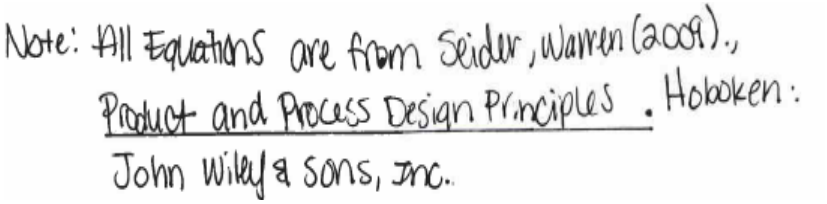


*Figure IX.B.2.2: Handwritten calculations.*

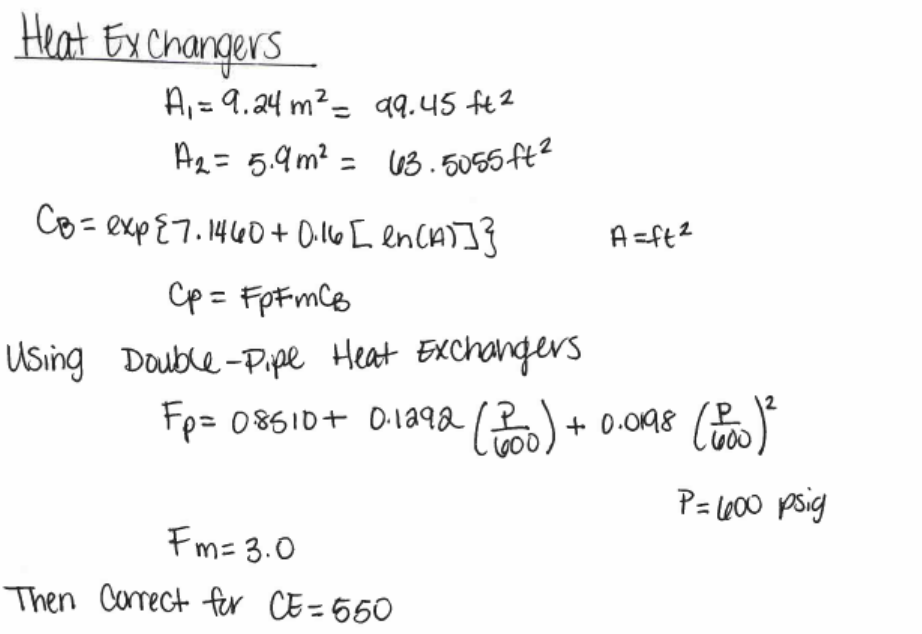


*Figure IX.B.2.3: Handwritten calculations.*

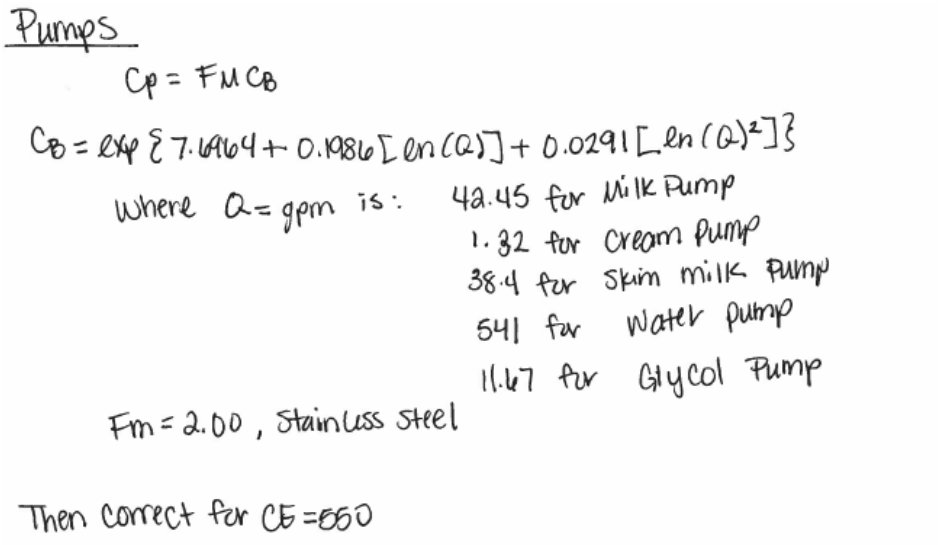


*Figure IX.B.2.4: Handwritten calculations.*

Cost For: Homogenizer

Personal communication, Troy Hancock, Shamrock Foods. 11 Feb. 2011

Milk Separator

Personal Communication, Troy Hancock, Shamrock Foods. 11 Feb. 2011.

Tanks

Personal Communication, Troy Hancock, Shamrock Foods. 11 Feb. 2011.

Vitamin Injector

Personal Communication, Troy Hancock, Shamrock Foods. 11 Feb. 2011.

Cheese Vat

New England Cheesemaking Supply Company. Web. Accessed 19 Apr. 2011. <http://www.cheesemaking.com/artisancheesevat.html>.

Milk Packaging Unit

Personal Communication, Troy Hancock, Shamrock Foods. 11 Feb. 2011.

Cheese Packaging Unit

"Automatic Cheese Packaging Machine." Alibaba. Web. 12 April 2011. <http://www.alibaba.com/Product-ags/335985523/automatic-Cheese-Packaging-machine.html>.

Cheese Press

Cheese Press. Web. 30 Mar. 2011. <http://www.Vikingmachine.com/Cmm.html>.

Were All priced by the following References
Then Correct for CE=550

*Figure IX.B.2.5: Handwritten calculations.*

Total Bare Module Cost - Fabricated Equipment

$C_{FE} = \leq C_{BM}$ (Sum of all equipment excluding Pumps and milk separator)

Total Bare Module Cost - Process Machinery

$C_{PM} = \leq C_{BM}$ (Sum of all Pumps and Milk separator)

Total Bare Module cost - spares

Sum of all Spares pumps, $C_{spare}$

Storage and Surge Tanks

Sum of all Packaging and tanks, $C_{storage}$

Catalyst Charges

$C_{catalyst} = 0$ (raw milk considered a feedstock, NO catalyst)

Computers and software

$C_{comp} = 1$ million (Process control Room)

Personal Communication, Troy Hancock, Shamrock Foods, 11 Feb 2011

*Figure IX.B.2.6: Handwritten calculations.*

Total Bare-Module Investment

$C_{TBM} = C_{FE} + C_{PM} + C_{spare} + C_{storage} + C_{catalyst} + C_{comp}$

Cost of Site Preparation

$C_{site} = (0.05) \cdot C_{TBM}$ (Integration complex)

Cost of Process Buildings

$C_{Building} = (0.1) \cdot C_{TBM}$ (Housed or Inside)

Cost of Service Building

$C_{serv} = (0.05) \cdot C_{TBM}$ (Integrated complex)

Total of Direct Permanent Investment

$T_{DPI} = C_{TBM} + C_{Buildings} + C_{offsite} + C_{site}$

Allocated cost Table 22.12, Seider

Process Water: $C_{alloc} = 1,000 S^{0.68}$ S = Flow rate, gpm

Electricity: $C_{alloc} = 2,600,000 S^{0.83}$ S = power, MW

$C_{alloc} = C_{alloc,steam} + C_{alloc,electricity}$

$C_{offse} = C_{serv} + C_{alloc}$

*Figure IX.B.2.7: Handwritten calculations.*

Cost of Contingincies and Contractor

$C_{cont} = (0.15) \cdot C_{DPI} + (0.03) \cdot C_{DFI}$

↑ Contingincies ↑ Contractor

Total Depreciable Capital

$C_{TDC} = C_{DPI} + C_{cont}$

Cost of Land

$C_{land} = 0$ (Integrated complex, already own land)

Cost of Royalties

$C_{royal} = (0.02) \cdot C_{TDC}$

Cost of Plant Start up

$C_{startup} = (0.1) \cdot C_{TDC}$

Total Permanent Investment

$C_{TPI} = C_{TDC} + C_{land} + C_{Royal} + C_{startup}$

*Figure IX.B.2.8: Handwritten calculations.*

## Labor-Related Operations

Annual Costs of Direct Wages & Benefits:

$$DW\&B, \frac{\$}{yr} = \left(\frac{\text{operators}}{\text{shifts}}\right)(5\ \text{shifts})\left(\frac{2080\ hr}{yr\text{-operation}}\right)\left(\frac{\$}{hr}\right)$$

Operator wage: $\$\ \frac{35}{hr}$

$\frac{6\ \text{Operators}}{\text{Shift}}$

5 Shifts

$\frac{2080\ hr}{yr\text{-operator}}$

Direct Salaries and Benefits = (0.15)(Annual DW&B)

Operating Supplies and Services = (0.06)·(Annual DW&B)

Technical Assistance to Manufacturing = $\$\ 60{,}000$ (5)

(5): Assistance Sales; shifts

Control Labratory = $\$\ 65{,}000$ (5)

## Total Labor Related Operations, O:

O = (Annual DW&B + Direct Salaries & Benefits + Supplies and Services + Technical Assistance to manufacturing + control lab)

*Figure IX.B.2.9: Handwritten calculations.*

Maintenance, M

Wages and Benefits (MW&B) = (0.035) · CTDC

Salaries and Benefits = (0.25) · MW&B

Materials and services = (1) · MW&B

Maintenance overhead = (0.05) · MW&B

Total Maintenance, M = (MW&B + Salaries & Benefits + materials and services + maintenance overhead)

*Figure IX.B.2.10: Handwritten calculations.*

Operating Overhead

Total Annual M&O-SW&B = (DW&B + MW&B + Direct Salaries & Benefits + Maintance Salaries & Benefits)

Total Annual Overhead = (0.228) · M&O-SW&B

*Figure IX.B.2.11: Handwritten calculations.*

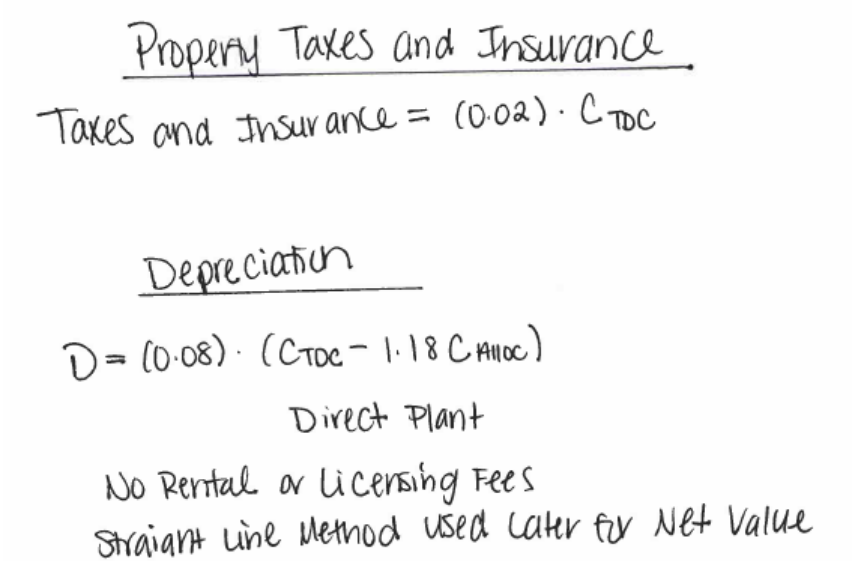


*Figure IX.B.2.12: Handwritten calculations.*

General Expenses, GE

Selling = (0.03) · Sales

Direct Research = (0.048) · Sales

Allocated Research = (0.005) · Sales

Administration = (0.02) · Sales

Management Incentive Compensation = (0.0125) · Sales

Total Production Costs

$C = GE + C_{com}$

*Figure IX.B.2.13: Handwritten calculations.*

Cost of Manufacture, Com

$C_{com}$ = (Feedstocks + Utilities + (labor-related operations) + maintenance + operating overhead + property taxes & insurance + depreciation).

*Figure IX.B.2.14: Handwritten calculations.*

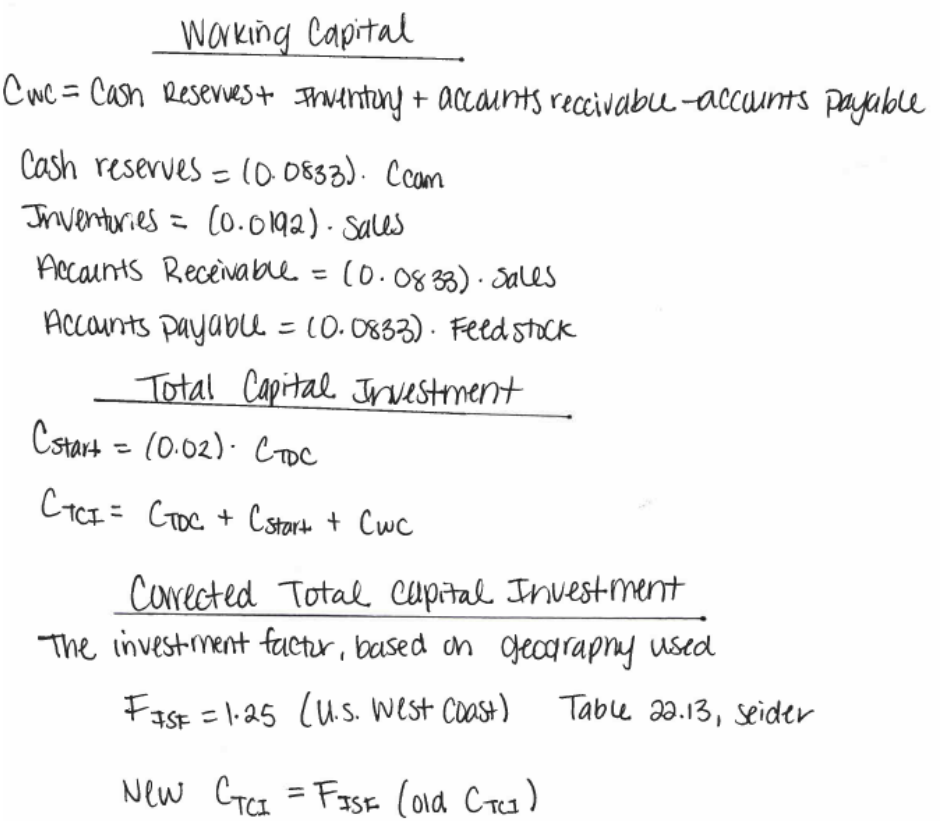


*Figure IX.B.2.15: Handwritten calculations.*

## Cost Analysis and Net Value

Values are obtained at the end of the specified year.

The total depreciable capital ($C_{TDC}$) is invested before and during the first year the process is running.

Work and capital ($C_{WC}$) starts the first year the process is running. It is fully recoverable and is recovered at the end of the 30th year.

Straight-line method is used for calculating the yearly depreciation of the $C_{TDC}$.

$$(SL) \quad D = \frac{\text{Total } C_{TDC}}{(\#\text{ of year process run})} = \frac{\text{Total } C_{TDC}}{30}$$

Assume the salvage value is $1 0.00

Sales are constant yearly and all milk and cheese sold quickly.

## Net Earnings

$$NE = (S - C_{excl\,D} + D - f\,C_{TDC} + C_{WC})(1 - t)$$

$$C_{excl\,D} = C_{com} + G_{TE}$$

$$t = 40\% \text{ (Federal + State tax)}$$

*Figure IX.B.2.16: Handwritten calculations.*

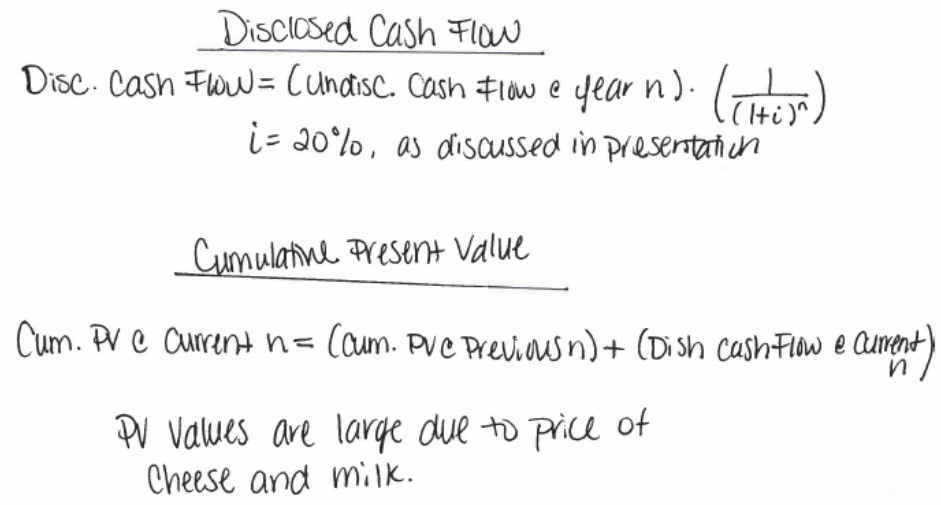


*Figure IX.B.2.17: Handwritten calculations.*

*IX.C. Overall Mass and Energy Balances*

IX.C.1 Mass Balance

***IX.C.1.1 Milk***

Mass of Milk Processed + Mass of Left Over Cream = Mass of Raw Milk

Mass of Skim Milk +( Mass of Skim Milk for 2% + Mass of Cream for 2%) + (Mass of Skim for Whole milk + Mass of Cream for Whole Milk) + Mass of Left Over Cream = Mass of Raw Milk

$$44279.9 + (128979 + 6465) + (78{,}959.9 + 6755.82) + 60893.2 = 326333 \quad (56)$$

*Table IX.C.1.1.1:Table of the mass balance for milk*

| | 2% Milk | | Whole Milk | | | |
|---|---|---|---|---|---|---|
| *Skim* | *Cream* | *Skim* | *Cream* | *Skim* | *Cream to sell* | *Total* |
| 44279.9 | 6,465 | 128,979 | 6755.82 | 78959.9 | 60,893 | 326332.8 |

***IX.C.1.2 Cheese***

Mass of Cheese Milk+ Mass of Rennet + Mass of Starter Culture - Mass of Whey + Mass of Salt - Mass of Water Out= Mass of Cheese Produced

$$4970 + 0.966 + 59.64 - 4485.91 + 14.9 - 26.37 = 533 \quad (57)$$

*Table IX.C.1.2.1: Table for the mass balance of cheese*

| Component | *Cheese Milk* | *Rennet* | *Starter Culture* | *Whey* | *Salt* | *Water* | *Total* |
|---|---|---|---|---|---|---|---|
| Mass [kg/day] | 4,970 | 0.966 | 59.64 | 4485.91 | 14.9 | 26.37 | 533 |

### *IX.C.1.3 Heat Exchanger Water & Ethylene Glycol*[1]

The total daily flow of the water and ethylene glycol was simply scaled by the right amount since the temperatures of the milk and the heat capacities of the various types of milk were assumed to be the same.

Because the skim mass flow rate was 44280 kg/day the mass fraction was found using the total mass flow of milk produced per day.

$$\frac{44280}{44280+135444+85716} = 0.167 \tag{58}$$

This ratio was then used to find the total overall mass flow of water and ethylene glycol by using the mass fraction and the mass flow rate found for skim milk.

$$Water: \ \frac{31778.6\,{}^{kg}/_{day}}{0.167} = 190291\,\frac{kg}{day} \tag{59}$$

$$Ethylene\ Glycol: \ \frac{22021.5\,{}^{kg}/_{day}}{0.167} = 131865\,\frac{kg}{day} \tag{60}$$

The mass fraction of whole milk and 2% milk were then found and multiplied by the overall totals to find the separates mass flow rates.

[1] See Appendix IX.C.2.1 for previous calculation of the mass flow rates for skim milk

2% Milk:

$$\frac{135444}{44280+135444+85716} = 0.51 \quad (61)$$

$$Water: 190291\ \frac{kg}{day} \times 0.51 = 97048.4\ \frac{kg}{day} \quad (62)$$

$$Ehtlyene\ Glycol:\ 131865\ \frac{kg}{day} \times 0.51 = 67251.15\ \frac{kg}{day} \quad (63)$$

Whole Milk:

$$\frac{85716}{44280+135444+85716} = 0.323 \quad (64)$$

$$Water: 190291\ \frac{kg}{day} \times 0.323 = 61463.99\ \frac{kg}{day} \quad (65)$$

$$Ehtlyene\ Glycol:\ 131865\ \frac{kg}{day} \times 0.323 = 42592.395\ \frac{kg}{day} \quad (66)$$

So the overall mass flow rates were

*Table IX. C.1.3.1: Overall Mass flow rates of water and ethylene glycol*

| | **Skim** | **2 %** | **Whole** |
|---|---|---|---|
| *Water* | 31778.6 kg/day | 97048.4 kg/day | 61464 kg/day |
| *Ethylene Glycol* | 22021.5 kg/day | 67251.2 kg/day | 42592.4 kg/day |

IX.C.2 Energy Balance

### *IX.C.2.1 Heat Exchanger Network*

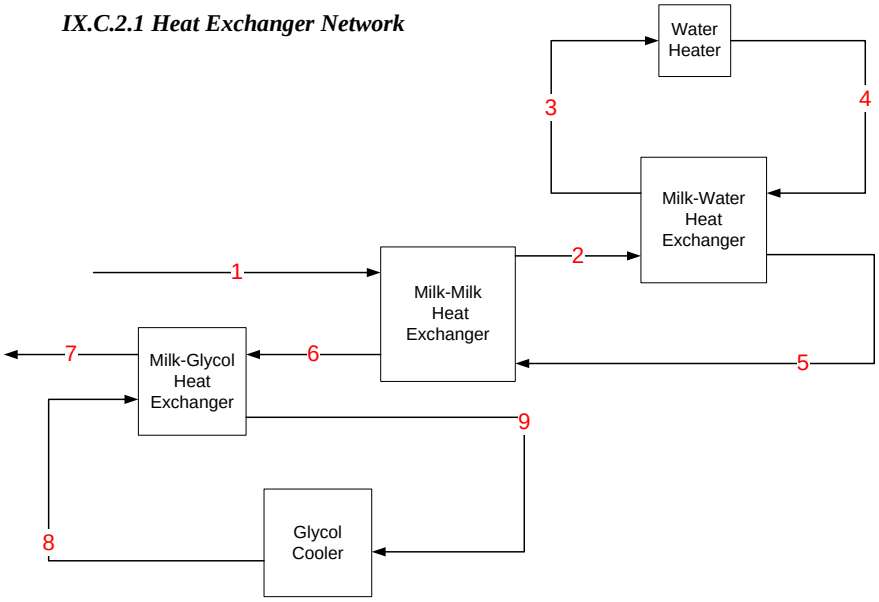


*Figure IX.C.2.1.1: Drawing of heat exchanger network*

The calculations were done on the basis of the kilograms per day of skim milk then scaled to the whole process. It was assumed that a 5.53°C unaccomplished temperature change occurred in each heat exchanger as a heuristic.

The heat exchanged in the Milk-Milk Heat Exchanger (see Figure IX.C.2.1.1) is $Q = \dot{m}C_p\Delta T$.

Where Q was the heat in kJ/day, m was the mass flow rate of the milk in kg/day, $C_p$ was the specific heat of the milk in kJ/kg°C (Hu, J., et al, 2009).

$$Q = \left(3.94\,\frac{kJ}{kg℃}\right)\left(44279.9\,\frac{kg}{day}\right)(82.2℃ - 5.53℃ - 2.2℃) = 1.29917 \times 10^7\,\frac{kJ}{day} \qquad (67)$$

The temperature in stream $6^{R}$ is

$$(82.2℃ - T℃)\left(3.94\frac{kJ}{kg℃}\right)\left(44279\frac{kg}{day}\right) = 1.29917 \times 10^{7}\frac{kJ}{day} \quad (68)$$

Where T=7.733°C

This needed to be brought back down to 2.2°C by the Milk-Glycol Heat Exchanger[R]. The heat exchanged in this unit was

$$Q = \left(3.94\frac{kJ}{kg℃}\right)\left(44279.9\frac{kg}{day}\right)(7.73℃ - 2.2℃) = 965303\frac{kJ}{day} \quad (69)$$

The temperature of stream $2^{R}$ was

$$(2.2℃ - T℃)\left(3.94\frac{kJ}{kg℃}\right)\left(44279\frac{kg}{day}\right) = 965303\frac{kJ}{day} \quad (70)$$

Where T=76.66°C

Thus the Milk-Water Heat Exchanger[R] had to raise that to 82.2°C.

The heat exchanged in this unit was

$$Q = \left(3.94\frac{kJ}{kg℃}\right)\left(44279.9\frac{kg}{day}\right)(82.2℃ - 76.6℃) = 966524\frac{kJ}{day} \quad (71)$$

The temperature of water (stream $4^{R)}$ had to be higher than the unaccomplished temperature change, but not too close to boiling.

[R] see Figure IX.C.2.1.1

The temperature chosen was 95°C, this was used to find the mass flow rate of the water.

$$(95℃ - 5.53℃ - 82.2℃)\left(4.184\frac{kJ}{kg℃}\right)\dot{m} = 965303\frac{kJ}{day} \quad (72)$$

Thus the temperature in stream 3[R] was

$$(95℃ - T℃)\left(4.184\frac{kJ}{kg℃}\right)\left(31778\frac{kg}{day}\right) = 965303\frac{kJ}{day} \quad (73)$$

Where T=87.73°C

According to the heuristic, the temperature of the glycol solution (stream 8[R] ) had to be at least

$$2.2℃ - 5.5℃ = -3.3℃ \quad (74)$$

The temperature of -10°C was chosen for a safety margin.

To find the mass flow rate of the glycol solution again $Q = \dot{m}C_p\Delta T$. Where Q was the heat in kJ/day, m was the mass flow rate of the glycol solution in kg/day, $C_p$ was the specific heat of the glycol solution[1] in kJ/kg°C (http://www.jtbaker.com/msds/englishhtml/e5125.htm, 2011).

$$-965303\frac{kg}{day} = \left(\frac{1}{3}2.214\frac{kJ}{kg℃} - \frac{2}{3}4.184\frac{kJ}{kg℃}\right)(-10℃ - 2.2℃)\dot{m} \quad (75)$$

Thus the mass flow rate for the glycol solution was 22021 kg/day and the temperature of the glycol solution after cooling the milk (stream 9[R]) would be 2.2°C (calculated the same way as stream 3 above).

[R] see Figure IX.C.2.1.1

[1] A 1:2 solution of Ethylene Glycol in water was used

### *IX.C.2.1 Water Heater & Ethylene Glycol Cooler*

The heat duty[1] of the water heater was

$$Q = \left(97048.4\,\frac{kg}{day}\right)\left(4.184\,\frac{kJ}{kg℃}\right)(95℃ - 87℃) = 3.248 \times 10^6\,\frac{kJ}{day} \quad (76)$$

Since the milk enters at 2.2°C and leaves at 2.2°C $Q_{added}$=$Q_{removed}$. Therefore Q for the ethylene glycol cooler was $3.248 \times 10^6\,\frac{kJ}{day}$.

[1] Largest flow rate of water used, see Appendix IX.C.1.3

*IX.D. Schematics for Equipment Descriptions*

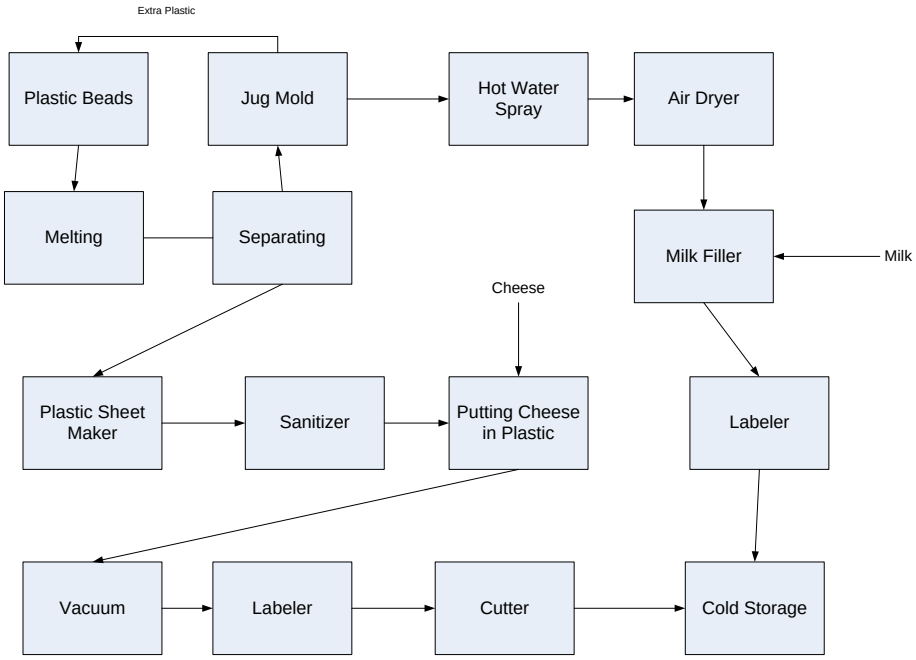


*Figure X.4.1. Block flow diagram for milk packaging unit.*

*IX.E. Personal Communication Logs*

Date: February 11, 2011

Members Present (name of senior design group members plus name and title of person providing information)

Alyssa Garcia

Summary of Information that pertains to the report.(costs, flow rates, sizes, assumptions).

Spoke to Troy Hancock, Director of Manufacturer, from Shamrock Foods in Phoenix, Arizona. He gave us lots of information on the phone and a personal tour of the plant. He gave us the cost of the storage tanks (200,000), cost of the milk separator ($450,000), maintenance cost per month ($120,000), vitamin pump (2,000), cost of materials for one-gallon plastic jug (17 cents a unit), and milk packaging equipment (6 Million). Also, the amount of water discharged, which is two gallons of water per one gallon of milk; and how 30 percent of that is steam. He also explained the heat exchanger since it is a specific one used only for milk processing. He also explained how skim milk and cream could only be stored in the holding tanks for 72 hours and the milk must be kept at 2.2 °C once it is in the packaging material. He also told use about how in recent milk industries it is common to separate the skim milk and cream and then add the cream back to the compositions for whole and 2%.

*IX.F. Un-Optimized Block Flow Diagrams*

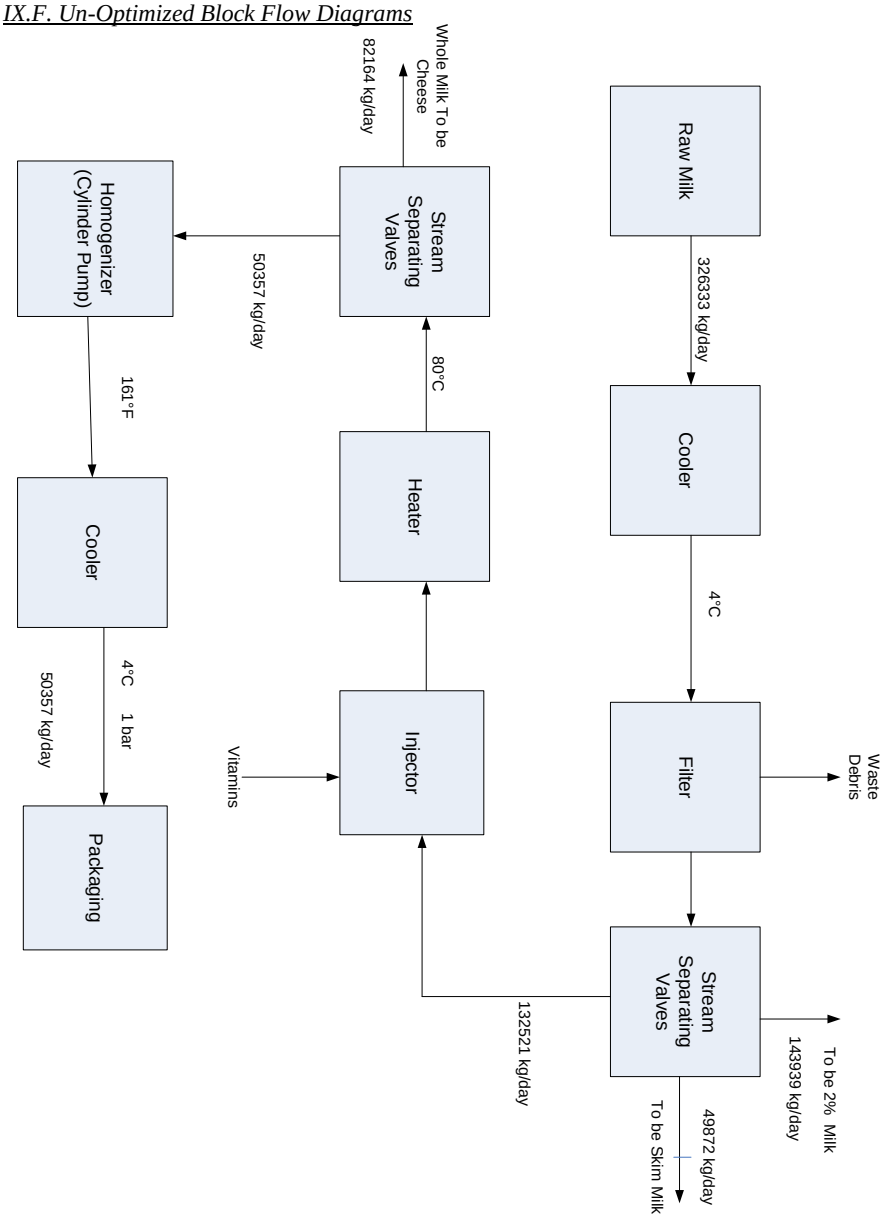


*Figure IX.F.1: Block flow diagram of raw and whole milk being processed by just separating out cream*

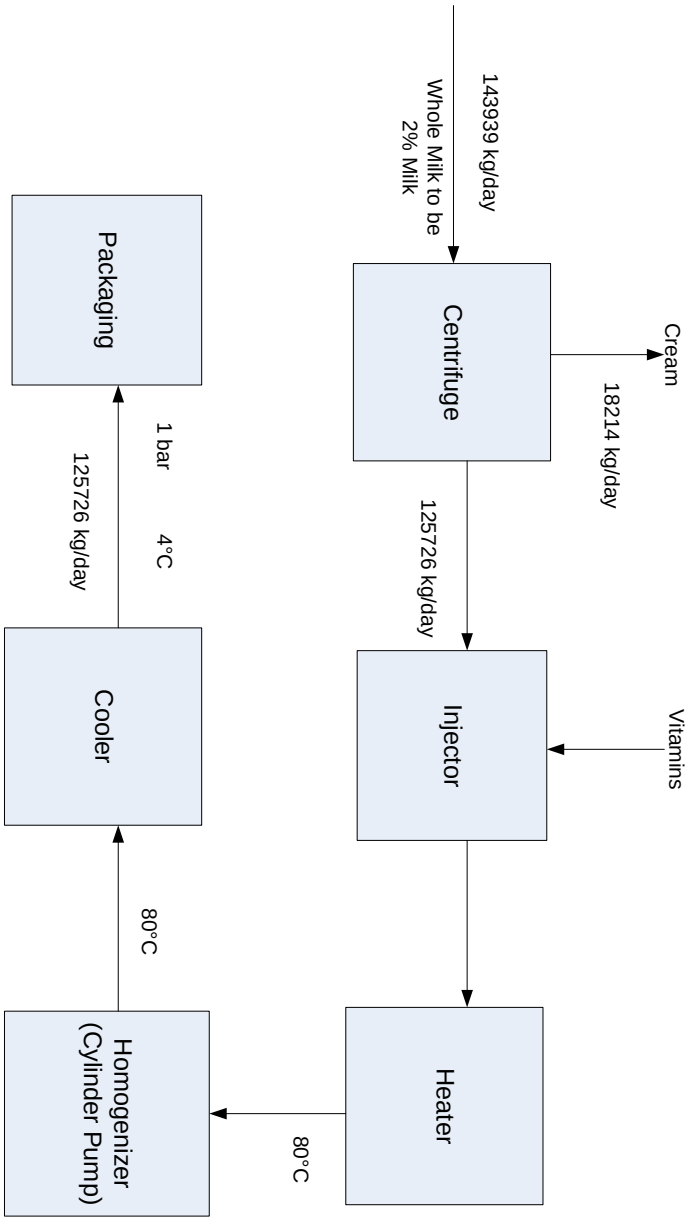


*Figure IX.F.2: Block flow diagram of 2% milk being processed by just separating out cream*

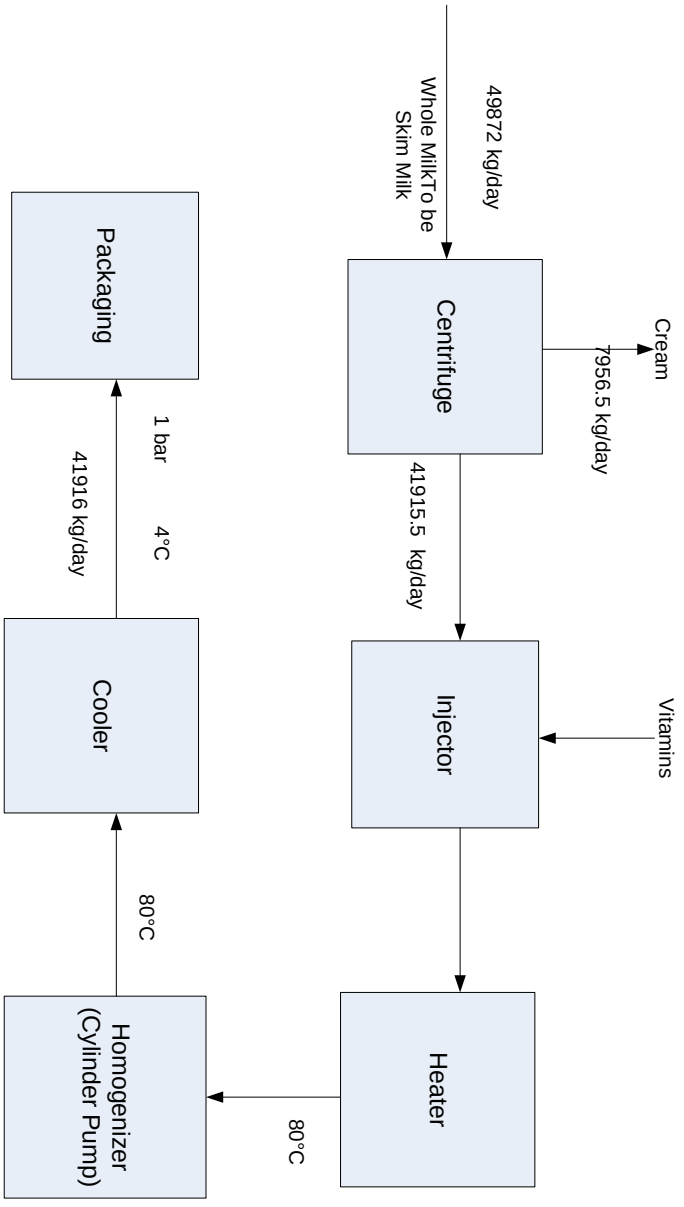


*Figure IX.F.2: Block flow diagram of skim milk being processed by just separating out cream*