THE NATIONAL UNIVERSITY OF MALAYSIA

FACULTY OF ENGINEERING AND BUILT ENVIRONMENT

CHEMICAL AND PROCESS ENGINEERING DEPARTMENT

INTEGRATED PROJECT

SEMESTER I

SESSION 2019/2020

PRODUCTION OF BUTTER

GROUP : 1-10

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DECLARATION

We hereby declare that the works in this project are our own except for our own except for quotations and summaries which have been duty acknowledged.

Date: 5 th November 2019

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Lastly, we would also like to thank the Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment for providing us experience and knowledge to complete this project. We hope that our integrated project will be beneficial to us in our future and we cannot deny that this project provides us a mountain of knowledge which is essential to us.

ABSTRACT

By doing this integrated project, we need to do a research on the production of butter. To complete this project, we have frequented ourselves to Perpustakaan Tun Sri Lanang to look for some sources. We also get many helpful advices from professors when we faced any obstacles.

Butter which composition are 80-82% milk fat,16-17% of water and 1-2% milk solid. The density of the butter is 911 grams per litre and it exist as pale yellow colour. Milk is the key raw material to produce butter via various processes. In the production of butter, there are totally 3 types waste products which are water, buttermilk and skim milk. In this project, we get to determine the global supply and demand of butter. By using the data that we found, we able to find out its plant capacity. The mass balance is calculated by using the plant capacity that I get from the graph. The mass balance and energy were done to ensure the flow rate of the input and output are the same. The process of the manufacturing is being drawn by using Microsoft Visio and each component were labelled in a systematically manner.

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CHAPTER I

1.1 INTRODUCTION

Butter is one of the most highly concentrated forms of fluid milk which produced through a phase inversion of an emulsion. The butter is in solid, waxy textures and different in color from white to deep yellow. Butter was always made form mammals milk and usually cow's milk was used but in Indian subcontinent, water buffalo's milk is used, in the Himalayas, yak's milk is used and in central Asia, sheep's milk is used. They are two types to produce the butter which is traditional small-scale method and NIZO technique. There are various types of butter such as salt butter, sweet butter, sour butter, and shea butter. Although the way of production not same but the main input is still the same. Butter will remain in solid shape when in a refrigerator and butter will soften to a spreadable when in a room temperature and above. Butter can be divided into four types which are based on their acidity of cream, salt content, end use and MFG practice. The principal constituents of a normal salted butter are fat (80 - 82%), water (15.6 - 17.6%), salt (about 1.2%) as well as protein, calcium and phosphorous (about 1.2%) and it also contains fat-soluble vitamins A, D and E.

1.2 THE USAGES OF BUTTER

Butter plays an essential role in baking process as is adding flavour to bakes goods and makes it become more tender. Some cake batters are leaved, by sugar and creaming butter, which introduces air bubbles into the butter. These bubbles trapped within the butter and it aerates the cookie and makes the butter expand during heating process. Cookies such as shortbread has only water in the butter and they do not have other source of moisture. Mixing butter into dough especially in preparing pies and tarts, it will help to increase its flakiness.

There is variety of food that can prepared by using butter as one of the ingredients such as Linzer torte, Torpedo dessert and so forth. Due to its low smoke point, butter is not generally used at high temperature or for deep frying. Butter has a rich flavor and creamy texture due to its high concentration of fat. It helps to prevent sticking while adding flavor.

1.3 PHYSICAL AND CHEMICAL PROPERTIES

Substances	Chemical Properties	Physical Properties
Raw milk	-The pH of milk at $25°C$ is in the range 6.5 and 6.7 -One cup of raw milk contains 8 grams of fat -Stable under normal temperatures and pressures.	-Have a milky taste -Specific gravity for milk is 1020-1030 -Freezing point for milk is around $-0.522°C$ -Boiling point is $100.5°C$ -Stable under recommended storage conditions.
Skim	-The pH for skim is 6.7 -No toxicity -Skim milk only have 0.3% fat.	-The colour of skim milk is light yellow. -Boiling point for skim is around $40-45°C$ -Water solubility is ca.700 g/l at 20°C -Bulk density is ca.500 kg/m3 -Stable under recommended storage conditions.
Cream	-Range pH for cream is 4.70-5.20 -Stable under normal temperatures and pressures. -Cream contain about 35% of fat.	-Slightly sour -The boiling point for cream is $130°C$ -Flash point for cream is $164°F$ -Soluble in water -specific gravity is 1.035
Buttermilk	-The pH for buttermilk is below 4.7 -Not reactive with water. -Butter milk contains only 1% of fat.	-Tangy and bitter taste -Freezing point for buttermilk is $4°C$ -Light cream colour. -Soluble in water. -Stable under normal conditions
Butter	-The pH of butter is around 9 -One cup of butter contains 184 g of fat. -Not reactive under normal conditions.	-Butter in water-in-oil emulsion -Various in colour from deep yellow to nearly white -Melting point for butter is $35\text{-}36°C$ -Smoke point for butter is at $150°C$ -Soluble in water

-The chemical stability for butter is stable.

Table 1.1 Physical and Chemical properties for the Substances

1.4 PROCESS DESCRIPTION

Based on our chemical plant, we use continuous buttermaker to produce butter. The raw materials that used to produce butter are raw milk and cream. The continuous buttermaker has four types which are traditional batch churning from 25%-35%. Milk fat cream, continuous flotation churning from 30-50% milk fat cream, the concentration process whereby "plastic" cream at 82% mf. is separated from 35% milk fat cream at 55℃ and then this oil-in-water emulsion cream is inverted to a water-in-oil emulsion butter with no further draining of buttermilk and the anhydrous milkfat process whereby water, SNF, and salt are emulsified into butter oil in a process very similar to margarine manufacture.

1.4.1 SEPARATION PROCESS

Milk and cream are collected from cows or buffalo, goats, camel and mares. Cream is separated from milk. The milk is separated through centrifugal separator device (CS-101). the separator spins dividing the raw milks fat from the rest of the liquid which is known as buttercream and the rest is skim milk. The speed of the device is about 6000 revolutions per minute. The raw milk is separated to raw skim milk and raw cream.

1.4.2 PASTEURIZATION PROCESS

The cream should be sweet which means their pH must greater than 6.6, not rancid, not oxidized, and free from off flavors. The cream is pasteurized at a temperature of 95°C or above to destroy enzymes and microorganisms. Specially designed plate heat exchangers may be used to minimize physical damage to the fat globules and the uptake of the copper onto the fat globule membrane from the serum can be prevented by avoiding the severe heat treatments. Through pasteurization, pathogenic bacteria, other bacteria and enzymes that could affect the keeping quality can be killed.

1.4.3 RIPENING PROCESS

The cream is ripened to pH 5.5 at 21°C which enables flavour development to occur. The colder the temperature during ripening the more the flavour development relative to acid production. After ripening, the cream is cooled to about 7°C for several hours to allow the fat to harden. The cream is then allowed to warm to at about 10°C in the warmer weather and 18°C in cooler weather and is poured into a butter churn.

1.4.4 AGING PROCESS

Before churning, cream is held at cool temperatures to crystallize the butterfat globules. The cream is subjected to a program of controlled cooling designed to give the fat the required crystalline structure. The ripening process usually takes about 12-15 hours. After ripening, the butter is then pumped to the churner. By setting the temperature at 16 ° C, the hardest part of the fat will be fixed in crystal form. The more violent the cooling process, the more fat will be crystallized to form the solid and less liquid fat that can squeezed out of the fat globules during churning process. The crystals bind the liquid fat to their surface by adsorption. After cooling for about 2 hours, most of the hard fat had crystallized and binding little of the liquid fat.

1.4.5 CHURNING PROCESS

After the aging process, butterfat had crystallized and then it undergoes churning process at about 7 °C to become butter granules which formed by aggregation of the action of fat globules under the action of air present in the cream. The air in the cream is beaten during churning process and dispersed into small bubbles. This process involved high-speed beaters (CN-101) which speed is around 2800rpm to destabilize the fat emulsion in chilled cream and caused the butter granules formed in few seconds. About 45.2% milk solid is formed during churning process and the rest is called buttermilk.

1.4.6 DRAINING AND WASHING PROCESS

After that, buttermilk and butter granules undergo draining and washing process. By the continuous buttermaker, the buttermilk had drained out continuously through a wire mesh which covers by the perforated cylinder and butter granules were worked in kneading section consists of screw type kneader. The butter was forced to flow through many perforated plates arranged in series to produce a fine dispersion of water in butter. The granules were pressed and kneaded together. After the buttermilk had drained off, the butter is worked to a continuous fat phase containing a finely dispersed water phase to remove any residual buttermilk and milk solids.

1.4.7 WORKING PROCESS

Then, the raw butter undergoes working process, water are added through an opening immediately in front of the perforated plates to adjust the moisture of the butter.The spreadability improved by using vacuum compartments to reduce the air content of the butter.

1.4.8 PACKAGING AND STORAGE PROCESS

For the packaging and storage, the butter was patted into shape and wrapped in waxed paper and then stored in a cool place. The butter became firm after it cooled. Butter can also be frozen to further extend its storage life.

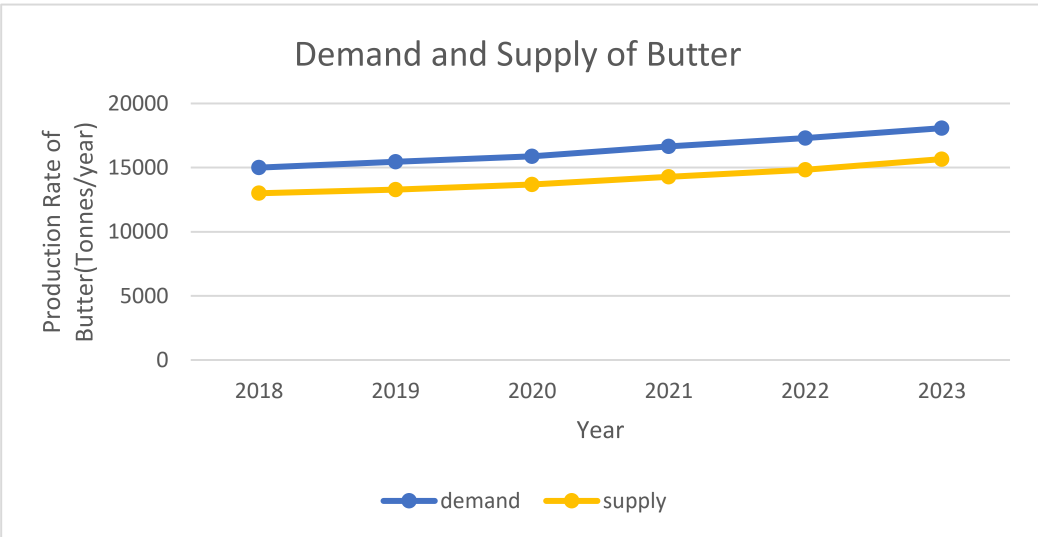
CHAPTER II

ECONOMIC ISSUES OF BUTTER

2.1 SUPPLY AND DEMAND GRAPH FOR BUTTER

During the forecast period,2018-2023 the global butter market is expected to grow at a CAGR of 3.8%. In 2018, the global butter exports expanded by 7.5 % to 917920 tonnes which contributed by New Zealand, the United States of America and India, but those of the European Union declined. The global butter import demand remained strong which include developing and developed countries such as China, United States of America, Egypt Australia, Saudi Arabia and Malaysia. China remained the largest butter importer and its imports grew to 147568 tonnes in 2018 which means the percentage of growth is about 16.2% due to the demand from an increasingly urbanized population with higher incomes.

Figure 2.1: Graph of global demand and supply of butter



(Dairy and Products Annual,2017)

2.2 FUTURE MARKETING POTENTIAL

Butter market has been segmented on basis of processing which are processed butter and non- processed butter and in 2016, processes butter holds a share of 6%. Butter plays vital role in marketing as it able to use in baking, sauce making, pan frying and cooking. Butter contains milk protein, water and butterfat. Due to its wide application in cooking and baking, the demand on it is high and butter has a huge market potential. The rise in home-baking and product innovation in developed countries become major driver for the market of butter. The top manufacturers of butter with the market share, production revenue and include Dairy farmers of America, Fonterra and so forth. In 2018, the largest region in the milk and butter manufacturing market- Asia Pacific which worth $126.9 billion, accounting for 45.3% of the global milk and butter manufacturing market. The second largest region is Western Europe at 22.3% and followed by North America at 17.0% respectively.

According to the latest research made by IMARC, the global table butter market grew of around 3.1% from the year 2009 until 2016 and finally reaching a volume of 4.6 Million Metric Tons in 2016.In a report from an analysis in some regions. We found that Asia is the biggest producer of butter followed by Western Europe, North America, Oceania and other regions. (“Table Butter Market | Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2017-2022” n.d.)

The main consumer of butter is France with a per capita consumption of 8.2 kg, and it followed by Denmark with a per capita consumption of 6.4 kg in the world. The third top consumer is Iceland with 6 kg and followed by Czech Republic with 5.4 kg while Switzerland closes the top five with 5.2 kg. New Zealand is the only country with a per capita consumption of above 5 kg. (“Countries Who Consume the Most Butter - WorldAtlas.com” n.d.)

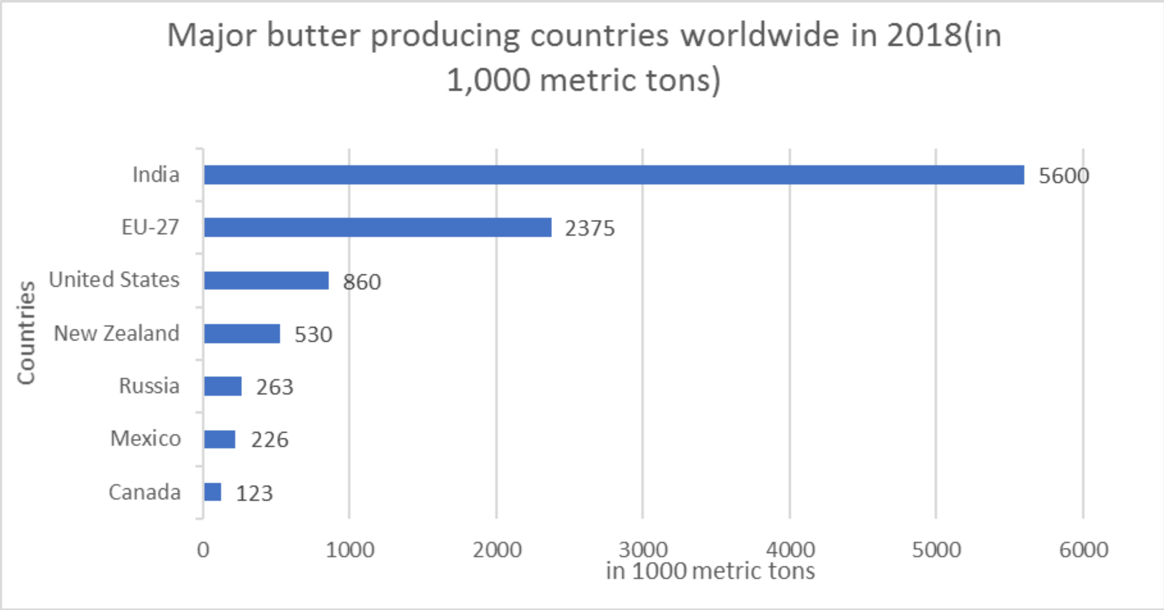


Figure 2.2: Major butter producing countries worldwide

Source: Statista,2019

2.3 MARKET PRICE OF BUTTER

Prices for butter and non-fat dry milk (NFDM) have posted stellar year-over-year gains so far this year and NFDM (NFDM) prices averaged 99.22 cents per pound in February versus 72.17 cents a year earlier. Butter prices in February averaged $2.2659 per pound, 14 cents higher than February 2017. In United States, butter usage during 2018 was up 2% from the previous year, but finished the year strongly, gaining 6% from the last quarter of 2017 based on calculations by USDA’s Economic Research Service. In January, the butter production was up 4% from a year earlier, but usage was good enough to keep domestic inventories from building as much as they usually do during January. Table below shows the price of butter in year 2018 in Western Europe.

Table 2.1: Price of Butter in Western Europe

Month	Price of butter in Western Europe in 2018 per ton
Jan	4.988
Feb	5.263
Mar	6.000
Apr	6.544
May	7.019
Jun	7.163
Jul	6.688

Aug	6.513
Sept	6.406
Oct	5.544
Nov	5.094
Dec	4.963

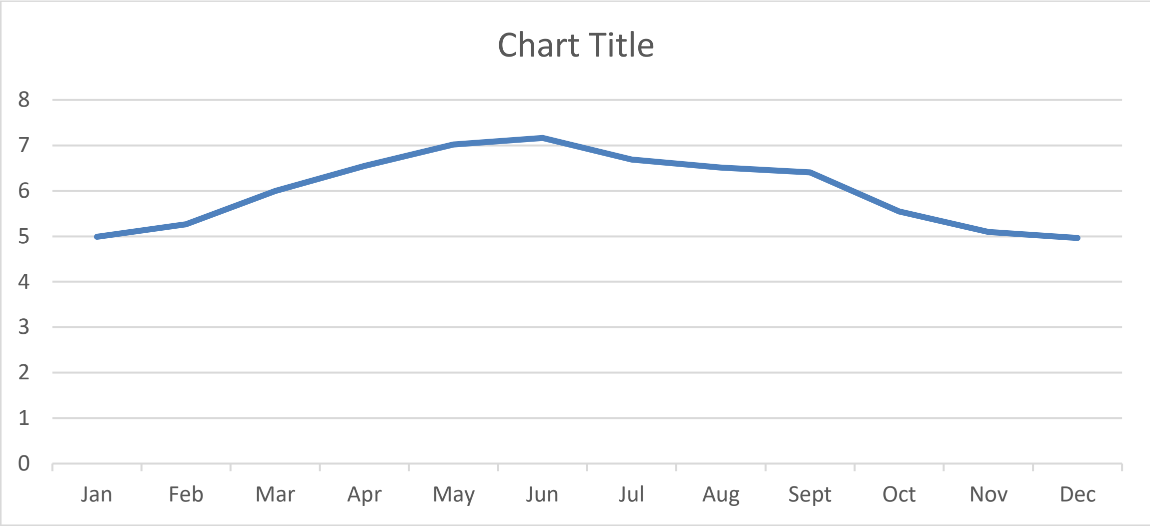


Figure 2.3 Price of Butter in 2019

Source: ("CLAL - Butter, International Market - Western Europe" n.d.)

2.4 LIST OF EXISTING COMPANY

The companies that produce butter are Tatura, Arla and Dairy Crest. It is predicted that that the capacity of the world butter by 2023 will reach around 18,075 millions tons /year. The list of butter production companies are shown in Table 2.4.1.

Table 2.2 List of Butter Production Company

Country	Company	Capacity (tonnes/year)
Australia	Tatura Milk Industries Ltd.	8000
Sweden	Arla Foods	76000
United Kingdom	Dairy Crest Group plc	56000
	Ornua Foods Ltd.	4000
India	AGRA	20000
Netherlans	FrieslandCampina N. V.	41666
New Zealands	Anchor	290000

2.5 PRODUCTION RATE AND PLANT CAPACITY

Due to the various usage of milk in many sectors especially in production of butter, the high and increasing demand of butter is expected. From the data obtained in Figure2.1, the supply and demand graph show positive trends. This indicates that the production of butter is constantly increased from year to year. Thus, in the coming year 2019, the production rate of plant is estimated as below:

Demand–Supply = 15450,000 tonne/year–13273,000 tonne/year

=,177,000tonne/year

=2,177kilotonne/year

Thus, by calculating in the coming year 2020, the proposed butter demand will be 2,177 kilotonne /year more than the supply. Which means the production of butter is lower than the global demand of butter.

Production time a year =350daysx24hours

= 8400hours

Plant capacity =0.02 x 2177kilotonne/year

=43.54kilotonne/8400hours

=5183kg/hr

Therefore, our plant capacity is set to produce 43.54kilotonne/year, which contribute

0.2% to the global demand.

CHAPTER III

ENVIRONMENTAL AND SAFETY ISSUES

3.1 ENVIRONMENTAL ISSUES

3.1.1 Waste By-products

Skim milk, buttermilk and whey are the waste product that be generated from the production of butter. For every pound of butter, it will produce about 3 pounds of buttermilk, 15-20 pounds of skim milk. The production of butter may probably cause the global warming potential, eutrophication potential and acidification potential. The land use for butter is about twice compared to margarine because more land is needed to produce the feed for dairy cows which is about 8.5 square metres per 500 grammes (m2/500g). The production of butter uses more water which is about 5,553 litres of water to produce 1 kg of butter and it also cause the air pollution problem to our environment. (“The Impact/Footprint of Producing & Eating Butter & Margarine - Better Meets Reality” n.d.)

3.1.2 Waste Treatment

Excess whey, skim milk and buttermilk can be reused to produce commercial industrial products in the hope to return farm patrons and eliminate legal problems. According to Utilization of By-Product of the Dairy by Henry E. Alvord, C.E., by feeding domestic animals of various kinds with skim milk-waste by-product from the production of butter, we will gain the most profitable use as the experiment conducted successfully proved that skim milk makes rapid growth of the domestic animals. Besides, the waste water of the production of the butter is treated by adjusting pH and by using strong coagulant chemistry to break any emulsions by cleaning agents and sanitizers. The chemicals are added to cause precipitation and coagulation. The predominant by-product should be processed into high value products like skim milk powder (SMP), buttermilk powder (BMP), whey powder, whey protein concentrates and casein rather than being dumped as waste. Hot water is suitable to be used to remove the residue butterfat from cream processing and butter making equipment. The temperature of the water must not be too high (below 65°C). Whey should be dried where possible. To maximize the production of butter, a waste management plan should be prepared according to the procedures outlined in Waste Minimisation Assessment.

3.1.3 Environmental Quality Acts in Malaysia

The dairy industry contributes many negative impacts to our environment. To cope with these impacts, the Malaysian Government has passed some important environmental laws and policies such as Environmental Quality (Clean Air) Regulations, Environmental Quality (Scheduled Wastes) Regulations 2005, Environmental Quality Act 1974, Environmental Quality (Amendment) Act 1998 and so forth. Environmental Quality (Scheduled Wastes) Regulations 2005 provide for the disposal, treatment, management, storage and transport of scheduled wastes. Environmental Quality Act 1974 is an act relating to the prevention, abatement, control of pollution and enhancement of the environment and for purposes connected therewith. This means that any pollution caused during the operation of the plant has to be within the range set by the standards in the national law. The waste products that need to treated have to be inspected first before released to the environment to ensure they follow the standard set by the Ministry of Environment. To encourage proper industrial waste management, there are a few incentives are currently available which includes pioneer status incentive for 5 years to companies which are principally engaged in an integrated operation for the storage, treatment and disposal of toxic and hazardous wastes.

3.2 SAFETY ISSUE ON PRODUCT ANDD RAW MATERIALS

3.2.1 Properties of Raw Materials

Table 3.1 Properties of Materials

Materials	Explanation
Butter	A creamy white ivory solid with a light odor, not flammable and toxic. This product is not reactive. Hazardous reaction will not occur under conditions of normal storage and use.
Milk protein	Light yellow to brown transparent liquid. It is under normal conditions, but may emit noxious fumes of CO.
Salt	Non-combustible. Hazardous polymerization will not occur. Over exposure may produce irritation of the mucous membrane, nose, throat, coughing and shortness of breath.
Carotene	A crystalline solid. Cause serious eye irritation. It may be harmful to inhalation or skin absorption. May be combustible in high temperature.

Source: Chemical Book 2017

3.2. Handling Methods and Storage

The handling methods and storage of butter is important to provide general information to persons who manufacture, consume and handle butter. The table below shows that the handling and storage precautions of butter.

Handling Precaution	**Storage Precaution**
Butter should be handled with good industrial hygiene and safety practice by wearing protective gloves or clothing.	Keep container tightly closed and store in a cool, dry and well-ventilated place.
Raw milk is usually pasteurized by low 40°F temperature pasteurization in which milk is to 145°F or higher for at least 30 minutes high temperature pasteurization,161°F for and quickly cooled.	Store the butter at the temperature below or below to protect the quality of milk. Heated This temperature should be maintained while or by
Consult the material safety data sheet.	Avoid butter exposed to light and strong odour Avoid extremes of temperature.
Do not breathe dust, fume, gas or spray. Wash face, hands and any exposed skin thoroughly after handling. Wash contaminated clothing before reuse.	Keep receptacle tightly sealed when not in used.

Source: (“Safe Handling of Milk & Dairy Products | Home & Garden Information Center” n.d.)

CHAPTER IV

4.1 MATERIAL BALANCE

Plant capacity for our plant covers the capacity of Malaysia’s production of butter throughout the year which is 55,020 tonne/year.

F = (43540 tonnes /year x 1000 kg/tonne) / (350 days x 24 hours)

= 5183 kg/hr

Mass balance is used to compare the inputs and outputs of the process so that the mass that enter the system must be equal to the mass that leave the system. By calculating the mass balance, we able to make sure that there is no mass loss during the process. In the material balance equation, we used plant capacity to find the initial flow rate of milk.

Mass Balance Calculation

The annotations that are used:

Water : W

Fat : F

Protein : P

Lactose : L

Mineral : M

4.1.1 Centrifugal separator CS-101

Figure 5.3 shows a separator where the milk separated into cream and skim milk.

$F_1 = 115087.08$ kg/h

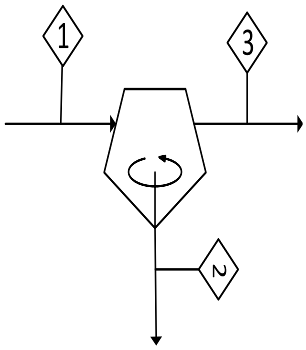
$F_{1W} = 100931.37$ kg/h

$F_{1F} = 3912.96$ kg/h

$F_{1P} = 3797.87$ kg/h

$F_{1L} = 5639.27$ kg/h

$F_{1M} = 805.61$ kg/h



$F_3 = 12547.08$ kg/h

$F_{3W} = 8030.13$ kg/h

$F_{3F} = 3810.42$ kg/h

$F_{3P} = 106.43$kg/h

$F_{3L} = 512.27$ kg/h

$F_{3M} = 87.83$ kg/h

$F_2 = 102540$ kg/h

$F_{2W} = 92901.24$ kg/h

$F_{2F} = 102.54$ kg/h

$F_{2P} = 3691.44$ kg/h

$F_{2L} = 5127$ kg/h

$F_{2M} = 717.78$ kg/h

Figure 4.1 Centrifugal Separator CS-101

Table 4.1 Mass Fraction and Mass Flow Rate of Each Component in Centrifugal Separator CS-101

	Stream 1		Stream 2		Stream 3	
component	w	F(kg/h)	w	F(kg/h)	W	F(kg/h)
Water	0.8770	100931.37	0.906	92901.24	0.6400	8030.13
Fat	0.0340	3912.96	0.001	102.54	0.3036	3810.42
Protein	0.0330	3797.87	0.036	3691.44	0.0084	106.43
lactose	0.0490	5639.27	0.05	5127	0.0410	512.27
mineral	0.0070	805.61	0.007	717.78	0.0070	87.83
total	1.0000	115087.08	1.000	102540	1.0000	12547.08

4.1.2 Pesteurizer PT-101

Figure 5.4 shows that the butter cream fed into pesteurizer to kill bacteria and produced evaporated water.

$F_4 = 1740.98$ kg/h

$F_{4W} = 1740.98$ kg/h

$F_{4F} = 0$ kg/h

$F_{4P} = 0$ kg/h

$F_{4L} = 0$ kg/h

$F_3 = 12547.08$ kg/h

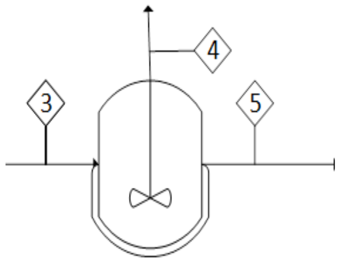
$F_{3W} = 8030.13$ kg/h

$F_{3F} = 3810.42$ kg/h

$F_{3P} = 106.43$ kg/h

$F_{3L} = 512.27$ kg/h

$F_{3M} = 87.83$kg/h



$F_5 = 10806.10$ kg/h

$F_{5W} = 6289.15$ kg/h

$F_{5F} = 3810.42$ kg/h

$F_{5P} = 106.43$ kg/h

$F_{5L} = 512.27$ kg/h

$F_{5M} = 87.83$ kg/h

Figure 4.2 Pesteurizer P-101

Table 4.2 Mass Fraction and Mass Flow Rate of Each Component in pasteurizer P-101

	Stream 3		Stream 4		Stream 5	
component	W	F(kg/h)	w	F(kg/h)	W	F(kg/h)
Water	0.6400	8030.13	1	1740.98	0.5820	6289.15
Fat	0.3036	3810.42	0	0	0.3526	3810.42
Protein	0.0084	106.43	0	0	0.00985	106.43
lactose	0.0410	512.27	0	0	0.0474	512.27
mineral	0.0070	87.83	0	0	0.00815	87.83
total	1.0000	12547.08	1	1740.98	1.00000	10806.1

4.1.3 Churner C-101

Figure 5.5 shows butter cream fed into churner to produced butter granules and buttermilk.

F_9 = 746.05 kg/h

F_{9W} = 746.05 kg/h

F_{9F} = 0 kg/h

F_{9P} = 0 kg/h

F_{9L} = 0 kg/h

F_{9M} = 0 kg/h

F_8 = 10806.10 kg/h

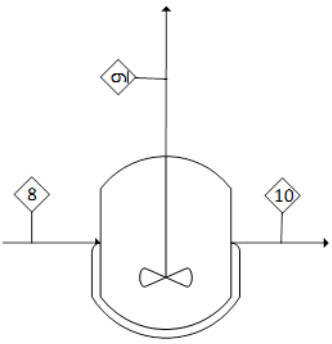
F_{8W} = 6289.15 kg/h

F_{8F} = 3810.42 kg/h

F_{8P} = 106.43 kg/h

F_{8L} = 512.27 kg/h

F_{8M} = 87.83 kg/h



F_{10} = 10060.05 kg/h

F_{10W} = 5543.1 kg/h

F_{10F} = 3810.42 kg/h

F_{10P} = 106.43 kg/h

F_{10L} = 512.27 kg/h

F_{10M} = 87.83 kg/h

Figure 4.3 Churner C-101

Table 4.3 Mass Fraction and Mass Flow Rate of Each Component in Churner C-101

	Stream 8		Stream 9		Stream 10	
component	w	F(kg/h)	w	F(kg/h)	W	F(kg/h)
Water	0.582	6289.15	1	746.05	0.551	5543.1
Fat	0.3526	3810.42	0	0	0.3896	3810.42
Protein	0.00985	106.43	0	0	0.0269	106.43
lactose	0.0474	512.27	0	0	0.0275	512.27
mineral	0.00815	87.83	0	0	0.005	87.83
total	1	10806.1	1	746.05	1	10060.05

4.1.4 Membrane Filter MF-101

Figure 5.6 shows the butter granules and buttermilk separated to continue the process.

F_{13} = 5260.4 kg/h

F_{13W} = 4734.33 kg/h

F_{13F} = 263.02 kg/h

F_{13P} = 105.21kg/h

F_{13L} = 99.97 kg/h

F_{13M} = 57.87 kg/h

F_{10} = 10060.05 kg/h

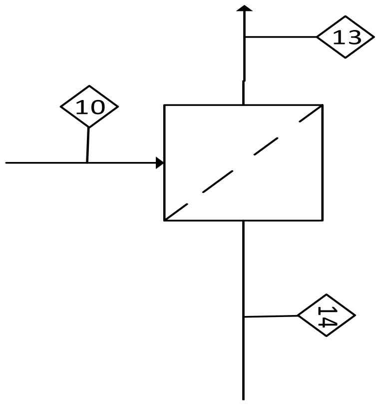
F_{10W} = 5543.1 kg/h

F_{10F} = 3810.42 kg/h

F_{10P} = 106.43kg/h

F_{10L} = 512.27 kg/h

F_{10M} = 87.83kg/h



F_{14} = 4799.65 kg/h

F_{14W} = 808.74 kg/h

F_{14F} = 3547.4 kg/h

F_{14P} = 1.22 kg/h

F_{14L} = 412.32 kg/h

F_{14M} = 29.97 kg/h

Figure 4.4 Membrane Filter MF-101

Table 4.4 Mass Fraction Mass Flow Rate of Rach Component in Membrane Filter MF-101

	Stream 10		Stream 13		Stream 14	
component	w	F(kg/h)	w	F(kg/h)	W	F(kg/h)
Water	0.551	5543.1	0.9	4734.33	0.1685	808.74
Fat	0.3896	3810.42	0.05	263.02	0.7391	3547.4
Protein	0.0106	106.43	0.02	105.21	0.0003	1.22
lactose	0.0509	512.27	0.019	99.97	0.086	412.32
mineral	0.0087	87.83	0.011	57.87	0.0062	29.97
total	1	10060.05	1	5260.4	1	4799.65

4.1.5 Mixer M-101

Figure 5.7 shows water and butter granules fed into mixer and formed butter.

F_{14} = 4799.65 kg/h

F_{14W} = 808.74 kg/h

F_{14F} = 3547.4 kg/h

F_{14P} = 1.22 kg/h

F_{14L} = 412.32 kg/h

F_{14M} = 29.97 kg/h

F_{15} = 383.35 kg/h

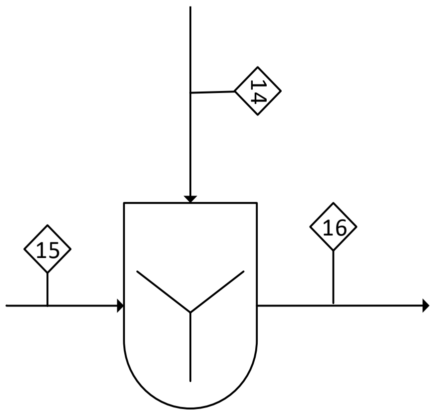
F_{15W} = 383.35 kg/h

F_{15F} = 0 kg/h

F_{15P} = 0 kg/h

F_{15L} = 0 kg/h

F_{15M} = 0 kg/h



F_{16} = 5183.00 kg/h

F_{16W} = 1192.09 kg/h

F_{16F} = 3547.4 kg/h

F_{16P} = 1.22 kg/h

F_{16L} = 412.32 kg/h

F_{16M} = 29.97 kg/h

Figure 4.5 Mixer M-101

Table 4.5 Mass Fraction and Mass Flow Rate of Each Component in Mixer M-101

	Stream 14		Stream 15		Stream 16	
component	w	F(kg/h)	w	F(kg/h)	W	F(kg/h)
Water	0.1685	808.74	1	383.35	0.23	1192.09
Fat	0.739	3547.4	0	0	0.6844	3547.4
Protein	0.0003	1.22	0	0	0.00023	1.22
lactose	0.086	412.32	0	0	0.0796	412.32
mineral	0.0062	29.97	0	0	0.00577	29.97
total	1	4799.65	1	383.35	1	5183

4.2 ENERGY BALANCE

Energy balance is the arithmetic of balancing of energy inputs versus outputs for an object, reactor, or other unit processes. During the reaction, energy balance is used to determine the heat released or absorbed. The reaction is endothermic if heat is absorbed and is exothermic if the heat is released. The energy balances are used to quantify the energy used or produced by a system.

The law of conversion of energy states that energy can neither be created nor destroyed; it can only be changed from one form to another or transferred from one body to another. The calculation of energy balance is to determine the heat change of the unit process.

The assumptions used in the calculations are as follow:

1. The flow in the unit processes are in steady state.
2. The reference temperature is fixed at 25℃.
3. There is no potential energy, kinetic energy and work done by the system.

Table 5.1: Specific heat capacity of each component

Component	A	B	C	D
Water	32.24	0.1923×10^{-2}	1.055×10^{-5}	13.63×10^{-8}
Protein	2.0082×10^{3}	1.2089	-1.3129×10^{-3}	-
Fat	1.9842×10^{3}	1.4733	-4.8008×10^{-3}	-
Ash	1.0926×10^{3}	1.8896	-3.6817×10^{-3}	-
Lactose	1.5488×10^{3}	1.9625	-5.9399×10^{-3}	-

4.2.1 Energy Balance at Pasteurizer (PT-101)

$F_4 = 1740.98$ kg/h

$F_{4W} = 1740.98$ kg/h

$F_{4F} = 0$ kg/h

$F_{4P} = 0$ kg/h

$F_{4L} = 0$ kg/h

$F_3 = 12547.08$ kg/h

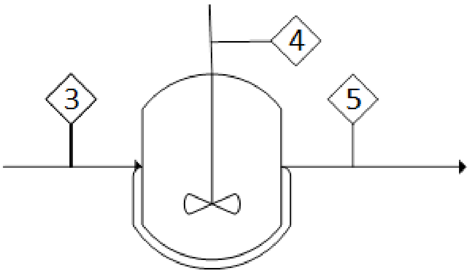
$F_{3W} = 8030.13$ kg/h

$F_{3F} = 3810.42$ kg/h

$F_{3P} = 106.43$ kg/h

$F_{3L} = 512.27$ kg/h

$F_{3M} = 87.83$kg/h



$F_5 = 10806.10$ kg/h

$F_{5W} = 6289.15$ kg/h

$F_{5F} = 3810.42$ kg/h

$F_{5P} = 106.43$ kg/h

$F_{5L} = 512.27$ kg/h

$F_{5M} = 87.83$ kg/h

Feed Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1= 298K to T_2= 301K

Stream 3:

Lactose

$\Delta H_L = \int_{298}^{301} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399\times 10^{-3})T^2\, dT$

$= 4.81126$ kJ/kg

Protein

$\Delta H_P = \int_{298}^{301} 2.0082 \times 10^{3} + (1.2089)\,T + (-1.3129\times 10^{-3})\ T^2\, dT$

$= 6.75749$ kJ/kg

Fat

$\Delta H_F = \int_{298}^{301} 1.984 \times 10^{3} + (1.4733)\,T + (-4.8008 \times 10^{-3})T^2\, dT$

$= 5.98445$ kJ/kg

Water

$\Delta H_W = \int_{298}^{301} 32.24 + (0.1923 \times 10^{-2})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3 \, dT$

$= 0.100997$ kJ/mol

$= 5.6109$ kJ/kg

Mineral

$\Delta H_M = \int_{298}^{301} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2 \, dT$

$= 3.985$ kJ/kg

Product Enthalpy, $\Delta H = \int_{T1}^{T2} Cp \, dT$

Temperature is from T_1=298 K to T_2= 368K

Stream 4:

Water

$\Delta H_W = \int_{298}^{368} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3 \, dT$

$= 2.374$ kJ/mol

$= 131.91$ kJ/kg

Stream 5:

Lactose

$\Delta H_L = \int_{298}^{368} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399 \times 10^{-3})T_2$

$= 2.374$ kJ/kg

Protein

$\Delta H_P = \int_{298}^{368} 2.0082 \times 10^3 + (1.2089)T + (-1.3129 \times 10^{-3}) T^2 \, dT$

= 158.525 kJ/kg

Fat

$\Delta H_F = \int_{298}^{368} 1.9842 \times 10^{3} + (1.4733)\,T + (-4.8008 \times 10^{-3})T^2\, dT$

= 135.834kJ/kg

Water

$\Delta H_W = \int_{298}^{368} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3\, dT$

= 2.374 kJ/mol

=131.91 kJ/kg

Mineral

$\Delta H_M = \int_{298}^{368} 1.0926 \times 10^{3} + 1.8896T + (-3.6817 \times 10^{-3})T^2\, dT$

= 91.845 kJ/kg

Protein = $H_{5p}F_{5p} + H_{4p}F_{4p} - H_{3p}F_{3p}$

= 16152.61 kJ/h

Fat = $H_{5F}F_{5F} + H_{4F}F_{4F} - H_{3F}F_{3F}$

= 494781.33 kJ/h

Lactose = $H_{5L}F_{5L} + H_{4L}F_{4L} - H_{3L}F_{3L}$

= 52801.69 kJ/h

Water = $H_{5W}F_{5W} + H_{4W}F_{4W} - H_{3W}F_{3W}$

= 1014198.19 kJ/h

Mineral = $H_{5M}F_{5M} + H_{4M}F_{4M} – H_{3M}F_{3M}$

= 7.72 x 10^3 kJ/h

Total = $H_p + H_F + H_L + H_W + H_M$

= 1585653.82 kJ/h (endothermic, since it is positive)

4.2.2 Energy Balance at Cooler (CE-101)

F_5 = 10806.10 kg/h

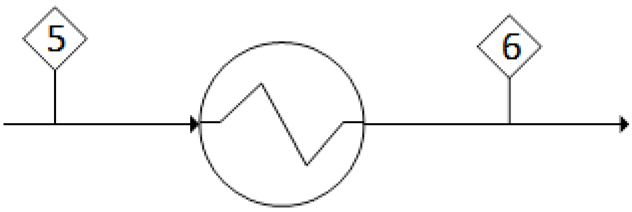
F_{5W} = 6289.15 kg/h

F_{5F} = 3810.42 kg/h

F_{5P} = 106.43 kg/h

F_{5L} = 512.27 kg/h

F_{5M} = 87.83 kg/h



F_6 = 10806.10 kg/h

F_{6W} = 6289.15 kg/h

F_{6F} = 3810.42 kg/h

F_{6P} = 106.43 kg/h

F_{6L} = 512.27 kg/h

F_{6M} = 87.83 kg/h

Feed Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1= 298K to T_2= 368K

Stream 5:

Lactose

$\Delta H_L = \int_{298}^{368} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399\times 10^{-3})T_2$

= 0.1079 kJ/kg

Protein

$\Delta H_P = \int_{298}^{368} 2.0082 \times 10^{3} + (1.2089)\, T + (-1.3129\times 10^{-3})\ T^2\, dT$

= 158.52 kJ/kg

Fat

$\Delta H_F = \int_{298}^{368} 1.984 \times 10^3 + (1.4733)\,T + (-4.8008 \times 10^{-3})T^2\, dT$

= 135.834 kJ/kg

Water

$\Delta H_W = \int_{298}^{368} 32.24 + (0.1923 \times 10^{-2})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3\, dT$

= 2.374 kJ/mol

=131.91 kJ/kg

Mineral

$\Delta H_M = \int_{298}^{368} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2\, dT$

= 3.985 kJ/kg

Product Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1=298 K to T_2= 306 K

Stream 6:

Lactose

$\Delta H_L = \int_{298}^{306} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399 \times 10^{-3})T_2$

= 0.0128 kJ/kg

Protein

$\Delta H_P = \int_{298}^{306} 2.0082 \times 10^3 + (1.2089)\,T + (-1.3129 \times 10^{-3})\, T^2\, dT$

= 18.028 kJ/kg

Fat

$\Delta H_F = \int_{298}^{306} 1.9842 \times 10^3 + (1.4733)\,T + (-4.8008 \times 10^{-3})T^2\, dT$

= 15.93 kJ/kg

Water

$\Delta H_W = \int_{298}^{306} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3\, dT$

= 0.2694 kJ/mol

=14.994 kJ/kg

Mineral

$\Delta H_M = \int_{298}^{306} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2 \, dT$

= 10.62 kJ/kg

Protein = $H_{6p}F_{6p} - H_{5p}F_{5p}$

= -14952.56 kJ/h

Fat = $H_{6F}F_{6F} - H_{5F}F_F$

= -456.88×10^3 kJ/h

Lactose = $H_{6L}F_{6L} - H_{5L}F_L$

= -48714 kJ/h

Water = $H_{6W}F_{6W} - H_{5W}F_W$

= 1014198.19 kJ/h

Mineral = $H_{6M}F_{6M} - H_{5M}F_M$

= -7.134×10^3 kJ/h

Total = $H_p + H_F + H_L + H_W + H_M$

=-1214317.53 kJ/h (exothermic, since it is negative)

4.2.3 Energy balance at Storage Tank (T-101)

F_6 = 10806.10 kg/h

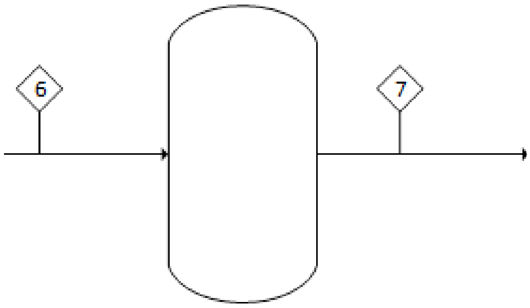
F_{6W} = 6289.15 kg/h

F_{6F} = 3810.42 kg/h

F_{6P} = 106.43 kg/h

F_{6L} = 512.27 kg/h

F_{6M} = 87.83 kg/h



F_7= 10806.10 kg/h

F_{7W} = 6289.15 kg/h

F_{7F} = 3810.42 kg/h

F_{7P} = 106.43 kg/h

F_{7L} = 512.27 kg/h

F_{7M} = 87.83 kg/h

Feed Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\ dT$

Temperature is from T_1= 298K to T_2= 306K

Stream 6:

Lactose

$\Delta H_L = \int_{298}^{306} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399\times 10^{-3})T_2$

= 0.0128 kJ/kg

Protein

$\Delta H_P = \int_{298}^{306} 2.0082 \times 10^{3} + (1.2089)\ T + (-1.3129\times 10^{-3})\ T^2\ dT$

= 18.028 kJ/kg

Fat

$\Delta H_F = \int_{298}^{306} 1.9842 \times 10^{3} + (1.4733)\ T + (-\ 4.8008 \times 10^{-3})T^2\ dT$

= 15.93 kJ/kg

Water

$\Delta H_W = \int_{298}^{306} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3$ dT

= 0.2694 kJ/mol

=14.994 kJ/kg

Mineral

$\Delta H_M = \int_{298}^{306} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2\, dT$

$= 10.62$ kJ/kg

Product Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1=298 K to T_2= 294 K

Stream 7:

Lactose

$\Delta H_L = \int_{298}^{294} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399 \times 10^{-3})T_2$

$= -0.00644$ kJ/kg

Protein

$\Delta H_P = \int_{298}^{294} 2.0082 \times 10^3 + (1.2089)\, T + (-1.3129 \times 10^{-3})\; T^2\, dT$

$= -9.004$ kJ/kg

Fat

$\Delta H_F = \int_{298}^{294} 1.9842 \times 10^3 + (1.4733)\, T + (-\, 4.8008 \times 10^{-3})T^2\, dT$

$= -7.999$ kJ/kg

Water

$\Delta H_W = \int_{298}^{294} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3$
dT

$= -0.1346$ kJ/mol

$= -7.478$ kJ/kg

Mineral

$\Delta H_M = \int_{298}^{294} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2\, dT$

$= -5.317$ kJ/kg

Protein = $H_{7p}F_{7p} - H_{6p}F_{6p}$

= -2.877×10^3 kJ/h

Fat = $H_{7F}F_{7F} - H_{6F}F_{6F}$

= -91.18×10^3 kJ/h

Lactose = $H_{7L}F_{7L} - H_{6L}F_{6L}$

= -9.85348 kJ/h

Water = $H_{7W}F_{7W} - H_{6W}F_{6W}$

= -141329.78 kJ/h

Mineral = $H_{7M}F_{7M} - H_{6M}F_{6}$

= -1399.71 kJ/h

Total = $H_p + H_F + H_L + H_W + H_M$

= -236796.34 kJ/h (exothermic, since it is negative)

4.2.4 Energy Balance at Crystallizer (CT-101)

F_7= 10806.10 kg/h

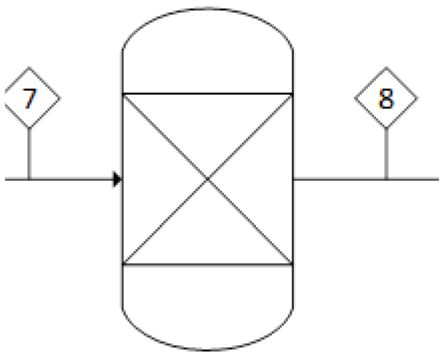
F_{7W} = 6289.15 kg/h

F_{7F} = 3810.42 kg/h

F_{7P} = 106.43 kg/h

F_{7L} = 512.27 kg/h

F_{7M} = 87.83 kg/h



F_8= 10806.10 kg/h

F_{8W} = 6289.15 kg/h

F_{8F} = 3810.42 kg/h

F_{8P} = 106.43 kg/h

F_{8L} = 512.27 kg/h

F_{8M} = 87.83 kg/h

Feed Enthalpy, ΔH

$= \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1= 298K to T_2= 294K

Stream 7:

Lactose

$\Delta H_L = \int_{298}^{294} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399\times 10^{-3})T_2$

= -0.00644 kJ/kg

Protein

$\Delta H_P = \int_{298}^{294} 2.0082 \times 10^{3} + (1.2089)\, T + (-1.3129\times 10^{-3})\ T^2\, dT$

= -9.004 kJ/kg

Fat

$\Delta H_F = \int_{298}^{294} 1.9842 \times 10^{3} + (1.4733)\, T + (-\, 4.8008 \times 10^{-3})T^2\, dT$

= -7.999 kJ/kg

Water

$\Delta H_W = \int_{298}^{294} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3\, dT$

= -0.1346 kJ/mol

$= -7.478$ kJ/kg

Mineral

$\Delta H_M = \int_{298}^{294} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2\, dT$

$= -5.317$ kJ/kg

Product Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1=298 K to T_2= 280 K

Stream 8:

Lactose

$\Delta H_L = \int_{298}^{280} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399\times 10^{-3})T_2$

$= -0.0292$ kJ/kg

Protein

$\Delta H_P = \int_{298}^{280} 2.0082 \times 10^3 + (1.2089)\, T + (-1.3129\times 10^{-3})\ T^2\, dT$

$= -40.462$ kJ/kg

Fat

$\Delta H_F = \int_{298}^{280} 1.9842 \times 10^3 + (1.4733)\, T + (-4.8008 \times 10^{-3})T^2\, dT$

$= -36.16$ kJ/kg

Water

$\Delta H_W = \int_{298}^{280} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3$
dT

$= -0.6046$ kJ/mol

$= -33.689$ kJ/kg

Mineral

$\Delta H_M = \int_{298}^{280} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2\, dT$

$= -23.96$ kJ/kg

Protein = $H_{8p}F_{8p} - H_{7p}F_{7p}$

= -3348.074 kJ/h

Fat = $H_{8F}F_{8F} - H_{7F}F_{7F}$

= -107306.38 kJ/h

Lactose = $H_{8L}F_{8L} - H_{7L}F_{7L}$

= -11.66 kJ/h

Water = $H_{8W}F_{8W} - H_{7W}F_{7W}$

= -164844.91 kJ/h

Mineral = $H_{8M}F_{8M} - H_{7M}F_{7M}$

= -1637.39 kJ/h

Total = $H_p + H_F + H_L + H_W + H_M$

= -277148.354 kJ/h (exothermic, since it is negative)

4.2.5 Energy Balance at Churner (C-101)

F_9 = 746.05 kg/h

F_{9W} = 746.05 kg/h

F_{9F} = 0 kg/h

F_{9P} = 0 kg/h

F_{9L} = 0 kg/h

F_{9M} = 0 kg/h

F_8= 10806.10 kg/h

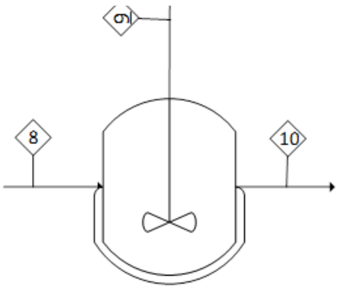
F_{8W} = 6289.15 kg/h

F_{8F} = 3810.42 kg/h

F_{8P} = 106.43 kg/h

F_{8L} = 512.27 kg/h

F_{8M} = 87.83 kg/h



F_{10} = 10060.05 kg/h

F_{10W} = 5543.1 kg/h

F_{10F} = 3810.42 kg/h

F_{10P} = 106.43 kg/h

F_{10L} = 512.27 kg/h

F_{10M} = 87.83 kg/h

Feed Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\ dT$

Temperature is from T_1= 298K to T_2= 280K

Stream 8:

Lactose

$\Delta H_L = \int_{298}^{280} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399 \times 10^{-3})T_2$

= -0.0292 kJ/kg

Protein

$\Delta H_P = \int_{298}^{280} 2.0082 \times 10^{3} + (1.2089)\ T + (-1.3129 \times 10^{-3})\ T^2\ dT$

= -40.462 kJ/kg

Fat

$\Delta H_F = \int_{298}^{280} 1.9842 \times 10^{3} + (1.4733)\ T + (-\ 4.8008 \times 10^{-3})T^2\ dT$

= -36.16 kJ/kg

Water

$\Delta H_W = \int_{298}^{280} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3$ dT

$= -0.6046$ kJ/mol

$= -33.689$ kJ/kg

Mineral

$\Delta H_M = \int_{298}^{280} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2\, dT$

$= -23.96$ kJ/kg

Product Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1=298 K to T_2= 289 K

Stream 9:

$\Delta H_W = \int_{298}^{289} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3\, dT$

$= -0.3026$ kJ/mol

$= -16.81$ kJ/kg

Stream 10:

Lactose

$\Delta H_L = \int_{298}^{289} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399 \times 10^{-3})T_2$

$= -0.01452$ kJ/kg

Protein

$\Delta H_P = \int_{298}^{289} 2.0082 \times 10^3 + (1.2089)T + (-1.3129 \times 10^{-3})T^2\, dT$

$= -20.249$ kJ/kg

Fat

$\Delta H_F = \int_{298}^{289} 1.9842 \times 10^3 + (1.4733)T + (-4.8008 \times 10^{-3})T^2\, dT$

$= -18.027$ kJ/kg

Water

$\Delta H_W = \int_{298}^{289} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3\, dT$

= -0.3026 kJ/mol

= -16.81 kJ/kg

Mineral

$\Delta H_M = \int_{298}^{289} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2 \, dT$

= -11.97 kJ/kg

Protein = $H_{9p}F_{9p} + H_{10p}F_{10p} - H_{8p}F_{8p}$

= 2151.27 kJ/h

Fat = $H_{9F}F_{9F} + H_{10F}F_{10F} - H_{8F}F_{8F}$

= 69.094 x 10^3 kJ/h

Lactose = $H_{9L}F_{9L} + H_{10L}F_{10L} - H_{8L}F_{8L}$

= 7.5218 kJ/h

Water = $H_{9W}F_{9W} + H_{10W}F_{10W} - H_{8W}F_{8W}$

= 106154.56 kJ/h

Mineral = $H_{9M}F_{9M} + H_{10M}F_{10M} - H_{8M}F_{8M}$

= 1.05 x 10^3 kJ/h

Total = $H_p + H_F + H_L + H_W + H_M$

= 178457.35 kJ/h (endothermic, since it is positive)

4.2.6 **Energy Balance at Membrane Filter (MF-101)**

F_{13} = 5260.4 kg/h

F_{13W} = 4734.33 kg/h

F_{13F} = 263.02 kg/h

F_{13P} = 105.21kg/h

F_{13L} = 99.97 kg/h

F_{13M} = 57.87 kg/h

F_{10} = 10060.05 kg/h

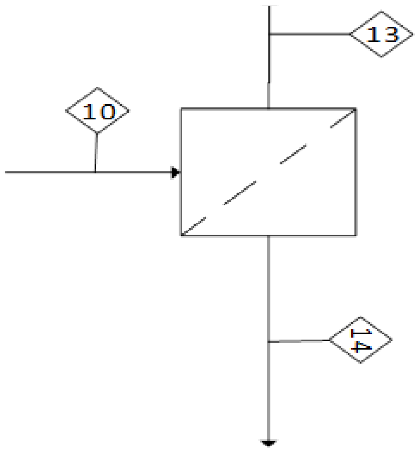
F_{10W} = 5543.1 kg/h

F_{10F} = 3810.42 kg/h

F_{10P} = 106.43 kg/h

F_{10L} = 512.27 kg/h

F_{10M} = 87.83 kg/h



F_{14} = 4799.65 kg/h

F_{14W} = 808.74 kg/h

F_{14F} = 3547.4 kg/h

F_{14P} = 1.22 kg/h

F_{14L} = 412.32 kg/h

F_{14M} = 29.97 kg/h

Feed Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\ dT$

Temperature is from T_1= 298K to T_2= 289K

Stream 10:

Lactose

$\Delta H_L = \int_{298}^{289} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399 \times 10^{-3})T_2$

$= -0.01452$ kJ/kg

Protein

$\Delta H_P = \int_{298}^{289} 2.0082 \times 10^{3} + (1.2089)\ T + (-1.3129 \times 10^{-3})\ T^2\ dT$

$= -20.249$ kJ/kg

Fat

$\Delta H_F = \int_{298}^{289} 1.9842 \times 10^{3} + (1.4733)\ T + (-\ 4.8008 \times 10^{-3})T^2\ dT$

$= -18.027$ kJ/kg

Water

$\Delta H_W = \int_{298}^{289} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3$ dT

= -0.3026 kJ/mol

= -16.81 kJ/kg

Mineral

$\Delta H_M = \int_{298}^{289} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2\, dT$

= -11.97 kJ/kg

Product Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1=298 K to T_2= 280 K

Stream 13 and 14:

Lactose

$\Delta H_L = \int_{298}^{280} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399 \times 10^{-3})T_2$

= -0.0292 kJ/kg

Protein

$\Delta H_P = \int_{298}^{280} 2.0082 \times 10^3 + (1.2089)T + (-1.3129 \times 10^{-3})T^2\, dT$

= -40.462 kJ/kg

Fat

$\Delta H_F = \int_{298}^{280} 1.9842 \times 10^3 + (1.4733)T + (-4.8008 \times 10^{-3})T^2\, dT$

= -36.16 kJ/kg

Water

$\Delta H_W = \int_{298}^{280} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3$ dT

= -0.6046 kJ/mol

= -33.689 kJ/kg

Mineral

$\Delta H_M = \int_{298}^{280} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2 \, dT$

$= -23.96$ kJ/kg

Protein = $H_{13p}F_{13p} + H_{14p}F_{14p} - H_{10p}F_{10p}$

$= -2151.27$ kJ/h

Fat = $H_{13F}F_{13F} + H_{14F}F_{14F} - H_{10F}F_{10F}$

$= -69094.34$ kJ/h

Lactose = $H_{13L}F_{13L} + H_{14L}F_{14L} - H_{10L}F_{10L}$

$= -7.495$ kJ/h

Water = $H_{13W}F_{13W} + H_{14W}F_{14W} - H_{10W}F_{10W}$

$= -93012.21$ kJ/h

Mineral = $H_{13M}F_{13M} + H_{14M}F_{14M} - H_{10M}F_{10M}$

$= -3.156 \times 10^3$ kJ/h

Total = $H_p + H_F + H_L + H_W + H_M$

$= -167421.32$ kJ/h (exothermic, since it is negative)

4.2.7 Energy Balance at Mixer (M-101)

F_{14} = 4799.65 kg/h

F_{14W} = 808.74 kg/h

F_{14F} = 3547.4 kg/h

F_{14P} = 1.22 kg/h

F_{14L} = 412.32 kg/h

F_{14M} = 29.97 kg/h

F_{15} = 383.35 kg/h

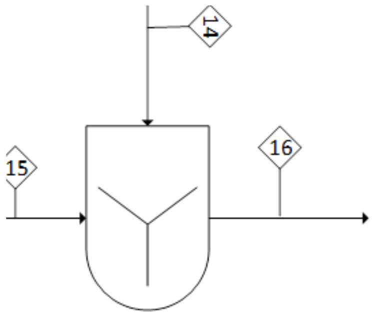
F_{15W} = 383.35 kg/h

F_{15F} = 0 kg/h

F_{15P} = 0 kg/h

F_{15L} = 0 kg/h

F_{15M} = 0 kg/h



F_{16} = 5183.00 kg/h

F_{16W} = 1192.09 kg/h

F_{16F} = 3547.4 kg/h

F_{16P} = 1.22 kg/h

F_{16L} = 412.32 kg/h

F_{16M} = 29.97 kg/h

Feed Enthalpy, ΔH = $\int_{T1}^{T2} Cp\ dT$

Temperature is from T_1= 298K to T_2= 280K

Stream 14:

Lactose

$\Delta H_L = \int_{298}^{280} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399\times 10^{-3})T_2$

= -0.0292 kJ/kg

Protein

$\Delta H_P = \int_{298}^{280} 2.0082 \times 10^{3} + (1.2089)\ T + (-1.3129\times 10^{-3})\ T^2\ dT$

= -40.462 kJ/kg

Fat

$\Delta H_F = \int_{298}^{280} 1.9842 \times 10^{3} + (1.4733)\ T + (-\ 4.8008 \times 10^{-3})T^2\ dT$

= -36.16 kJ/kg

Water

$\Delta H_W = \int_{298}^{280} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3$
dT

= -0.6046 kJ/mol

= -33.689 kJ/kg

Mineral

$\Delta H_M = \int_{298}^{280} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2\, dT$

= -23.96 kJ/kg

Temperature is from T_1= 298K to T_2= 301K

$\Delta H_W = \int_{298}^{301} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3$ dT

= 0.100997 kJ/mol

= 5.61 kJ/kg

Product Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1=298 K to T_2= 301 K

Stream 16:

Lactose

$\Delta H_L = \int_{298}^{301} 1.5488 \times 10^{-3} + 1.9625T + (-5.9399 \times 10^{-3})T_2$

= -0.00481 kJ/kg

Protein

$\Delta H_P = \int_{298}^{301} 2.0082 \times 10^3 + (1.2089)T + (-1.3129 \times 10^{-3})T^2\, dT$

= 6.758 kJ/kg

Fat

$\Delta H_F = \int_{298}^{301} 1.9842 \times 10^3 + (1.4733)T + (-4.8008 \times 10^{-3})T^2\, dT$

= 5.984 kJ/kg

Water

$\Delta H_W = \int_{298}^{301} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3$ dT

$= 0.100997$ kJ/mol

$= 5.61$ kJ/kg

Mineral

$\Delta H_M = \int_{298}^{301} 1.0926 \times 10^3 + 1.8896T + (-3.6817 \times 10^{-3})T^2 \, dT$

$= 3.985$ kJ/kg

Protein $= H_{1p}F_{16p} - H_{14p}F_{14p}$

$= 57.61$ kJ/h

Fat $= H_{16F}F_{16F} - H_{14F}F_{4F}$

$= 149501.62$ kJ/h

Lactose $= H_{16L}F_{16L} - H_{14L}F_{14L}$

$= -10.297$ kJ/h

Water $= H_{16W}F_{16W} - H_{15W}F_{15W} - H_{14W}F_{14W}$

$= 31702.61$ kJ/h

Mineral $= H_{16M}F_{16M} - H_{14M}F_{14M}$

$= 837.51$ kJ/h

Total $= H_p + H_F + H_L + H_W + H_M$

$= 182089.05$ kJ/h (endothermic, since it is positive)

4.2.8 Energy Balance at Condenser (CN-101)

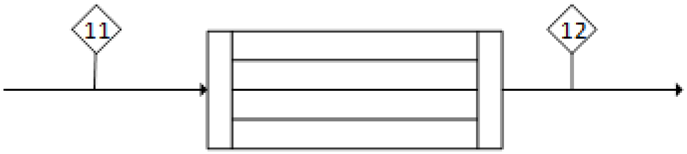
F_4 = 2487.03 kg/h

F_{4W} = 2487.03 kg/h

F_{4F} = 0 kg/h

F_{4P} = 0 kg/h

F_{4L} = 0 kg/h



F_4 = 2487.03 kg/h

F_{4W} = 2487.03 kg/h

F_{4F} = 0 kg/h

F_{4P} = 0 kg/h

F_{4L} = 0 kg/h

Feed Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1=298 K to T_2= 368 K

Stream 11:

$\Delta H_W = \int_{298}^{368} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3\, dT$

= 2.374 kJ/mol

= 131.88 kJ/kg

Product Enthalpy, $\Delta H = \int_{T1}^{T2} Cp\, dT$

Temperature is from T_1=298 K to T_2= 308 K

Stream 12:

$\Delta H_W = \int_{298}^{368} 32.24 + (0.1923 \times 10^{-3})T + (1.005 \times 10^{-5})T^2 + (-3.595 \times 10^{-4})T^3\, dT$

= 0.3369 kJ/mol

= 18.72 kJ/kg

Water

$H_{12W}F_{1W} - H_{11W}F_{11W}$

=-28.1432.32 kJ/h (exothermic since it is negative.)

CHAPTER V

CONCLUSION

The objectives of this study in chapter 1 and 2 is to introduce the process and for us to learn about the chemical and physical properties of butter. The production of butter including separation, ripening, aging, churning, draining and washing, working and packaging and storage process.

In addition, we learnt the way to measure and calculate the values of material balance and energy balance in the production of butter. Besides, this study also helps us to draw process flow diagram (PFD) in a systematic way which help us a lot on how to determine the material balance and energy balance more effectively

In chapter 3, we learnt the waste product that will be produced by the production of butter and also the ways to overcome these issues. In this process, the plant is designed to produce 43.54kilotonne butter per year. The plant design assumes that the days of operation for the design is 360 days per year which is equal to 8400 hours per year.

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APPENDIX

CALCULATION FOR MATERIAL BALANCE

CENTRIFUGAL SEPARATOR (CS-101)

$F_1 = F_2 + F_3$

$F_1 = F_2 + 12547.08$

H_2O balance

$0.877\ F_1 = 0.906\ F_2 + 8030.13$

$0.877(F_2 + 12547.08) = 0.906\ F_2 + 8030.13$

$0.877\ F_2 + 11003.789 = 0.906\ F_2 + 8030.13$

$-0.029\ F_2 = -\ 2973.66$

$F_2 = 102540\text{kg/h}$

$F_1 = 102540 + 12547.07$

$= 115087.07\text{kg/h}$

PASTEURIZER (P-101)

$F_3 = F_4 + F_5$

$F_3 = F_4 + 10806.1\text{kg/h}$

H_2O balance

$0.1685\ F_{14} + F_{15} = 0.23(5183)$

$0.1685\ F_{14} + F_{15} = 1192.09$

$0.1685\ F_{14} + 5183 – F_{14} = 1192.09$

$-0.8315F_{14} = - 3990.91$

$F_{14} = 4799.65$kg/h

$F_3 = 1740.98$kg/h + 10806.1kg/h

= 12547.07kg/h

CHURNER (C-101)

$F_8 = F_9 + F_{10}$

$F_8 = F_9 + 10060.05$

H_2O balance

$0.582\ F_8 = F_9 + 0.551(5543.07)$

$0.582\ F_8 = F_9 + 0.55(10060.05)$

$0.582\ F_8 = F_9 + 5543.1$

$0.582\ (F_9 + 10060.05) = F_9 + 5543.1$

$0.582F_9 + 5854.95= F_9 + 5543.1$

$-0.481\ F_9 =-311.85$

F_8 = 746.05kg/h +10060.05kg/h

= 10806.1kg/h

MEMBRANE FILTER (MF-101)

H_2O balance

$0.551\ F_{10} = 0.9\ F_{13} + 0.1685(4799.65)$

$0.551(F_{13} + 4799.65) = 0.9\ F_{13} + 808.74$

$0.551\ F_{13} + 2644.61 = 0.9\ F_{13} + 808.74$

$-0.349\ F_{13} = -1835.87$

$F_{13} = 5260.4 kg/h$

$F_{10} = 5260.4 kg/h + 4799.65 kg/h$

$= 10060.05 kg/h$

MIXER (M-101)

$F_{14} + F_{15} = F_{16}$

$F_{14} + F_{15} = 5183$

$F_{15} = 5183 – F_{14}$

$F_{15} = 5183 – 4799.65$

$= 383.35 kg/h$

H_2O balance

$0.1685\ F_{14} + F_{15} = 0.23(5183)$

$0.1685\ F_{14} + F_{15} = 1192.09$

$0.1685\ F_{14} + 5183 – F_{14} = 1192.09$

$-0.8315 F_{14} = - 3990.91$

$F_{14} = 4799.65 kg/h$

ENERGY BALANCE CALCULATION

ENERGY BALANCE AT PASTEURIZER

Protein = $H_{5p}F_{5p} + H_{4p}F_{4p} - H_{3p}F_{3p}$

= 158.5249 (106.43) – 6.75749 (106.43)

= 16871.81 – 719.2

= 16152.61 kJ/h

Fat = $H_{5F}F_{5F} + H_{4F}F_{4F} - H_{3F}F_{3F}$

= 135.834 (3810.42) – 5.98445 (3810.42)

= 517584.6 – 22803.27

= 494781.33 kJ/h

Lactose = $H_{5L}F_{5L} + H_{4L}F_{4L} - H_{3L}F_{3L}$

= 107.8852 (512.27) – 4.81126 (512.27)

= 55266.35 – 2464.66

= 52801.69 kJ/h

Water = $H_{5W}F_{5W} + H_{4W}F_{4W} - H_{3W}F_{3W}$

= 131.91 (6239.15) + 131.91 (1740.98) – 5.6109 (8030.13)

= 829601.78 + 229652.67 – 45056.26

= 1014198.19 kJ/h

Mineral = $H_{5M}F_{5M} + H_{4M}F_{4M} – H_{3M}F_{3M}$

=91.845 (87.83) – (3.985) (87.83)

= 8066.75 - 350 kJ/h

= 7.72 x 10^3 kJ/h

Total = $H_p + H_F + H_L + H_W + H_M$

= 16152.61 + 494781.33 + 52801.69 + 1014198.19 + 7.72 x10^3

= 1585653.82 kJ/h (endothermic, since it is +ve)

ENERGY BALANCE AT COOLER (CE-101)

Protein

$H_{6p}F_{6p} - H_{5p}F_{5p}$

$= 18.029(106.43) - 158.52(106.43)$

$= 1918.72 - 16871.28$

$= -14952.56$ kJ/h

Fat

$H_{6f}F_{6f} - H_{5f}F_{5f}$

$= 15.930(3810.42) - 135.834(3810.42)$

$= 60699.99 - 517584.59$

$= -456.88 \times 10^3$ kJ/h

Lactose

$H_{6l}F_{6l} - H_{5l}F_{5l}$

$= 0.012798(512.27) - 0.1079(512.27)$

$= 6.556 - 55.27$

$= -48.715$ kJ/h

Water

$H_{6w}F_{6w} - H_{5w}F_{5w}$

$= 14.994(6289.15) - 131.91(6289.15)$

$= 94299.52 - 829601.78$

$= -735302.26$ kJ/h

Mineral

$H_{6m}F_{6m} - H_{5m}F_{5m}$

$= 10.6196(87.83) - 91.845(87.83)$

$= 932.72 - 8066.75$

$= -7.134 \times 10^3$ kJ/h

Total$= -14952.56 + (-456.88 \times 10^3) + (-48.714) + (-735302.26) + (-7.134 \times 10^3)$

$= -1214317.53 \mathrm{kJ/h}$ (exothermic since it is negative)