Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

BE 487 - Spring 2022
Biosystems Design Projects

BE 487 – Whey Protein and Lactose Recovery

Peyton Carroll, Hannah Craig Malich, Stephanie Starr, Zach Tonnerre, & Sierra Veenkant
Client: Tillamook Faculty Advisor: Bahar Aliakbarian

Tillamook®

Under NDA

Background

The cheese making process is the transformation of raw milk into a solid cheese product. During this, solid curds move on to become cheese and liquid whey is drained as a by-product. Currently at Tillamook, the liquid whey is separated during curd formation, and it flows to large holding tanks before undergoing centrifugal clarification process.

There are two steps to centrifugal whey processing: clarification, followed by skimming. Both the clarifying separator and skimming separator work by spinning the whey at high speeds to allow the different components to separate and remove the undesired components, cheese fines and fat, respectively.

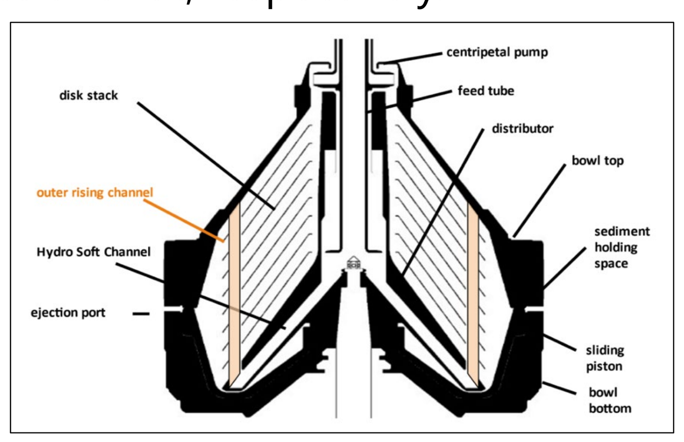

Figure 1: Cross section of the clarifying separator

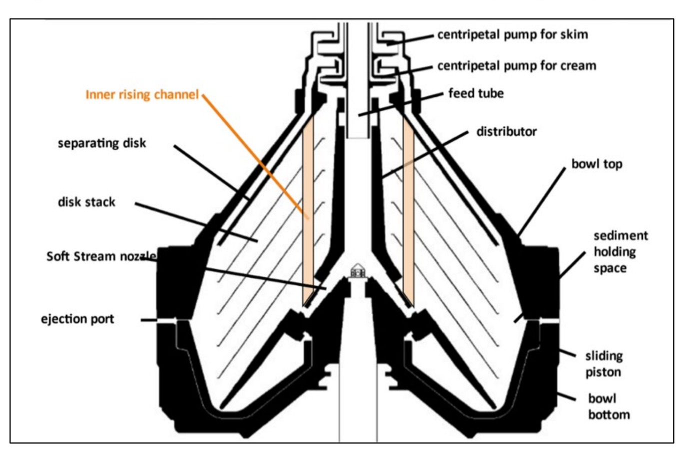

Figure 2: Cross section of the skimming separator

The problem statement is to optimize the centrifugal whey process to increase whey protein and lactose recovery from the liquid by-product of the cheese making process.

Objectives

The goal is to quantify whey and lactose proteins and minimize the protein loss to optimize Tillamook's unit operations of clarification and separation of the liquid whey by-product generated from the cheese manufacturing process. Project objectives are:

- Quantify whey protein and lactose of samples through laboratory analysis.
- Design a method for achieving minimum protein losses while keeping to industry standards and budget constraints.

Constraints

Design constraints are:

- Maximum cheese fine accumulation of 35 lb before discharge in the clarifying separator
- Modifications of operational parameters for clarifying separator and skimming separator are limited to discharge time.
- Meet Tillamook's budget of $1M.
- Meet BAE Department's senior design budget of $1,000.

Testing

Initial Testing Methods

- Lactose: Reversed-Phased High Performance Liquid Chromatography (RP-HPLC)
- Whey Protein : Bicinchoninic Acid (BCA) Protein Assay

Results

- Establishes baseline quantities
- Determined that the clarifier is the area of focus due to decrease in lactose and whey protein quantities post-clarification

Imhoff Cone Verification

- Used to measure the cheese fines ratio in the whey stream for Tier 1
- Showed decrease of cheese fine concentration after clarification
- Improvements verify the discharge interval matrix

Table 1: Testing results for quantities of lactose and whey protein present in liquid whey samples before any implementation. The Imhoff cone results for cheese fine concentrations at 6- and 8-minute discharge times.

Sample Location	AVG Lactose (mg)	AVG Whey Protein (g/L)	AVG fines @ 6-min discharge (%)	AVG fines @ 8-min discharge (%)
Pre-Clarify	254.10	9.66	0.26	0.22
Post-Clarify	242.56	9.49	0	0.004
Post-Skim	248.66	10.35		

Tier 1 – Discharge Matrix

Cheese Fine Accumulation ($\dot{m}$)

$$\dot{m} = Q * C$$

C = cheese fines (ml cheese fines/ml whey)

Q = flowrate (lb/hr)

Discharge Time (t)

$$t = \frac{0.75V}{(\dot{m})(Q)(\rho)}$$

V = maximum clarifying separator holding space (35 lb)

$\dot{m}$ = fines accumulation (%)

Q = flowrate (GPM → lb/min)

ρ = density of whey (8.68 lb/gal)

Table 2: Optimal discharge timing matrix

Flowrate (GPM)	Fines Load (%)														
	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8
154	19.7	13.1	9.8	7.9	6.6	5.6	4.9	4.4	3.9	3.6	3.3	3.0	2.8	2.6	2.5
157	19.2	12.8	9.6	7.7	6.4	5.5	4.8	4.3	3.8	3.5	3.2	3.0	2.7	2.6	2.4
161	18.8	12.5	9.4	7.5	6.3	5.4	4.7	4.2	3.8	3.4	3.1	2.9	2.7	2.5	2.3
165	18.3	12.2	9.2	7.3	6.1	5.2	4.6	4.1	3.7	3.3	3.1	2.8	2.6	2.4	2.3
169	17.9	11.9	8.9	7.2	6.0	5.1	4.5	4.0	3.6	3.3	3.0	2.8	2.6	2.4	2.2
173	17.5	11.7	8.8	7.0	5.8	5.0	4.4	3.9	3.5	3.2	2.9	2.7	2.5	2.3	2.2
177	17.1	11.4	8.6	6.8	5.7	4.9	4.3	3.8	3.4	3.1	2.9	2.6	2.4	2.3	2.1
180	16.8	11.2	8.4	6.7	5.6	4.8	4.2	3.7	3.4	3.0	2.8	2.6	2.4	2.2	2.1
184	16.4	10.9	8.2	6.6	5.5	4.7	4.1	3.6	3.3	3.0	2.7	2.5	2.3	2.2	2.1
188	16.1	10.7	8.0	6.4	5.4	4.6	4.0	3.6	3.2	2.9	2.7	2.5	2.3	2.1	2.0
192	15.8	10.5	7.9	6.3	5.3	4.5	3.9	3.5	3.2	2.9	2.6	2.4	2.3	2.1	2.0
196	15.4	10.3	7.7	6.2	5.1	4.4	3.9	3.4	3.1	2.8	2.6	2.4	2.2	2.1	1.9
200	15.1	10.1	7.6	6.1	5.0	4.3	3.8	3.4	3.0	2.8	2.5	2.3	2.2	2.0	1.9
204	14.9	9.9	7.4	5.9	5.0	4.2	3.7	3.3	3.0	2.7	2.5	2.3	2.1	2.0	1.9
207	14.6	9.7	7.3	5.8	4.9	4.2	3.6	3.2	2.9	2.7	2.4	2.2	2.1	1.9	1.8
211	14.3	9.5	7.2	5.7	4.8	4.1	3.6	3.2	2.9	2.6	2.4	2.2	2.0	1.9	1.8

(green) = Optimal discharge time; (yellow) = Under 4 mins (not recommended); (red) = Under 3 mins (not feasible)

Tier 2 – Automatic Turbidity Sensor

S40-3HY

Placed pre-Clarifying Separator to measure a higher concentration of suspended solids.

T30-3HY

Placed post-Clarifying Separator to ensure cheese fines are removed before future steps.

Installation

- MDX75 transmitter connects 3 sensors and automatically controls the clarifier's discharge via HMI or alarm activation.
- Install the sensors on vertical flow pipes and away from pumps to reduce bubbles that would affect the readings.
- Turn off the sensors during CIP to lengthen the lifespan; the CIP liquid is too hot for the sensors.

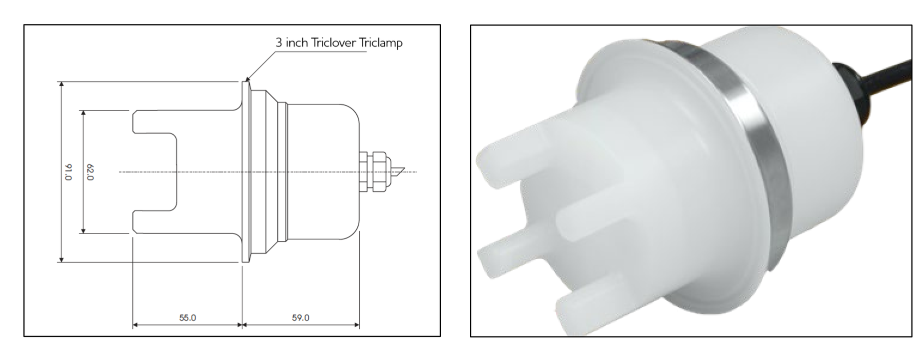

Figure 3a: S40-3HY schematic (left) and snapshot (right)

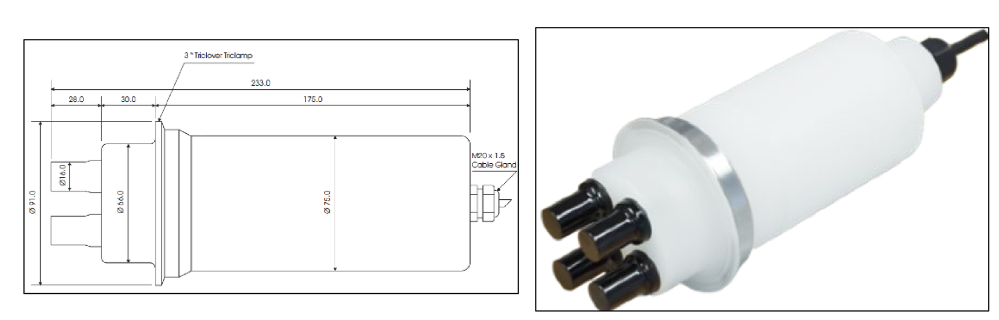

Figure 3b: T30-3HY schematic (left) and snapshot (right)

Tier 3 – Plant Retooling

Plant 1

- Plant 2's current clarifying and skimming separator are integrated into Plant 1's setup
  - Clarifying separators placed in parallel prioritizes longer discharge times
  - Clarifying separators placed in series prioritizes optimal cheese fine removal

Plant 2

- Purchase of larger clarifying and skimming separator for better capacity and performance

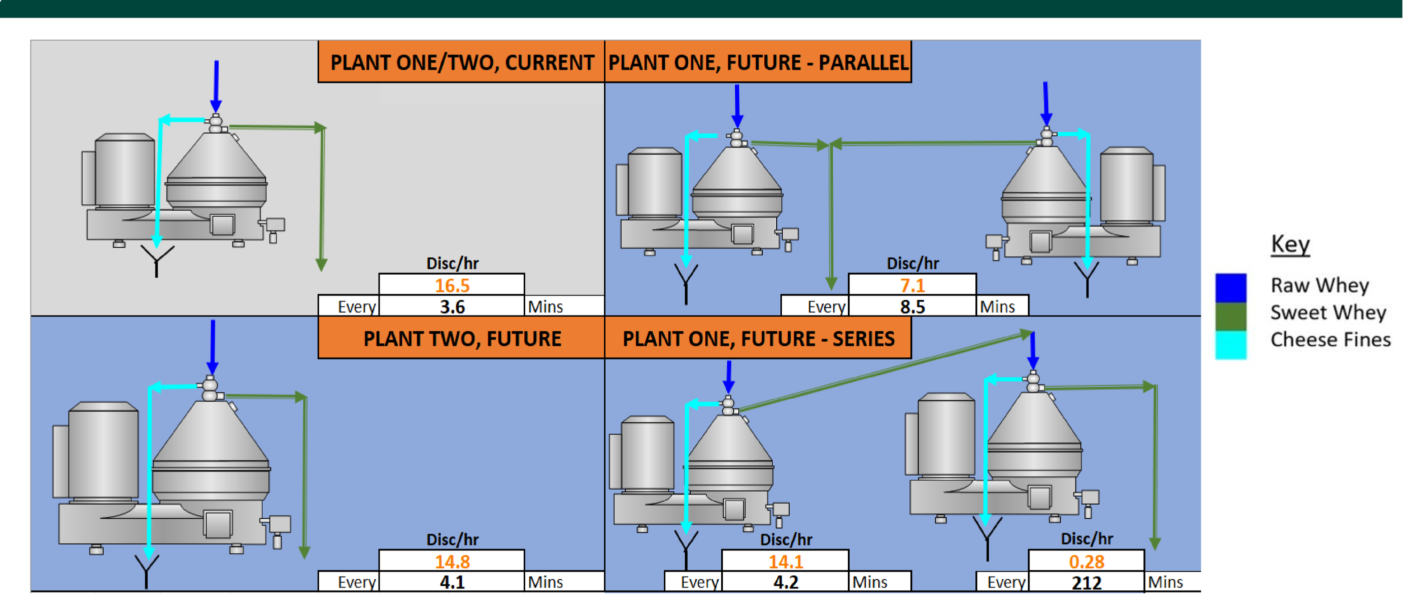

Figure 4: Current setup (top left) alongside plant one's (right) and two's (bottom left) future setup with corresponding discharge times

Cost Benefit Analysis

Cost Breakdown

Material	Cost (USD)
Tier 1	
Testing	$349
Tier 2	
S40-3HY Sensor	$2,252
T30-3HY Sensor	$2,865
MDX75 Transmitter	$3,300
Shipping	$180
Total	$8,597
Tier 3	
Centrifuge Equipment	$1,090,740
Sanitary Piping & Installation	$140,000
Foundation Drawings	$2,500
Instruments & Controls	$60,000
Programming/Integration	$30,000
Whey Balance Tanks	$80,000
Centrifuge Foundation	$85,000
Utility connections	$50,000
Electrical/Controls	$50,000
Floor Restoration	$7,500
Total	$1,595,740
30% Contingency	$478,722
Total	$2,074,462

Benefits

Tier 1: Improves operations by discharging at more accurate timing with no implementation cost to Tillamook.

Tier 2: Same as Tier 1 but additionally can account for variability in real time.

Tier 3: Would lead to 25% capacity increase solving a current problem with over capacity.

Payback Period

The increase in profit, given Tier 3, is estimated to be $23,849 per day, an increase of $5,962 per day.

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- Dr. Eric Hegg & Zhen Fang
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