RESEARCH ARTICLE

Evaluation of potential methods to minimize solid loss during the manufacture of coconut milk powder

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ABSTRACT

A coconut milk powder manufacturing plant encountered about 4.7% solid loss. This study was undertaken to identify measures to minimize this solid loss. Solid losses through different modes were quantified. Sample size for determination of total solid in coconut milk and conductivity cut-off point of the drain plate were optimized. Solid losses (kg run^{-1}) through the dryer (2,954.6±106.2), drain plate (2,575.1±734.1) and due to over estimation of total solid in coconut milk (394.7±69.1) accounted for 46.5, 40.5 and 6.2% of the total solid loss, respectively. About 63% reduction in solid loss through the drain plate was evident when the conductivity cut-off point reduced from 4 to 1 mS cm^{-1}. It was also revealed 92% reduction in over estimation of total solid when the sample size of coconut milk reduced from 2.0 to 1.5 g. In conclusion, sample size of 1.5 g for rapid total solid determination and 1 mS cm^{-1} conductivity cut-off point for the drain plate are recommended to minimize solid loss of this plant.

***Keywords**: Coconut milk, coconut milk powder, solid loss, conductivity cutoff point, drain plate*

INTRODUCTION

Coconut (*Cocos nucifera* L.) is an important commercial plant of palm family Arecaceae. Coconut milk is obtained by pressing grated mature coconut endosperm (kernel) with or without added water (Patil and Benjakul, 2018). It is mainly used as a culinary ingredient in traditional cuisines around the world. Coconut milk contains about 74-77% moisture, 19-21% fat and 2-3% protein (Nadeeshani, 2015). Coconut milk is basically an oil-in-water emulsion which is stabilized by natural emulsifiers such as globulins and albumins proteins and phospholipids (Onsaard *et al.*, 2005). Composition of coconut milk varies with the method of extraction and amount of water added during extraction (Nadeeshani, 2015). Rich nutrients contents and high water activity make coconut milk highly susceptible to deterioration due to microbial and enzymatic activities. Therefore, untreated coconut milk can be spoiled even under chilled storage. Further, preparation of coconut milk in day-today cooking is laborious. Various techniques such as canning, aseptic packaging, and sprays drying are used as means of preservation of coconut milk. Coconut milk powder is a fat–

filled product which contains more than 50% of fat (Seow and Gwee, 2003) and it can easily be packed and stored for relatively a longer period of time. Coconut milk powder manufacturing process involves two major steps; preparation of the emulsion and drying the emulsion (Fatimah *et al.*, 2017). Commercially, coconut milk with added additives is sprayed dried to a powder with about 2.5% (w/w) moisture (Abdullah *et al.*, 2020). Optimum inlet temperature and feed rate for spray drying of coconut milk were reported to be 180 °C and 0.9 L h^{-1}, respectively (Zafisah *et al.,* 2018).

Preparation of the emulsion is the key factor for the production of high-quality coconut milk powder. Too high water content in coconut milk might lead to increase the moisture content of the spray dried powder. Coconut milk dried without using drying agents will remain in a liquid state at room temperature due to high fat content (Fatimah *et al.*, 2017). Therefore, it is vital to add drying agents and emulsifiers to the emulsion prior to the spray drying process to have free flowing powder (Seow and Gwee, 2003). Additives such as maltodextrin, sodium caseinate and tri-sodium phosphate are used in manufacturing coconut milk powder (Santana *et al.*, 2017). These additives aid the spray drying process and help to convert a high fat material such as coconut milk into free flowing powder through encapsulation of the fatty substances (Lee *et al.*, 2018; Seow and Gwee, 2003). Sodium caseinate encapsulates small oil droplets which prevents them from lumping together, forming a powdery product (Vega and Roos, 2006). High-fat powders are inherently sticky which causes problems during drying and results drying losses (Paterson *et al.,* 2007). Maltodextrin is used to maintain the fat content and tri sodium phosphate is used to maintain the pH level of coconut milk powder. Amount of each additive to be added is decided based on total solid content (TS) of coconut milk. Total solid includes both the suspended solids and dissolved solids. There is no information available on solid loss of industry best coconut milk powder manufacturing plant which can serve as target. Nevertheless, ideally operated plant should convert maximum amount of solid used in the manufacturing process into final product without losing much.

Ranawaka *et al.* (2019) reported about 0.5% total solid loss in EGRON spray dried coconut milk powder manufacturing plant of Nestle Lanka PLC. Present study was carried out at the Niro-2 spray dried coconut milk powder manufacturing plant of Nestle Lanka PLC which is a fully automated plant. A production run of this plant consists of 4 d (96 h) and it uses about 252,000 kg of coconut milk (about 97,000 kg of coconut milk solid) per run. It has been observed that this plant lost about 4.7% of solid during its manufacturing process. Solid loss perceived in this plant was very high as compared to the industry norm of 1-2% in plants manufacturing similar type of products such as milk powder. Therefore, this study was conducted to quantify solid losses occurred in different modes and to optimize operating procedures so as to minimize total solid loss in this plant.

MATERIALS AND METHODS

Estimation of total solid (TS) loss of the factory

Amount of coconut milk (kg), Total solid content in percent (TS%) of coconut milk, additives and rework quantities (kg in dry weight basis) used and output (kg in dry weight basis) of a production run of the plant were recorded. Total solid loss (kg run^{-1}) was calculated using following equations. This study was repeated for three production runs.

$$\text{Total solid loss (kg run}^{-1}\text{)} = (WtRM - WtCMP) \qquad \text{Eq. 1}$$

WtRM – Weight of raw materials used per production run (kg in dry weight basis
WtCMP – Weight of coconut milk powder produced per a production run (kg in dry weight basis)

Identification of modes of solid losses and estimation of solid losses

Manufacturing process of the plant was divided into four sections; milk reception, liquid section, mixing section and drier section and modes of solid loss in each section were identified. In each section, solid losses occurred via identified modes were estimated in triplicates.

Milk reception section

Estimation of coconut milk solid loss due to over estimation

Over estimation of TS% will be reflected as a solid loss in the process. Therefore, correct estimation of TS% is very important. TS% of incoming coconut milk were checked by rapid method using a moisture analyzer (OHAUS, MB45). The sample quantity generally used for the analysis was about 2 g. It was observed that reading of the moisture analyzer varied with the sample quantity used. Solid loss due to over estimation of TS% was estimated in triplicate as explained below. TS% of a coconut milk sample was measured by drying 2.0 g of coconut milk at 103 °C to a constant weight (ISO 6731:2010). TS% of the same sample was measured by the moisture analyzer using 2.0 g of sample (rapid method).

Coconut milk solid loss (kg run^{-1}) due to over estimation of TS content was calculated using the following equation.

$$SL_{OE}\ (\text{kg run}^{-1}) = (TSRM – TSSM) \times AQM \qquad \text{Eq. 2}$$

SL_{OE} – Solid loss due to over estimation of TS%
TSRM – Total solid % (mass fraction) of coconut milk in bowser as determined by the rapid method.
TSSM – Total solid % (mass fraction) of coconut milk in bowser as determined by the standard method

AQM – Average quantity of coconut milk used per production run (251,907 kg)

Optimization of rapid total solid determination procedure

An experiment was conducted to determine the sample quantity to be used in determination of TS% by moisture analyzer. Total solid (%) of a coconut milk sample was measured by drying 2 g of coconut milk at 103 °C to a constant weight. TS% of the same coconut milk sample was measured by the moisture analyzer using different sample quantities (1.5, 1.6, 1.7, 1.8, 1.9 and 2.0 g).

Difference between the TS% of coconut milk measured by the rapid method and standard method at each sample quantity was calculated using the Equation 2. This experiment was conducted in triplicate. Data were subjected to analysis of variance and mean separation by Fisher pairwise comparison using Minitab software (Version 16).

Estimation of coconut milk solid loss through the drain plate during unloading to Coconut Milk Buffer Storage Tanks (CBST)

At initial and latter stages of unloading process coconut milk is drained out via drain plate due to their low TS contents. This is done based on conductivity measurement which is directly proportionate to the TS% of coconut milk. This plant maintained the cut-off point of the conductivity drain plate at 4 mS cm^{-1}.

Coconut milk drained out at initial and latter stages of unloading process were collected separately, their weights were recorded and their TS percentages were measured using the moisture analyzer. Coconut milk solid loss through drain plate (kg run^{-1}) was calculated using following equation.

$$SL_{DP}\left(\text{kg run}^{-1}\right) = \left(\frac{(W_3 \times TS_2)+(W_4 \times TS_3)}{(W_1\text{-}W_2) \times TS_1}\right) \text{x AQMS} \qquad \text{Eq. 3}$$

SL_{DP} – Solid loss through drain plate
W_1 – Weight of bowser with coconut milk (kg)
W_2 – Empty weight of the bowser (kg)
TS_1 – Total solid % (mass fraction) of coconut milk in bowser
W_3 – Weight of coconut milk drained at initial stage (kg)
TS_2 – Total solid% (mass fraction) of coconut milk drained at initial stage
W_4 – Weight of coconut milk drained at latter stage (kg)
TS_3 – Total solid% (mass fraction) of coconut milk drained at latter stage
AQMS – Average quantity of milk solid used per production run (97,085 kg)

Estimation of coconut milk solid loss due to milk remaining in bowsers after unloading

After unloading, coconut milk remaining inside the bowser was flush out with water and collected into a bucket of known weight. Weight of the bucket with flush out coconut milk was recorded. TS% of the flush out coconut milk was measured using the moisture analyzer. Solid loss due to milk remaining in bowsers (kg run^{-1}) was calculated using the following equation.

$$SL_{MRB}\left(\text{kg run}^{-1}\right) = \left(\frac{(W_3 \times TS_4)}{(W_1 - W_2) \times TS_1}\right) \text{x AQMS} \qquad \text{Eq. 4}$$

SL_{MRB} – Solid loss due to milk remaining in browser
W_1 – Weight of bowser with coconut milk (kg)
W_2 – Empty weight of the bowser (kg)
W_3 – Weight of flush out coconut milk (kg)
TS_1 – Total solid % (mass fraction) of coconut milk in bowser
TS_4 – Total solid% (mass fraction) of flush out coconut milk
AQMS – Average quantity of milk solid used per production run (97,085 kg)

Optimization of the cut-off point of the conductivity drain plate

It was identified that the highest milk solid loss occurred at the milk reception section through the drain plate. Solid loss through drain out depends on the conductivity cut-off point of the drain plate. Therefore, an experiment was conducted to identify the most suitable conductivity cut-off point. This experiment was laid in Complete Randomized Design (CRD) having 08 conductivity cut-off points (4, 3, 2, 1, 0.9, 0.8, 0.7 and 0.6 mS cm^{-1}) as treatment with four replicates.

Coconut milk drained out through the drain plates during unloading at different conductivity cut-off points were collected separately, their weights were recorded and their TS percentages were measured using the moisture analyzer. Coconut milk solid loss (kg run^{-1}) through drain plate at different conductivity cut-off points was calculated using the following equation.

$$\text{Solid loss}\left(\text{kg run}^{-1}\right) = \left(\frac{(W_3 \times TS_2)}{(W_1 - W_2) \times TS_1}\right) \text{x AQMS} \qquad \text{Eq. 5}$$

W_1 – Weight of bowser with coconut milk (kg)
W_2 – Empty weight of the bowser (kg)
W_3 – Weight of coconut milk drained out through the drain plate per bowser (kg)
TS_1 – Total solid % (mass fraction) of coconut milk in bowser
TS_2 – Total solid % (mass fraction) of coconut milk drained out through the drain plate
AQMS – Average quantity of milk solid used per production run (97,085 kg)

Data were subjected to analysis of variance and mean separation by Fisher pairwise comparisons using Minitab software (Version 16).

Usage of coconut milk with very low TS% will not be economically feasible because of higher energy requirement to recover unit weight of solid material.

Monetary gain that can be achieved by recovering coconut milk solid at different conductivity cut-off points compared to the current cut-off point of 4 mS cm^{-1} were calculated as explained below.

Energy requirement to evaporate water = [(100-15) x 4.2 + 2,264.7] x (100/80)
= 3,277.125 kJ kg^{-1}
Power requirement to evaporate water = (3,277.125)/3600 = 0.91 kWh kg^{-1}
Energy cost for evaporating water = 0.91 x 16.5 = Rs. 15.02 kg^{1}

Assumptions:

Temperature of coconut milk receiving to the factory is about 15 °C
Energy conversion efficiency is 80%
Average industrial rate of electricity is Rs. 16.5 kWh^{-1}

Total solid % of recovered coconut milk was calculated using the following equation.

$$TS_{RCM} = (TS_{pcp} - TS_{ccp})/2 \qquad \text{Eq. 6}$$

TS_{RCM} – TS% (mass fraction) of recovered coconut milk
TS_{pcp} – Total solid% (mass fraction) of drain out coconut milk at preceding cut-off point
TS_{ccp} – Total solid% (mass fraction) of drain out coconut milk at cut-off point concerned

Energy cost to recover unit weight of coconut milk solid was calculated using the following equation.

$$EC_{RCMS}\,(\text{Rs kg}^{-1}) = \left(\frac{(100 - TS_r)}{TS_r}\right) x15.02 \qquad \text{Eq. 7}$$

EC_{RCMS} – Energy cost to recover coconut milk solid (Rs kg^{-1})
TS_r – Total solid% (mass fraction) of recovered coconut milk

Coconut milk solid recovery at each conductivity cut-off point was calculated using the following equation.

$$\text{Coconut milk solid recovered (kg run}^{-1}) = (SL_{ic} - SL_{pc}) \qquad \text{Eq. 8}$$

SL_{ic} – Coconut milk solid loss (kg run^{-1}) at conductivity cut-off point of 4 mS cm^{-1}
SL_{pc} – Coconut milk solid loss (kg run^{-1}) at the conductivity cut-off point concerned

Energy cost needed to bear for recovering solid per one run at particular conductivity cut-off point was calculated using the following equation.

$$EC_{RCMS}\ (\text{Rs run}^{-1}) = (CMSR \times ECU) \qquad \text{Eq. 9}$$

EC_{RCMS} – Energy cost to recover coconut milk solid (Rs run^{-1})
CMSR – Coconut milk solid recovered (kg/run) at the conductivity cut-off point concerned
ECU – Energy cost (Rs.) required recovering 1 kg of coconut milk solid at the conductivity cut-off point concerned

Monetary value of coconut milk recovered per run was calculated by multiplying quantity of coconut milk solid recovered per run by buying price of coconut milk solid (Rs. 450 kg^{-1}).

Monetary savings (Rs run^{-1}) that can be achieved by recovering coconut milk solid at each conductivity cut-off point was calculated using the following equation.

$$\text{Monetary savings (Rs run}^{-1}) = (VCMS - ECR) \qquad \text{Eq. 10}$$

VCMS – Value of coconut milk solid recovered per run (Rs run^{-1})
ECR – Energy cost needed to bear for recovering coconut milk solid (Rs run^{-1})

Most suitable conductivity set points was decided based on the monetary savings that can be achieved by recovering coconut milk solid.

Liquid section

Estimation of coconut milk solid loss due to milk remaining in CBST after unloading for production

Agitator of the CBST mixes coconut milk intermittently until the milk is taken for production. After a certain level, final milk quantity cannot be taken out for the production because of solidification. This milk is taken out by flushing water. Solid loss due to coconut milk remaining in CBST was estimated as explained below.

Initial weight of the CBST with coconut milk was recorded and the TS% of coconut milk was measured using the moisture analyzer. At the latter stage of unloading, solidified coconut milk was taken out by water flushing. After that the weight of the CBST with remaining coconut milk was recorded and the TS% of the remaining coconut milk was measured using the moisture analyzer.

Solid loss due to the coconut milk remaining in CBST (kg run^{-1}) was calculated using the following equation.

$$SL_{MRCBST}(\text{kg run}^{-1}) = \left(\frac{(W_2\text{- } W_3)\times TSR}{(W_1\text{-}W_3)\times TSI}\right) \text{x AQMS} \qquad \text{Eq. 11}$$

SL_{MRCBST} – Solid loss due to milk remaining in CBST (kg run^{-1})
W_1 – Weight of the CBST with coconut milk before unloading (kg)
W_2 – Weight of the CBST with coconut milk remaining after water flushing (kg)
W_3 – Empty weight of the CBST (kg)
TSI = Initial total solid % (wt/wt) of coconut milk
TSR – Total solid % (wt/wt) of the coconut milk remaining after water flushing
AQMS – Average quantity of milk solid used per production run (97,085 kg)

Estimation of coconut milk solid loss during changing filters

During the production process, 'Scanima' filters changed in every 8 h and Plate Heat Exchanger cooler filter is changed in every 12 h. Milk removed during changing these filters were collected into trays separately and weighed using an electronic balance. Total solid percentage of the collected coconut milk samples were measured using the moisture analyzer. Solid losses during changing filters (kg run^{-1}) were calculated using following equations.

$$SL_{SFC}\ (\text{kg run}^{-1}) = W_{sf} \text{ x TS x NSF} \qquad \text{Eq. 12}$$

$$SL_{CFC}\ (\text{kg run}^{-1}) = W_{cf} \text{ x TS x NSF} \qquad \text{Eq. 13}$$

SL_{SFC} – Solid loss during 'Scanima' filter change (kg run^{-1})
SL_{CFC} – Solid loss during cooler filter change (kg run^{-1})
W_{sf} – Weight of coconut milk collected during 'Scanima' filter change (kg)
W_{cf} – Weight of coconut milk collected during cooler filter change (kg)
TS – Total solid % (mass fraction) of coconut milk
NSF – No of 'Scanima' filter changes per run (12)
NCF – No of cooler filter changes per run (08)

Mixing section

Estimation of additive materials remaining in bags

In this section, additives are added to the coconut milk and mixed before spray drying. Some amounts of additives remain in bags after delivering their contents. After discharging additives into mixing tanks, bags were collected and materials remained in bags were removed separately into containers and weighed using an electronic balance. Solid loss during mixing (kg run^{-1}) was calculated.

Estimation of coconut milk solid loss during feed tank change over

Feed tank is generally changed in every 24 h. Milk remaining in the feed tank was taken out and weighed by using an electronic balance. Total solid percentage of coconut milk was measured using the moisture analyzer. Solid loss during feed tank changeover (kg run^{-1}) was calculated using the following equation.

$$SL_{FTCO} \text{ (kg run}^{-1}) = W_1 \times TS \times NFTC \qquad \text{Eq. 14}$$

SL_{FTCO} – Solid loss during feed tank change over (kg run^{-1})
W_1 – Weight of mixture of material remaining in feed tanks (kg)
TS – Total solid % (mass fraction) of mixture material remaining in feed tank
NFTC – No of feed tank changes per run (04)

Dryer section

Estimation of coconut milk solid loss due to sampling

Coconut milk powder samples are taken for analysis of various quality parameters such as bulk density, moisture etc. Amounts of coconut milk powder taken daily as samples were recorded. Solid loss due to sampling (kg run^{-1}) was calculated.

Estimation of coconut milk solid loss due to spill out

Coconut milk powder spilled out in the dryer section was collected and weighed. Solid loss due to spilling out (kg production run^{-1}) was calculated.

Estimation of dryer losses

Practically it was difficult to estimate solid loss through dryer. Therefore, solid lost through dryer was estimated (kg/production run) using the following equation.

$$\text{Dryer loss (kg run}^{-1}) = TSL - SSLIM \qquad \text{Eq. 15}$$

where;

TSL – Total solid loss per production run (kg)
SSLIM – Sum of solid losses via identified modes per production run (kg)

RESULTS AND DISCUSSION

Total solid loss of the factory

This plant used about 134,357±1,122 kg of total solid and produced about 128,005±1,027 kg of coconut milk powder in average per production run (Table 1). The estimated average solid loss of this plant was about 6,352±95 kg run^{-1} and it was about 4.7% loss of the total solid used. Ranawaka *et al.* (2019) reported much lower total solid loss (0.5%) in the "EGRON" spray dried coconut milk powder manufacturing plant of Nestle Lanka PLC. Ranawaka *et al.* (2019) had estimated total solid loss by summing up estimated solid loss through identified modes but not based on actual mass balance of the factory. Further, in their study, failure to estimate solid losses due to over estimation of solid in coconut milk and solid losses through drain plate and dryer might have led to underestimation of total solid loss.

In this present study, total solid loss was estimated based on actual mass balance of three runs of the factory and solid losses through dryer, drain plates and due to over estimation of solid in coconut milk were identified as main solid loosing modes. Generally, solid loss of ideally operated plant manufacturing similar kind of products such as milk powder lies between 1-2%. Therefore, there is a potential to reduce solid loss of this plant to a greater extent.

Table 1: Mass balance of coconut milk powder manufacturing process.

Input/Output	Quantity of materials (kg run^{-1} in dry weight basis)			
Input	Run 36	Run 37	Run 38	Average
Coconut milk solid	97,754.0	97,720.0	95,780.0	97,084.7
Maltodextrin	21,185.5	21,181.2	21,191.8	21,186.2
Sodium caseinate	3,459.9	3,485.0	3,467.5	3,461.8
Trisodium phosphate	324.0	322.5	330.0	325.5
Rework	12,287.2	12,317.8	12,292.1	12,299.0
Total input	135,010.6	134,999.4	133,061.4	134,357.1
Output				
Coconut milk powder	120,254.0	120,229.3	118,684.3	119,722.5
Rework generation	8,354.8	8,357.8	8,135.4	8,282.6
Spill out (waste)	29.7	29.7	24.7	28.0
Total output	128,608.8	128,587.0	126,819.0	128,004.9
Loss quantity	6,401.8	6,412.4	6,242.4	6,352.2

Modes of solid loss

Over estimation of TS% at coconut milk reception can be reflected as solid loss. Coconut milk remaining in bowsers and tanks can contribute to solid loss in the process. Further, coconut milk solid loss occurred via conductivity drain plate during unloading coconut milk from bowsers to coconut milk buffer storage tanks (CBSTs). Filters (filters at 'Scanima' mixer and cooler) are required to change at regular intervals. It was observed that some amount of coconut milk lost during filter change causing solid loss. Solid remaining in bags after discharging their contents into the mixing tanks was found to be another form of solid loss. During drying, solid can be lost along with exhaust air. Solid losses were also perceived due to powder samples taken for various analyses and due to spillage of powder. Although, Ranawaka *et al.* (2019) also reported most of the above as possible solid loosing modes, they failed to identify the over estimation of solid in coconut milk and solid losses through drain plate and dryer exhaust as substantial modes of solid loss in coconut milk powder manufacture.

Milk reception section

Solid loss occurred in milk reception section (3,148.7 kg run^{-1}) accounted for 49.6% of total solid loss in the plant (Table 2). The main solid losing mode of this section was the solid loss via the conductivity drain plate. In a production run, about 2,575±734.1 kg of coconut milk solid lost through the conductivity drain plate and it accounted for about 40.5% of the total solid loss in the plant (Table 2) and to 82% solid loss in this section (Figure 1). At the initial stage of unloading, coconut milk with less TS% comes out due to layer separation. This stage is known as water to milk stage. Similarly, at the latter stage of unloading, TS% of coconut milk is low due to water flush. This stage is known as milk to water stage. During unloading process the conductivity of coconut milk is measured by an online conductivity meter. Conductivity of coconut milk is directly proportionate to its TS%. During unloading, coconut milk is directed either to storage tanks or drain out through drain plate based on conductivity measurement. This plant maintained conductivity cut-off point of the drain plate at 4 mS cm^{-1}. Therefore, solid loss through drain plate can be reduced by reducing the conductivity cut-off point of the drain plate.

Solid losses due to coconut milk solid remaining in bowsers (179.0±12.1 kg run^{1}) and incorrect determination of TS% (394.7±69.1 kg run^{-1}) accounted for 2.8% and 6.2% of the total solid loss of the plant, respectively. Ranawaka *et al.* (2019) reported that solid loss due to coconut milk solid remaining in bowsers was 0.17% of the total production quantity. This is about 33% of the total solid loss in the plant [(0.17/0.5)×100] and this reported higher contribution of bowser remaining to total solid of the plant might be resulted due to under estimation of total solid loss in their study.

Table 2: Solid loss in different sections via different modes.

Section	Mode of solid loss	Solid loss (kg run^{-1})	% of total solid loss
Milk reception	Solid remaining in bowser	179.00±12.10	2.82
	Incorrect determination of TS	394.70±69.10	6.21
	Through conductivity drain plate	2,575.10±734.1	40.54
	Subtotal – 1	3148.71	49.57
Liquid	Solid remaining in CBST	67.50±17.8	1.06
	Through filter changing	26.00±2.30	0.41
	Subtotal – 2	93.40	1.47
Mixing	Solid remaining in bags	31.20±0.60	0.49
	Solid remaining in feed tanks	64.90±2.30	1.02
	Subtotal – 3	96.10	1.50
Dryer	Sampling loss	31.30±3.10	0.49
	Spill out powder	28.00±2.90	0.44
	Dryer exhaust	2,954.60±106.20	46.51
	Subtotal – 4	3013.90	47.45
	Total loss	6,352.20±95.20	

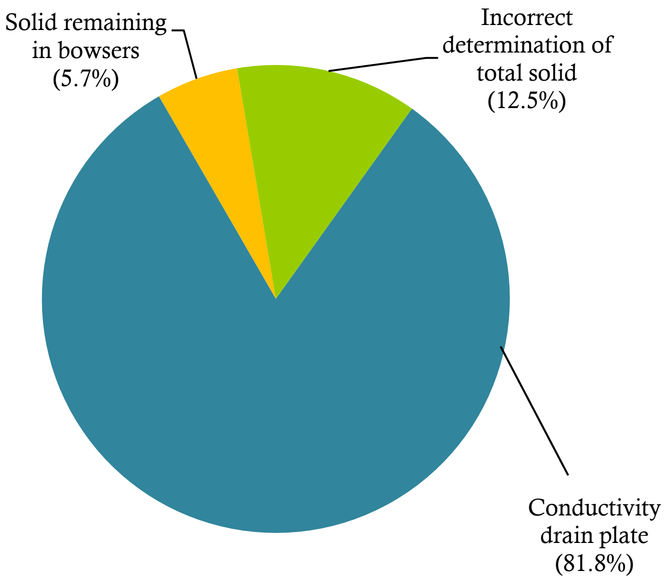

Figure 1: Contribution of solid loss from each mode to the total solid loss of the milk reception section in percent.

Optimization of rapid total solid determination procedure

A total solid content (% w/w) of the coconut milk supplied to the factory is measured using a Halogen moisture analyzer (MB 45). Suppliers are paid based on the TS% of the coconut milk they supplied. Over estimation of TS% will be reflected as a solid loss in the process. Generally, about 2 g of sample is used to determine the TS% by using moisture analyzer. As compared to the reference method, sample quantity used in rapid TS% determination affected on accuracy of the results (Table 3). Estimated solid loss due to over estimation of TS% at 2.0 g of sample quantity (394.7±69.1 kg run^{-1}) reduced to 31.5±22.3 kg run^{-1} at 1.5 g of sample quantity (Table 3). This is about 92% reduction of solid loss due to over estimation.

Table 3: Effects of sample quantity used in rapid total solid determination on solid loss. Figures are mean ± standard deviation (SD). Figures with different superscript letters differ significantly (P<0.05).

Sample quantity (g)	Estimated solid loss (kg/run) due to over estimation of TS %
2.0	394.7 ± 69.1^{a}
1.9	300.9 ± 67.2^{b}
1.8	229.7 ± 58.3^{c}
1.7	172.7 ± 31.0^{d}
1.6	90.0 ± 32.1^{e}
1.5	31.5 ± 22.3^{f}

Further reduction of sample quantity used in rapid TS% determination will also affect the accuracy and precision of the results. Therefore, it can be recommended to use 1.5 g of coconut milk sample in determination of TS% using moisture analyzer.

Optimization of cut-off point of the conductivity drain plate

Solid loss through drain out depends on the conductivity cut-off point of the drain plate. The estimated solid loss through the conductivity drain plate at 4 mS cm^{-1} cut-off point was 2,575±734 kg run^{-1} (Table 4).

Table 4: Estimated solid loss at different set points of the conductivity drain plate.

Sample quantity (g)	Solid loss (kg run^{-1})	Solid recovery (kg run^{-1})
4	2,575±734^{a}	0
3	1,824±128^{b}	751±128^{g}
2	1,280±65^{bc}	1,295±65^{f}
1	964±21^{cd}	1,611±21^{e}
0.9	758±44^{cd}	1,817±44^{d}
0.8	512±24de	2,064±24^{c}
0.7	354±15de	2,221±15^{b}
0.6	125±34^{e}	2,450±34^{a}

Figures are mean ± standard deviation (SD). Figures with different superscript letters differ significantly (P<0.05).

As per the results, solid loss through the conductivity drain plate can be reduced significantly (P<0.05) by changing its set point from 4 to 0.6 mS cm^{-1} (Table 4).

Table 5: Estimation of monetary benefits of recovering coconut milk solid at conductivity cut-off point below 4 mS cm^{-1}.

Conductivity cutoff point (mS cm^{-1})	Average TS% of drain out milk	TS% of recovered milk	Value of solid recovered per run (Rs.)	Energy cost for solid recovery (Rs kg^{-1})	Energy cost for recovery of solid per run (Rs.)
4	21.88				
3	15.49	18.69	338,102	65.4	49,111
2	10.88	13.19	582,706	98.9	128,062
1	8.19	9.54	724,939	142.5	229,572
0.9	6.44	7.32	817,643	190.3	345,793
0.8	4.35	5.40	928,622	263.4	543,524
0.7	3.01	3.68	999,341	393.1	873,051
0.6	1.07	2.04	1,102,374	721.3	1,766,872

Nevertheless, with the reduction of conductivity set point much diluted coconut milk will be directed to the storage tanks increasing the energy requirement to evaporate water in coconut milk. Monetary savings that can be obtained by recovering coconut milk solid at different conductivity cut-off points were calculated as explained above considering amount of coconut milk solid that can be recovered, value of recovered coconut milk solid and energy cost needed to bear for evaporation of water in coconut milk. Solid loss through conductivity drain plate at its cut-off point 4 mS cm^{-1} (2,575 kg run^{-1}) can be reduced by 63% by reducing its set point to 1 mS cm^{-1}. Further, the highest monetary savings (Rs. 495,367 run^{-1}) can be achieved by reducing the conductivity cut-off point to 1 mS cm^{-1} (Tables 4 and 5). Therefore, 1 mS cm^{-1} can be considered as the optimum set point for conductivity drain plate.

Liquid section

Solid loss occurred in liquid section (93.4 kg run^{-1}) accounted for 1.5% of total solid loss in the plant (Table 2). Solid remaining in CBST which accounted for 72% of the solid loss in liquid section was found to be the main mode of solid loss in this section (Figure 2). It is necessary to investigate possibility of reducing the coconut milk remaining in CBST after discharging to production.

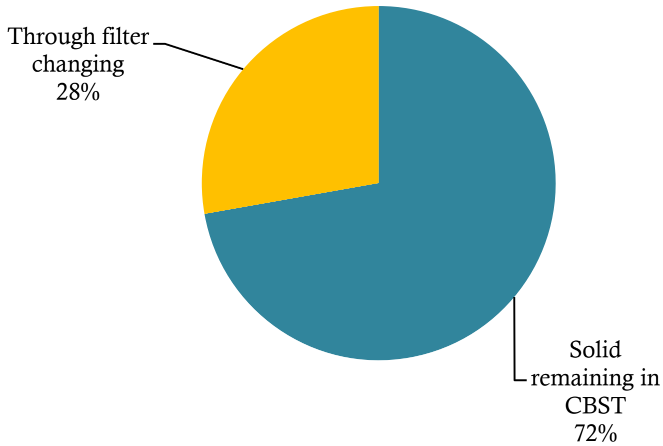

Figure 2: Contribution of solid loss from each mode to the total solid loss of the liquid section in percent.

Mixing section

Solid loss occurred in mixing section (96.1 kg run^{-1}) accounted for 1.5% of total solid loss in the plant. The main mode of solid loss in this section was found to be solid loss during feed tank change over (64.9±2.3 kg run^{-1}) and it accounted for 68% of the solid loss of this section (Figure 3). Solid remaining in bags (31.2±0.6 kg run^{-1}) contributed to 0.49% of total solid loss in plant and 32% of solid loss in this section. As reported by Ranawaka *et al.* (2019), solid loss due to solid remains in bags was 0.007% of the total production quantity. This is about 1.4% of the total solid loss in the plant [(0.007/0.5)×100] and this reported higher contribution of solid remaining in bags to total solid of the plant might be resulted due to the same reason of under estimation of total solid loss in their study.

Educating workers to unload additives completely into mixing tanks without leaving any materials inside the bags will be a promising strategy to minimize this solid loss.

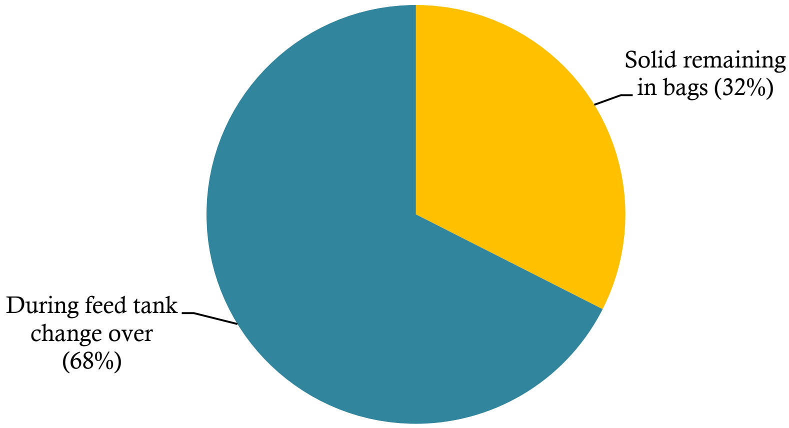

Figure 3: Contribution of solid loss from each mode to the total solid loss of the mixing section in percent.

Dryer section

Solid loss occurred in dryer section (3,013.9 kg run^{-1}) accounted for about 47.5% of total solid loss in the plant (Table 2). In dryer section, about 96% of solid lost through the dryer (Figure 4). Fine particles can be lost through the exhaust air of the dryer. It will be able to minimize this loss to a greater extent by installing a system to recover fine particles from exhaust air and reintroduce into the dryer. Standardizing sampling procedure will also contribute to reduce solid loss in this plant. Further, measures are needed to take to minimize powder spillage in dryer section. Solid loss due to sampling accounted for 0.49% of total solid of this plant. Contrarily, the previous study reported that solid loss due to sampling was 0.06% of the total production quantity (Ranawaka *et al.* 2019). This is about 12.7% of the total solid loss in that plant [(0.06/0.5)×100] and this reported higher contribution of sampling loss to total solid of the plant might be resulted due to the very same oversight evident in their study.

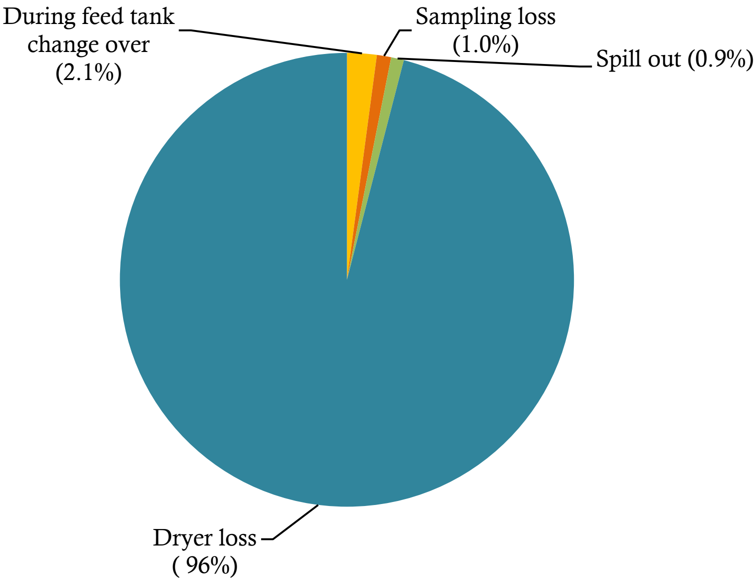

Figure 4: Contribution of solid loss from each mode to the total solid loss of the dryer section in percent.

CONCLUSION

Solid losses through the dryer and conductivity drain plate and solid loss due to over estimation of total solid percentage of incoming coconut milk are the three main modes of solid losing in this plant. Use of 1.5 g of coconut milk sample in rapid total solid determination and setting the conductivity cut-off point of the drain plate to 1 mS cm^{-1} will serve as optimum means of reducing current solid loss in this plant. Further studies are required to identify possible means of reducing solid loss through dryer during manufacturing coconut milk powder.

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