SYSTEMATIC EVALUATION AND ANALYSIS SYSTEM FOR YIELD CONTROL IN LARGE CHEESE FACTORIES

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by

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ABSTRACT

The objective of the first part of this work was to develop and test a method to evaluate cheese yield performance and identify sources of cheese yield loss, particularly fat losses, through the use of well-established cheese yield relationships in large cheese manufacturing factories and to determine the sensitivity of the outcome of the evaluation due to uncertainty in various input parameters. Uncertainty in the accuracy of cheese composition data was identified as a major a factor that limited the accuracy of manufacturing performance evaluation. It was observed that the mean bias error in near infrared cheese composition analysis was as high as ± 0.5% for fat and moisture in commercial cheese factories.

The second objective of our work was to develop and evaluate the performance of a rapid method for measuring fat, protein, moisture, and salt content of cheddar cheese using a combination mid-infrared transmittance (MIR) analysis and conductivity using a commercially available MIR milk analyzer. To achieve this, cheddar cheese was dispersed with a solution to dissolve the cheese and produce a liquid sample similar to milk. The MIR method produced more accurate results than the near-infrared (NIR) method validation study run with four cheese factories. Standard error of prediction (SEP) values for moisture and fat on the NIR were 0.30 and 0.45, respectively, whereas the MIR produced SEP values of 0.28 and 0.23 for moisture and fat, respectively. MIR also out-performed the coulometric method for salt determination with SEP values of 0.036 and 0.139, respectively. The MIR had an SEP value of 0.19 for estimation of protein which suggests that MIR could be an easy and effective way for cheese producers to measure protein to determine protein recovery in cheese making. It was determined that annatto colored cheddar cheese can be successfully analyzed in multiple cheese factories using a calibration set of cheeses produced from cheese made in one factory. Based on our findings, we believe that a centralized calibration set can be made and distributed to various cheese factories for calibration of MIR for cheese analysis and more accurate results can be obtained than with

locally calibrated NIR. More work is needed to determine if a separate calibration is required for colored and non-colored cheddar cheeses.

BIOGRAPHICAL SKETCH

Brenda Joy Margolies was born on June 29^{th}, 1994 in Belleville, New Jersey. She graduated from Wayne Valley High School in Wayne, NJ in 2012 and began her undergraduate studies at Cornell University. As an undergraduate Brenda studied Food Science and minored in Nutritional Science. During that time, she held research positions in a variety of areas, such as texture analysis of fish gelatin, examination of microbial communities in composted soil, and evaluation of structural changes to milk casein and whey proteins when subjected to high hydrostatic pressure.In addition to undergraduate research, Brenda served as the Head of Research and Development for Worthy Jerky, a food start-up on campus, from 2013 to 2015. During her time with the company, she led the scale up of an artificial preservative-free beef jerky from home recipe to commercial product sold in Cornell stores and local Ithaca eateries. The Company was awarded the title of "Student Business of the Year"and received a $5,000 prize in the spring of 2014 for their efforts.

Brenda's ambition led to the successful completion of her undergraduate degree in just three years. She graduated with Cum Laude distinction and was also awarded the Unilever Undergraduate Award for excellence in new product development in the spring of 2015. Her passion for product development led her to pursue two internships with PepsiCo at their beverage headquarters in Valhalla, NY during the summers of 2014 and 2015.

As she began her graduate degree, Brenda became involved in theIFTSA &MARSproduct development competition and was a member of the Cornell team that earned honorable mention at the IFT16 annual meeting. Subsequently, Brenda was appointed to the IFTSA Board of Directors as VP of IFT Relations. At the conclusion of her studies, Brenda was awarded the Western New York IFT Scholarship for her excellence in Food Science. Upon graduation, Brenda will begin a full-time position as a Research& Development Scientist with PepsiCo in Valhalla, NY.

I dedicate this work to my parents, Beverly and Mitchell, and my brother, Robert. Without whom, I would not be here today.

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LIST OF ABBREVIATIONS

AOAC…………………………………………………. Association of Official Analytical Chemists

ATR…………………………………………………………..………Attenuated total reflectance

CN%TP……………………………………………...……………Casein as a percent of true protein

CPRF……………………………………………………….……Calcium phosphate retention factor

DMC………………………………………………………….…………Draining-matting conveyors

FDB…………………………………………………………...………………………Fat dry basis

FFA……………………………………………………………………………………Free fatty acids

FTIR………………………………...………………………Fourier transform infrared spectroscopy

GMP……………………………………...………………………………Glycomacropeptide

HTST………………………………………………………………………High temperature short time

LFT……………………………………………………………..………………………Legal for trade

LVDT……………………………………………………… Linear variable differential transformers

MD………………………………………………………………...………………Mean difference

MFFC…………………………………………...…...………………Moisture in fat-free cheese

MFGM………………………………………………………...…………Milk fat globule membrane

MIR……………………………………………………………………...…………Mid-infrared

MNFS…………………………………………………………Moisture in the non-fatty substance

NIR………………………………………………………………………...………Near-infrared

NIST……………………………………….…………National institute of standards and technology

NMR……………………………………………………………………Nuclear magnetic resonance

NTEP………………………………………………………………National type evaluation program

PLS…………………………………………………………………….……………Partial least squares

QC……………………………………………………………….…….……………………Quality control

RSD_r…………………………………...…………………….Relative standard deviations of repeatability

SCC……………………………………………………………….……………Somatic cell count

SDD……………………………………………………..…………Standard deviation of the difference

SECV………………………………………………………………Standard error of cross validation

SEF……………………………………………………………………………Solute exclusion factor

SEP……………………………………………………………………Standard error of prediction

SMEDP……………………………………………Standard methods for the evaluation of dairy products

SNF……………………………………………………...……………………………………Solids not fat

S_r……………………………………………………………………….Repeatability standard deviation

TP…………………………………………………...……………………………………… True protein

UF…………………………………………..………………………………………………Ultra-Filtration

CHAPTER ONE

FACTORS INFLUENCING THE MEASUREMENT OF CHEESE YIELD AND QUALITY

MILK QUALITY FACTORS INFLUENCING CHEESE YIELD

Fat and Protein/Casein Content

The amount of fat and protein in whole milk will vary over the course of a year due type of feed, lactation, environment, milking practices, cow breed, age, and health. Schutz et al. (1990) found that fat and protein percentages were reduced with increasing parity. Additionally, seasonal variation of fat and protein has been noted by numerous studies. Bruhn and Franke (1976) found that fat and protein concentration for all herds were lower from May through August and higher from November through February than other months ($p<0.05$). Similar results for seasonal variation in fat, protein, casein and other milk chemistry parameters in different regions of New York State were reported by Herrington et al. (1972). By evaluating milk composition in Canada overtime, Phelan (1981) found that seasonal variation in milk protein can have a significant impact on potential cheese yield. It was observed that there was a decrease in the percentage of fat recovered in June and July and a decrease in casein/fat ratio in July and August. Phelan recommends milk standardization in order to overcome these variations (1981). Barbano (1990) reported that average fat content of milk occurred in the Southern region and the highest was in the West and upper Midwest regions of the U.S. in 1984. For protein, it was found that the Northeast had the lowest crude protein. However, in all regions it was found that the fat and protein were lowest in June, July, and August (Barbano, 1990). Similarly, in a study by Heck et al. (2009), it was found that protein content of milk was lowest in June and highest in December and fat content was lowest in in June and highest in January. The reason for this seasonal variation has been believed to be due to differences in feed (Chapman and Burnett, 1972) or heat stress (Bernabucci et al., 2002). Having a constant casein to fat ratio prior to cheese making helps to control cheese composition (i.e., fat on a dry basis and moisture).

Raw Milk Psychrotrophic Bacteria Count

Cheese yield is affected by initial psychotropic populations and length of time that raw milk is stored. Hicks et al. (1986) found that losses were significant if aerobic counts exceed 10^6 cfu/ml. Yield of direct-acid cheese manufactured from inoculated milk decreased as psychotrophic inoculation level increased (Hicks et al., 1982). Yield reduction resulted from lipid and protein degradation and accounted for 45 and 55% of the dry matter loss, respectively. Breakdown products were soluble in whey (Hicks et al., 1982). Psychotrophic bacteria are particularly problematic because their extracellular lipases remain active even after pasteurization has occurred. Law et al. (1976) found that some strains of psychotrophic bacteria retained 20-25% of their lipase activity even after being treated at 100°C for 10 minutes. In a study by Cousin and Marth (1976), psychotrophic counts in raw and pasteurized milks increased from an average of 10^5 to 10^8 CFU/ml after storage for 8 days at 7°C. Further, it was found that raw milks inoculated with *Lactobacillusspp*. and *Pseudomonasspp*. were coagulated more slowly by rennet than un-inoculated raw milk and the time needed for all milks to coagulate steadily decreased over the 8-day incubation period (Cousin and Marth, 1976).

Mastitis and Milk Somatic Cell Count

The concentration of somatic cells, also known as somatic cell count (**SCC**), in milk increases when a cow has mastitis. Somatic cells activate the proteolytic enzyme plasmin, which breaks down casein, thus reducing cheese yield (Barbano, 2000). Casein and fat are lost to the whey when SSC is high (Barbano, 2000). Barbano et al. (1991) found that SCC greater than 100,000 cells/ml will have negative impacts on cheese yield efficiency. Additionally, Politis and Ng-Kwai-Hang (1988b) found that milks containing 200,000 to 900,000 SCC/ml had a moisture adjusted cheese yield of 0.44 to 0.60% lower than milk with <100,000 SCC/ml. It was also found that high milk SCC caused increased protein loss into cheese whey (Politis and Ng-Kwai-Hang, 1988a), increased moisture content (Munro et al., 1984; Politis and Ng-Kwai-Hang, 1988a), increased quality defects in cheddar cheese (Munro et al., 1984), increased rennet coagulation time and slower rate of curd firming (Politis and Ng-Kwai-Hang, 1988c).

Physical Damage to Milk Fat and Casein

Mechanical abuse of milk can cause damage to the milk fat globule membrane (**MFGM**). Once damaged, free fat may leach out and become susceptible to lipase attack (Deeth and Fitz-Gerald, 1978). Shearing of milk fat globules can occur during every pumping. In a study by Escobar and Bradley (1990), it was found that a higher concentration of free fatty acids (**FFA**)was present in milk that went through a 3500 rpm rotor pump when compared with milk run through a 1750 rpm rotor. The higher FFA concentration led to rancidity after storage, and was due to inclusion of air into the milk which disrupted the fat globule membrane (Escobar and Bradley, 1990). Further, agitation of milk at low temperatures (below 10^{o}C) and warmer temperatures (above 37^{o}C) can lead to increased lipase activity and FFA (Deeth and Fitzgerald, 1977).

INFLEUNCE OF STEPS IN CHEESE MAKING ON CHEESE YIELD

Pasteurization

Heat treatment of milk adversely affects rennet's ability to coagulate milk (Kannan and Jenness, 1960). It is believed that the retardation of the enzymatic reaction in heated milk is related to the denaturation of β-lactoglobulin and its interaction with κ-casein (van Hooydonk et al., 1986; Singh and Waungana, 2001). Van Hooydonk et al. (1986) found that complete denaturation of β-lactoglobulin caused a reduction of 20% in the rate of κ-casein conversion. During heat treatment, denatured whey proteins adhere to the surface of the casein micelles, which impairs both the primary and secondary phases of the rennet coagulation process. Lowering of pH during milk heating was found to be effective at improving the renneting properties of the milk (van Hooydonk, 1986). Although heating milk is associated with long coagulation times and weak curd structure, it can also lead to higher yield in cheese due to incorporation of the denatured why proteins (Singh and Waungana, 2001).

Milk Ripening

Coagulant Type, Temperature, and Coagulant Handling

The coagulation process of milk by rennet consists of two parts: the enzymatic phase, and the non-enzymatic phase (Fox et al., 2017, Chapter 7: Enzymatic Coagulation of Milk). The enzymatic phase involves the hydrolysis of the micelle-stabilizing protein, κ-casein, while the non-enzymatic phase involves the ionic calcium dependent aggregation and gelation of the rennet-altered micelles. During renneting, κ-casein is cleaved to become para-k-casein, which remains attached to the micelle, and glycomacropeptide (**GMP**) which is lost to the surrounding aqueous phase. pH, ionic strength, and temperature have a strong influence on the hydrolysis of κ-casein by rennet (Fox, 1969; Michelson and Ernstrom, 1967).

It is recommended that the rennet be transported between -5 and 20^{o}C with a maximum transit time of 4 days outside this interval. Prolonged exposure to heat above 20^{o}C may influence the shelf life and activity of the enzyme (Chr Hansen, 2013). During use, the coagulant can be diluted prior to addition. Dilution water must have a pH< 6.4 and be free of chlorine (Chr Hansen). Water with a pH above 6.4 will contain minerals that will inhibit the efficacy of the enzyme. The activity of coagulants is dependent on pH. As such, the addition of calcium chloride to milk will increase the ionic calcium concentration which will enhance the secondary phase of non-enzymatic coagulation (Chr Hansen, 2013). When fortifying with nonfat milk solids, the addition of calcium chloride is unnecessary due to the high concentration of calcium being added from the fortification. However, when fortifying with milk protein concentrate, the addition of calcium chloride may be useful in keeping the ionic calcium to protein ratio constant. Sbodio et al. (1997) concluded that a decrease in pH between 6.8 and 5.6 and an increase in temperature between 30 and 40^{o}C led to increased curd firmness. It was found that with a microbial enzyme, temperature was the driving factor, whereas pH was paramount for bovine rennet.

The primary phase of rennet coagulation is dependent on temperature and pH. Nájera et al. (2003) found that rennet coagulation time was decreased with increasing temperature (between 26 and 46^{o}C). Further, it was found that the gel firming rate was increased with increasing temperature (Nájera et al., 2003). This is likely due to the increased enzyme activity at higher temperatures. As pH is increased, rennet coagulation time also increases (Nájera et al., 2003), which is due to the fact that rennet is an acid protease; thus, changes to the pH change the accessibility of the enzyme's active site.

After the hydrolysis of 85% of the κ-casein, the stability of the micelles is reduced so much that when the micelles collide, they remain in contact and ultimately form a coagulum or gel. Kowalchyk and Olson (1977) found that reducing the pH from 6.8 to 6.3 caused increased rate of coagulum firming; this is due to the fact that more calcium leaches out of the micelle at lower pH. Calvo et al. (1993) found that acidification bylactic acid or CO_2 addition reduced coagulation time by increasing calcium activity. However, the solubility of the calcium carbonate formed during CO_2 addition was not as soluble as the Ca^{2+} from milk acidified with lactic acid. Further, increasing temperature from 31 to 40^{o}C increased the firming rates even more drastically, which is a result of increased enzyme kinetics due to the warmer temperature. It is likely that lower pH reduces negative charge on casein micelles and reduces charge repulsion among casein micelles, thus increasing aggregation. The effect of temperature suggests that hydrophobic interactions also are strongly influential in micelle aggregation (Kowalchyk and Olson, 1977).

The set temperature of cheese primarily effects the secondary, non-enzymatic phase of coagulation. Temperature between 27 to 28°C allows the optimal growth of mesophilic starter bacteria. The cooler temperature also helps to improve the structure of the coagulum (Fox et al., 2017, Chapter 4: Post-Coagulation Treatment of the Renneted-Milk Gel). There are six rennet substitutes appropriate for cheese production: bovine, porcine, and chicken pepsins and the acid proteinases from *Rhizomucor miehei*, *R. pusillus*, and *Cryphonectria parasitica* (Fox et al., 2017, Chapter 7: Enzymatic Coagulation of Milk). Barbano and Rasmussen (1992) found that fermentation-produced chymosin had a higher cheese yield efficiency than proteases from *Mucor miehei*, *Mucor pusillus*, and bovine pepsin, and about the same yield efficiency as calf rennet. Reduced cheese yield efficiency is caused by losses of fat and protein in the whey and salt whey during cheese making (Barbano and Rasmussen, 1992). Barbano and Rasmussen (1992) found that fat losses in the whey during the earlier stages of cheese making were similar between *M. pusillaus* and *M. miehei*. However, fat loses in the salt whey were much higher for *M. pusillus*. Protein loses for both *M. pusillaus* and *M. miehei* were higher than the fat losses, and occurred primarily in the whey. The daily soluble protein loss in the whey for the two strains is more than twice the fat loss for fermentation-produced chymosin.

Mechanics of Cutting, Cooking, and Stirring

Rate of gelation and the firmness of the gel at cutting are affected by milk temperature, pH, time between the addition of the coagulant and cutting, rennet strength, amount of rennet added, and protein and calcium concentrations (Johnson, 2000). Cutting the coagulum when it is too soft or too firm will result in shattering the curd, and subsequent losses of protein and fat (Johnson, 2000). It is suggested that commercial cheese producers monitor the fat and fines in the whey at draining as a metric of assessing the level of firmness of the curd (Johnson, 2000) and as an index of yield loss.

The cutting of the curd allows moisture to exit the curd during the process of syneresis. The size of the cut curd affects the surface area of the curd, and thus how much moisture is able to exit. The cutting and stirring sequence determines the curd size and the fat and fines losses to whey (Johnston, 2000). Johnston et al. (1991) created a model to predict particle size, whey fat, and fine losses when using particular cutting and stirring options. It was found that short duration of cutting at slow speeds produced small curd particles and high fat losses into the whey. As duration and/or speed of cutting was increased, the average curd particle size increased while the fat losses into the whey decreased. Additionally, longer cutting times at low speeds gave curds more time to heal, thus reducing fat and protein losses. It was concluded that curd particle sized is determined by a combination of the speed and duration of cutting, as well as the subsequent speed of stirring prior to cooking (Johnson et al., 1991). Bynum and Olsen (1982) found that higher curd rigidity at cutting increased yield of cheese per unit of milk fat and increased retention of milk fat and casein. The stirring facilitates cooking, prevents curd pieces from matting, and promotes syneresis via collisions between curd pieces and between curd pieces and the vat wall (Fox et al., 2017, Chapter 8: Post-Coagulation Treatment of Renneted-Milk Gel). For cheddar, curds are held in the whey until pH of approximately 6.2 is achieved. Retention of fat during cheesemaking is a function of cutting time and temperature (Fagan et al., 2007). In New Zealand, milk for cheddar production is typically coagulated at 32^{o}C for 40 min. It was found that although cheese moisture increased with gelation time, cutting 10 min earlier or later than the optimum 40 min did not significantly increase fat loss or fines to the whey (Johnson, 2000). During cooking, moisture is lost from the curd due to the temperature difference between set and cook and the development of acid by the starters (Johnson, 2000). How much moisture is lost is dependent on curd particle size, the size of the temperature differential, the rate at which the final cook temperature is reached, the rate of acid development, and the time for which the curd is held at the final cook temperature (Johnson, 2000).

Fagan et al. (2007) suggested that between 28 and 35^{o}C is the ideal temperature range for the cut of the gel. Below this range, the gel is too fragile and results in high fat loss; above this range, the network becomes rigid, the gel has great porosity, and the fat is liquid, which also leads to higher loss of fat.

Yield Losses During Cheddaring and Stirred Curd Processes

Cheddaring Process. After removal of the whey, the curds mat and form a continuous mass during the "cheddaring" process. Traditional cheddaring process involves piling blocks of curd on top of each other, with regular turning and stacking. Today, however, continuous draining – matting conveyors **(DMC)** are commonly used. (Fox et al., 2017, Chapter 3: Rennet-Coagulated Cheeses). Cheddaring subjects the curds to gentle pressure which assists in whey drainage and transforms the texture of the curds from soft to tough and pliable (Fox et al., 2017, Chapter 3: Rennet-Coagulated Cheeses). During cheddaring, temperature is maintained at about 38^{o}C and pH decreases from about 6.1 to 5.4, which allows colloidal calcium phosphate to be released from the casein matrix and become soluble in the aqueous phase of the cheese. If the pH is allowed to decrease below 5.4, too much calcium phosphate will leach out with the whey instead of being in the water phase of the cheese. This decreases the buffering capacity of the cheese and produces an acidic taste. Further, without the buffering capacity of the calcium phosphate, it becomes very difficult to control final cheese pH. As the pH of the curd decreases and salt is added, the water holding capacity of the cheese decreases, thus making it difficult to control the final moisture of the cheese due to temperature dependent expulsion of moisture from the curd. Given these factors, it is paramount that the pH not drop below 5.4 before salting. Temperature is of utmost importance for milling and salting. If the temperature is too high going into the salting step, high fat and moisture losses will occur with the whey exiting from the curd.

Stirred Curd Process. The stirred curd method involves continuous stirring of curd after draw instead of packing, cheddaring, and milling (Barbano et al., 1994). For mozzarella, the stirred curd process is advantageous because it makes the cheese making operation more mechanized, simpler, and shorter (Nilson and LaClair, 1976). In one study, three different stirred curd techniques were studied: dry stirred, whey stirred, and water stirred. In dry stirred, the whey is drained after cooking, whereas in whey stirred, the whey is only partially drained. In water-stirred, the whey is drained and warm water (44^{o}C) is added. In all of the methods, after the whey draining or water adding step, the curd was continuously stirred to prevent matting (Nilson and LaClair, 1976). The dry-stirred curd cheese showed the lowest yield and moisture of the three methods. The whey-stirred curd had the most difficulty in controlling the pH, whereas the water-stirred method was the easier to control.

Yield Losses During Salting (Moisture, Fat, and Protein)

When the pH of the curd reaches 5.4, the curd is milled into small pieces and dry-salted. Salting enhances whey expulsion from the curd. Growth and acid production by starter bacteria is slowed down by salting, and the pH of the cheese will typically decrease only slightly (5.2 to 5.1) as a result of continued activity of lactic acid bacteria (Fox et al., 2017, Chapter 9: Salting of Cheese Curd). As salt is distributed over the surface of milled curd, some is dissolved into the curd causing shrinkage of the outer layer and expulsion of whey. The whey then dissolves the remaining salt crystals, which are then absorbed by the curd or disposed of with the whey (Sutherland, 1974). The rate of whey draining is a significant component influencing the amount of salt taken up by the curd. An increase in the amount of salt added will lead to greater temperature dependent whey explosion and ultimately, a lower cheese moisture and higher salt content (Sutherland, 1974). Variation in salt in the moisture of the cheese can lead to variation in the pH, which ultimately leads to acidic flavors. Curd temperature is another important factor during salting. An increase in curd temperature in the range 24 to 41^{o}C during dry salting will lead to a decrease in salt and salt-in-moisture due to greater whey expulsion and thus a larger loss of salt drained away by the whey (Sutherland, 1974). Higher temperature, specifically above 35^{o}C, also caused an increased fat loss (Sutherland, 1974). Sutherland (1974) found that stirring times greater than one minute caused a significant decline in the amount of salt lost. It was also found that an increase in the holding time can greatly improve the degree of salt absorption. Increasing the holding time from 20 to 30 minutes increased the salt in the moisture by 0.4%, which is useful in controlling maturity rate of the cheese and growth of undesirable organisms.

If moisture content of the cheese is on target but the salt content is too low, the cheese manufacturer can increase the stirring or holding times, lower curd temperature, lower curd moisture, or use shallower curd depths. Just increasing the amount of salt applied does not necessarily fix a low salt problem because adding more salt will lead to increased loss of moisture content (Sutherland, 1974).

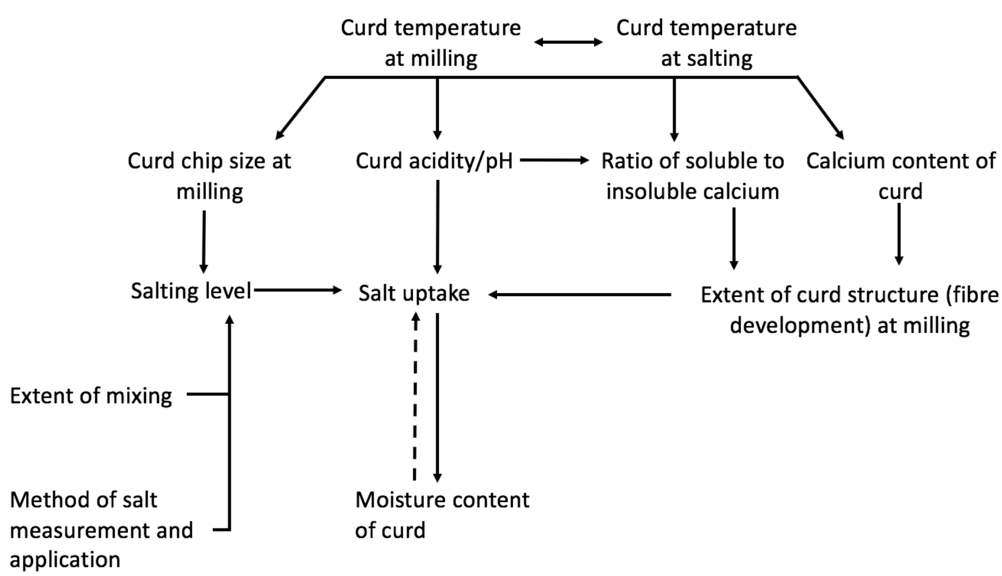

Figure 1.1. Principal factors that affect the uptake of salt by cheddar curd. Amended from Fig. 9.10 in Fox et al., 2017.

Post Salting Yield Losses

Cheddar – PressingBlock-forming towers are an integral part of many cheddar cheese manufacturing systems today. The design of a tower is a silo which can hold and drain the curd to allow acid development until milling acidity has been reached (Robertson and Bysouth, 1971). Below the upper section of the tower is a parallel-sided drainage ring which serves to confine whey and direct it to a drainage tube (Robertson and Bysouth, 1971).

Vedamuthu et al. (1969) explored post-hoop curd-handling procedures across several commercial cheddar cheese manufacturers. It was found that 227 kg barrel-type operations led to considerable variation in the length of the whey drainage period and the time needed for the packed curd to reach 4.4^{o}C in the curing room. Similarly, block-type operations (8.2 kg) saw variation in cooling rates in the curing room, which were influenced by the stacking of blocks. Of the factories observed, stacking occurred on pallets (6), on shelves (1), and chimney stacks (6). Of factories wrapping cheeses in boxes, wood (4), cardboard-veneer (4) and cardboard alone (5) were all used. However, greater control was found with the block-type operation due to the relative size (8.2 kg) and convenience of handling blocks compared to barrels (Vedamuthu et al., 1969).

In another study, Reinbold et al. (1992) explored how temperature, pH, and moisture profiles evolve in 290-kg stirred-curd cheddar blocks. It was found that temperature gradients from the interior to the exterior of the block developed with 24 hours. Initially, the blocks had an interior pH and moisture of 5.40 and 41% and the exterior was 5.25 and 39%, respectively. However, after 24 hours, the pH and moisture gradients were reversed, with the interior averaging 5.1 and 35% and the exterior average 5.2 and 38% for pH and moisture, respectively (Reinbold et al., 1992). It is likely that the moisture transferred from the interior to the exterior in response to the large temperature gradient of the block. The effect of temperature gradients during cooling of cheese on moisture migration was also demonstrated by Olabi et al. (2002). Moisture migrated from warm areas (center) to cold areas (external surfaces) of 290 kg blocks during cooling. Barbano (2001) reported systematic gradients of moisture of about 5% from the center to the outside surface of 290 kg cheddar blocks which produces a gradient of flavor and texture of cheese from the center to the surface (Carunchia Whetstine et al., 2007). Variables other than simple cooking may affect moisture distribution in cheese, therefore it is paramount that cheese manufacturers take care to ensure uniform whey drainage, pressure application, vacuum treatment, and cooling of all positions within blocks (Reinbold et al., 1992).

Mozzarella – Stretching and Brine SaltingFat losses during mozzarella production (i.e., pasta filata style cheese) are higher than those in cheddar and are largely due to the stretching step. Barbano et al. (1994) found that cheese yield efficiency increased with increasing stretching temperature and decreasing screw speed. Higher screw speed damaged the cheese curd in the screws before the curd temperature had increased sufficiently to allow the curd to soften and stretch under the shear force of the screws. High screw speed resulted in cheeses with lower moisture, lower fat dry basis (**FDB**), and higher protein content, thus impacting the functional properties of the cheese and yielding a firmer texture (Renda et al, 1997). Additionally, it was found that fat loss during stretching increased with decreasing mixer temperature (i.e., cheese temperature) and increasing screw speed. During stretching, casein micelles conjoin to become long strands of protein; the fat and whey become squeezed into long column-like structures as the protein fibers are compressed and elongated in the stretcher (Oberg et al., 1993). This process is highly dependent on the temperature during stretching, as that effects the fluidity of the fat to be forced out of the protein matrix and into the columns (Oberg et al., 1993). Dry salting prior to stretching causes whey expulsions from the surface of the curd particles and increased the density of protein matrix (Oberg et al., 1993). At low curd temperature the curd structure is harder and the mixer screws tear the curd causing fat loss into the stretching water thus increasing fat loss. At high curd temperature (i.e., 66^{o}C) the curd is softer and high screw speed promotes emulsification and better retention of fat in the cheese **(**Barbano et al., 1994)**.** In a research study, Rudan et al., (1999) reported total fat recoveries for a low moisture part skim Mozzarella between 84 and 85%.Generally, default targets for fat recovery in the cheese for pasta filata cheeses should be in the range of 85 to 90% depending on the stretching conditions and equipment used for stretching.

THE MASS BALANCE APPROACH TO CHEESE YIELD EVALUATION IN RESEARCH

Mass balance calculations can assist in monitoring the cheese manufacturing process in yield terms and isolating sources of milk constituent losses (Lawrence and Johnston, 1991). In a commercial setting, reliable flowmeters are integral in executing mass balance and accounting for all liquid inputs and outputs (Lawrence and Johnston, 1991), however proper calibration can be a challenge when measuring different liquids with different densities at different temperatures. In a commercial factory, the cheese would be measured by weight. In small scale research laboratories, weights of all inputs and outputs of the cheese making process are recorded to achieve total accountability for mass in and mass out of the process. Analysis of samples and effluents are a safeguard to ensure raw material is not being lost or unaccounted for (Lawrence and Johnston, 1991). The dutch system, which meticulously tracks the weight of milk used, whey produced, and curd washing water added, allows cheesemakers to estimate the water content of cheese. The data is input into a computer system containing formulae based on previously obtained commercial data to calculate the average water content of the cheese (Lolkema, 1991; Wilbrink, 1979). However, this system is less accurate in plants using mechanized equipment because of the continuity of the system that mixes curd from one vat with that of another (Lawrence and Johnston, 1991). Metzger et al. (2000) describes a mass balance system for mozzarella and Barbano and Rasmussen (1992) describes the mass balance system for cheddar. The three final products of cheese making, whey, salt whey, and cheese, are weighed to the nearest gram, the fat and protein content of each are determined, and the fat and protein recovered are expressed as a percentage of pasteurized or raw milk weight. The total accountability for fat and protein should not be significantly different than 100%. Lau et al. (1990) used this method and accounted for 98.75% of the fat and 100.37% of the protein in the original milk.

THE MASS BALANCE APPROACH TO CHEESE YIELD EVALUATION UNDER COMMERCIAL CONDITIONS

Milk Weight Measurement

Milk Plus Ingredient Weight. The weight of water (i.e., to dilute rennet, calcium chloride, and to flush lines for automated delivery of the ingredients directly to the vats) added per vat becomes important later in evaluation of cheese and whey plant performance because added water directly impacts the amount of energy used to concentrate and dry the whey. The amount of added water can be surprisingly large in some factories. Generally, in-line meters are used to measure the volume or weight of milk plus starter going into each vat. There are several types of meters that are currently used to measure milk weight and knowledge of the principle of operation and calibration of meters is useful to ensure accurate results. The two general types of meters are volume meters and mass flow meters.

Turbine Volume Flow Meters. Turbine flow meters use mechanical energy of the fluid to turn a rotor. The bladed rotor is designed to cut through the fluid with each revolution representing a calculable volume (Baker, 2000, Chapter 10). Rotor rotation is approximately proportional to volume flow in the pipe (White, 2011). Milk weight is calculated by multiplying the temperature corrected weight per volume of liquid by the total volume measured by the meter. Drag forces on the blade, hub, and faces of the rotor affect the otherwise exact relationship between fluid volume and rotor rotation and lead to nonlinearity (Baker, 2000, Chapter 10). Thus, the meter may react differently to highly concentrated versus dilute milk ingredients. Flat section blades are used in many turbine meters in order to cut smoothly through the flow in a perfect helix. Based on this, V_z, the axial velocity of the flow approaching the blades, can be calculated from the frequency of passing point f (Baker, 2000, Chapter 10).

$V_z = W/\tan\beta$, and $f = N\tan\beta V_z/2\pi r$ where f is the frequency of blade passing, W is the blade velocity, β is the blade angle, N is the number of blades, and r is the radius of the blades at the measurement point (Baker, 2000, Chapter 10). The above equations can be used to calculate $f = Kq_v$, where q_v is volume, which provides the basis for calculation of constant K, which is also known as the meter coefficient or calibration factor, and is measured in pulses per cubic meter.

It is suggested that the hub of the rotor have a radius of approximately half of the tip radius and the axial length of the blades should be approximately equal to the length of the blade from hub to tip. The turbine should be designed as to create as minimal a disturbance on the flow as possible. Flat blades will cause large flow disturbance so it is recommended to use helically twisted blades which have a smaller incidence angles, thus having less flow disturbance and drag (Baker, 2000, Chapter 10).

The correct volume to weight conversion factors need to be entered into the memory of the meter for the specific product being measured, or the weight delivered needs to be calculated outside the meter to convert volume to weight. If the cheese factory is making many different types of cheeses with and without added skim solids for fortification, this becomes a challenge for a meter where only one volume to weight conversion factor can be used in the meter calibration. In this case it may be better to report volume and convert to weight using the volume to milk weight conversion factors at different temperatures based on USDA weight volume conversion equations (USDA, 1965) in software outside the meter. Turbine meters provide precision, corrosion resistance, intrinsic safety, good temperature and pressure ratings, ease of installation, rapid response, and are accurate to ± 0.25% (Baker, 2000; White, 2011).

Magnetic Volume Flow Meters. Another common flowmeter is the magnetic flow meter, also technically an electromagnetic flow meter or more commonly just called a mag meter. Magnetic flowmeters measure the velocity of conductive liquids in pipes and report volumetric flow. Appropriate conversion of volume to weight needs to be done specifically for the temperature and density of the fluid being measured, as indicated above for turbine meters. A magnetic field is applied to the metering tube, which causes the induction of voltage across the conductor, resulting in a potential difference proportional to the flow velocity perpendicular to the flux lines (Baker, 2000). The operation of a magnetic flowmeter is based on Faraday's Law, which states that as voltage induced across a conductor moves across a magnetic field it is proportional to the velocity of the conductor, represented by the equation voltage = BlV, where B is the magnetic flux, l is the length of the field, and V is the velocity. (Baker, 2000, Chapter 12). Advantages of the magmeter are the linear response and the lack of the moving parts.

Mass Flow Meters. Unlike flow meters that measure volume, the Coriolis meter takes measurements that are directly proportional to the mass flow based on the principle of Coriolis acceleration (Baker, 2000, Chapter 17). The mass flow meter does not measure the volume per unit time (e.g., cubic meters per second) passing through the device; it measures the mass per unit time (e.g., kilograms per second) flowing through the device. Volumetric flow rate can be calculated by the mass flow rate divided by the fluid density at the temperature and composition of the fluid. In the Coriolis meter, the flow enters a double-loop, double-tube arrangement, which is electromagnetically vibrated ata high natural frequency, or harmonic of the natural frequency (Baker, 2000; White, 2011).

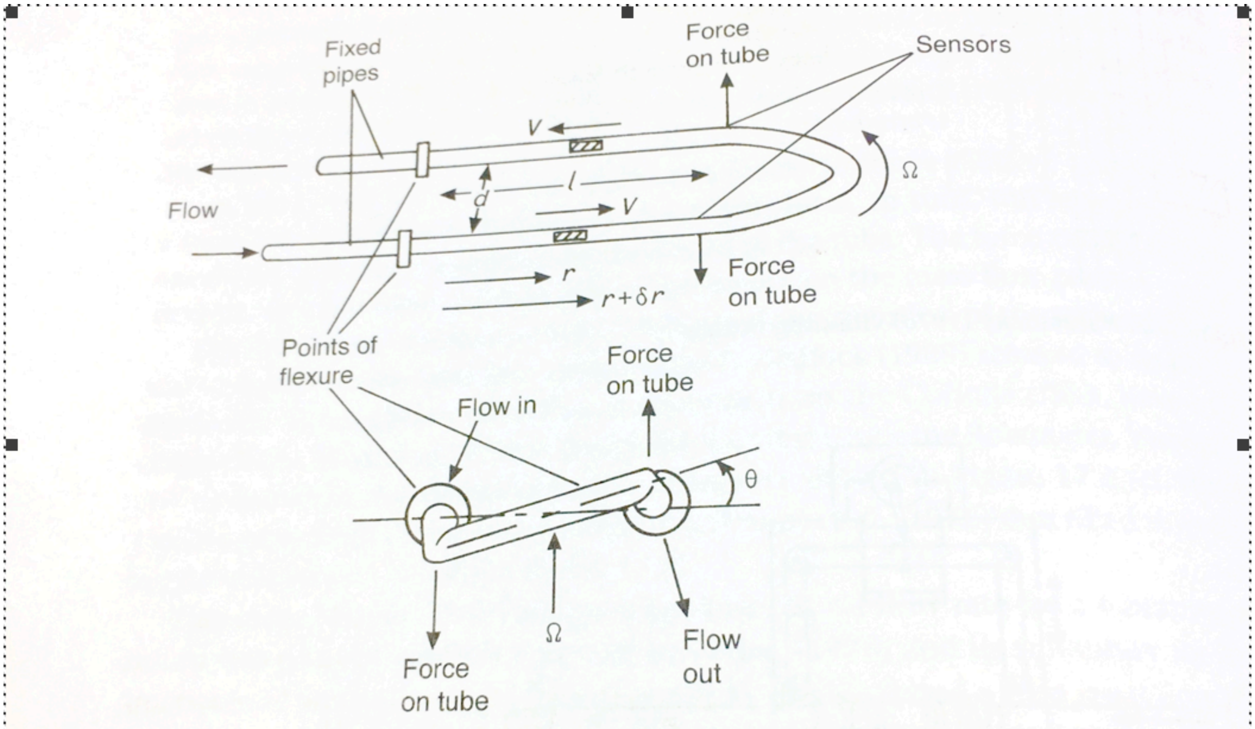

Figure 1.2. Diagram of the U-tube meter to show motion of the vibrating tube and consequent forces during the upward movement (reproduced from Baker, 2000, Chapter 17: Coriolis Flowmeters).

The opposite forces on the two sides of the tube result in the near side of the tube being forced down and far side is forced up when liquid flows through the tubes. The transit time of the two halves of the tube past the mid-plane are measured by sensors and the difference is related to the mass flow through the tube (Baker, 2000). One of the advantages of Coriolis meters is that they measure mass flow as opposed to volumetric flow. Additionally, they are compact, require little maintenance, have a sanitary design and have high accuracy (Baker, 2000).

Whey Weight Measurement

Under commercial conditions, measurement of whey weight is a challenge because the whey flow is intermittent, comes from multiple sources in the processing line, and is difficult to measure. When whey is collected in tanks it is fed into subsequent processing (i.e., fine saver, cream separator, pasteurizer, ultra-filtration (**UF**), evaporators) very quickly so there is no easy place to get a reliable measure. Thus the most simple, consistent, and probably the most accurate method of estimating whey weight is to subtract the total cheese weight from the total milk weight. While this may be a bit of an over estimation, it will be consistent across time within the same factory and will be based on two weight measures that are accessible and controlled. The accuracy of this method relies on the accuracy of the milk and cheese weight measurements.

Cheese Weight Measurement

In a commercial setting, cheese weigh is most frequently measured using load cells. Load cells turn sensed weight into an electrical signal to accurately produce measurements (Closs et al., 2013, Chapter 5: Load Cells). Load cells come in various different forms such as, Linear Variable Differential Transformers (**LVDT**), strain gauge, and vibrating wire. Vibrating wire is generally only used in small weigh feeders (e.g., in packaging retail size cheese pieces) because there are high costs associated with using it with belts scales. LVDTs read deflection from conveyor loading through the movement of a transformer core inside the core of a cylindrical transformer in order to provide frictionless mechanical to electrical transduction. The voltage of the secondary coils is outputted and is proportional to the movement of the core and measured in AC volts. The LVDT design requires a large amount of deflection in order to have a usable signal. Further, excess weigh idler movement reduces accuracy. In order to achieve suitable movement without excess deflection, the weighbridge design requires pivots, levers, and coil springs to stabilize the movement. These additional features slow the reaction time and therefore make the LVDT design less popular with belt scale suppliers (Closs et al., 2013, Chapter 5: Load Cells).

The strain gauge design is the most commonly used in commercial cheese plants. The strain gauge design is based on the principle of interconnected gauges placed at select locations on the load cell element, creating a resistive circuit. When there is no force on the element, the circuit provides a 0 mV reading. As tension or compression forces are administered to the element, the circuit reads the level of force in mV/V. An analog to digital converter can be mounted internally to the load cell to provide digital output calibrated and transformed into a weigh readout (Closs et al., 2013, Chapter 5: Load Cells).

The National Institute of Standards and Technology (**NIST**) classifies weighing applications into classes I, II, III, IIIL and IIII. Commercially used load cells are usually class III, while larger operations (such as to weigh livestock or vehicles) would fall into class IIIL (NIST Handbook 44, 2017). The classes can be further subdivided into Single or Multiple, which refers to whether there are one or several load cells in a system (VPG Transducers, 2015). The load cell error tolerance for Single is set at 0.7 times the scale divisions, while Multiple is set at 1.0 times the scale divisions (VPG Transducers, 2015).

The National Type Evaluation Program (**NTEP**) tests scales and load cells for compliance with the provisions of the NIST Handbook 44: Specification, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices. An NTEP certificate of Conformance is required for Legal for Trade (**LFT**) operations in most states in the U.S. (Scale Manufacturers Association, 2010). The performance characteristics of a load cell are assessed by parameters such as: non-linearity, hysteresis, non-repeatability, temperature effect on rated output, temperature effect on zero load output, and creep and minimum dead load output return. NTEP does not specify error limits for individual parameters. Instead, they use an “error envelope” or combined error concept to evaluate the total error of measurement while still achieving results (VPG Transducers, 2015).

Utilization of the measuring range will affect the load cell accuracy. Decreasing the measuring range can improve the linearity and hysteresis of the machine. As the working range of the scale nears the scale’s capacity, creep will also become more significant (VPG Transducers, 2015). Temperature effect on zero load output is a fixed error percentage of the load cell output at a certain utilization. Given these facts, it is suggested that the overall accuracy of a weighing system will improve when load cells are used over a small part of their measuring range, and further below their capacity (VPG Transducers, 2015).

Table S.6.
Parameters for Accuracy Classes

		Number of Divisions (n)	
Class	**Value of the Verification Division (e)**	**Minimum**	**Maximum**
	SI Units		
III	0.1 to 2 g, inclusive	100	10 000
	equal to or greater than 5 g	500	10 000
	U.S. Customary Units		
III	0.0002 lb to 0.005 lb, inclusive	100	10 000
	0.005 oz to 0.125 oz, inclusive	100	10 000
	equal to or greater than 0.01 lb	500	10 000
	equal to or greater than 0.25 oz	500	10 000
IIIS	greater than 0.01 lb	100	1 000
	greater than 0.25 oz	100	1 000

For Class III devices, the value of e is specified by the manufacturer as marked on the device; d shall not be smaller than 0.1 e. e shall be differentiated from d by size, shape, or color.

Figure 1.3. Parameters for accuracy classes (reproduced from NIST Handbook 44, 2017).

Chemical Methods for Milk, Whey, and Cheese Analysis

Milk. In a commercial setting milk fat and true protein (**TP**) values are typically data from a mid-infrared (**MIR**) milk analyzer. Because infrared analyzers are a secondary measurement, it is important to ensure that they are calibrated correctly, as explained by Barbano and Clark (1989). The accuracy of reference values used to calibrate is an important factor in determining the accuracy of analytical values produced by the instrument (Barbano and Lynch, 2006) as is the design of the calibration sample set (Kaylegian et al., 2006a, b). The analytical uncertainty of reference values using the Mojonnier ether extraction and Kjeldahl true protein methods was reported by Wojciechowski and Barbano (2016).

Whey. For analysis of whey at draining, the reference method is either the Babcock test (Hooi et al., 2004, method 15.083) or the Mojonnier test (Hooi et al., 2004, method 15.086). The key parameter that cheese makers are interested in measuring is usually the fat content of the whey from the vats and after the cream separator. From the time of cut to the time of whey draining, the concentration of fat in whey decreases. If everything is working properly in the cheese vat, most of the fat lost into whey occurs at the time of cut. As the cut surfaces of the curds heal, further loss of fat should be minimal. During the cooking, whey is being expelled from the curd and this expulsion of water from the curd decreases the concentration of fat in whey. Fat is generally retained in the curd unless the stirring in the vat is much too fast or if the rate of temperature increase during cooking was too fast. To obtain a representative sample that reflects the fat content of the total volume of whey at draining, the sample should be taken at time of whey draining, not before. For separated whey that should have a fat test less than 0.05% fat, cheese factories usually send out whey samples to an outside laboratory for Mojonnier ether extraction fat testing to get an accurate evaluation of their cream separator performance.

Cheese. For cheese analysis, moisture, protein, fat, acidity, and salt are typically measured according to standard methods published by the International Dairy Federation (Fox et al., 2017), methods from Standard Methods for Examination of Dairy Products (**SMEDP**), or the Association of Official Analytical Chemists (**AOAC**). For determination of moisture content of cheese, a vacuum oven or forced air over should be used (Hooi et al, 2004, method 15.111). Cheese samples should be blended to create small pieces before being placed in a pan to be heated. For the determination of protein/nitrogen content, the Kjeldahl method is used (Hooi et al., 2004, method 15.130). The principle is based on the digestion of a sample with a mixture of concentrated sulfuric acid and potassium sulfate, using copper (II) sulfate as a catalyst to convert organic nitrogen present to ammonium sulfate. Excess sodium hydroxide is added to the cooled digest to liberate ammonia. Ammonia is distilled into an excess of boric acid solution and titrated with hydrochloric acid solution and nitrogen is calculated from the amount of ammonia produced (Hooi et al., 2004, method 15.130).

The reference methods for fat determination in cheese are the Babcock and Mojonnier ether extraction methods. The Mojonnier method (Hooi et al., 2004, method 15.086) has been shown to be more precise than the Babcock and therefore is widely accepted as a more accurate method (Hooi et al., 2004, method 15.081), but ether extraction of cheese is not practical to be done in a cheese factory and the Babcock method is commonly used in factories as a reference method. For cheese analysis, the sample should be shredded using a grater or blended prior to testing. The principle of the Babcock method is that concentrated sulfuric acid is mixed with the sample to create an exothermic reaction that releases fat from the cheese structure (Barbano, et al., 1988; Hooi et al., 2004, method 15.083). The free fat is collected in the graduated portion of the neck of the Babcock flask. Additionally, the full digestion of the cheese may take longer to release the fat than the same method on a milk sample.

The principle of the gravimetric Mojonnier method is an extraction of fat from a sample using ethyl ether and petroleum ether (Barbano et al., 1988). The ether-fat mixture is decanted into dried weigh dishes and the ether is evaporated and the pans plus fat residues are dried (Hooi et al., 2004, method 15.086). The difference in the weight of the pan before extraction, and after evaporation is calculated to determine the fat content of the cheese. The cheese must be completely dissolved to achieve complete recovery of fat from the cheese. Various techniques are used to assist digestion, such as the addition of 60°C water, an increase in the amount of added ammonium hydroxide, and extended shaking times. It is suggested that the sample size not exceed 10 g and fat content be between 0.3 to 0.6 g per flask. It is important to note that if the cheese contains a stabilizer or emulsifier that is soluble in ether, the Mojonnier test may yield erroneous results.

Cheese salt can be determined used the Volhard method (AOAC, 2000, method number 935.43 or SMEDP 15.052) and this is considered the reference method. The principle of the Volhard method is that a sample is heated and digested with nitric acid and potassium permanganate in the presence of a known number of moles of silver nitrate. The added silver nitrate needs to be in excess of the amount of chloride in sample. The acid digestion allows the chloride in the sample to be freed and reacted with the silver to form AgCl. The remaining unreacted silver in the sample is then titrated with potassium thiocyanate with a ferric ammonium indicator to indicate when all of the free silver has become silver thiocyanate. This is a back titration that determines the amount of chloride in the sample based on how much silver remains during the titration versus the total amount of silver added.

Validation of Mass Balance for Fat and Protein

The mass balance approach to measuring cheese yield efficiency involves the measurement of the weights of all inputs (milk, starter, rennet, salt) and all of the outputs (cheese and whey) (Fox et al., 2017). The yield is then measured by the following equation:

Actual Yield = 100 x (weight of cheese / (weight of milk + starter + salt))

In controlled research studies at the pilot plant level, it is possible to do mass balance where all inputs (milk, starter, rennet, etc.) and outputs (whey, salt whey, fines, and cheese) are accurately weighed and representative samples of each are analyzed for fat and protein content. The first step in validation of mass balance cheese making system used in research is to determine if all of the fat and protein in the milk are accounted for in the whey, salt whey, fines, and cheese within the expected uncertainty of experimental error. Typically, if the accountability is not close to 100%, then there is a problem with representative sampling and accuracy of testing, or there has been an error in weight measurement. Before conducting a cheese research study to determine the effect of a specific treatment or ingredient on cheese yield, several control cheese batches should be run to ensure that accountability for fat and protein are near 100% (generally, between 99 and 101%). In evaluation of the results of cheese making experiment, the total accountability fat and protein amount among treatments should not be significantly different ($P > 0.05$), and should be near 100%. If this is not the case, then the data for fat recovery, protein recovery, and cheese yield efficiency need to normalized to 100% before comparing the effect of treatment. Examples of cheddar cheese (Barbano and Rasmussen, 1992) and mozzarella (Metzger et al., 2000) mass balance cheese yield studies are in the literature.

Mass balance is more difficult to achieve in commercial cheese making than it is in pilot scale operations. In commercial cheese making the multi-batch continuous process involves overlapping of curds from two of more vat making it impossible to accurately weigh all of the materials in each batch. Industrial level mass balance tends to be performed on a day's production. Quantities of milk, starter, and whey are usually measured using in-line flow meters (Fox et al., 2017).

Most factories calculate fat recovery in the cheese as the weight of the cheese multiplied by its percentage of fat content and then divided by the total weight of fat present in the original milk and multiplied by 100 (Lau et al., 1990). Systematic cheese sampling errors and laboratory testing bias can cause estimated fat recovered in cheese in a factory to be higher or lower than predicted target fat recovery in theoretical cheese yield formulae. If fat lost in the whey from the vats and fat lost in the whey from cheddaring, salting, and pressing is not accounted for then it is difficult to know if there is a systematic bias in the estimation of recovery in the cheese. If total mass balance data was available, then the error would be detected by comparing the total amount of fat into the cheese making versus the total amount of fat out of the complete process. A systematic cheese sampling error or systematic bias in the measurement of fat content of cheese could cause errors in the estimates of fat recovery which can go undetected.   To minimize the risk of these errors, participation of the factory's laboratory in proficiency testing for reference methods of cheese analysis and periodic in-house tests for duplicate sampling and testing of the same vats is needed. Development of a statistically based cheese sampling plan that incorporates knowledge of the systematic variation in cheese composition within vat and within blocks within each factory is recommended (Barbano, 2000; Kindstedt et al., 2001).

There are approaches that can be used in a commercial cheese factory to estimate the total fat accountability for a day.   The total fat in the milk used for the day can be estimated from the fat test in milk and milk weight. The weight of fat in cheese can be calculated as the cheese weight for the day multiplied by fat content of the cheese. The maximum total weight of whey at draining can be estimated as the weight of milk minus the weight of cheese. The maximum total weight of whey for the day multiplied by the fat concentration of the whey at draining estimates the total weight of fat lost in whey. The sum of the estimates of fat in the cheese and the fat in the whey should not be higher than 100%, if is, then there is major problem in the fat testing in the milk, cheese or whey or the weight of milk or cheese. The sum of fat recovered in the cheese plus whey at draining for Cheddar should be between 97 and 98% of total fat if the complete cheese making process is going to achieve a 93% fat recovery in the cheese. A similar approach could be used for protein, but cheese makers generally do not have analytical data for the protein content of the cheese.

PREDICTION OF THEORETICAL CHEESE YIELD

Important Parameters in Theoretical Yield Equations

Cheese is considered as a three-phase system of fat, para-casein, and water and water solubles (Emmons et al., 1990). The moisture, fat, and casein are the primary components of the cheese, and therefore the most important components of the theoretical yield equations. The percentages of casein and fat in the milk are also important, as they reflect the total casein and fat that can be recovered into the cheese.

Several smaller cheese components, such as salt, calcium phosphate, whey, and citrate, can have a sizable impact on the yield of cheese (Emmons, 1991). The amounts of these parameters may vary, therefore it is important that yield equations consider them and be adjusted accordingly.

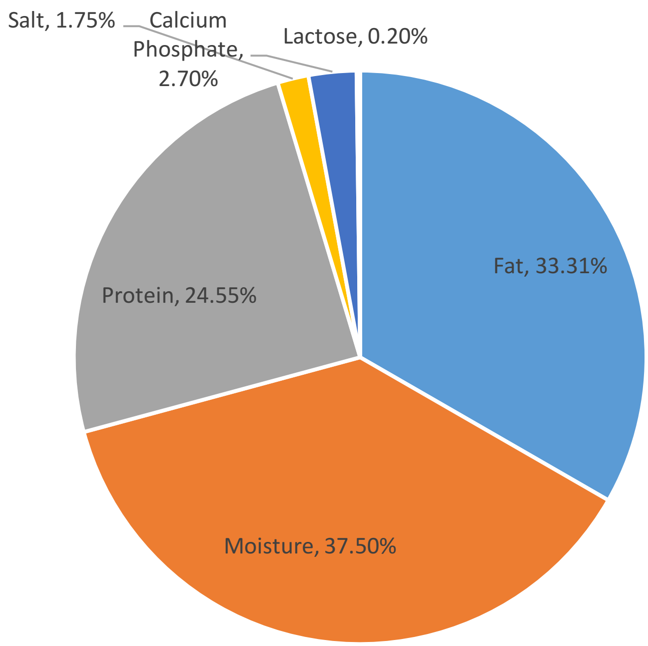

Figure 1.4. Percentage of cheese weight by component.

Fat Recovery

Milk fat is responsible for imparting smoothness, body, richness, taste, and palatability (Van Slyke and Publow 1909). Poor quality milk and mechanical abuse of milk will influence fat and protein loss in the whey. For cheddar varieties, a good theoretical fat recovery target is 93% in cheese (Van Slyke and Publow, 1909). Mozzarella cheese is a pasta filata cheese with a hot water curd stretching step where additional loss of fat from the cheese can occur compared to cheddar. For mozzarella, 85 to 87% fat recovery in cheese is a realistic target for fat with a 40% fat on dry basis; most fat loss occurs in the vat and in the pasta filata mixing step (Rudan et al., 1999; Barbano, 1996). Fat lost in the mixer is harder to recover than fat lost in the whey at draining from the vat. The quality of the fat recovered from the mixer is lower than the quality of the fat recovered from whey draining because the water from the mixer contains salt (Barbano, 1996).

Protein/Casein Recovery

Casein loss can occur in two forms: (1) soluble casein lost in the whey at draining and (2) curd fines lost in the whey from draining, cheddaring, stretching, and pressing. Soluble casein losses in whey are usually caused by enzymatic damage to milk casein versus curd fine losses that are more related to mechanical issues in the cheese making process. A value of casein as a percent of true protein (**CN%TP**) of 82% is a reasonable default value for estimation of casein from true protein for yield calculations for good quality (i.e., low SCC and bacteria count) Holstein milk (Kindstedt et al., 1983). High milk SCC (Barbano et al., 1991) and high psychrotrophic bacteria count (Hicks et al., 1982) will result in lower CN%TP due to proteolysis of casein and higher losses of soluble casein in whey. Sapru et al. (1997) found that milk from cows late in lactation had a lower casein as a percentage of true protein than cows early in lactation. Milk from late in lactation was correlated with a higher moisture content in the cheese. and was also associated with higher fat and protein losses in the whey at draining.

The high SCC and psychotrophic bacteria count cause the milk casein to be damaged by proteolytic enzymes, resulting in soluble casein that is lost in the whey (Barbano and Rasmussen, 1991; Hicks et al., 1982). The cut time and speed, heal time, and speed of stirring during cooking need to be optimized to achieve minimum loss of fines (Barbano, 1996). It is paramount that the curd achieve an optimal level of firmness before cutting. Cutting a fragile curd will lead to increased fat and fines in whey from subsequent stirring and pumping (Callahan, 1991). Some large scale industrial systems are available to help recover fines and return them to the curd in order to minimize economic loss (Callahan, 1991).

Recovery of Whey Solids in Cheese: Solute Exclusion Factor

The solute exclusion factor (**SEF**) is a representation of the fraction of the water available in the cheese that can dissolve whey solids and is not tightly bound by protein. Water bound by protein isnot available to dissolve whey solids (Emmons et al., 1991). SEF varies with cheese moisture since the moisture acts as a solvent for nonfat, noncasein milk solids. For a target cheese moisture of 37%, a solute exclusion factor of 0.6885 is appropriate, based on the polynomial equation SEF = 0.0142x +0.1631 where x = cheese moisture (%) (Neocleous, 2002*)*.The amount of nonfat, noncasein + calcium phosphate, milk solids recovered in the cheese is heavily influenced by the total solids content of the separated whey and the total moisture content of the cheese (Barbano, 1996). Both of these parameters can be adjusted for using the Barbano Theoretical Yield equation, which is necessary when using fortified milk, which changes the amount of milk solids in the water phase of the cheese.

Recovery of Calcium Salts in Cheese: Calcium Phosphate Retention Factor

Calcium and inorganic phosphate in milk are bound to the casein micelles in the cheese. As the pH of the cheese decreases during cheese making, a portion of the bound calcium and phosphate is released into the whey. The calcium and inorganic phosphates in Cheddar cheese can account for 1.60% of yield (Emmons, 1991). Additionally, the amount of $CaCl_2$ added to cheese, and pH of cheese coagulation can affect the amount of calcium and phosphate that are retained (Emmons et al., 1990). A value of 1.092 for calcium phosphate retention factor (**CPRF**) is recommended for whey draining between pH 6.1 and 6.4. Different types of direct acid additions (e.g., citric, acetic, etc.) and whey draining pH can result in lower calcium retention and therefore the factor should be adjusted as necessary for the type of acid (Metzger et al., 2000). Metzger et al. (2000) used calcium phosphate retention values of 1.092, 1.077, 1.062, 1.084, and 1.076 for control, pH 6.0 with citric acid, pH 5.8 with citric acid, pH 6.0 with acetic acid, and pH 5.8 with acetic acid treatments, respectively.

Mozzarella cheese made by direct acidification will have a lower retention of calcium phosphate than mozzarella cheese made with cultures, due to the lower pH at whey draining. The CPRF in the Barbano Theoretical yield formula allows the user to adjust for these different methods of mozzarella production (Barbano, 1996).

Target Cheese Moisture, Fat, and Salt

When setting cheese composition targets, the first step is to look at the legal composition limits for the type of standardized cheese to be made. For cheddar, the legal maximum is 39% moisture (Code of Federal Regulations, 2006). The target cannot exceed this. Lawrence and Gilles (1980) found, assuming a moisture in the non-fatty substance (**MNFS**) less that 56%, that the moisture of cheese could be as high as 37% without any loss in quality. Subsequently FDB must be at least half of 100 minus moisture; in this case the legal minimum for a cheddar cheese with 37% moisture would be a wet fat of about 31.5%. A reasonable target FDB for a high quality long hold cheddar is about 53.3%, which would correspond to a fat on wet basis of about 33.3%, at a moisture of 37.5%.

The primary milk composition factor that influences the fat and moisture content of cheese is the casein to fat ratio in the milk. This parameter in milk standardization is under the control of the cheese maker and can be used to make course adjustments in fat on a dry basis in the cheese and that will also impact cheese moisture. Other factors in the cheese making process, including loss of fat, will lead to small variations in fat and moisture content of the cheese. Monitoring and controlling casein (or true protein) to fat ratio is one process control parameter to achieve more consistent cheese composition. At constant casein to fat ratio, the selection and control of the sum of casein plus fat percentages is a further parameter that must be controlled when using a milk fortification strategy that will increase the number of pounds of cheese produced per man hour of labor and spread fixed costs across more pounds of cheese produced in a day.

There are no legal limits in cheddar cheese standard of identity for salt and pH. The target values for these will be decided by what values for these parameters gives the optimum quality aged cheddar cheese. The salt-in-moisture ratio in dry-salted cheese controls the final pH of the cheese, degradation of lactose, and activity of the residual chymosin (Lawrence et al., 1987). Pearce and Gilles (1979) suggest a salt in moisture between 4.6-4.8% for cheddar cheese. The salt-in-moisture is calculated by the cheese salt (%) / cheese moisture (%) x 100. From the salt-in-moisture required for good quality long hold cheddar, a corresponding target salt on a wet basis can be calculated.

The cost of salt per unit weight versus the value of cheese per unit weight is low, therefore controlling salt concentration and not letting it go out of control low, will ensure that cheese quality will be consistent and also achieve an added value because of salt's low cost. It can be surprising how much economic opportunity is lost in a large cheese factory when the concentration of salt in the cheese is low by 0.1%. The principle effects of salt in cheese are control of microbial growth (both starter and nonstarter) and activity, control of the various enzyme activities in cheese, physical changes in cheese proteins which influence texture, protein solubility, and protein conformation (Guinee and Fox, 2004). Increasing the moisture and fat content of cheese will increase yield, but the opportunity will be limited by negative impacts on cheese functionality and quality. Increasing moisture increases yield by direct impact of increased water weight, and indirect impact of increase in the total amount of other milk solids that can be retained in the water phase of the cheese (Barbano, 1996), but again, quality considerations will set the upper limits of these gains. In spite of that, a controlled and deliberate achievement of a 0.1% higher moisture in a large cheese factory will have a large impact on profitability of cheese production if it can be achieved without negative impacts on cheese quality, and without increased downgraded lower-value cheese.

Philosophy of a Theoretical Yield Prediction

Cheese manufacturing industry management needs to understand that prediction of cheese yield for performance improvement in a cheese making factory and for business model projections of expected performance are different and play separate roles in business management. Theoretical yield provides benchmarks and gold standard for performance evaluation in cheese manufacturing relative to best practice performance based on research data and industrial experience. A cheese plant's actual performance is compared with these theoretical yield projections and root causes for deviations are identified and corrected. Magnitude of deviations can be converted to economic value and opportunities for improvement. Yield prediction based on regression equations using previous performance data from that factory to predict expected future performance is useful for business and financial planning over the short run, but is not useful to understand causes of poor performance and identification of specific points of opportunity for improvement and the projected economic impact that those improvements could have on the business. The focus of our research study is on theoretical yield metrics and identification of opportunities for improvement.

Emmons et al. (1990) describes a classification system for cheese yield equations. There are two classes of formulas: those based on target compositions (type A, B, C, D, F, G) and those derived from actual yield of cheese (type E). Type A has a formula that distributes moisture, whey solids, and salt proportionally to para-casein and fat (Emmons et al., 1990).

The general format of a type A formula would take the following form:

$$\text{Yield} = \frac{\text{Fat + Para-casein x calcium phosphate}}{\text{((Fat + para-casein x calcium phosphate)/(1-Moisture))}} \times \frac{1}{\text{(1-Moisture)}}$$

Type B formulas are those that have whey solids and salt included with para-casein and moisture distributed proportionally to fat and fat-free dry cheese. Type B formulas take the following form:

$$\text{Yield} = \left(\text{Fat} + \frac{\text{Para-casein x calcium phosphate}}{\text{((para-casein x calcium phosphate)/(1-Moisture - Fat))}}\right) \times \frac{1}{\text{(1-Moisture)}}$$

Type C formulas are those where salt, whey solids, and moisture are combined only with para-casein, with moisture as moisture in fat-free cheese (**MFFC**). Type C formulas take the following form:

$$\text{Yield} = \text{Fat} + \frac{\text{Para-casein x calcium phosphate}}{\text{((1-Moisture-Fat))}} \times \frac{1}{\text{(1-MFFC)}}$$

Formula types A, B, and C are based on the principle that yield is equal to the sum of recovered fat, complex of recovered para-casein and calcium phosphate, cheese whey solids, and cheese moisture (Emmons et al., 1990) and this approach is best suited for evaluation of yield performance in a factory.

Type E formulas are based on actual yields in cheese making and generally take the form of a linear equation with constant multipliers for fat and protein and potentially an intercept term. These formulas are useful to make estimate of future performance of a factory based on past performance from a business management and financial perspective, but they are not useful for identification of specific points in the cheese manufacturing process where technical parameters can be adjusted to improve the yield performance.

The Van Slyke and Publow (1909) equation for cheddar cheese (shown below) is classified as a Type A formula because it contains a fat and casein/calcium phosphate terms in the numerator, and the moisture term in the denominator.

$$\text{Yield of cheese} = [(0.93 \times \text{Fat}) + (\text{Casein} - 0.1)] \times 1.09 / (1 - \text{Moisture})$$

However, the Modified Van Slyke equation (shown below) is considered a Type C formula because it has a fat term separate from the casein and moisture related terms, which are presented together in a fraction.

$$\text{Yield of cheese} = (0.93 \times \text{Fat}) + (1.1682 \times \text{Casein} / (1- \text{Moisture in Fat-Free Cheese}))$$

Cheese yield formulas are valuable tools in improving cheese yield efficiency. Actual yield can be compared to theoretical yield as a way to identify the occurrence of losses and/or inaccuracies in measurement techniques (Emmons et al., 1991). Predictive yield formulae can be used for detection of biases in measurement, sampling, and analysis. Additionally, they can be used to evaluate the effect of changes in milk composition and deviations from recovery targets on yield (Emmons and Lacroix, 2000). The Van Slyke formula for Cheddar cheese yield has been used for over 100 years. This formula allows for Cheddar cheese yield to be predicted at any given moisture based on the fat and casein content of the milk used. While fairly accurate at predicting cheddar cheese yield, this formula could not predict yield for other types of cheeses, or allow for the use of fortified milk due to the 1.09 factor which represents the retention of nonfat, nonprotein solids + salt in the water phase of the cheese.

Because of this, a more generalized equation was created. The Barbano Theoretical Yield formula (Metzger et al., 2000) contains parameters that allow the user to predict yield across a variety of different cheeses and can adjust theoretical cheese yield to accommodate a wide range of milk fortification strategies. The general format of the Barbano theoretical cheese yield formula takes the following form:

$$\text{Yield} = \frac{(A + B + C)}{1 - ((\text{target cheese moisture} + \text{target cheese salt})/100)}$$

A = (percentage of fat recovery in cheese) x (percent fat in milk)

B = (percent casein in milk – 0.1) x (calcium phosphate retention factor)

C = (((A+B)/(1-target cheese moisture percent/100)) – (A+B)) x (separated whey solids percent/100) x (solute exclusion factor)

The term A in the equation is the portion of the fat in the milk that is retained in the cheese and should reflect achievable best practice fat recovery for the specific variety of cheese being made (e.g., for Cheddar 93%). The term B in the equation is the portion of casein in the milk and calcium phosphate bound to that casein that will be retained in the cheese. The calcium phosphate retention factor will vary as a function of the pH of the whey at draining (Metzger et al., 2000). The term C is one key difference from the other two formulas above. This term uses three pieces of input information (i.e., the target cheese moisture, the separated whey solids typical for that cheese given the milk solids fortification strategy being used, and the solute exclusion factor) that are appropriate for the cheese (Metzger et al., 2000). The expected mass of water in the salt-free cheese is calculated as: ((A+B)/(1-target cheese moisture percent/100)) – (A+B)). That amount of moisture multiplied by the solute exclusion factor provides the amount of the moisture portion of cheese (i.e., unbound water) that is able to carry dissolved whey solids. The unbound water multiplied by the percent separated whey solids/100 provides the estimate of the amount of whey solids (lactose, whey protein, glycomacropeptide, soluble minerals, etc.) dissolved in the water phase of the cheese and their separate contribution to cheese yield. The impact of different milk solids fortification strategies on theoretical cheese are more correctly adjusted for by this term in the equation.

CHALLENGES IN EVALUATION OF CHEESE YIELD PERFORMANCE IN LARGE FACTORIES

Measurement of Milk Weight

Milk Plus Ingredient Weight. Milk plus ingredient weight is one of the most important input data in cheese yield determination and also one of the most challenging to measure accurately in large cheese factories. Generally, various types of meters are used to measure the weight of milk plus starter pumped into each cheese vat. Different types of flow meters have different strengths and weaknesses. In addition, there is water added to each vat that is not reflected in the meter readings. The weight of water (i.e., to dilute rennet, calcium chloride, and to flush lines for automated delivery of the ingredients directly to the vats) added per vat becomes important later in evaluation of cheese and whey plant performance because added water directly impacts the amount of energy used to concentrate and dry the whey. The amount of added water can be surprisingly large in some factories. Generally, in-line meters are used to measure the volume or weight of milk plus starter going into each vat. There are several types of meters that are currently used to measure milk weight and knowledge of the principle of operation and calibration of meters is useful to ensure accurate results. The two general types of meters: volume meters and mass flow meters.

Considerations in Placement and Selection of Flow Meters

There is normally a flow meter in high temperature short time (**HTST**) milk pasteurization systems that pasteurizes milk before it goes to the cheese vats. Unfortunately, these meters are usually in the recirculation loop of the pasteurizer and if the pasteurizer goes into divert, the meter will not provide an accurate measure of the milk that went into the cheese vats because any diverted milk will be effectively measured twice. Therefore, it is desirable to have a meter between the milk pasteurizer and cheese vats in-line after all ingredients are mixed together and milk standardization and starter culture injection has occurred. At that point in the process, the milk will be entering the vat at the temperature for rennet addition. At this temperature the appropriate factor for volume to weight conversion given the fat and SNF content of the standardized milk can be determined. There are several types of meters that could be used in this scenario.

Turbine meters measure volume and are sensitive to fluids that have particulate inclusions in them, which would not be the case for milk going to a cheese vat (Baker, 2000), however entrained air in milk will influence the accuracy of a turbine meter. Cavitation can occur when local pressure drops below the vapor pressure of the liquid and results in increased volume from the two-phased flow. This increased volume causes an over-reading from the meter. It is recommended that the pressure downstream of the meter be at least 1 bar above atmospheric pressure to avoid cavitation (Baker, 2000). Because turbine meters measure volume, appropriate volume to weight conversion factors specific to the composition and temperature of the liquid being measured are needed, as described in the USDA publication on volume to weight conversion factors for milk products (USDA, 1965). The conversion factor either needs to be installed in the meter calibration or needs to be done outside the meter in a data handling system. The reality in most plants is that meters are used with a default calibration setting for water with a one size fits all density factor. For accurate cheese yield evaluation in large cheese factories, this is not sufficient for a high quality process control evaluation.

The major disadvantage for the magnetic flow meter is its limitation to conducting liquids only, but this is not a problem for milk based fluids. Because magnetic flow meters measure volume, they have the same volume to weight conversion issue as mentioned above for turbine meters.

Mass flow meters of the Coriolis design measure mass (and density) instead of volume. This is an advantage because volume to weight conversions and temperature corrections are not needed to estimate the weight of liquid delivered. Corilolis meters are available in sanitary designs and large capacities. The main disadvantage of the Coriolis meter is the high initial cost (Baker, 2000).

Measurement of Composition of Milk in the Vats

Milk fat and true protein values are the typical data from a MIR milk analyzer. Because infrared analyzers are a secondary measurement, it is important to ensure that they are calibrated correctly, as explained by Barbano and Clark (1989). The accuracy of reference values (Wojciechowski et al., 2016) used to calibrate and the design of the calibration sample set is an important factor in determining the accuracy of analytical values produced by the instrument (Barbano and Lynch, 2006; Kaylegian et al., 2006a; Kaylegian et al., 2006b).

Generally, MIR milk analyzers are calibrated for testing milk without starter culture. The milk sample is usually collected at the point when the cheese vat is nearly full of milk. Because the milk is continuously agitated while the vat is filling, it is relatively easy to get a representative sample. However, the vat milks also contain starter culture that produces lactic acid. The lactic acid produced by the starter causes the milk pH to decrease, thus changing the sample’s MIR absorbance spectrum and interfering with predicted values for fat and protein. Barbano and Dellavalle (1987) acidified milk with acetic and phosphoric acid (Barbano and Dellavalle, 1987) to precipitate casein and produce clear filtrates to analyze on a MIR. The difference between the MIR protein readings for milk minus the protein measured in the filtrate produced an estimate of casein. Barbano and Dellavalle (1987) demonstrated that carboxylic acids (e.g., acetic acid) have a large impact on infrared protein readings. Lactic acid produced by starter culture growth in milk will have a similar impact on infrared protein readings. Injection of CO_2 into milk will also lower milk pH by production of carbonic acid. Addition of a low level of CO_2 to milk is used in commercial cheese factories to improve firmness of milk coagulation by rennet. Carney et al. (1993) found that carbonation significantly reduced the growth of proteolytic and lipolytic bacteria. Further, the increased acidity due the carbonation made it so only 50% of the rennet normally required was sufficient to coagulate the cheese. Milk treated with CO_2 also showed a lower cheese yield (Carney et al., 1993), which could be the result of the influence of decreased pH due to the carbonation which changes the casein solubility by causing a shift in calcium and casein into the soluble phase (Ali et al., 1980). However, the decreased growth rate of psychotrophs during storage in CO_2-treated milk could prevent the decrease in cheese yield observed in refrigerated milks (Calvo et al., 1994). Ma et al., (2001), reported that CO_2 in milk produced carbonic acid that changed the infrared absorption spectrum of milk and caused the corrected lactose readings to decrease and the fat readings to increase. Milk should be analyzed as quickly as possible after the milk sample is taken to minimize the impact of the starter culture growth and acid production on the MIR fat and protein results.

Measurement of Whey Composition

The key parameter that cheese makers are interesting in measuring is usually the fat content of the whey at draining. More and more today, cheese factories are not running reference chemistry themselves and rely on an external laboratory that makes reference standards to provide whey standards for calibration of an infrared analyzer for testing whey. Many factories send unseparated whey and separated whey to an outside lab that does reference chemistry on their whey and makes a set of calibration for the factory from their own whey samples. Because these samples may decrease in pH with time because of starter culture growth, it would be best to heat shock the whey at 140°F and add a bronopol preservative to stop starter culture growth before shipping samples to an outside lab for reference testing or making whey calibration samples. Like the vat milk, the whey contains starter and the starter is growing and producing acid that will cause MIR milk analyzer readings to change with changing pH. Thus, the whey samples collected from the vats should be tested immediately. It is best to have a separate calibration of the infrared milk analyzer specifically for whey.

Measurement of Cheese Fines

Determining the fat percent of the whey at draw from each vat, and multiplying it by the estimated weight of whey will yield the total kilograms of fat in the whey (Barbano and Sherbon, 1984). When fines are more broken up and abundant, their fat content and FDB decreases due to damage to the curd structure which allows the fat to leach into the whey prior to the cheddaring step. The FDB of cheddar cheese is typically between 50 and 54%. Measurement of FDB of curd fines in combination with the amount of curd finds per day is a useful index of curd damage. However, the FDB has the advantage over weight of curd fines collected because it is not dependent on the efficiency of curd recovery by the fine saver. The closer the FDB of the curd fines is to that of the finished cheese product, the less damage that has been done to curd structure in the cheese making process. Thus, an FDB of 45 to 50% for cheddar curd fines would indicate minimal mechanical damage, while an FDB < 35% would indicate more damage to curd structure in the vats prior to whey draining.

Measurement of Cheese Composition

Cheese Moisture and Fat. The classical reference methods for determination of the moisture content of cheese are thermal oven drying methods. Typically, a forced air oven (Hooi et al., 2004, method 15.114**)** or a vacuum oven method (Hooi et al., 2004, method 15.111) is recommended. A detailed study of both vacuum oven and forced air oven methods identified critical parameters on both methods with respect to hardware, drying time/temperature, and sample handling (Bradley and Vanderwarn, 2001).

In a commercial quality assurance laboratory, the classical reference methods for moisture determination (and for other cheese components) are often too slow and labor intensive in the context of today's large-scale, fast-paced commercial factories. Therefore, rapid methods such as microwave total solids and near infrared (**NIR**) cheese analysis are more common in routine quality assurance laboratories.

Microwave determination of moisture content of cheese is dependent on the microwave absorptivity of the sample and therefore microwave drying conditions (sample size, microwave power, drying time) for each type of product needs to be determined by comparison to results from a vacuum oven or forced air oven reference method (Barbano and Dellavalle, 1984). Samples with high salt content absorb a different amount of energy per unit of time than samples with low salt content and therefore require different drying times (Barbano and Dellavalle, 1984). Samples with higher salt content dry more rapidly in a microwave oven.

NIR has become common for a rapid method for cheese moisture and fat analysis. The NIR regions are a mixture of overtones and a combination of fundamental frequencies in the MIR region (McKenna, 2001). While NIR analysis of cheese is easy to use, the calibration and accuracy of the method can be a challenge. NIR is a secondary method that requires calibration against primary reference methods for each component (e.g., moisture and fat) and usually requires a large number of samples (i.e., 200 to 400) from each specific cheese type produced within the same factory to calibrate (McKenna, 2001; Barbano and Lynch, 2006). McKenna (2001) describes how several different forms of the partial least squares (**PLS**) technique exist for creating calibration equations. Cheese samples are grated, diced, or packed into a sample cup and then positioned in front the monochromator beam. The sample is rotated in the beam and several measurements are taken (Mckenna, 2001). Because factory laboratories are not routinely running reference chemistry testing, the analytical accuracy of reference values produced in a cheese factory laboratory for PLS modeling may not be the best, and the range of variation in cheese composition in the factory may be small and not adequate for developing a good PLS calibration model. This will lead to within cheese factory development of weak NIR models for cheese analysis. This is unfortunate given the economic importance of the accuracy of cheese analysis results for process control.

Nuclear magnetic resonance (**NMR**) can also be used to measure fat in foods. Both time domain low resolution NMR (also called pulsed NMR) and frequency domain NMR (NMR spectra) can be used for fat analysis (Min and Steenson, 1998). Advantages of this technology are that the sample is analyzed without being destroyed, unlike in the chemical methods described above. In time domain NMR, the signal from the hydrogen nuclei of the various food components are identified by their rate of decay and nuclear relaxation is measured (Min and Steenson, 1998). The intensity of the signal is proportional to the hydrogen content and can be converted to oil content using calibration methods. This method can be used for water content, oil content, solid fat content, and solid-to-liquid ratio. Sometimes it may be necessary to dry the sample before analysis in order to isolate the fat signal. Frequency domain NMR allows food components to be identified by resonance frequency of their peaks in an NMR spectrum.

Cheese Protein. In the milk coagulation process the protein is what gives the curd its structure, and it is highly correlated with yield. A lot of focus is given to the recovery of fat, however, protein recovery is equally important. Currently there is no rapid method for the determination of cheese protein. Accurate reference chemistry is available for calibration of a rapid method. The development of such a method would be of great use in maximizing yield efficiency.

Cheese Salt. The coulometric method is a rapid method for salt determination based on the principle of coulometric titration. Coulometry measures the amount of electricity needed to complete an oxidation or reduction reaction (Varcoe, 2001). In this method, an electric potential is applied across two silver electrodes. Silver ions are generated at the anode and interact with chloride ions in solutions, forming insoluble silver chloride (Varcoe, 2001). Silver ions are added to the solution at a constant rate and when all of the chloride has reacted, the silver ions increase in concentration (Varcoe, 2001). When the electrodes sense this change in silver ion concentration, the titration is stopped (Hooi et al., 2004, method 15.053). Hooi et al. (2004, method 15.053) describes the procedure of determining chloride content in milk and cheese samples. Cheese requires an addition of nitric acid to assist in releasing the chloride ions, followed by filtering the sample to remove suspended particles (Hooi et al., 2004, method 15.053). The coulometric method is commonly used in quality control (**QC**) laboratories in cheese factors for cheese salt determination and seems to be very well accepted in the cheese industry in North America.

Infrared Spectroscopy. NIR spectroscopy has been shown to be useful for analysis of major components in solid and semisolid foods. Unlike many other analytical procedures, NIR is direct, rapid and non-destructive to the sample (Pierce and Wehling, 1994). Pierce and Wehling (1994) compared data treatment methods of NIR cheese data and found that PLS regression of first derivative reflectance data yielded a calibration with the lowest standard error of prediction (**SEP**) for moisture (0.335%).

Transmittance spectra gave higher SEP values than reflectance spectra. For Fat, a PLS regression of log 1/R spectral data performed best (SEP = 0.330%). Overall it was concluded that moisture and fat could be measured reliably in cheddar cheese using NIR reflectance measurements from grated samples (Pierce and Wehling, 1994). On the basis of their results, the authors concluded that it should be possible to develop successful calibrations for varieties of hard and reduced fat cheeses using NIR reflectance spectra (Pierce and Wehling, 1994). No data for NIR protein analysis of cheese was reported by Pierce and Wehling (1994).

Similarly, Blazquez et al. (2004) used NIR reflectance spectroscopy and multivariate data analysis to predict the moisture, fat, and inorganic salts in processed cheese. In the study, a series of processed cheese samples were produced with varying levels of fat, moisture and inorganic salts. Cheese samples were then subject to chemical and spectroscopic analysis. Ultimately, it was found that the most accurate models used spectral data in the 1100-2498 nm range for the three constituents tested based on their R and standard error of the cross validation (**SECV**) values (Fat: SECV=0.45, R=0.98; moisture: SECV=0.50, R=0.99: inorganic salts: range 1100-2500, SECV=0.26, R=0.90). Further, the authors advise that NIR testing is suitable for industrial applications (Blazquez et al., 1994). In another study, Frankhuizen (2007) determined NIR reflectance data for cheese moisture (R=0.991, SEP=0.35), fat (R=0.992, SEP = 0.28), and protein (R=0.995, SEP=0.36).

Many large cheese factories utilize this rapid secondary method for analysis of cheese. However, NIR relies on the accuracy of the calibration to give accurate results. Unique calibrations, with 200 to 400 samples, are required to create PLS models for the NIR instrument (Barbano and Lynch, 2006; Mckenna, 2001). Frequently the calibrations are not robust enough, or reference chemistry on the cheese is performed inaccurately, leading to inaccurate measurements.

Mid infrared (**MIR**) analyzers have been used successfully as a rapid method to determine milk components (Barbano and Clark, 1989, Lynch et al., 2006). Belton et al. (1987) compared three methods of sample preparation of starch gels for fourier transform infrared spectroscopy (**FTIR**): attenuated total reflectance (**ATR**), diffuse reflectance, and photoacoustic detection and found that the ATR method had the widest application and is a valuable candidate for relatively low-cost, quantitative analytical testing. Chen et al., (1998) reports an exploration of infrared spectra in relation to differences in spectra from cheeses with different fat levels and at different degrees of aging with MIR using an ATR cell on the intact cheese. Chen et al., (1998) reported difficulty in generating a calibration graph due to interference from the absorption of water on the amide I band and did not report any quantitative analysis results or the use of PLS data modeling. They did report age related changes in the MIR spectra and indicated that it might be possible to monitor cheese aging using MIR.

Within Cheese Block Composition Variation

The distribution of components within a block of cheddar cheese can vary both randomly and systematically, within and among blocks of cheese from the same vat. To obtain a representative sample of cheese the analyst needs to understand both the nature and degree of random and systematic variation in composition with the block of product to be sampled. The nature of the systematic variation can be different depending on the size of the cheese block (18 versus 290 kg blocks) and conditions of manufacture (milled curd versus stirred curd). Within cheddar cheese blocks, moisture migrates as a function of the temperature gradient (Reinbold et al., 1998, 1992, Olabi and Barbano, 2002) from the center (warm) to the surface (cold) during cooling. This creates a systematic variation in moisture with in the block (Barbano, 2001). The gradient of moisture content in 290 kg blocks can produce a range of moisture from the center (low) to all surfaces (high) of the block of about 5% with a nonsymmetrical but systematic distribution (Barbano, 2001) that will also influence flavor and texture development (Carunchia Whetstine et al., 2007).

Brine salting produces Mozzarella cheese with heterogeneous chemical composition (Kindstedt et al., 1992, 2001). Similar systematic nonuniformity in cheese composition is observed in other types of brine salted cheeses and can be influenced by brine concentration and presalting (Melilli et al., 2003a), brine temperature (Melilli et al., 2003b), and the interactions of these factors (Mellili et al., 2004a, 2006). These variations will cause different enzymatic actions, and gradients of pH, that produce differences in cheese flavor and texture (Melilli et al., 2004b, 2005). Melilli et al. (2003) found that in brine-salted cheeses such as Mozzarella cheese, brine with a higher salt content can cause rapid loss of moisture from the cheese surface, causing shrinkage of the cheese structure and formation of a surface barrier layer the prevents salt penetration. Additionally, variation and size and shape of the cheese can affect the homogeneity (Guinee and Fox, 1986). Gradients of salt and moisture within the cheese can make representative sampling problematic. In order to avoid the problems associated with brine salting, Barbano et al. (1994), developed a no-brine, method for making low-moisture part-skim mozzarella with homogenous composition. Taking a cross sectional slice of a loaf of Mozzarella and grinding the slice, or dicing the complete loaf and mixing the dice to select random pieces to grind are approaches that can be used to help achieve representative sampling (Kindstedt, 2001).

RESEARCH GOALS AND OBJECTIVES

Inaccuracies in analysis of cheese can lead to significant yield and economic losses for cheese producers because incorrect information is used as the basis for process control. Research is needed to establish a more accurate methodology for routine analysis of cheese composition. The objectives of our work were (1) to demonstrate a data collection and analysis method to evaluate cheese yield performance and identify sources of cheese yield loss, particularly fat losses, through the use of well-established cheese yield relationships in large cheese manufacturing factories and to determine the sensitivity of the outcome of the evaluation to uncertainty in various input parameters and (2) develop a more robust, rapid secondary method for routine cheese analysis for fat, protein, moisture and salt content.

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CHAPTER TWO

IMPACT OF UNCERTAINTY IN COMPOSITION AND WEIGHT MEASURES IN CONTROL OF CHEESE YIELD AND FAT LOSS IN LARGE CHEESE FACTORIES

ABSTRACT

Our objective was to develop a computer based cheese yield, fat recovery, and composition control performance measurement system to provide quantitative performance records for a cheddar and mozzarella cheese factory. The system can be used to track trends in performance of starter cultures and vats, as well as systematically calculate theoretical yield. Yield equations were built into the spreadsheet to evaluate cheese yield performance and fat losses in a cheese factory. Based on observations in commercial cheese factories, sensitivity analysis was done to demonstrate the sensitivity of cheese factory performance to analytical uncertainty of data used in the evaluation. Analytical uncertainty in the accuracy of milk weight and milk and cheese composition were identified as important factors that influence the ability to manage consistency of cheese quality and profitability. It was demonstrated that an uncertainty of ± 0.1% milk fat or milk protein in the vat causes a range of theoretical cheddar cheese yield from 10.05 to 10.37% and an uncertainty of yield efficiency of ± 1.5%. This equates to ± 1,451 kg (3,199 pounds) of cheese per day in a factory processing 907,185 kg (2 million pounds) of milk per day. The same is true for uncertainty in cheese composition, where the impact of being 0.5% low on moisture or fat is about 484 kg (1,067 pounds) of missed revenue opportunity from cheese for the day. Missing the moisture target causes other targets such as FDB and salt in the moisture to be missed. Similar impacts were demonstrated for mozzarella cheese. In analytical performance evaluations of commercial cheese quality assurance laboratories it was found that analytical uncertainty was typically a bias that was as large as 0.5% on fat and moisture. The impact of having a high bias of 0.5% moisture or fat will

produce a missed opportunity of 484 kg of cheese per day for each component. More accurate, rapid methods for determination of moisture, fat, and salt content of cheese in large cheese factories will improve the accuracy of yield performance evaluation and control of consistency of cheese composition and quality.

INTRODUCTION

Perhaps the most important factors affecting the efficiency of cheese production are milk composition and milk quality. Milk composition influences cheese yield and varies seasonally and regionally (Barbano, 1990). Higher milk fat and casein content translates into more fat and casein that can be incorporated into the cheese, assuming low milk psychrotropic bacteria count (Hicks et al., 1982) and low milk somatic cell count (**SCC**) (Barbano et al, 1991; Barbano, 1996; Klei et al., 1998).

The Van Slyke formula hasbeen used for over 100 years to predict theoretical cheddar cheese yield (Van Slyke and Publow, 1909) allowing cheddar cheese yield to be predicted at any given moisture based on the fat and casein content of the milk used. The VanSlyke theoretical cheese yield formula is as follows:

$$\text{Cheddar cheese yield} = \frac{[(\text{milk fat \%} \times 0.93) + (\text{milk casein \%} - 0.1)] \times 1.09}{1 - (\text{target cheese moisture}/100)}$$

Where 0.93 represents a fat recovery in the cheese of 93%, (milk casein – 0.1%) represents a fixed amount of casein lost in whey that is equivalent to about 0.1% casein, and 1.09 is a factor that accounts for a salt level of 1.7% and the retention of non-fat, non-casein milk solids in cheddar cheese with about 37% moisture.

While accurate predictions of theoretical cheddar cheese yield (Barbano and Rasmussen, 1992) have been reported, the 1.09 value in the Van Slyke formula does not correctly predict yield for reduced fat cheddar or other types of cheeses, when fortified milk is used for cheese making. Because of these shortcomings, a more generalized theoretical cheese yield equation was created.

The Barbano theoretical yield formula contains parameters that allow the user to predict yield across a variety of different cheeses, target compositions, and whey draining pH's (Rudan et al., 1999; Metzger et al., 2000). The Barbano theoretical cheese yield formula is as follows:

Theoretical cheese yield = (A + B + C)/(1 − ((target cheese moisture + target cheese salt)/100))

Where:

A is the milk fat recovered in the cheese. A = [percent fat in the milk x (percent fat recovery in cheese/100)]

B is the milk casein plus calcium phosphate recovered in the cheese. B = [(percent casein in the milk – 0.1) x calcium phosphate retention factor)]

C is the other milk solids recovered in the cheese (i.e., nonfat, noncasein, noncalcium phosphatemilk solids). C = [(((A+B)/(1 - actual cheese moisture percent/ 100)) - (A + B) x (separated whey solids percent/100)] x (solute exclusion factor)

A fat recovery target of 93% has been accepted as an achievable target for cheddar (Van Slyke and Publow, 1909). A fat recovery of 84 to 85% was suggested for mozzarella, according to Barbano (1996) and Rudan et al. (1999). However, due to improved mozzarella cheese manufacturing technology fat recoveries of between 85 to 90% can be expected. In a theoretical yield formula the recovery parameters are fixed and reflect best case achievable performance. The VanSlyke and Barbano formulae were used and compared in a nonlinear programming optimization modelto maximize net revenue in cheese and whey product manufacture (Papadatos et al., 2002).

The Barbano theoretical yield formula contains parameters A, B, and C, which allow it to predict theoretical yield for any type of cheese using any composition of milk. The A represents the fat recovery in the cheese, B represents the casein and calcium phosphate retention in the cheese, and C represents the retention of nonfat whey solids in the water phase of the cheese. The target moisture and salt content of the cheese are specified in the equation. The accuracy of the formula is limited by the milk composition data (fat and protein/casein) and separated whey solids measurement accuracy.

Many large cheese factories utilize rapid secondary methods for analysis of cheese. Near infrared (**NIR**) spectroscopy is commonly used for cheese analysis. NIR calibrations require 200 to 400 cheese samples with accurate reference chemistry values for each cheese type that are created using partial least squares (**PLS**) models for each NIR instrument (McKenna, 2001; Barbano and Lynch, 2006). Producing accurate reference chemistry on a large number of cheese samples for each type of cheese produced in that factory is a challenge because the factory laboratories no longer run large numbers of reference tests on cheese. As a result, the accuracy of the reference chemistry may be weak and result in poor NIR prediction calibration for moisture and fat that lead to incorrect management decisions that affect the company's financial performance.

The objectives of our work were to demonstrate a method to evaluate cheese yield performance and identify sources of cheese yield loss, particularly fat losses, through the use of well-established cheese yield relationships in large cheese manufacturing factories and to determine the sensitivity of the outcome of the evaluation to uncertainty in various input parameters.

MATERIALS AND METHODS

Computer Software Platform Used for the Study and General Organization

A computer based cheese yield, fat recovery, and composition control performance evaluation system was developed using Microsoft Excel 2010 (Microsoft Way Redmond, WA) spreadsheet program to provide quantitative performance records for a cheddar and mozzarella cheese factory. In an Excel workbook, worksheets are separated in different tabs and used in this study as an example, but a database program could also be developed using the same analytical approach and equations. An explanation of all the equations is given below.

It is common for large cheddar cheese factories to produce different varieties of cheddar and related cheeses (e.g., colby, monterey jack, washed curd, low or reduced fat cheddar, etc.) or for mozzarella cheese factories to produce a range of pasta filata cheese varieties (whole milk, part skim, low moisture, provolone, etc.). Each variety of cheese is called a cheese type and could be made with different starter culture strains and have different cheese composition targets and control limits. The Excel workbook (one for each month of the year) was developed with multiple worksheets within the monthly workbook. There are three worksheets (i.e., tabs) of default parameters: one for setting default values for starter cultures strains (as many as 50) and physical number of cheese vats used (as many as 15), a second for the definition of the default cheese composition and cheese yield equation parameters used for each cheese type (as many as 30), and the third for milk and whey composition targets for each cheese type produced. There are another 31 worksheets (i.e., tabs) for recording the daily production for each day of the month. A daily production worksheet will have both data input and output zones that will be discussed in more detail in the daily input data and daily output summaries sections of this paper.

Summaries of daily output data for each cheese type are transferred by a cell formula to appear in a monthly summary worksheet for each cheese type (i.e., 30 worksheets). Each different cheese type has an individual monthly output summary worksheet with one column for each day of the month.

Weighted average calculations for the month are performed to summarize the total composition and yield control data for each cheese type for the month. The monthly summaries allow a user to review cheese production performance across days within month. There is one monthly summary worksheet with a column for total amount of each cheese type for the month and the weighted average of the various output parameters. Finally, summaries of monthly data are transferred into a yearly summary workbook for each type of cheese with a column for each month. Monthly and yearly summaries have appropriate graphs to show seasonal variation.

Default Parameters for Starters and Vats

Cheddar and Mozzarella Cheese. The starter and vats default worksheet allows the analyst to list all the starter strains used in the factory, and indicate if the starter is a bulk starter or a direct vat set culture. Data for 50 different cultures can be specified. The physical number of vats in the factory is also specified on this tab. When starter or physical vat number are identified in the daily data input worksheets, the yield, cheese composition, cheese pH, fat recovery will be automatically tracked for each starter culture type and each physical vat. This enables the analyst to determine the performance of each individual starter culture type or each physical vat in the factory. The parameters for the starters and vats are listed in Table 2.1.

Table 2.1. Default worksheet parameters for starters and physical vat identification (ID)

Blend type	Starter name	Starter ID	Pouch weight (g)	Pouch weight (kg)
Bulk	A2	A2 (Bulk)	n/a	n/a
Bulk	DSM1	DSM1 (Bulk)	n/a	n/a
Bulk	DSM2	DSM2 (Bulk)	n/a	n/a
Bulk	DSM3	DSM3 (Bulk)	n/a	n/a
Bulk	DSM4	DSM4 (Bulk)	n/a	n/a
Bulk	DSM6	DSM6 (Bulk)	n/a	n/a
Bulk	CH108	CH108 (Bulk)	n/a	n/a
Direct	1060	1060 (Direct)	1000	1.00
Direct	CUC4	CUC4 (Direct)	1300	1.30
Direct	3010	3010 (Direct)	1000	1.00

Vat number	Physical vat ID
1	Vat (1)
2	Vat (2)
3	Vat (3)
4	Vat (4)
5	Vat (5)
6	Vat (6)
7	Vat (7)
8	Vat (8)
9	Vat (9)
10	Vat (10)
11	Vat (11)
12	Vat (12)
13	Vat (13)
14	Vat (14)
15	Vat (15)

Default Parameters for Milk and Whey

Cheddar and Mozzarella Cheese. An example of default milk and whey parameters for pasteurized long hold cheddar cheese and for low moisture part skim mozzarella are given in Table 2.2. The default milk and whey worksheet allows the user to input the specifics of the target milk composition and set temperature being used for each cheese type. The workbook is set up to handle 30 different cheese types made in a factory. These default values (milk fat, milk solids-not-fat (**SNF**), casein as percent of true protein, and whey SNF) can be set separately for each cheese type.

Table 2.2. Default worksheet parameters for milk and whey for long hold cheddar and low moisture part skim (LMPS) mozzarella

Monthly tab number	3	4
Cheese milk ID	Long hold cheddar (3)	LMPS mozzarella (4)
Set temperature target (°C)	31.11	36.67
Milk fat target (%)	3.67	2.22
Milk solid-not-fat target (%)	8.95	8.95
Milk density (kg/L)	1.0266	1.0256
Casein/protein (%)	82.00	82.00
Whey solids-not-fat target (%)	6.45	6.45
Temperature of water (°C)	31.11	36.67
Density of water (kg/L)	0.9943	0.9928
Temperature of milk (°C)	31.11	35.56
Fat factor	0.08541	0.09085
Solids-not-fat factor	0.37655	0.37459

For the long hold cheddar example, the target milk temperature at rennet addition is 31°C. Using the default temperature and the percent fat and SNF targets for milk in the vat, the density of the milk (weight per unit volume) for each type of cheese is calculated. The calculation of milk density is done using the equations published by the USDA for weight to volume conversion factors (USDA, 1965).The calculation of the weight of one gallon of milk is done using an equation of the following form: 100/(100+ (%F x F factor) – (% SNF x SNF factor)) x weight of a gallon of water = weight of a gallon of milk in the vat, where F = fat and SNF = solids-not-fat. The F factor and SNF factors are dependent on milk temperature. The F factors and SNF factors for 4.4, 10.0, 20.0, and 38.9°C are: F factors: 0.03928, 0.04811, .07181, and 0.09493 and SNF factors: 0.39221, 0.38556, 0.38146, and 0.37312, respectively. The weight of one gallon of water also varies with temperature temperatures correspond to 8.3364, 8.3341, 8.3217, and 8.2752 pounds per gallon, respectively (USDA, 1965). The polynomial regression equation density = -0.00001369 x (temperature)^2 + 0.00095326 x temperature + 8.32033859 was used within the spreadsheet to interpolate between 4.4 and 38.9°C to calculate the weight per gallon of water at intermediate temperatures, The F and SNF parameters allow the calculation of the weight of milk in pounds per gallon at a specified fat and SNF content at various temperatures. Pounds of milk can be converted to kilograms by multiplying by 0.453592.

Estimation of milk density is particularly important when the milk in the cheese vat is fortified and milk measured into the cheese vat is done by volume. The daily data input worksheets (to be described later) will convert milk volume to milk weight for each type of cheese based on the set temperature and the target milk fat and SNF in the vat for each type of cheese. The default value for casein as a percentage of true protein (**CN%TP**) will be used in the calculation of yield to convert true protein content (%, mass/mass) of the milk used in each vat to an estimated casein content. The CN%TP of milk is influenced by breed of cow (Rolleri et al., 1956), parity (Barbano et al., 1991), stage of lactation (Barbano et al., 1991), and milk somatic cell count (Barbano et al., 1991). A value of CN%TP of 82% is a reasonable default value for estimation of casein from true protein for yield calculations for good quality (i.e., low SCC and bacteria count) Holstein based milk supply (Kindstedt et al., 1983). CN%TP is lower with higher milk SCC. Milk SCC increases with time in lactation and number (i.e., parity) of lactations (Shultz et al., 1990, Barbano et al., 1991). Milk from the factory can be tested using the Kjeldahl method for casein determination (Lynch et al., 1998) to establish cheese factory specific default values. The casein in the vat of milk (%, mass/mass) is used later in the theoretical cheese yield calculation for each type of cheese. The default value for whey SNF for each cheese type will be used later in the theoretical cheese yield calculation for each cheese type. The default whey SNF value becomes more important when milk for cheese making is being fortified with nonfat milk solids. The SNF content of the whey will be used to adjust the theoretical yield for increased retention of whey solids in the water phase of the cheese.

Default Parameters for Cheeses

Cheddar Cheese. The cheese default worksheet contains a list default values for each of 30 cheese types and corresponds to the parameters listed in Table 2.3. The default values for minimum, maximum, and target (i.e., moisture, fat, whey draining pH, 4 day cheese pH, and salt) can be set separately for each cheese type (up to 30 different types). From the default cheese wet basis composition parameters for each type of cheese the following parameters for each cheese type are calculated and shown: solute exclusion factor (**SEF**), and target fat on a dry basis (**FDB**), calcium phosphate retention factor, and target percentage salt in the moisture phase of the cheese. Typical default values for pasteurized long hold cheddar are listed in Table 2.3.

Table 2.3. Default parameters for long hold cheddar and low moisture part skim (LMPS) mozzarella cheeses

Monthly tab number	**3**	4
Cheese name	Longhold cheddar	LMPS mozzarella

Cheese ID	Longhold cheddar (3)	LMPS mozzarella (4)
Moisture minimum (%)	36.00	46.00
Moisture maximum (%)	38.00	50.00
Moisture target (%)	37.5	48.00
Solute exclusion factor (%)	0.70	0.84
Fat minimum (%)	32.31	19.70
Fat maximum (%)	34.31	20.70
Fat target (%)	33.31	20.20
Fat dry basis minimum (%)	51.70	37.88
Fat dry basis maximum (%)	54.90	39.81
Fat dry basis target (%)	53.29	38.85
Fat retention factor (%)	0.93	0.87
Draining pH minimum	6.25	6.05
Draining pH maximum	6.35	6.30
Draining pH target	6.30	6.18
Calcium phosphate retention factor	1.09	1.09
4 day pH minimum	4.96	4.96
4-day cheese pH maximum	5.20	5.20
4-day cheese pH target	5.05	5.15
Salt minimum (%)	1.46	1.50
Salt maximum (%)	2.00	2.00
Salt target (%)	1.75	1.75
Salt-in-moisture target (%)	4.67	3.65

Emmons et al. (1990, 1991) reviewed and classified different types of theoretical cheese yield equations and described that basis for various terms in different equations. The SEF is a representation of the fraction of the water available in the cheese that can dissolve whey solids (i.e., not tightly bound by protein). Water bound by protein isnot available to dissolve whey solids (Emmons et al., 1991). SEF varies with cheese moisture because moisture acts as a solvent for unbound nonfat, and noncasein milk solids (including the glycomacropeptide and unbound calcium phosphate). For a target cheese moisture of 37%, the spread sheet calculates a SEF of 0.6885 from the polynomial equation SEF = 0.0142x +0.1631 where x = cheese moisture (%) (Neocleous et al., 2002*).* The retention of whey solids in the water phase of the cheese can account for 3.1 to 4.6% of cheese yield when milk is not fortified with additional nonfat milk solids (Emmons, et al., 1991).

Calcium and inorganic phosphate in milk are bound to the casein micelles in the cheese. As the pH of the cheese curd decreases during cheese making, a portion of the bound calcium and phosphate is released (Emmons et al., 1990). The calcium and inorganic phosphates in cheddar cheese can account for 2.9% of yield (Emmons, 1991). Additionally, the amount of $CaCl_2$ added to milk, and pH of milk coagulation can affect the amount of calcium and phosphate that is retained (Emmons et al., 1990). A value of 1.092 for calcium phosphate retention factor is recommended for whey draining between pH 6.1 and 6.4 (Metzger et al., 2000). Different types of direct acid additions (e.g., citric, acetic, etc.) or CO_2 addition (Nelson et al., 2004) to milk can influence whey draining pH. Lower whey draining pH can result in lower calcium retention and therefore the calcium phosphate retention factor should be adjusted as necessary for the type of acid when direct acidification is used (Metzger et al., 2000). Metzger et al. (2000) used calcium retention factors of 1.092, 1.077, 1.062, 1.084, and 1.076 for control, pH 6.0 with citric acid, pH 5.8 with citric acid, pH 6.0 with acetic acid, and pH 5.8 with acetic acid treatments, respectively. The use of each of these parameters in Table 2.3 will be described later in the section on daily data output by cheese type.

The target fat recovery (i.e., best industry practice) in the cheese is entered by the user for each type of cheese. For cheddar varieties, a good theoretical fat recovery target is 93% in cheese (Van Slyke and Publow, 1909). When setting cheese composition targets, the first step is to determine the legal composition limits for the type of cheese. Using regulations in the U.S. as an example, for cheddar, the legal maximum is 39% moisture (Code of Federal Regulations, 2006). The target cannot exceed this. Lawrence and Gilles (1980) found, assuming a moisture in the non-fat substance (MNFS) less than 56%, that the moisture of cheese could be as high as 37% without any loss in quality. Today cheddar cheese manufacturers in the U.S. are trying to maximize moisture and yield, therefore a target moisture of 37.5% was used in our example for long hold cheddar (Table 2.3). For cheddar the legal minimum for FDB is 50% (Code of Federal Regulations, 2006). Consequently, FDB must be at least half of 100 minus moisture; in this case the legal minimum for a cheddar cheese with 37.5% moisture would be a wet fat of about 33.25% and this would translate to a target FDB of 53.29%. A reasonable target FDB for a long hold cheddar is about 53.3% with 1.75% salt at 37.5% moisture (i.e., salt in moisture of 4.67%). When applying this approach, the user would need to reference to local regulations for their specific cheese type in their country. Emmons et al. (1991) reported that salt accounts for about 3.1% of cheddar cheese solids, while for the cheddar cheese in our study salt would be about 2.8% of the cheese solids.

Pearce and Gilles (1979) related commercial cheese composition to quality grading over 3 years for cheese produced in New Zealand and reported that optimum aged cheddar cheese quality was achieved with compositional targets of moisture in the non fat substance (MNFS) of 52 to 54%, pH 4.95 to 5.15, and salt in the moisture of 4.2 to 5.2%. These target ranges of composition of young cheese can be used to select cheeses that have a high probability of having excellent aged cheese quality versus young cheese that does not meet these standards and therefore should not be held for aging based on its composition (Lawrence and Gilles, 1980). However, the overall economic performance of a cheese factory is a balance between cheese yield and quality, thus a factory will target the highest possible moisture and salt that will give aged cheddar of acceptable quality.

There are no legal limits in cheddar cheese standard of identity for salt and pH. The target values for these will be decided by values for these parameters that give the optimum quality aged cheddar cheese. Reasonable default values for these parameters are provided in Table 2.3. The salt-in-moisture ratio in dry-salted cheese is partially responsible for control of the final pH of the cheese, degradation of lactose, and activity of the residual chymosin (Lawrence et al., 1987). The salt-in-moisture is calculated in the spreadsheet by the cheese salt (%) / cheese moisture (%) x 100. From the salt-in-moisture required for good quality long hold cheddar, a corresponding target salt on a wet basis can be calculated.

Mozzarella Cheese. The cheese default worksheet contains similar information for mozzarella as it does for cheddar with the target values of moisture, fat, FDB, whey draining pH, 4-day cheese pH, and salt, plus the calculated SEF, target FDB, calcium phosphate retention factor, and percentage salt in the moisture phase of the cheese for up to 30 types of Mozzarella cheese. The target moisture for mozzarella is much higher than cheddar with a target value of 48% for the part skim mozzarella used in this example (Table 2.3). Additionally, the target fat recovery in the cheese for each cheese type needs to be entered by the user. Fat losses during mozzarella production (i.e., pasta filata style cheese) are higher than those in cheddar and are largely due to the stretching step. Barbano et al. (1994a) found that cheese yield efficiency increased with increasing stretching temperature due to increased fat recovery; these conditions also impacted the functional properties of the cheese (Renda et al, 1997). Rudan et al., (1999) reported total fat recoveries for a low moisture part skim Mozzarella between 84 and 85%. Generally, default targets for fat recovery in the cheese for pasta filata cheeses should be in the range of 85 to 90% depending on the stretching conditions and equipment used for stretching.

Modification of the Spreadsheet by the User

The default parameters defined and illustrated in Tables 2.1, 2.2, and 2.3 are adjustable by the user of the spreadsheet. Thus, the yield and composition control evaluation system can be adjusted by a knowledgeable user to adapt the system to use with other cheese varieties. The user will need to understand the meaning of various cheese variety specific parameters in the cheese yield equation. Explanation of these factors in the current paper will hopefully provide the reader with the understanding needed to develop appropriate adaptations for other cheese varieties.

Daily Input Data by Vat

The daily input worksheets (same for cheddar and mozzarella) contain multiple input variables that allow the use of formulas to calculate values for yield parameters, fat recovery, weights of cheese lost or gained, and composition control. The input variables are listed in order in Table 2.4, along with default values for the pasteurized long hold cheddar and part skim mozzarella examples. The user enters the physical vat number, which allows the worksheet to track performance of each individual physical vat and enables the detection of mechanical problems unique to one vat that may influence cheese composition or fat loss.

Table 2.4. Daily input data for long hold cheddar and low moisture part skim (LMPS) mozzarella cheese produced and input data by vat

Input Parameter		
Cheese type	Long hold cheddar	LMPS mozzarella
Daily Batch Number	1-40	1-40
Physical vat ID	1-6	1-6
Cheese type	Long hold cheddar	LMPS mozzarella
Starter type	A2(Bulk)	I460 (Direct)
Starter weight (kg)	127.01	0.45
Milk amount (kg)	31,297.85	21,092.03
Milk volume (L) or weight (kg)	31,297.85	21,092.03
Milk weight (kg)	31,297.85	21,092.03
Water weight (kg)	151.50	26.44
Milk + starter fat (%)	3.67	2.22
Milk + starter protein (%)	3.05	3.00
Milk + starter casein (%)	2.5	2.46
Whey fat (%)	0.17	0.22
Cheese moisture (%)	37.5	48.0
Cheese fat (%)	33.3	20.2
Cheese FDB (%)	53.29	38.85
Cheese salt (%)	1.75	1.75
Cheese salt-in-moisture (%)	4.67	3.65
Draining pH	6.3	6.21
Mill pH	5.3	5.16
4 day cheese pH	5.08	5.18

Cheese Type and Starter. Next the user designates the type of cheese being produced, the starter type, and the starter weight. Designating the type of cheese allows the worksheet to track all the vats creating that type of cheese to come up with average yield values for that day. Similarly, designating the starter type allows the worksheet to track vats using the same starter and allows the user to recognize when one starter culture is consistently associated with off target values for moisture and pH.

Milk Plus Ingredient Weight. The weight of water (i.e., to dilute rennet, calcium chloride, and to flush lines for automated delivery of the ingredients directly to the vats) added per vat becomes important later in evaluation of cheese and whey factory performance because added water directly impacts the amount of energy used to concentrate and dry the whey. The amount of added water can be surprising large in some factories. Milk amount is entered in the daily worksheet and can be entered as weight or volume. If the milk amount is entered in volume, the worksheet will convert the volume to weight using the volume to milk weight conversion factors described above and entered in the milk and whey default worksheet based on USDA weight volume conversion equations (USDA, 1965). Generally, in-line meters are used to measure the volume or weight of milk plus starter going into each vat. There are several types of meters that are currently used to measure milk weight and knowledge of the principle of operation and calibration of meters is useful to ensure accurate results. The two general types of meters are volume meters and mass flow meters.

Volume Flow Meters. Turbine flow meters use mechanical energy of the fluid to turn a rotor. The bladed rotor is designed to cut through the fluid with each revolution representing a calculable volume (Baker, 2000, Chapter 10 – Turbine and Related Flowmeters). Rotor rotation is approximately proportional to volume flow in the pipe (White, 2011). Milk weight is calculated by multiplying the temperature corrected weight per volume of liquid by the total volume measured by the meter. The correct volume to weight conversion factors need to be entered into the memory of the meter for the specific product being measured. However, if the cheese factory is making many different types of cheeses with and without added skim solids for fortification, this becomes a challenge for a meter where only one volume to weight conversion factor is used. In this case it may be better to report volume and enter it into the spreadsheet and allow the spreadsheet to use an appropriate volume to weight conversion factor. Turbine meters provide precision, corrosion resistance, intrinsic safety, good temperature and pressure rating, ease of installation, rapid response, and are accurate to ± 0.25% (Baker, 2000; White, 2011). However, turbine meters are sensitive to fluids that have particles in them which may affect calibration (Baker, 2000). Cavitation can occur when local pressure drop below the vapor pressure of the liquid and in increased volume from the two-phased flow. This increased volume causes an over-reading from the meter. It is recommended that the pressure downstream of the meter be at least 1 bar above atmospheric pressure to avoid cavitation (Baker, 2000).

Another common flowmeter is the magnetic flow meter. Magnetic flowmeters measure the velocity of conductive liquids in pipes and report volumetric flow. Appropriate conversion of volume to weight needs to be done specifically for the temperature and density of the fluid being measured. A magnetic field is applied to the metering tube, which causes the induction of voltage across the conductor, results in a potential difference proportional to the flow velocity perpendicular to the flux lines (Baker, 2000, Chapter 12 – Electromagnetic Flowmeters). The operation of a magnetic flowmeter is based on Faraday's Law, which states that as voltage induced across a conductor moves across a magnetic field it is proportional to the velocity of the conductor (Baker, 2000). Advantages of the magnetic flow meter are the linear response and the lack of the moving parts. The major disadvantage is its limitation to conducting liquids only, but this is not a problem for dairy fluids.

Mass Flow Meters. Unlike flow meters that measure volume, Coriolis meter measurements are directly proportional to the mass flow based on the principle of Coriolis acceleration (Baker, 2000, Chapter 17 – Coriolis Flowmeters). Anklin et al. (2006) reviewed recent advances in Coriolis meter design. The mass flow meter does not measure the volume per unit time (e.g., cubic meters per second) passing through the device; it measures the mass per unit time (e.g., kilograms per second) flowing through the device. Volumetric flow rate can be calculated by the mass flow rate divided by the fluid density. The flow enters a double-loop, double-tube arrangement, which is electromagnetically vibrated at a high natural frequency, or harmonic of the natural frequency (Baker, 2000; White, 2011). The opposite forces on the two sides of the tube result in the near side of the tube being forced down and far side is forced up when liquid flows through the tubes. The transit time of the two halves of the tube past the mid-plane are measured by sensors and the difference is related to the mass flow through the tube (Baker, 2000). One of the advantages of Coriolis meters is that they measure mass flow as opposed to volumetric flow. Additionally, they are compact, require little maintenance, have a sanitary design and have high accuracy (Baker, 2000). Coriolis meters with an accuracy for liquid measures of 0.05% are readily available (O'Banion, 2013). However, a disadvantage is the high initial cost (Baker, 2000).

Milk and Whey Composition. Next the user enters the measured fat and protein concentration in the milk plus starter for each vat of cheese. The milk fat and true protein **(TP)** values are typically data from a mid-infrared milk analyzer. Because infrared analyzers are a secondary measurement, it is important to ensure that they are calibrated correctly, as explained by Barbano and Clark (1989). The accuracy of reference values used to calibrate is an important factor in determining the accuracy of analytical values produced by the instrument (Barbano and Lynch, 2006).

Generally, MIR milk analyzers are calibrated for testing milk without starter culture. The milk sample is usually collected at the point when the vat is nearly full of milk. Because the milk is agitated, it is relatively easy to get a representative sample. However, the vat milks also contain starter culture that produces lactic acid. The lactic acid produced by the starter causes the milk pH to decrease, thus changing the sample's MIR absorbance spectrum and interfering with predicted values for fat and protein. Barbano and Dellavalle (1987) acidified milk with acetic or phosphoric acid (Barbano and Dellavalle, 1987) to precipitate casein and produce clear filtrates to analyze on a MIR. The difference between the MIR protein readings for milk minus the protein measured in the filtrate produced an estimate of casein. Barbano and Dellavalle (1987) demonstrated that carboxylic acids (e.g., acetic acid) have a large impact on infrared protein readings. Lactic acid produced by starter culture growth in milk will have a similar impact on infrared protein readings. Injection of CO_2 into milk will also lower milk pH by production of carbonic acid. Ma et al., (2001), reported that CO_2 in milk produced carbonic acid that changed the infrared absorption spectrum of milk and caused the corrected lactose readings to decrease and the fat readings to increase. Milk should be analyzed as quickly as possible after the milk sample is taken to minimize the impact of the starter culture growth and acid production on the fat and protein results. The equation used in the data input portion of the spreadsheet to estimate casein in "milk +starter protein" casein/protein ratio is listed in the milk default value worksheet for the given cheese type. In this example of long hold cheddar, the casein/protein (%) is 82, therefore the casein is calculated by: milk + starter protein x (82/100).

For analysis of whey at draining, a MIR milk analyzer is also commonly used, however some factories use the Babcock test (Hooi et al., 2004, method 15.083). The key parameter that cheese makers are interesting in measuring is usually the fat content of the whey. From the time of cut to the time of whey draining, the concentration of fat in whey decreases. If everything is working properly in the cheese vat, most of the fat lost into whey occurs at the time of cut. As the cut surfaces of the curds heal, further loss of fat should be minimal. During the cooking, whey is being expelled from the curd. Fat is generally retained in the curd unless the stirring in the vat is much too fast. To obtain a representative sample that reflects the fat content of the total volume of whey at draining, the sample should be taken at time of whey draining, not before. Again, like the vat milk, the whey contains starter and the starter is growing and producing acid that will cause MIR milk analyzer readings to change with changing pH. Thus, the whey samples should be tested immediately. It is best to have a separate calibration of the infrared milk analyzer specifically for whey.

Cheese Sampling and Composition Analysis

Sampling Cheddar. Liquids (i.e., vat milk and whey at draining) are relatively easy to mix and remove a representative sample. Sampling solid materials is more of a challenge if they are not homogeneous. Generally, blocks of cheese are not homogeneous, both within one vat of cheese and within one block of cheese. In large cheese factories today, it is not uncommon for one vat of milk to produce 2200 to 3200 kg of cheese. The distribution of components within a block of cheese can vary both randomly and systematically, within and among blocks of cheese from the same vat. To obtain a representative sample of cheese the analyst needs to understand both the nature and degree of random and systematic variation in composition with the vat of cheese and within blocks of product to be sampled. The nature of the systematic variation can be different depending on the size of the cheese block (18 versus 290 kg blocks) and conditions of manufacture (milled curd versus stirred curd). Within cheddar cheese blocks, moisture migrates as a function of the temperature gradient (Reinbold et al., 1988, Reinbold et al., 1992; Olabi and Barbano, 2002) from the center (warm) to the surface (cold) during cooling. This creates a systematic variation in moisture with in the block (Barbano, 2001). The gradient of moisture content in 290 kg blocks can produce a range of moisture from the center (low) to all surfaces (high) of the block of about 5% with a nonsymmetrical but systematic distribution (Barbano, 2001) that will also influence flavor and texture development (Carunchia Whetstine, et al., 2007). Given this distribution, the impact of cheese sampling core position and length within a 290 kg block of cheddar on estimation of moisture was described (Barbano, 2001). Composition gradients within direct formed smaller blocks (i.e., 18 kg) of cheddar cheese are less severe, however there are different challenges in a factory environment when sampling small blocks. There will be a systematic variation in moisture from the first to the last block of cheese (270 to 400 blocks per vat) from the same vat. A statistically based sampling standard operating procedure should be used to achieve representative sampling based on known systematic and random variations in composition. Once a core of cheese is removed from the block, the post sampling handling of the cheese can also influence moisture test (Emmons, et al., 2000) due to moisture loss.

Sampling Mozzarella. Brine salting produces Mozzarella cheese with heterogeneous chemical composition (Kindstedt et al., 1992; Kinstedt, 2001). Similar systematic nonuniformity in cheese composition is observed in other types of brine salted cheeses and can be influenced by brine concentration and pre-salting (Melilli et al., 2003b), brine temperature (Melilli et al., 2003a), and the interactions of these factors (Mellili et al., 2004a, 2006). These variations will cause different enzymatic actions that produce differences in cheese flavor and texture (Melilli et al., 2004b, 2005). Additionally, variation in size and shape of the cheese can affect the homogeneity (Guinee and Fox, 1986). Gradients of salt and moisture within the cheese can make representative sampling problematic. In order to avoid the problems associated with brine salting, Barbano et al. (1994b), developed a no-brine, method for making low-moisture part-skim mozzarella with homogenous composition. If sampling a brine-salted mozzarella, extra care must be taken to ensure that a representative sample is taken (Kindstedt, 2001). Taking a cross sectional slice of a loaf of Mozzarella and grinding the slice, or dicing the complete loaf and mixing the dice to select random pieces to grind are approaches that can be used to help achieve representative sampling (Kindstedt, 2001). The optimum sampling design will vary from factory to factory depending on the size of the loaves and the characteristics of the systematic nonuniformity of composition of cheese produced in that factory. Similar within vat variations in Mozzarella cheese composition occur, as in cheddar, for large vats of mozzarella. The analytical method for cheese analysis can be no better than the representativeness and quality of the sample used for composition analysis.

Moisture Analysis. Theclassical reference methods for determination of the moisture content of cheese are thermal oven drying methods. Typically, a forced air oven (Hooi et al., 2004, method 15.114**)** or a vacuum oven method (Hooi et al., 2004, method 15.111) is recommended. A detailed study of both vacuum oven and forced air oven methods identified critical parameters on both methods with respect to hardware, drying time/temperature, and sample handling (Bradley and Vanderwarn, 2001). However in a commercial quality assurance laboratory, the classical reference methods for moisture determination (and for other cheese components) are often too slow and labor intensive in the context of today's large-scale, fast-paced commercial factories. Therefore, rapid methods such as microwave total solids and near infrared (NIR) cheese analysis are more common in routine quality assurance laboratories.

Microwave determination of moisture content of cheese is dependent on the microwave absorptivity of the sample and therefore microwave drying conditions (sample size, microwave power, drying time) for each type of product needs to be determined by comparison to results from a vacuum oven or forced air oven reference method (Barbano and Dellavalle, 1984). Samples with high salt content absorb a different amount of energy per unit of time than samples with low salt content and therefore require different drying times (Barbano and Dellavalle, 1984). Samples with higher salt content dry more rapidly in a microwave oven.

NIR has become common for a rapid method for cheese moisture and fat analysis. The NIR regions are a mixture of overtones and a combination of fundamental frequencies in the MIR region (McKenna, 2001). While NIR analysis of cheese is easy to use, the calibration and accuracy of the method can be a challenge. NIR is a secondary method that requires calibration against primary reference methods for each component (e.g., moisture and fat) and usually requires a large number of samples (i.e., 200 to 400) from each specific cheese type produced within the same factory to calibrate (McKenna, 2001; Barbano and Lynch, 2006). McKenna (2001) describes how several different forms of the PLS technique exist for creating calibration equations. NIR spectra can be quite complex and calibration of NIR instruments can be a challenge. Cheese samples are grated, diced, or packed into a sample cup and then positioned in front the monochromator beam. The sample is rotated in the beam and several measurements are taken (McKenna, 2001). Because factory laboratories are not routinely running reference chemistry testing, the analytical accuracy of reference values produced in a cheese factory laboratory for PLS modeling may not be the best, and the range of variation in cheese composition in the factory may be small and not adequate for developing a good calibration model. This will lead to within cheese factory development of weak NIR models for cheese analysis. This is unfortunate given the economic importance of the accuracy of cheese analysis results for process control. There is a need for more robust and accurate routine methods for determination of the composition of cheese that are not cheese type specific and that could be the same from one factory to another.

Fat Analysis. The reference methods for fat determination in cheese are the Babcock and Mojonnier ether extraction methods. The Mojonnier method (Hooi et al., 2004, method 15.086) has been shown to be more precise than the Babcock and therefore is widely accepted as a more accurate method (Hooi et al., 2004, method 15.081). The free fat is collected in the graduated portion of the neck of the Babcock flask (Hooi et al., 2004, method 15.083). For cheese analysis, the sample should be shredded using a grater or blended prior to testing. The principle of the Babcock method is that concentrated sulfuric acid is mixed with the sample to create an exothermic reaction that releases fat from the cheese structure (Barbano, et al., 1988; Hooi et al., 2004, method 15.083). The free fat is collected in the graduated portion of the neck of the Babcock flask. Additionally, the full digestion of the cheese may take longer to release the fat than the same method on a milk sample.

The principle of the gravimetric Mojonnier method is an extraction of fat from a sample using ethanol, ethyl ether, and petroleum ether. The ether-fat mixture is decanted into dried weigh dishes and the ether is evaporated and the pans plus fat residues are dried (Hooi et al., 2004, method 15.086). The difference in the weight of the pan before extraction, and after evaporation is calculated to determine the fat content of the cheese .The cheese must be completely dissolved to achieve complete recovery of fat from the cheese. Various techniques are used to assist digestion, such as the addition of 60^{o}C water, an increase in the amount of added ammonium hydroxide, and extended shaking times. It is suggested that the sample size not exceed 10g and fat content be between 0.3 to 0.6 g. It is important to note that if the cheese contained a stabilizer or emulsifier that is soluble in ether, the Mojonnier test may yield erroneous results.

Nuclear magnetic resonance (**NMR**) can also be used to measure fat in foods. Maher and Rochfort (2014) reviewed applications of NMR in dairy research. Single sided NMR has been applied to analysis of fat content of foods (Guthausen et al., 2008) and a method for determination of fat in dairy product has been reported (Cartwright et al., 2005).

Salt Analysis. Cheese salt can be determined used the Volhard method (AOAC, 2000, method number 935.43) and this is considered the reference method. The coulometric method is a rapid method for salt determination based on the principle of coulometric titration. Coulometry measures the amount of electricity needed to complete an oxidation or reduction reaction (Varcoe, 2001). In this method, an electric potential is applied across two silver electrodes. Silver ions are generated at the anode and interact with chloride ions in solutions, forming insoluble silver chloride (Varcoe, 2001). Silver ions are added to the solution at a constant rate and when all of the chloride has reacted, the silver ions increase in concentration (Varcoe, 2001). When the electrodes sense this change in silver ion concentration, the titration is stopped (Hooi et al., 2004, method 15.053). Hooi et al. (2004, method 15.053) describes the procedure of determining chloride content in milk and cheese samples. Cheese requires an addition of nitric acid to assist in releasing the chloride ions, followed by filtering the sample to remove suspended particles (Hooi et al., 2004, method 15.053). The salt-in-moisture is calculated in the spreadsheet by the cheese salt (%) / cheese moisture (%) x 100.

Whey pH at Draining, Curd Milling pH, and Final Cheese pH. One method of pH measurement in cheese is using a gold/quinhydrone electrode (Hooi et al., 2004, method 15.024). The method uses an electrode to measure oxidation and reduction potentials of samples, which is related to pH values. The meter is calibrated with buffers of known pH values that correspond to specific millivolt readings at specific temperatures (Hooi et al., 2004, method 15.024).

All pH meters use the difference between the potential of a hydrogen ion-sensitive electrode, and a non-sensitive reference electrode, to determine the pH of a solution (Mettler-Toledo, 2007). There are several types of electrodes and selection of an electrode is dependent on the chemical composition, homogeneity, temperature, and pH range of the sample (Mettler-Toledo, 2007). The ceramic junction electrode is suitable for standard measurements in aqueous solutions. It is one of the most widely used junctions because of its simplicity but its main drawback is that the porous structure of the junction makes it relatively easy for organic material to block the junction. Additionally, samples with a high protein concentration can have protein precipitation occur if they come in contact with the reference electrolyte, which is often KCl (Mettler-Toledo, 2007). Because of these considerations, the ceramic junction electrode is not advisable for cheese samples.

An open junction electrode allows the reference electrode to have complete contact with the sample. This is possible because of the solid-state polymer reference electrolyte (Mettler-Toledo, 2007).

Disadvantages of this type of electrode include slower reaction times and low electrolyte flow, making it difficult to measure the pH of samples with low ion concentrations. However, because this electrode is completely open, it seldom clogs, making it an ideal candidate for pH testing of a solid food such as cheese (Mettler-Toledo, 2007).

To calibrate a pH meter, first the electrodes must be immersed in a buffer solution of known pH (Sadler and Murphy, 1998). The temperature of the electrode, sample, and calibration buffers should be the same (e.g., if the cheese temperature in process is 38^{o}C). One cause of unstable (i.e., drifting) pH results occurs when the temperature of the electrode body is different than the temperature of the sample. Until the electrode and sample reach temperature equilibrium, the pH reading will drift. Drift can be avoided by having the electrode storage solution (e.g., KCl) and buffer solutions at the same temperature as the sample. The pH values of the calibration buffers are temperature dependent and there is a table on the label of the pH buffer solution container. Temperature sensitivity of pH reference buffer solutions may be different from one manufacturer to another. The correct pH of the reference buffer for the sample temperature should be used for pH meter calibration and reference values may differ from one buffer manufacturer to another. For cheese, a two-point calibration (typically pH 4 and 7) is recommended and electrode efficiency should be 95 to 102% (i.e., slope 0.95 to 1.02) (Hooi et al., 2004, method 15.022).

The sample pH, particularly with milk, is also temperature dependent due to temperature dependent mineral equilibria with pH of milk at 4^{o}C being about 6.85, at 32^{o}C about 6.65, while at the 80^{o}C, the pH of the same milk can be as low as 6.25 (Ma and Barbano, 2003). The most accurate calibration is achieved when using at least two different buffer solutions, which enables the zero pH and the slope (sensitivity) to be determined (Sadler and Murphy, 1998; Hooi et al., 2004, method 15.022). pH measurements are based on the Nernst equation, which contains a temperature dependent variable.

Because of this, pH instruments have either automatic or manual compensation for change of pH due to changes in temperature response of the electrode (Sadler and Murphy, 1998). However, automatic temperature compensation of the pH meter does not account for the temperature dependent change in pH of calibration buffers or in the sample (e.g., due to temperature dependent changes in mineral equilibria in milk that change pH). The pH values at whey draining and curd milling have important impacts on yield and quality and will be discussed later. Typical default pH values for long hold cheddar and low moisture part skim mozzarella made from unfortified milks that achieve the output yield efficiency, fat recovery and composition targets can be found in Table 2.4.

Daily Input Data for Total Cheese Produced in a Day by Cheese Type

The spreadsheet tracks all of the vats of a given cheese type made on a single day. The user inputs the cheese type, total weight of the cheese produced on that day, and the spreadsheet counts the number of vats made (Table 2.5). Today's electronic load cell based balances are very robust and accurate and generally the reported weight of cheese for the day has minimal uncertainty. The spreadsheet then divides the total amount of cheese made by the number of vats to approximate the weight of cheese per vat for each type of cheese in that day. The daily weight of cheese lost to the floor is also recorded by the user to account for losses during production.

Table 2.5. Daily input data for long hold cheddar and low moisture part skim (LMPS) mozzarella cheese produced in total for the day

Input Parameter		
Cheese type	Long hold cheddar	LMPS mozzarella
Weight of cheese produced (kg)	96,715	60,595
Number of vats made	30	30
Cheese weight per vat (kg)	3,224	2,020
Daily weight of cheese lost to floor (kg)	0	0

Daily Output Data by Cheese Type

Milk Composition and Weights. An example of the mean output data for all vats of cheese of a cheese type (e.g., long hold cheddar and low moisture part skim mozzarella) for milk composition and weights for one day is shown in Table 2.6.The calculated values in Table 2.6 are derived from the default values in Tables 2.1, 2.2, and 2.3 for each type of cheese and the input values by vat of cheese in Tables 2.4 and 2.5. If more than one cheese type is produced on a given day, multiple columns of output data will be generated, one for each cheese type made on that day. The weighted average (based on milk weight in each vat) for fat and casein content of milk + starter for each cheese type is calculated**.** The casein-to-fat ratio is the ratio of average milk casein to average milk fat for each cheese type. The weight of milk + starter + water is the total weight of milk, starter, and water used during production and is calculated by summing the total weight of milk, weight of water and weight of starter for all vats within each cheese type produced on that day. The percent starter used is the total weight of starter divided by the total weight of milk, multiplied by 100. The cheese weight is the total weight of cheese produced and is the sum of the weight of cheese produced in each vat for each cheese type that day. The estimated whey weight at whey draining is calculated by taking the difference of the total weight of milk + starter + water used and the total cheese weight produced for each cheese type each day.

Table 2.6. Example of daily data output for long hold cheddar and low moisture part skim (LMPS) mozzarella cheese for milk, whey, and cheese composition, fat recovery, theoretical yield, cheese yield efficiency and the impact of cheese composition control on cheese yield by type of cheese made in the day

Milk composition and weights	Long hold cheddar	LMPS mozzarella
Average fat content of milk + starter (%)	3.674	2.224
Average casein content of milk + starter (%)	2.501	2.460
Average casein-to-fat ratio	0.681	1.106
Weight of milk + starter + water (kg)	947,291	633,567
Weight of starter (kg)	3,810	14
Weight of milk (kg)	938,935	632,761
Weight of water (kg)	4,545	793
Starter as a percentage of milk (%)	0.406	0.002

Weight of cheese (kg)	96,715	60,595
Estimated weight of whey at draining (kg)	850,576	572,972
Cheese yield: milk + starter + water		
Yield parameter: solute exclusion factor	0.696	0.845
Yield parameter: calcium phosphate retention factor	1.092	1.090
Yield parameter: A	3.417	1.934
Yield parameter: B	2.622	2.572
Yield parameter: C	0.163	0.299
Actual yield (%)	10.21	9.56
Moisture and salt adjusted yield (%)	10.21	9.56
Theoretical yield (%)	10.21	9.56
Cheese yield: milk		
Yield parameter: solute exclusion factor	0.696	0.845
Yield parameter: calcium phosphate retention factor	1.092	1.090
Yield parameter: A	3.447	1.937
Yield parameter: B	2.646	2.576
Yield parameter: C	0.164	0.300
Actual yield (%)	10.30	9.58
Moisture and salt adjusted yield (%)	10.30	9.58
Theoretical yield (%)	10.30	9.58

Cheese Yield: Theoretical, Moisture and Salt Adjusted, and Actual. Yields are calculated both on a milk plus all ingredients basis and a milk only basis, because different companies prefer one of these options. Both are included in the output section of the daily report. Example data for long hold cheddar and mozzarella cheese are provided in Table 2.6. In the cheese yield section of the daily output, the spreadsheet calculates the variables needed in the Barbano theoretical cheese yield equation (Metzger et al., 2000). The solute exclusion factor is calculated by SEF = 0.0142x +0.1631 where x = cheese moisture (%) (Neocleous et al., 2002*)* and default values of 0.7 and 0.84 (Table 2.3) were used for long hold cheddar and mozzarella cheese, respectively. A value of 1.092 for calcium phosphate retention factor is recommended for whey draining between pH 6.1 and 6.4 (Metzger et al., 2000) and that value (Table 2.3) was used for both cheddar and mozzarella. Barbano theoretical cheese yield parameter A (i.e., best case fat recovery in the cheese) is equal to the best practice percentage of fat recovery in cheese multiplied by the actual percent fat in milk or milk plus starter. In this case, 93% and 87% were used for fat recovery for cheddar and mozzarella, respectively (Table 2.3). Barbano yield parameter B (i.e., best case casein plus mineral recovery in the cheese) is the (percent casein in milk – 0.1) x (bound calcium phosphate retention factor) using calcium phosphate retention factors (Table 2.3) that are described above. Colloidal calcium phosphate is solubilized faster as pH drops between 5.6 and 5.0 (van Hooydonk et al., 1986; Dalgleish and Law, 1989). Calcium is lost to the whey more rapidly than phosphate as whey pH decreases, which decreases the calcium to phosphate ratio (Kindstedt and Kosikowski, 1988). Thus, the calcium phosphate retention factor needs to be adjusted for different pH of the curd at whey draining (Metzger et al., 2000). Lastly, Barbano yield parameter C (i.e., the retention of nonfat, noncasein milk solids including the glycomacropeptide and soluble calcium phosphate in the water phase of the cheese) is [((A+B)/(1-actual cheese moisture percent/100)) – (A+B)] x (separated whey solids percent/100) x (solute exclusion factor). The separated whey solids and solute exclusion factor are specified for each type of cheese, as shown in Tables 2.2 and 2.3, respectively. The actual yield is calculated by dividing weight of cheese produced by the total weight of milk, starter, and water. Moisture and salt adjusted yield is calculated by [Actual yield x (100% – actual moisture – actual salt)] / (100% – target moisture – target salt). Finally, the Barbano theoretical yield is calculated by the equation (A+B+C)/(1 - ((target cheese moisture + target cheese salt) /100)).

Fat Recovery and Yield Efficiency. Percentage of total fat recovered in cheese is calculated by (total weight of cheese x cheese fat (%))/((weight of starter+weight of milk) x (average fat content of milk + starter/100)) and is compared to the target fat recovery in the cheese (Table 2.7). For the example of long hold cheddar, the target used is 93% (Van Slyke and Publow, 1909). The average fat in whey at draining is calculated by averaging the values for whey fat for all vats of the given cheese made on that day. This is an important parameter for monitoring process control to ensure that large losses are not occurring. Percentage of total fat recovered in whey at draining is calculated by (Average whey fat at draining x estimated weight of whey at draining)/((average fat content of milk + starter/100) x (weight of starter + weight of milk)). This parameter takes into account the fat content of the milk. It would be expected that the average fat in the whey at draining would be variable depending on the fat content of the milk and casein to fat ratio. Poor coagulation, cutting, and rough handling of the curd will cause higher fat loss in the whey at whey draining (Barbano and Sherbon, 1984). The percentage of total fat lost after draining is calculated by 100 minus the percentage of total fat recovered in cheese plus the percentage of total fat recovered in whey. This equation assumes that all fat that is not in the cheese or recovered in the whey is lost after draining. The above calculation will always add to 100%, so it does not reflect a true mass balance accounting, as can be achieved in research studies on cheese yield (Barbano and Rasmussen, 1992, Rudan et al., 1999; Metzger et al., 2000). A complete mass balance accounting (measuring and adding together the weight of fat in cheese, whey cream, and whey product to determine if the sum is equal to 100%) in a large cheese factory is difficult to do in practice. Ideally, one would measure the weight of fat in the cheese, whey cream, and separated whey for the day to determine if the sum equals 100% of the weight of fat that was present in the milk, within expected analytical uncertainty. If the total accountability is much lower or much higher than 100%, then there is a problem with the accuracy of one or more of the fat measurements, or the estimation of milk weight. In practice, factories often do not have accurate weights of whey cream produced for the day, so this metric was not included in the evaluation system presented in this paper. Cheese yield efficiency can be calculated on moisture and salt adjusted yield basis by ((moisture and salt adjusted yield based on milk + starter x 100)/Barbano theoretical yield based on milk + starter), or on actual yield basis by ((actual yield based on milk + starter x 100)/Barbano theoretical yield based on milk + starter).

Table 2.7. Daily output for fat recovery, yield efficiency, composition control, and yield loss or gain for long hold cheddar and low moisture part skim (LMPS) mozzarella

Parameter	Long hold cheddar	LMPS mozzarella
Fat recovery		
Percentage of total fat recovered in cheese (%)	93.00	87.00
Target fat recovery in cheese (%)	93.00	87.00
Average fat in whey at draining (%)	0.17	0.22
Percentage of total fat recovered in whey at draining (%)	4.17	8.96
Percentage of total fat lost after draining (%)	2.83	4.04
Cheese yield efficiency		
Efficiency based on moisture and salt adjusted yield (%)	100	100
Efficiency based on actual yield (%)	100	100
Composition control		
Target fat on dry basis (%)	53.29	38.85
Actual fat on dry basis (%)	53.29	38.85
Fat on dry basis standard deviation (vat-to-vat variation) (%)	0.00	0.00
Fat gain or loss due to deviation from target (weight)	0.00	0.00
Target moisture (%)	37.5	48.00
Actual moisture (%)	37.5	48.00
Moisture standard deviation vat-to-vat variation (%)	0.00	0.00
Moisture gain or loss due to deviation from target (weight)	0.00	0.00
Target salt (%)	1.75	1.75
Actual salt (%)	1.75	1.75
Actual salt-in-moisture (%)	4.67	3.65
Salt standard deviation (vat-to-vat variation (%)	0.00	0.00
Salt gain or loss due to deviation from target (weight)	0.00	0.00
Target fat on wet basis (%)	33.31	20.20
Actual fat on wet basis (%)	33.31	20.20
Fat on a wet basis standard deviation (vat-to-vat variation) (%)	0.00	0.00
Target 4 day cheese pH	5.05	5.15
Actual 4 day cheese pH	5.08	5.18
pH standard deviation (vat-to-vat variation)	0.00	0.00

Composition Control. The compositional control section lists several parameters (FDB, moisture, salt, fat on wet basis, and target cheese pH) that relate to compositional targets for each parameter (Table 2.7). The standard deviation for vat-to-vat variation for FDB, moisture, salt, fat on a wet basis, and cheese pH are calculated for each cheese type as follows: standard deviation is $\sigma = \sqrt{[\sum(x_i - x)^2 / N]}$ where σ is the standard deviation, x_i is the value for the parameter of interest for a specific vat, x is the target value for the parameter, and N is the total number of vats. Additionally, the average salt-in-moisture is calculated by (salt in cheese/cheese moisture x 100), averaged for all vats for each cheese type on the particular day. The salt-in-moisture ratio in dry-salted cheese is a factor that affects final cheese pH, degradation of lactose, and activity of the residual chymosin during cheese aging (Lawrence et al., 1987). The weight of cheese yield losses or gains due to mean deviation from the target FDB, moisture, and salt are calculated for each type of cheese on a processing day using the following equations: ((Actual FDB - Target FDB)/100) x (weight of cheese – (actual moisture x weight of cheese/100)); (Actual moisture x weight of cheese/100) – (target moisture x cheese weight/100); and ((Actual salt – target salt)/100) x cheese weight), respectively. The information can be used to calculate the economic impact of lack of composition control by multiplication of the weight of cheese loss or gain by the value per unit weight of cheese.

The average 4-day cheese pH is also recorded to compare with the target 4-day cheese pH. The whey pH at draining affects the rate of mineral loss in the curd and a lower whey pH at draining will reduce mineral content and the buffering capacity of the cheese. Varying the whey draining pH will vary the loss of minerals from the curd in the whey thus reducing calcium phosphate retention in the cheese and influencing the final cheese pH and the basic structure and texture of the cheese (Lawrence et al., 1983; Lawrence et al., 1984). Young cheese has a high buffering capacity between pH 5.5 and 4.5 (Dolby, 1941; Lucey, 1992). The buffering potential of cheese is strongly determined by the concentrations of undissolved calcium phosphate, casein, and lactate. The rate of acid production and the pH of whey at draining determines the extent of solubilization of colloidal calcium phosphate from the casein micelles, and therefore its contribution to cheese yield and to buffering capacity during cheese manufacture (Lucy and Fox, 1993).

Data Interpretation

Daily Output Summaries. Once data input is complete, data interpretation for yield performance and composition control can begin. In the beginning of data interpretation, we assume that all weight and composition data are correct. The first step is to compare the moisture and salt adjusted yield to theoretical yield. If they are equal, then the recovery of fat, casein, and noncasein, nonfat milk solids is equal to theoretical expectations. Moisture and salt adjusted yield eliminates the effect of not meeting the salt and moisture targets on cheese yield. If moisture and salt adjusted yield is lower than theoretical cheese yield, then there may be a higher loss of fat, casein, or nonfat, noncasein milk solids than expected. If the cause of the lower than expected cheese yield is due to fat loss, then the percentage fat recovery in the cheese may be lower than target (i.e., 93% for cheddar). Use of a cream separator to standardize fat level of milk prior to cheese making may cause damage to native milk fat globules and lower fat recovery in the cheese from 93 to 90% (Nelson and Barbano, 2005). Next, one would look at the proportion of the fat lost before and after whey draining. In cheddar, with excellent conventional cheese making technology it is normal to lose about 4.5% of the milk fat in the whey at draining and about 2.5% after draining. If the fat loss is about 4.5% up to whey draining but the fat loss after whey draining is 5%, then the focus of efforts to reduce fat and yield losses needs to be on the steps in the cheese making process after whey draining. Other possible causes of low moisture and salt adjusted cheese yield (i.e., low cheese yield efficiency) would be high loss of casein due to either excessive loss of curd fines or very low curd pH at whey draining that would reduce the calcium phosphate retention in the cheese. It would be unusual to have a high loss of curd fines without having low fat recovery in the cheese. If moisture and salt adjusted yield efficiency is close to 100% but actual yield efficiency is lower that 100%, then it is likely that there is a moisture, fat, or salt control problem and these composition parameters are lower than the target.

If the moisture and salt adjusted cheese yield efficiency is much greater than 100%, it is possible that there is a source of error in the milk weight, cheese weights, or cheese composition data. If proper type and control of the milk and cheese weighing hardware has been done, then it is more common for the source of error to be due to either non-representative sampling of the cheese (as described above) or systematic bias in cheese moisture, fat, or salt analysis. Using the data collection and analysis procedures described above, identification of sources of error will assist in ensuring that the *correct* problem is addressed and that an accurate evaluation of cheese yield performance is achieved.

Monthly Output Summaries.There is an output data summary (i.e., worksheet) for each cheese type. The monthly output summaries follow the same format as the daily summaries, as outlined in Tables 2.6 and 2.7, with a column in the summary worksheet for each day of the month within each cheese type. The monthly summaries contain weighted averages across all days of production of all of the vats of each cheese type made in the entire month. From this, appropriate control charts can be made for each cheese type. The column on the far right of the monthly worksheet for each cheese type contains the weighted average performance for the month.

Yearly Output Summaries. The monthly summary described above for each cheese type can be compiled in a separate workbook to view data over the course of a year or multiple years. Viewing the temporal pattern of changes in yield or composition control that occur over time help cheese factory management to identify changes that are associated with a certain time period, season, or major change in equipment or operational technology in the factory.

Sensitivity Analysis

The spreadsheet data collection system described above was used in a large commercial cheddar and mozzarella cheese factory over a period of one year to better understand the range of variation in composition control under commercial conditions and the challenges due to the uncertainty in various types of data within a cheese factory. Using the experience gained working with large commercial cheese factories, a sensitivity analysis was performed to demonstrate the relative importance and economic impact of accuracy in measurement of fat and protein content of milk, and moisture, fat, and salt of cheese on cheese yield and process control in long hold cheddar and LMPS mozzarella manufacture using the data calculation and summary system described above. Fat and protein content of milk was varied by ± 0.1% in 0.02% increments around the targets of 3.67 and 3.05%, respectively. Moisture and fat content of the cheese were varied by ± 0.5 in 0.1% increments around the target, while the salt content was varied by ± 0.25 in 0.05% increments around the target. The sensitivity ranges used reflect the observed variation in composition control and the range of bias errors observed in composition analysis of milk and cheese based on proficiency testing data. Effects on total cheese yield, as well as other parameters were determined. Systematic organization and tracking of yield information enables cheese factory management to quickly identify places in the process, or in the laboratory, that can improve the financial performance of the business.

Our sensitivity analysis can have two distinct interpretations. The first assumes that that the analytical tests are accurate and the sampling procedure provides a representative sample. If this is the case, the sensitivity tests show the consequences of missing cheese composition targets. Missed targets can be addressed by identification of the causes and making the appropriate corrections to improve the actual yield. The second interpretation provides a scenario where it is determined that the analytical tests were not accurate, or the samples were not representative. In this instance, the sensitivity analysis displays what the analytical and testing biases cost in quality and yield losses.

RESULTS AND DISCUSSION

Sensitivity Analyses Milk Composition

Uncertainty in the accuracy of determination of the fat and protein content of the mixture of milk plus other ingredients has an impact on estimation of the theoretical cheese yield, which is used as the reference point for evaluation of cheese yield performance. Sources of uncertainty were discussed above. The range of values used in the sensitivity analysis reflects the deviations observed in the field in preliminary work with cheese factories (data not shown).

Cheddar. The impact of uncertainty in the measure of milk fat (Table 2.8) and milk protein (Table 2.9) of the milk plus all ingredients in the vat for a cheddar cheese factory are shown when all other input parameters were held constant. The results of sensitivity analyses provided in the tables were produced with the spreadsheet provided as supplemental material with this manuscript. As can be seen in Table 2.8, the uncertainty of $\pm$ 0.1% fat in the vat causes a range of theoretical cheddar cheese yield from 10.05 to 10.37% and an uncertainty of yield efficiency of ± 1.5%. This would equate to about ± 1,489 kg (3,283 pounds) of cheese per day in a factory processing 938,935 kg (2.07 million pounds) of milk per day, as shown in Table 2.8. The value of the weight of cheese (kg multiplied by price per kg) represented by this uncertainty can be used as a guide for management to decide what cost is appropriate to budget for calibration standards and quality assurance proficiency testing to ensure that the milk testing results have an accuracy that is fit for purpose in cheese yield performance evaluation. An example of the performance of a milk analysis proficiency testing scheme was presented by Wojciechowski et al. (2016). In addition, uncertainty in fat content of the milk plus ingredients in the cheese vat produces uncertainty in the estimation of total fat recovery (Table 2.8) in the cheese (i.e., 90.5 to 95.6% fat recovery in the cheese) and in the proportional fat loss before and after whey draining. The default values in the column for 3.67% fat for percentage of total fat loss up to whey draining and after whey draining are good performance guides for cheddar cheese production if a cheddar cheese factory is aiming to achieve 93% fat recovery in the che

Table 2.8. Cheddar cheese milk fat sensitivity with the target fat in the milk being 3.674% fat and sensitivity analysis range of ± 0.1% fat

Milk fat sensitivity (%milk fat)	3.57	3.59	3.61	3.63	3.65	3.67	3.69	3.71	3.73	3.75	3.77
Milk composition and weights											
Average fat content of milk + starter (%)	3.57	3.59	3.61	3.63	3.65	3.67	3.69	3.71	3.73	3.75	3.77
Average casein content of milk + starter (%)	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Average casein-to-fat ratio	0.70	0.70	0.69	0.69	0.68	0.68	0.68	0.67	0.67	0.67	0.66
Weight of milk+starter+water (kg)	947,291	947,291	947,291	947,291	947,291	947,291	947,291	947,291	947,291	947,291	947,291
Weight of starter (kg)	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810
Weight of milk (kg)	938,935	938,935	938,935	938,935	938,935	938,935	938,935	938,935	938,935	938,935	938,935
Weight of water (kg)	4,545	4,545	4,545	4,545	4,545	4,545	4,545	4,545	4,545	4,545	4,545
Starter as a percentage of milk (%)	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Weight of cheese (kg)	96,715	96,715	96,715	96,715	96,715	96,715	96,715	96,715	96,715	96,715	96,715
Estimated weight of whey at draining (kg)	850,576	850,576	850,576	850,576	850,576	850,576	850,576	850,576	850,576	850,576	850,576
Cheese yield: milk + starter + water											
Barbano yield parameter: SEF[1]	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Barbano yield parameter: CPRF[2]	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Barbano yield parameter: A	3.32	3.34	3.36	3.38	3.40	3.42	3.44	3.45	3.47	3.49	3.51
Barbano yield parameter: B	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62
Barbano yield parameter: C	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17
Actual yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Moisture and salt adjusted yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Barbano theoretical yield (%)	10.05	10.08	10.11	10.15	10.18	10.21	10.24	10.27	10.30	10.33	10.37
Fat recovery and yield efficiency											
Total fat recovered in cheese (%)	95.60	95.07	94.54	94.01	93.51	93.00	92.49	92.00	91.50	91.02	90.53
Target fat recovery in cheese (%)	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00
Average fat in whey at draining (%)	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Total fat recovered in whey at draining (%)	4.29	4.27	4.24	4.22	4.20	4.17	4.15	4.13	4.11	4.09	4.06
Total fat lost after draining (%)	0.11	0.67	1.21	1.77	2.30	2.83	3.35	3.87	4.39	4.90	5.40
Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	101.6	101.2	100.9	100.6	100.3	100.0	99.7	99.4	99.1	98.8	98.5
Efficiency based on actual yield (%)	101.6	101.2	100.9	100.6	100.3	100.0	99.7	99.4	99.1	98.8	98.5

[1]SEF = solute exclusion factor.

[2]CPRF = calcium phosphate retention factor

Table 2.9. Cheddar milk protein sensitivity analysis with the target true protein in the milk being 3.05% and sensitivity analysis range of ± 0.1% protein

Milk protein sensitivity (% milk protein)	2.95	2.97	2.99	3.01	3.03	3.05	3.07	3.09	3.11	3.13	3.15
Milk composition and weights											
Average fat content of milk + starter (%)	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67
Average casein content of milk + starter (%)	2.42	2.44	2.45	2.47	2.48	2.50	2.52	2.53	2.55	2.57	2.58
Average casein-to-fat ratio	0.66	0.66	0.67	0.67	0.68	0.68	0.69	0.69	0.69	0.70	0.70
Cheese yield: milk + starter + water											
Barbano yield parameter: A	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42
Barbano yield parameter: B	2.53	2.55	2.57	2.59	2.60	2.62	2.64	2.66	2.68	2.69	2.71
Barbano yield parameter: C	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Actual yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Moisture and salt adjusted yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Barbano theoretical yield (%)	10.06	10.09	10.12	10.15	10.18	10.21	10.24	10.27	10.30	10.33	10.36
Fat recovery and yield efficiency											
Percentage of total fat recovered in cheese (%)	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00
Target fat recovery in cheese (%)	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00
Average fat in whey at draining (%)	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Total fat recovered in whey at draining (%)	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
Total fat lost after draining (%)	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	101.5	101.2	100.9	100.6	100.3	100.0	99.7	99.4	99.1	98.8	98.5
Efficiency based on actual yield (%)	101.5	101.2	100.9	100.6	100.3	100.0	99.7	99.4	99.1	98.8	98.5

It's easy to look at the values in Table 2.8 in the column for 3.57% milk fat and be very happy with a 95.6% fat recovery in the cheese and a total fat loss after whey draining of 0.11%. However, this should be signal to management that something is wrong because based on careful mass balance cheese yield studies (Barbano and Rasmussen, 1992), these values are not realistic for cheddar cheese. A composition adjusted cheese yield that is higher than theoretical yield is also not realistic. In the interpretation of the data, the cheese plant management should be asking what input error could cause this behavior of the data. The answer is that an evaluation of the accuracy of milk analysis is needed. The issue at the other end of the range at 3.77% fat in the milk in Table 2.8 is not as easy to diagnose. The key diagnostic clue that makes the data analyst suspect the milk fat test is wrong is the fact that total fat loss after draining is 5.4% of the total fat used. That is not realistic and if it was true then the volume of whey from salting and pressing should be very high and/or the fat test of that whey should be high. If the amount of whey post draining and fat content of whey post draining are being monitored routinely and have not changed, then it is likely the fat test on the milk is wrong in the high direction. This would also explain the lower apparent fat recovery in the cheese with no change in fat test of the whey at draining or increase in fat on dry basis in the cheese (data not shown).

The sensitivity of theoretical yield and yield efficiency to variation in milk protein measurement uncertainty (Table 2.9) is equal to that of milk fat. The default values in the column for 3.05% true protein in Table 2.9 show theoretical yield and moisture and salt adjusted yield in agreement and all fat recovery values look normal. It easy to look at the values in Table 2.9 in the column for 2.95% milk protein and be very happy with moisture and salt adjusted yield higher than theoretical yield at same cheese composition. However, this should be signal to management that something is wrong because based on careful mass balance cheese yield studies

(Barbano and Rasmussen, 1992). A composition adjusted cheese yield that is higher than theoretical yield is also not realistic. In the interpretation of the data, the cheese plant management should be asking what input error could cause this behavior of the data. The answer is that an evaluation of the accuracy of milk analysis is needed. The issue at the other end of the range at 3.15% true protein in the milk in Table 2.9 is not as easy to diagnose. The fact that fat recovery is at 93% and both the fat lost before and after whey draining are realistic, would make the analyst question either the milk protein test, or the accuracy of the moisture test of cheese. If cheese factories had a rapid and accurate test for protein content of cheese, protein recovery in the cheese could be calculated and similar diagnostics could be done for protein recovery as are done currently for fat recovery.

Thus, if for example both fat and protein are off in the same direction (low or high), the magnitude of the uncertainty of theoretical yield is doubled. The examples in Tables 2.8 and 2.9 do not reflect the common practice in large scale cheese making where milk is concentrated or fractionated before cheese making to increase total fat plus protein in the cheese vat and increase the total weight of cheese per vat and per man hour of labor. This approach of milk fortification has become common in large cheddar and mozzarella cheese factories (Papadopolis et al, 2002, 2003).

When milk is fortified with nonfat dry milk, condensed skim milk, or cream and UF retentate, the challenges to the accuracy of the MIR milk analysis system are increased and additional measures to ensure accuracy are warranted. Proper MIR homogenizer performance, properly functioning intercorrection factors in the MIR milk analyzer (Lynch et al. 2006), and accurate milk calibration standards (Kaylegian et al. 2006) become even more important as fat content will be higher than in unfortified milk, and lactose content may increase when nonfat dry milk or condensed skim milk are used for milk fortification. Inaccuracy in milk fat and protein tests will result in an incorrect casein to fat ratio. This will impact the composition of the cheese (moisture and fat composition control) in a way that is not reflected by data in Tables 2.8 and 2.9. Instead, this will be seen in routine evaluation data when there is a shift in the accuracy of the milk fat or protein tests in the vat and then the mean fat on dry basis value for the day of production shifts. Variations in mean fat content of the cheese should always be cross-referenced to dates of calibration adjustment on the infrared milk analyzer. If protein content of cheese was measured and included in the mass balance analysis, similar effects of uncertainty in milk composition measurement would be seen in protein on dry basis in the cheese. Given the cost of milk protein, a rapid and practical cheese analysis method that allows for the evaluation of control and recovery of protein would be desirable.

There will always be uncertainty in the values used in the cheese yield evaluation equation therefore the challenge is to understand and control the uncertainty in the input data to allow the complete yield evaluation approach to be fit for purpose. It is important to remember that as the capacity of a cheese factory gets larger, the financial impact of the same absolute amount of uncertainty is magnified. However, the impact on financial performance may not be linear because net margins may be smaller in a larger factory.

Mozzarella. The impact of uncertainty of the measure of milk fat (Table 2.10) and milk protein (Table 2.11) of the milk plus all ingredients in the vat for a mozzarella cheese factory are shown when all other input parameters were held constant. Mozzarella cheese yield for unfortified milk is lower than cheddar because of the higher casein to fat ratio. Thus, the same analytical uncertainty in milk analysis causes a larger variation in cheese yield efficiency. The impact of uncertainty of the milk fat percentage in the vat on estimated fat recovery in the cheese

(83.25 to 91.09%) and on loss of fat after whey draining (i.e., stretching) is large. Typically, the theoretical total fat recovery in mozzarella is lower than cheddar (i.e., 87 versus 93%) due primarily to fat loss at the pasta filata step of cheese making (Barbano et al, 1994a; Renda et al, 1997). In the example in Table 2.10, a fat test on the milk that is low by 0.1% will cause the estimate of fat loss after whey draining to appear to decrease from 4.04% of the total fat to -0.48%. The same diagnostic approach and logic described from Tables 2.8 and 2.9 above for cheddar applies to the diagnostic trouble shooting for Tables 2.10 and 2.11 for mozzarella cheese with the same conclusions.

Table 2.10. Mozzarella cheese milk fat sensitivity with target milk fat of 2.22% and sensitivity analysis range of $\pm$ 0.1%

Milk fat sensitivity (% milk fat)	2.12	2.14	2.16	2.18	2.20	2.22	2.24	2.26	2.28	2.30	2.32
Milk composition and weights											
Average fat content of milk + starter (%)	2.12	2.14	2.16	2.18	2.20	2.22	2.24	2.26	2.28	2.30	2.32
Average casein content of milk + starter (%)	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46
Average casein-to-fat ratio	1.16	1.15	1.14	1.13	1.12	1.11	1.10	1.09	1.08	1.07	1.06
Weight of milk+starter+water (kg)	633,568	633,568	633,568	633,568	633,568	633,568	633,568	633,568	633,568	633,568	633,568
Weight of starter (kg)	13.61	13.61	13.61	13.61	13.61	13.61	13.61	13.61	13.61	13.61	13.61
Weight of milk (kg)	632,761	632,761	632,761	632,761	632,761	632,761	632,761	632,761	632,761	632,761	632,761
Weight of water (kg)	793	793	793	793	793	793	793	793	793	793	793
Starter as a percentage of milk (%)	0	0	0	0	0	0	0	0	0	0	0
Weight of cheese (kg)	60,595	60,595	60,595	60,595	60,595	60,595	60,595	60,595	60,595	60,595	60,595
Estimated weight of whey at draining (kg)	572,972	572,972	572,972	572,972	572,972	572,972	572,972	572,972	572,972	572,972	572,972
Cheese yield: milk + starter + water											
Barbano yield parameter: SEF	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Barbano yield parameter: CPRF	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Barbano yield parameter: A	1.85	1.86	1.88	1.90	1.92	1.93	1.95	1.97	1.99	2.00	2.02
Barbano yield parameter: B	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
Barbano yield parameter: C	0.29	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.31
Actual yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Moisture and salt adjusted yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Barbano theoretical yield (%)	9.38	9.42	9.45	9.49	9.53	9.56	9.60	9.64	9.67	9.71	9.75
Fat recovery and yield efficiency											
Total fat recovered in cheese (%)	91.09	90.24	89.41	88.59	87.79	87.00	86.22	85.46	84.71	83.98	83.25
Target fat recovery in cheese (%)	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00
Average fat in whey at draining (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Total fat recovered in whey at draining (%)	9.38	9.29	9.21	9.12	9.04	8.96	8.88	8.80	8.72	8.65	8.57
Total fat lost after draining (%)	-0.48	0.46	1.38	2.29	3.17	4.04	4.90	5.74	6.57	7.38	8.17
Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	102.0	102.0	101.1	100.8	100.4	100.0	99.6	99.2	98.9	98.5	98.1
Efficiency based on actual yield (%)	102.0	102.0	101.1	100.8	100.4	100.0	99.6	99.2	98.9	98.5	98.1

Table 2.11. Mozzarella cheese milk protein sensitivity with target milk protein of 3.00% and sensitivity analysis range of $\pm$ 0.1%

Milk protein sensitivity (% milk protein)	2.90	2.92	2.94	2.96	2.98	3.00	3.02	3.04	3.06	3.08	3.10
Milk composition and weights											
Average fat content of milk + starter (%)	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22
Average casein content of milk + starter (%)	2.38	2.39	2.41	2.43	2.44	2.46	2.48	2.49	2.51	2.53	2.54
Average casein-to-fat ratio	1.07	1.08	1.08	1.09	1.10	1.11	1.11	1.12	1.13	1.14	1.14
Cheese yield: milk + starter + water											
Barbano yield parameter: A	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93
Barbano yield parameter: B	2.48	2.50	2.52	2.54	2.55	2.57	2.59	2.61	2.63	2.64	2.66
Barbano yield parameter: C	0.29	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.31
Actual yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Moisture and salt adjusted yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Barbano theoretical yield (%)	9.37	9.41	9.45	9.49	9.53	9.56	9.60	9.64	9.68	9.72	9.75
Fat recovery and yield efficiency											
Total fat recovered in cheese (%)	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00
Target fat recovery in cheese (%)	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00
Average fat in whey at draining (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Total fat recovered in whey at draining (%)	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96
Total fat lost after draining (%)	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04
Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	102.0	101.6	101.2	100.8	100.4	100.0	99.6	99.2	98.8	98.4	98.1
Efficiency based on actual yield (%)	102.0	101.6	101.2	100.8	100.4	100.0	99.6	99.2	98.8	98.4	98.1

Sensitivity Analysis for Cheese Composition

Cheddar Moisture. The focus of all trouble shooting for yield and fat loss should be on the average for the day, not the individual vats. Large cheese factories do not have precise vat-to-vat identity of the exact weight of cheese that came from each vat. The total weight of the cheese for the day is normally an accurate number and the number of vats produced in the day is a known number.Assuming the moisture tests are correct from a representative sampling and analytical perspective, the data presented in Table 2.12 can be interpreted as follows:As the moisture content of the cheese was varied around the target (i.e., 37.5%) there were changes in moisture and salt adjusted yield, FDB, pounds of cheese yield lost or gained (due to missing the target FDB and target moisture), and salt in the moisture content of the cheese. If the moisture for the day is lower than the target, an opportunity for higher yield is missed. If the moisture is higher than the target, there is a yield gain but there may be a risk of a negative impact on cheese quality. If a factory converts about 938,935 kg (2.07 million pounds) of milk to cheese in a day, the impact of being 0.5% low on moisture is about 484 kg (1,067 pounds) of missed revenue opportunity for the day, assuming the moisture test is correct. If the moisture test is correct at 37%, then the FDB for the cheese is below target. Looking at the FDB in isolation, the management reaction might be to increase the fat level in the milk (i.e., lower the casein to fat ratio). If this is done without fixing the true cause of the low moisture, then this will probably make the moisture control problem worse because lowering the casein to fat ratio will make it more difficult to retain moisture in the curd in the vat. The root cause of the moisture deviation from target needs to be corrected *before* reacting by changing the fat or protein in the milk standardization. The focus should be on the set and cook temperatures in the vat and pH of the whey at draining (indirectly starter) assuming cutting and rennet are the same, in order to fix the moisture variation. Because the moisture variation is the root cause of the problem, the other deviations may be fixed by addressing this issue as well.

Table 2.12. Cheddar cheese moisture sensitivity analysis with target cheese moisture of 37.50% and sensitivity analysis range of ± 0.5%

Moisture sensitivity (% moisture)	37.00	37.10	37.20	37.30	37.40	37.50	37.60	37.70	37.80	37.90	38.00
Milk composition and weights											
Average fat content of the milk + starter (%)	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67
Average casein content of milk + starter (%)	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Average casein-to-fat ratio	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Weight of milk + starter + water (kg)	947,291	947,291	947,291	947,291	947,291	947,291	947,291	947,291	947,291	947,291	947,291
Weight of starter (kg)	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810
Weight of milk (kg)	938,935	938,935	938,935	938,935	938,935	938,935	938,935	938,935	938,935	938,935	938,935
Weight of starter + milk (kg)	942,746	942,746	942,746	942,746	942,746	942,746	942,746	942,746	942,746	942,746	942,746
Weight of water (kg)	4,545	4,545	4,545	4,545	4,545	4,545	4,545	4,545	4,545	4,545	4,545
Starter as a percentage of milk (%)	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Weight of cheese (kg)	96,715	96,715	96,715	96,715	96,715	96,715	96,715	96,715	96,715	96,715	96,715
Estimated weight of whey at draining (kg)	850,576	850,576	850,576	850,576	850,576	850,576	850,576	850,576	850,576	850,576	850,576
Number of vats	30	30	30	30	30	30	30	30	30	30	30
Cheese yield: milk + starter + water											
Barbano yield parameter: SEF[1]	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Barbano yield parameter:CPRF[2]	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Barbano yield parameter: A	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42
Barbano yield parameter: B	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62
Barbano yield parameter: C	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.17
Actual yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Moisture and salt adjusted yield (%)	10.29	10.28	10.26	10.24	10.23	10.21	10.19	10.18	10.16	10.14	10.13
Barbano theoretical yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Fat recovery, yield efficiency & compositional control											
Total fat recovered in cheese (%)	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00
Target fat recovery in cheese (%)	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00
Average fat in whey at draining (%)	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Total fat recovered in whey at draining (%)	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
Total fat lost after draining (%)	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	100.9	100.7	100.5	100.4	100.2	100.0	99.8	99.7	99.5	99.3	99.1

Efficiency based on actual yield (%)	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9
Target fat on dry basis (%)	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29
Actual fat on a dry basis (%)	52.87	52.95	53.03	53.12	53.20	53.29	53.37	53.46	53.55	53.63	53.72
Fat gain or loss due to deviation from target (kg)	-258	-206	-155	-103	-52	0	52	103	155	206	258
Target moisture (%)	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50
Actual moisture (%)	37.00	37.10	37.20	37.30	37.40	37.50	37.60	37.70	37.80	37.90	38.00
Moisture gain or loss due deviation from target (kg)	-484	-387	-290	-193	-97	0	97	193	290	387	484
Target salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Actual salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Actual salt-in-moisture (%)	4.73	4.72	4.70	4.69	4.68	4.67	4.65	4.64	4.63	4.62	4.61
Salt gain or loss due deviation from target (kg)	0	0	0	0	0	0	0	0	0	0	0
Target fat on a wet basis (%)	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31
Actual fat on a wet basis (%)	33.31	33.31	33.31	33.30	33.31	33.31	33.31	33.31	33.31	33.31	33.31
Total cheese yield gain or loss per day (kg)	-741	-593	-445	-297	-148	0	148	-297	445	593	741

In the second approach to interpretation of the data, we ask the question, "what if the average cheese moisture test for the day is wrong?" How could this happen? In large cheese factories today, routine cheese testing is done by high speed secondary testing methods that require complex calibration. Often the NIR calibration for cheese analysis must be developed in the laboratory of the cheese factory and assumes that the equipment and staff in that laboratory can produce high quality reference chemistry results. This assumption may not be correct, thus the quality of the analytical results on cheese becomes the weakness of the performance evaluation system. Incorrect analytical data creates a much more serious problem for the cheese factory management than just missing targets alone when it comes to process control decision making. This situation is simulated by looking at the data in Table 2.12 and assuming that the laboratory produced a result of 38% moisture, but the cheese instead really had 37.5% moisture. The management thinks the moisture is too high and reacts by changing the cheese making process to reduce moisture by 0.5%. The result of this management decision would lower the yield for the day by 484 kg of cheese and make the actual cheese moisture 37%, which will negatively affect the quality of the cheese by changing the firmness and slowing down the flavor development. Even small inaccuracies in analytical data can make a big difference. If a factory of this production capacity (i.e., 938,935 kg or about 2.07 million pounds of milk per day) is only 0.1% high for its moisture test while operating at 6 days per week, it adds up to a missed opportunity of approximately 30,360 kg of cheese over the course of a year for that factory. At $4.40 per kg of cheese that is a loss of about $134,000 for the year due to just 0.1% high bias in the moisture test. Many cheese factories in North America are much larger than this, meaning their economic loss would be even more severe. This risk provides some guide to justifiable expenditures for proficiency testing to maintain and verify the accuracy of analytical results from the laboratory.

Cheddar Fat. Doing a similar evaluation as used above for moisture, we can look at the impact of variation of fat on a wet basis in the cheese from both perspectives with data shown in Table 2.13. Assuming that the test values for fat content of the cheese are accurate, management needs to consider the factors that will influence fat content on a wet basis, fat recovery in the cheese, and ultimately cheese FDB. The fat content of the cheese can be low or high because the ratio of casein to fat was not on target in the milk standardization process, or it can be low because there was a higher loss of fat in the cheese making process (i.e., less than 93% fat recovery). In factories that are using fortification of milk to increase both fat and protein content of the milk in the vats, the control of casein to fat ratio will influence vat-to-vat variation in cheese composition. The example in Table 2.13 assumes the milk composition and moisture content of the cheese were constant and correct, while the fat content of cheese varied. In this case, the 0.5% lower wet fat in the cheese than the target (i.e., 32.81% fat vs 33.31% fat target) leads to a fat recovery in the cheese of 91.6% instead of 93.0%. This is a missed opportunity of 484 kg of cheese for the day. Assuming that the fat content of the whey remained constant at 0.17% fat at whey draining, the loss after whey draining is increased from the target of 2.83% to 4.22% of the starting fat, as shown in Table 2.13. Fat lost in the process after whey draining is more difficult to recover as whey cream and is of lower quality if recovered. This typically is fat lost during the salting and pressing of cheese. An error of just a few degrees higher temperature of the cheese curd at the start of salting or going into the press can cause increased fat loss in cheddar cheese making. On the other hand (not shown in Table 2.13), if the fat content of the whey at draining increased from 0.17% to a higher value, then this could also explain the lower wet fat and higher fat loss. In this case, the focus of the problem solving shifts to the milk coagulation, cutting, stirring and cooking parameters that would influence the fat loss at whey draining. Changes in mechanical damage to the fat due to pumping, air incorporation and shear of milk fat globules prior to the vats should also be evaluated.

Table 2.13. Cheddar cheese fat sensitivity analysis with target cheese fat 33.31% and sensitivity analysis range of $\pm$ 0.5% (milk composition and weights same as in Table 12)

Fat sensitivity (% fat)	32.81	32.91	33.01	33.11	33.21	33.31	33.41	33.51	33.61	33.71	33.81
Cheese yield: milk + starter + water											
Barbano yield parameter: SEF	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Barbano yield parameter: CPRF	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Barbano yield parameter: A	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42
Barbano yield parameter: B	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62
Barbano yield parameter: C	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Actual yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Moisture and salt adjusted yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Barbano theoretical yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Fat recovery, yield efficiency & compositional control											
Total fat recovered in cheese (%)	91.60	91.88	92.16	92.44	92.72	93.00	93.28	93.56	93.83	94.11	94.39
Target fat recovery in cheese (%)	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00
Average fat in whey at draining (%)	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Total fat recovered in whey at draining (%)	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
Total fat lost after draining (%)	4.22	3.95	3.67	3.39	3.11	2.83	2.55	2.27	1.99	1.71	1.43
Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Efficiency based on actual yield (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Target fat on dry basis (%)	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29
Actual fat on a dry basis (%)	52.49	52.65	52.81	52.97	53.13	53.29	53.45	53.61	53.77	53.93	54.09
Fat gain or loss due to deviation from target (kg)	-484	-387	-290	-193	-97	0	97	193	290	387	484
Target moisture (%)	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50
Actual moisture (%)	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50
Moisture gain or loss due deviation from target (kg)	0	0	0	0	0	0	0	0	0	0	0
Target salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Actual salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75

Actual salt-in-moisture (%)	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67
Salt gain or loss due deviation from target (kg)	0	0	0	0	0	0	0	0	0	0	0
Target fat on a wet basis (%)	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31
Actual fat on a wet basis (%)	32.81	32.91	33.01	33.11	33.21	33.31	33.41	33.51	33.61	33.71	33.81
Total cheese yield gain or loss per day (kg)	-484	-387	-290	-193	-97	0	97	193	290	387	484

If the fat test data for the cheese is incorrect, the consequences in management decision-making and yield are different. If the reported cheese wet fat test is 33.81% and it is actually 33.31% fat it will make management think that the FDB is 0.5% too high when it is actually on target. The management reaction, particularly when fresh cream prices are high, would be to lower the fat content of the milk (i.e., increase casein to fat ratio). This will reduce the theoretical yield of cheese and will likely cause the moisture content of the cheese to increase, if all other processing conditions are held equal. As one can see, it becomes easy to start spiraling out of control. Therefore, accuracy of the cheese and milk analysis is critical for both yield and quality of cheese.

Cheddar Salt. The following evaluation of salt control was done in a similar fashion as was done for cheese moisture and fat above, with data shown in Table 2.14. Assuming that the test values for salt content of the cheese are accurate, management needs to consider the factors that will influence cheese salt content. Assuming that the cheese moisture, fat, and salt test results are correct, then missing the salt target by being 0.25% low represents a missed opportunity of 242 kg of cheese for the day (Table 2.15). Numerous factors (e.g., curd temperature, curd moisture at salt application, time and number of salt applications, mixing, etc.) can influence salt uptake by the curd (Lawrence et al., 1987; Guinee and Fox, 2004). Typically, if a cheddar factory is having troubles with moisture control and is running low on moisture, they may reduce their salt application rate with the hope that they will achieve higher cheese moisture by having lower whey expulsion during salting. However, when one looks at the yield penalty (242 kg) for a reduction of salt of 0.25% (Table 2.14) versus an increase in moisture of 0.2% with a corresponding increase of only 193 kg of cheese (Table 2.12), the net effect on yield is loss even though the management believes they have been successful at increasing the moisture.

Thus, looking at all of the parameters together gives a more comprehensive view of controlling the cheese yield and composition for the complete process.

Table 2.14. Cheddar cheese salt sensitivity analysis with target cheese salt of 1.75% and sensitivity analysis range of $\pm$ 0.25% (milk composition and weights same as in Table 12)

Salt sensitivity (% salt)	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
Cheese yield: milk + starter + water											
Barbano yield parameter: SEF	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Barbano yield parameter: CPRF	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Barbano yield parameter: A	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42
Barbano yield parameter: B	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62
Barbano yield parameter: C	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Actual yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Moisture and salt adjusted yield (%)	10.25	10.24	10.23	10.23	10.22	10.21	10.20	10.19	10.18	10.18	10.17
Barbano theoretical yield (%)	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21	10.21
Fat recovery, yield efficiency & compositional control											
Total fat recovered in cheese (%)	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00
Target fat recovery in cheese (%)	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00	93.00
Average fat in whey at draining (%)	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Total fat recovered in whey at draining (%)	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
Total fat lost after draining (%)	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	100.4	100.3	100.2	100.2	100.1	100.0	99.9	99.8	99.8	99.7	99.6
Efficiency based on actual yield (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Target fat on dry basis (%)	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29
Actual fat on a dry basis (%)	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29	53.29
Fat gain or loss due to deviation from target (kg)	0	0	0	0	0	0	0	0	0	0	0
Target moisture (%)	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50
Actual moisture (%)	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50	37.50
Moisture gain or loss due deviation from target (kg)	0	0	0	0	0	0	0	0	0	0	0
Target salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Actual salt (%)	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
Actual salt-in-moisture (%)	4.00	4.13	4.27	4.40	4.53	4.67	4.80	4.93	5.07	5.20	5.33
Salt gain or loss due deviation from target (kg)	-242	-193	-145	-97	-48	0	48	97	145	193	242

Target fat on a wet basis (%)	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31
Actual fat on a wet basis (%)	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31	33.31
Total cheese yield gain or loss per day (kg)	-242	-193	-145	-97	-48	0	48	97	145	193	242

Table 2.15. Mozzarella cheese moisture sensitivity analysis with target cheese moisture of 48.00% and sensitivity analysis range of ± 0.5%

Moisture sensitivity (% moisture)	47.50	47.60	47.70	47.80	47.90	48.00	48.10	48.20	48.30	48.40	48.50
Milk composition and weights											
Average fat content of milk + starter (%)	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22
Average casein content of milk + starter (%)	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46
Average casein-to-fat ratio	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
Weight of milk + starter + water (kg)	633,568	633,568	633,568	633,568	633,568	633,568	633,568	633,568	633,568	633,568	633,568
Weight of starter (kg)	13.61	13.61	13.61	13.61	13.61	13.61	13.61	13.61	13.61	13.61	13.61
Weight of milk (kg)	632,761	632,761	632,761	632,761	632,761	632,761	632,761	632,761	632,761	632,761	632,761
Weight of starter + milk (kg)	632,774	632,774	632,774	632,774	632,774	632,774	632,774	632,774	632,774	632,774	632,774
Weight of water (kg)	793	793	793	793	793	793	793	793	793	793	793
Starter as a percentage of milk (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Weight of cheese (kg)	60,595	60,595	60,595	60,595	60,595	60,595	60,595	60,595	60,595	60,595	60,595
Estimated weight of whey at draining (kg)	572,972	572,972	572,972	572,972	572,972	572,972	572,972	572,972	572,972	572,972	572,972
Number of vats	30	30	30	30	30	30	30	30	30	30	30
Cheese yield: milk + starter + water											
Barbano yield parameter: SEF	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Barbano yield parameter: CPRF	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Barbano yield parameter: A	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93
Barbano yield parameter: B	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
Barbano yield parameter: C	0.29	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.31
Actual yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Moisture and salt adjusted yield (%)	9.66	9.64	9.62	9.60	9.58	9.56	9.55	9.53	9.51	9.49	9.47
Barbano theoretical yield (%)	9.55	9.55	9.56	9.56	9.56	9.56	9.57	9.57	9.57	9.57	9.58
Fat recovery, yield efficiency & compositional control											
Total fat recovered in cheese (%)	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00
Target fat recovery in cheese (%)	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00
Average fat in whey at draining (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Total fat recovered in whey at draining (%)	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96
Total fat lost after draining (%)	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04

Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	101.12	100.89	100.67	100.45	100.22	100.00	99.77	99.55	99.33	99.10	98.88
Efficiency based on actual yield (%)	100.12	100.10	100.07	100.05	100.02	100.00	99.97	99.95	99.92	99.90	99.87
Target fat on dry basis (%)	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85
Actual fat on a dry basis (%)	38.48	38.55	38.62	38.70	38.77	38.85	38.92	39.00	39.07	39.15	39.22
Fat gain or loss due to deviation from target (kg)	-118	-94	-71	-47	-24	0	24	47	71	94	118
Target moisture (%)	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00
Actual moisture (%)	47.50	47.60	47.70	47.80	47.90	48.00	48.10	48.20	48.30	48.40	48.50
Moisture gain or loss due deviation from target (kg)	-303	-242	-182	-121	-61	0	61	121	182	242	303
Target salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Actual salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Actual salt-in-moisture (%)	3.68	3.68	3.67	3.66	3.65	3.65	3.64	3.63	3.62	3.62	3.61
Salt gain or loss due deviation from target (kg)	0	0	0	0	0	0	0	0	0	0	0
Target fat on a wet basis (%)	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20
Actual fat on a wet basis (%)	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20
Total cheese yield gain or loss per day (kg)	-421	-337	-252	-168	-84	0	84	168	252	337	421

Table 16. Mozzarella cheese fat sensitivity analysis with target cheese far of 22.00% and sensitivity analysis range of ± 0.5% (milk composition and weights same as in Table 15)

Fat sensitivity (% fat)	19.70	19.80	19.90	20.00	20.10	20.20	20.30	20.40	20.50	20.60	20.70
Cheese yield: milk + starter + water											
Barbano yield parameter: SEF	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Barbano yield parameter: CPRF	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Barbano yield parameter: A	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93
Barbano yield parameter: B	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
Barbano yield parameter: C	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Actual yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Moisture and salt adjusted yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Barbano theoretical yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Fat recovery, yield efficiency & compositional control											

Total fat recovered in cheese (%)	84.84	85.27	85.71	86.14	86.57	87.00	87.43	87.86	88.29	88.72	89.15
Target fat recovery in cheese (%)	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00
Average fat in whey at draining (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Total fat recovered in whey at draining (%)	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96
Total fat lost after draining (%)	6.20	5.77	5.34	4.91	4.47	4.04	3.61	3.18	2.75	2.32	1.89
Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Efficiency based on actual yield (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Target fat on dry basis (%)	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85
Actual fat on a dry basis (%)	37.88	38.08	38.27	38.46	38.65	38.85	39.04	39.23	39.42	39.62	39.81
Fat gain or loss due to deviation from target (kg)	-303	-242	-182	-121	-61	0	61	121	182	242	303
Target moisture (%)	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00
Actual moisture (%)	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00
Moisture gain or loss due deviation from target (kg)	0	0	0	0	0	0	0	0	0	0	0
Target salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Actual salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Actual salt-in-moisture (%)	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65
Salt gain or loss due deviation from target (kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Target fat on a wet basis (%)	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20
Actual fat on a wet basis (%)	19.70	19.80	19.90	20.00	20.10	20.20	20.30	20.40	20.50	20.60	20.70
Total cheese yield gain or loss per day (kg)	-303	-242	-182	-121	-61	0	61	121	182	242	303

Table 2.17. Mozzarella cheese salt sensitivity analysis with target cheese salt of 1.75% and sensitivity analysis range of ± 0.25% (milk composition and weights same as in Table 15)

Salt sensitivity (% salt)	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
Cheese yield: milk + starter + water											
Barbano yield parameter: SEF	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Barbano yield parameter: CPRF	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Barbano yield parameter: A	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93
Barbano yield parameter: B	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57

Barbano yield parameter: C	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Actual yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Moisture and salt adjusted yield (%)	9.61	9.60	9.59	9.58	9.57	9.56	9.55	9.55	9.54	9.53	9.52
Barbano theoretical yield (%)	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56	9.56
Fat recovery, yield efficiency & compositional control											
Total total fat recovered in cheese (%)	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00
Target fat recovery in cheese (%)	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00	87.00
Average fat in whey at draining (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Total fat recovered in whey at draining (%)	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96	8.96
Total total fat lost after draining (%)	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.04
Cheese yield efficiency											
Efficiency based on moisture and salt adjusted yield (%)	101.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Efficiency based on actual yield (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Target fat on dry basis (%)	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85
Actual fat on a dry basis (%)	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85	38.85
Fat gain or loss due to deviation from target (kg)	0	0	0	0	0	0	0	0	0	0	0
Target moisture (%)	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00
Actual moisture (%)	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00	48.00
Moisture gain or loss due deviation from target (kg)	0	0	0	0	0	0	0	0	0	0	0
Target salt (%)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Actual salt (%)	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
Actual salt-in-moisture (%)	3.13	3.23	3.33	3.44	3.54	3.65	3.75	3.85	3.96	4.06	4.17
Salt gain or loss due deviation from target (kg)	-151	-121	-91	-61	-30	0	30	61	91	121	151
Target fat on a wet basis (%)	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20
Actual fat on a wet basis (%)	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20
Total cheese yield gain or loss per day (kg)	-151	-121	-91	-61	-30	0	30	61	91	121	151

Sensitivity Analysis LMPS Mozzarella. All the same explanations of yield and process control given above for cheddar cheese apply to mozzarella cheese at various target moisture, fat, and salt levels and similar sensitivity analysis data are provided for LMPS mozzarella in Tables 2.15, 2.16, and 2.17. The most important differences between mozzarella and cheddar cheese manufacture are the pasta filata (i.e., stretching step) and brine salting that occurs in mozzarella production. The pasta filata step will mainly influence fat loss. Operational parameters such as curd temperature, pH, screw speed, and presence of salt during stretching all will influence fat loss during stretching (Barbano et al., 1994a; Barbano, 1996; Renda et al., 1997). Fat lost during stretching, particularly if the stretching water contains salt, is difficult to recover and fat that is recovered usually has much lower value due to the presence of salt than whey cream recovered from the whey at draining (Barbano, 1996). Brine salting of blocks of cheese produces gradients of composition from the center to surface of each block of cheese and this makes control of moisture and fat content of mozzarella cheese a challenge. The impact of incorrect cheese analysis data (whether due to testing or sampling) is similar to that for cheddar.

Troubleshooting Yield Variation in Real Data.

The sensitivity tables provide a view of the format of the data produced by this yield evaluation approach, but these tables are simple cases of the variation of one dimension of input data at time. In reality all of these parameters will be changing at the same time. When looking at real factory data in the format shown in Tables 2.8 to 2.17, the data in columns would be from successive days of the month for one cheese type. The challenge is to separate and identify shifts in analytical measures of milk and cheese composition or measures of weights from changes in the manufacturing process performance. There will always be noise in the data. The data analyst needs to develop skills to differentiate data patterns that represent weaknesses in the accuracy of input data versus physical changes in manufacturing performance. Recognition of input data quality problems is gained by understanding patterns of changes in multiple parameters simultaneously, which can be observed by looking at data for cheddar across Tables 2.8, 2.9, 2.12, 2.13, and 2.14. In a cheese manufacturing environment, adjustments to calibration and repair events for milk and cheese weighing and analysis equipment can produce apparent changes in behavior of manufacturing performance that are not real. Example 1: if the measurement of the fat content of the milk was lower than the true fat content of the milk (Table 2.8) and the protein test was correct, then the calculated theoretical cheese yield would be lower over a series of days. However, if the measured FDB of the cheese did not decrease on those days and the cheese yield efficiency increased (Table 2.8), then it is likely the milk fat test in the vats was incorrect. If the concentration of fat in the whey did not change, then the fat loss after whey draining will decrease (Table 2.8). There is a minimum level of fat loss after whey draining that is normal for cheddar cheese making (i.e., about 2.5%). If the value for fat loss goes far below this level, then there is probably an error the fat test of the milk (i.e., lower than it really is) or of the cheese (i.e., higher than it really is). When this happens for several days running and corresponds to the date of a calibration change or repair to the milk or cheese analyzer, then there is an action that can be taken to determine if control of the analytical system has changed. Example 2: when the fat test in the cheese is high (Table 2.13), the actual cheese FDB will increase, but again when the calculated fat loss after whey draining goes lower than a reasonable level (Table 2.13) and the fat recovery in the cheese becomes too high, then there is reason to question the accuracy of the fat or moisture test of the cheese. If the fat test in the cheese is unreasonably low, the fat loss after whey draining will be very high (Table 2.13). The apparent higher fat loss can be verified by measuring the weight of whey cream and weight of fat in the whey cream for the day. If the fat in whey cream does not go up and down with the fat recovery changes from day to day, or if there is a major shift in the temporal pattern of FDB, then a fat testing error needs to be eliminated as the cause before changes are made in the cheese manufacturing process. Similar examples of these multiple relationships in data can be observed in Tables 2.8 to 2.17 due to shifts in accuracy of milk protein or cheese moisture determination in both cheddar and mozzarella. Within the data there will always be some level of noise and the noise in all of these parameters is linked. Given these inter relationships in the data, there is an opportunity for the application of multivariate statistics to automate the differentiation, identification, and correction of sources of analytical noise from true changes in manufacturing performance. Differentiation of true changes in yield and composition control from analytical noise will allow improved financial performance of the cheese plant by allowing management to properly control cheese composition and maximize cheese yield.

CONCLUSIONS

A systematic approach based on theoretical cheese yield equations was developed for evaluation of cheese yield performance and fat losses in a cheese factory. Systematic evaluation of composition and yield performance data can aid management in taking an approach to identify and fix root causes of deviations from target specifications, such as managing the root cause of moisture deviations prior to making adjustments in milk standardization. Based on observations in commercial cheese factories, sensitivity analysis was done to demonstrate the sensitivity of the evaluation outcome to analytical uncertainty of data used in the evaluation. Uncertainty in the accuracy of milk weight, composition of milk and composition of cheese were identified as important factors that influence the ability to manage business profitability and consistency of cheese quality. It was demonstrated that an uncertainty of $\pm$ 0.1% milk fat or milk protein in the vat causes a range of theoretical cheddar cheese yield from 10.05 to 10.37% and an uncertainty of yield efficiency of ± 1.5%. This equates to ± 1,489 kg (3,283 pounds) of cheese per day in a factory processing 938,935 kg (2.07 million pounds) of milk per day. The same is true for uncertainty in cheese composition, where the impact of running 0.5% low on moisture or fat is about 484 kg (1,067 pounds) of missed revenue opportunity for the day. Missing the moisture target also leads to missing targets such as FDB and salt in the moisture, which are dependent on the cheese moisture. Similar impacts were demonstrated for mozzarella cheese. In analytical performance evaluations of commercial cheese quality assurance laboratories, it was found that analytical uncertainty was typically a bias that was as large as 0.5% on fat and moisture. The impact of having a high bias of 0.5% moisture or fat will produce a missed opportunity of 484 kg of cheese per day for each. More accurate, rapid methods for determination of moisture, fat, and salt content of cheese in large cheese factories will improve the accuracy of yield performance evaluation and control of consistency of cheese composition and quality.

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CHAPTER THREE

DETERMINATION OF FAT, PROTEIN, MOISTURE, AND SALT CONTENT OF CHEDDAR CHEESE USING MID-INFRARED TRANSMITTANCE SPECTROSCOPY

ABSTRACT

The objective of our work was to develop and evaluate the performance of a rapid method for measuring fat, protein, moisture, and salt content of cheddar cheese using a combination mid-infrared (**MIR**) transmittance analysis and conductivity sensor. Cheddar cheese was blended with a dissolving solution containing pentasodium triphosphate and disodium metasilicate to achieve a uniform, particle free dispersion of cheese, which had a composition similar to milk and could be analyzed using a MIR transmittance milk analyzer. Annatto colored cheddar cheese samples (34) from one cheese factory were analyzed using reference chemistry methods for fat (Mojonnier ether extraction), protein (Kjeldahl), moisture (over-drying total solids), and salt (Volhard silver nitrate titration). The same 34 cheese samples were also dissolved using the cheese dissolver solution, and then run through the MIR. Validation was done using a total of 36 annatto colored cheddar cheese samples from four cheese factories. The 36 validation cheese samples were also analyzed using near-infrared (**NIR**) spectroscopy for fat, moisture, and the coulometric method for salt in each factory where they were produced. The validation cheeses were also tested using the same chemical reference methods used for analysis of the calibration samples. Standard error of prediction (SEP) values for moisture and fat on the NIR were 0.30 and 0.45, respectively, whereas the MIR produced SEP values of 0.28 and 0.23 for moisture and fat A, respectively. MIR also out-performed the coulometric method with SEP

values of 0.036 and 0.139, respectively. The MIR had an SEP value of 0.19 for estimation of protein which suggests that MIR could be an easy and effective way for cheese producers to measure protein to determine protein recovery in cheese making.

INTRODUCTION

Measurement of cheese yield, recovery of fat and protein, and evaluation of cheese compositional control in large scale cheese factories is an important aspect of cheese factory management. A system for evaluation and control of these parameters was presented by Margolies et al. (2017). During the testing of a cheese yield evaluation system in large commercial cheese factories, it was observed that the mean bias error in measurement was as high as ± 0.5% for fat and moisture in commercial cheese factories. Given this, it was determined that accuracy of rapid secondary testing methods needed improvement. (Margolies et al., 2017).

The chemical reference methods for measurement of fat (e.g., Babcock and Mojonnier ether extraction), protein (Kjeldahl), moisture (forced air oven-drying) and salt (Volhard silver nitrate titration) are accurate but are too slow and impractical for rapid analysis of large numbers of cheese samples in a commercial quality assurance (**QC**) laboratory. Therefore, more rapid and cost effective methods such as near infrared (**NIR**) reflectance for fat, protein, and moisture (Rodriguez-Otero et al., 1995; McKenna, 2001) and coulometric methods (Varcoe 2001) for salt analysis are commonly used in cheese factories today.

NIR methods for measurement of cheese composition use partial least squares (**PLS**) calibration models that are developed locally in each cheese factory and often require a large number of cheese samples (200 to 400) of each cheese type to be tested by reference chemistry and the NIR within each cheese factory (McKenna, 2001; Barbano and Lynch, 2006). While using NIR for cheese compositional analysis is appropriate in terms of the ease of sample preparation and speed of analysis, the work required to develop calibrations for each cheese type within each cheese factory is not very practical or cost effective. Holroyd (2011) indicated that there has been an evolution of NIR calibration approaches using multiple linear regression and

PLS over the years that are equipment manufacturer specific. If a factory has more than one NIR analyzer within their lab, separate calibration development is often required for each instrument. The accuracy of each prediction model for each cheese type is dependent on the accuracy of the reference chemistry performed in the cheese factory and the concentration range and distribution of fat, protein, and moisture in the specific calibration samples used for PLS model development (McKenna, 2001; Barbano and Lynch, 2006). Consistency of sample presentation (particle size distribution) is often a source of analytical variation in NIR cheese analysis (Holroyd 2011). In a review of NIR analysis of cheese, Holroyd (2011) gave the Fonterra Research Centre, (Palmerston North, 4442, New Zealand) perspective on the evolution of NIR analysis of cheese for a large system of cheese factories in New Zealand over the last 30 years, and on the evolution of NIR analytical technology. Holroyd (2011) reported that careful sample preparation: 1) using a number of cheese cores that are (2) representative of the block (3) using sample matrix knowledge and that are (4) grated or blended to uniform and representative state is a vital part of the success of NIR analysis of cheese. In the end, analytical performance with respect to accuracy of indirect measurement method prediction (e.g., **SEP**, standard error of prediction) of reference chemistry by the secondary method is the metric for method performance evaluation. Holroyd (2011) reported the SEP metrics from many studies of NIR cheese analysis performance from 0.2 to 0.5% for fat, protein, and moisture during the period from 1993 to 2003. In 2003, FTIR instruments became more common and some individual companies developed global PLS models for cheese analysis that reduced the amount of reference chemistry, time, and cost required at the local level while maintaining SEP values more consistently in the range of 0.2 to 0.35% for fat and moisture prediction (Holroyd, 2011).

Mid-infrared (**MIR**) milk analyzers are commonly used in cheese factories for analysis of milk, cream, and liquid whey products. The understanding of measurement of fat and protein using MIR is well developed (Kaylegian et al., 2006b, 2009) and accepted in official methods for milk (AOAC, 2016, method number 972.16). While various instrument manufactures have developed applications notes for analysis of cheese samples using MIR liquid analyzers, utilization of this approach for cheese analysis is not common. Unlike NIR, MIR methods use well documented wavelengths for measurement of fat, protein, and lactose (Kaylegian et al., 2009) and this approach could be applied to cheese analysis. The challenge is sample preparation to convert the solid cheese into a particle free liquid that could be pumped through the MIR milk analyzer. A system for dissolving cheese for MIR analysis was described by Sjaunja (1999) using a solution of disodium metasilicate and pentasodium triphosphate. The potential advantage of this approach would be that liquid calibration samples might be prepared centrally and used on multiple instruments in multiple factories as is currently done for milk (Kaylegian et al., 2006a, 2006b) and whey analysis by MIR. This would reduce the need for reference chemistry analysis of cheese in QC laboratories in cheese factories and provide an analytical alternative to NIR analysis of cheese using a piece of equipment that is normally available in cheese factories. The objective of our work was to develop and evaluate the performance of a rapid method for measuring fat, protein, moisture, and salt content of cheddar cheese using a combination MIR transmittance analysis and conductivity sensor.

MATERIALS AND METHODS

Experimental Design

Calibration. Cheese samples were diluted about 10:1 (w/w) with a dispersing liquid, blended, and pumped through a MIR milk analyzer (LactoScope FTIR Advanced, Delta

Instruments, Kelvinlaan 3, 9207 JB Drachten, Netherlands). Cheese samples were between 5 and 10 days of age at the time of analysis. Calibration of the MIR milk analyzer was done using 34 individual annatto colored full-fat cheddar cheese samples that represented different individual batches of cheese from one large commercial cheese factory. Reference chemistry for fat, protein, salt, and total solids was determined for each cheese sample and a linear slope and intercept adjustment was made for estimation of fat (separately for A, B, and A+B), protein, salt, and total solids. Moisture was calculated as 100 minus total solids.

Validation. While the calibration was based on full fat annatto colored cheddar cheese from one factory, validation was done with 36 full-fat colored cheddar cheeses from 4 different factories (6 from each of two factories and 12 from each of the other two factories). One of the four factories (6 cheese samples) was the same factory that produced the cheeses used as the 34 calibration samples for the MIR. Cheeses from different cheese factories were used to determine if the calibration developed for cheese produced in one factory was robust enough to be applied across multiple factories. Reference chemistry for all cheese samples was done in the Cornell University laboratory. The validation cheese samples from each factory were analyzed for fat, moisture, and salt in their own factory using their locally calibrated NIR for fat and moisture and a coulometric method for salt analysis. The data from the in-factory analysis was reported and performances of each locally calibrated NIR on predicting fat and moisture, the locally used coulometric method for predicting salt, and the MIR were compared.

Cheese Analysis

Cheese Grinding and Storage. Cheese samples (4^{o}C) were cut into 1 cm cubes and then ground using a blender (E8442, Eberbach Corporation, 505 S Maple Rd, Ann Arbor, MI 48103) until a homogenous particle size of about 3 to 4 mm was achieved. Ground cheese was packed into 90 g snap lid vials (CPP03EDM-CL, Capitol Plastic Products, 1030 Riverfront Center, Amsterdam, NY 12010) and kept at 4°C until testing. The vials were filled to the top with no head space to minimize loss of moisture from the cheese into the head space. At the time of weighing, the top 2 cm of cheese in the vial was discarded due to possible loss of moisture during storage. Separate vials of cheese were saved for each test to be done.

Cheese Dissolver Solution. The cheese dissolver solution **(**Sjaunja, 1999**)** was prepared by combination of 12.7 g of pentasodium triphosphate ($Na_5P_3O_{10}$) and 5.3 g of disodium metasilicate ($Na_2Si_2O_3$) in 1982 g of water at 40°C. This cheese dissolver chemical is available from the equipment manufacturer (MA00090055, Delta Instruments, Kelvinlaan 3, 9207 JB Drachten, Netherlands) in a premixed form.

Cheese Preparation Using Cheese Dissolver. Cheese dissolver solution was heated to 65 $\pm$ 2°C and approximately 81 g of dissolver solution were added to a 120 g capacity snap-lid vial (CPP04, Capitol Plastic Products, 1030 Riverfront Center, Amsterdam, NY 12010). The dissolver + vial weight was recorded to 4 decimal places, dissolver was transferred into a high shear stainless steel blender with a stainless steel blade assembly, (E8580, Eberbach Corporation, 505 S Maple Rd, Ann Arbor, MI 48103) and weight of the vial plus residual dissolver was recorded. The weight of solver transferred into the blender (81 $\pm$ 0.2 g) was calculated by difference. Next, 9 $\pm$ 0.05 g of ground cheese was placed in a plastic 150 mL cup (RK5, Fabri-Kal, Plastics Place, Kalamazoo, MI 49001) and the weight of the cheese plus cup was recorded. The cheese was transferred to the high shear blender containing the warmed dissolver. The empty cup was recorded and the weight of cheese transferred to the blender was calculated as the difference

Prior to blending, 3 drops of antifoam (MA00090060, Delta Instruments, Kelvinlaan 3, 9207 JB Drachten, Netherlands) were added to the high shear blender. The cheese samples were weighed and blended one at a time to achieve consistent temperature of the mixture during blending. The stainless steel blender jar was placed on a 2-speed blender base (E8420, Eberbach Corporation, 505 S Maple Rd, Ann Arbor, MI 48103). The blender jar was capped and run at low speed for 15 s, followed by high speed for 45 s, then poured into a snap lid plastic 120 g vial (CPP04, Capitol Plastic Products, 1030 Riverfront Center, Amsterdam, NY 12010). When pouring the liquid into a clear plastic vial, the analyst can observe the liquid and see if there are any cheese particles remaining. Our experience was that the blending worked very well with very few small cheese particles in the liquid. If for some reason a particle of cheese remained stuck out of the liquid in the blender, the liquid could be poured back into the blender and bended for another 15 s on high to disperse the remaining particle(s). The plastic vial containing the blended cheese plus solver was placed in the 40°C water bath for about 20 m to allow the foam to break and entrapped air to dissipate into the head space. A portion of the blended cheese solution was run through the MIR analyzer and other portions were removed for Kjeldahl protein and Mojonnier ether extraction fat analysis.

Chemical Reference Methods

Fat. The determination of fat content of cheese was done by analysis of the cheese that had been diluted and blended with dissolver 65 $\pm$ 2^{o}C. This sample preparation produces a homogeneous liquid emulsion of the cheese. The cheese plus dissolver achieved analytical repeatability that was comparable to that achieved with the Mojonnier method testing milk (Barbano et al., 1988; Wojciechowski et al., 2016). Cheese plus dissolver (10 g) was weighed into a Mojonnier ether extraction flask and tested in duplicate just like a milk sample (Barbano et al., 1988). The repeatability of the method was much better than running the ether extraction directly on 1 g of cheese. Duplicate tests on cheese plus dissolver were typically within 0.01% fat. The final result was then multiplied by the weight/weight dilution factor (cheese + dissolver) to calculate the amount of fat in the cheese.

Protein. For the determination of nitrogen content, the Kjeldahl method was used (Barbano and Clark, 1990; Lynch and Barbano, 1999) and the total nitrogen content was multiplied by 6.38 to determine total protein. Similar to the ether extraction, the Kjeldahl method was performed in duplicate on the cheese + dissolver mixture. The Kjeldahl total nitrogen method used was exactly the same as the official method used for milk (Barbano and Clark, 1990) and the analytical performance was similar to that of milk (Wojciechowski et al., 2016). The repeatability of the method was much better than when trying to do the Kjeldahl directly on 1 g of cheese. Duplicate tests were typically within 0.01% protein. The final result was then multiplied by the 6.38 total protein factor and the weight/weight dilution factor (cheese + dissolver) to calculate the amount of protein in the cheese.

Salt. Cheese salt was determined in duplicate with the Volhard method (AOAC, 2000, method number 935.43; SMEDP 15.052) directly on the cheese (approximately 3 g), not a cheese + dissolver mixture. Cheeses were heated and digested with nitric acid and potassium permanganate in the presence of a known number of moles of silver nitrate. The acid digestion allows the chloride in the sample to be freed and reacted with the silver to form AgCl. The salt was determined by back-titration of the remaining unreacted silver using potassium thiocyanate with a ferric ammonium indicator.

Total Solids. The reference method for determination of the solids content of cheese was 24 h at 100°C in a forced air oven using a 2 g sample (Hooi et al., 2004, method 15.114). Oven drying was done in triplicate for each cheese.

Mid-infrared Analysis

Cheese was prepared using the dissolver as described above, and then allowed to de-gas in 40°C water bath for approximately 20 m before being run through the MIR. Pre-calibration of the MIR and primary slopes for the main milk components were set as described by Lynch et al. (2006). The optimized virtual filter wavelengths and bandwidths used for fat B, lactose, protein, and fat A were as described by Kaylegian et al. (2009). As is the case with milk analysis, fat A + B was calculated as [(0.7 x fat B corrected) + (0.3 x fat A corrected)]. Intercorrection factors (Barbano and Clark, 1989; Lynch et al., 2006) for the instrument used in this study were the same as those used for milk. Salt was determined using an in-line conductivity sensor within the MIR pumping system. Total solids was calculated as the sum of [(fat) + (protein) + (salt)] with a slope and intercept adjustment using the reference chemistry for oven-drying. Based on the analytical performance (i.e. lowest SEP) for fat, the fat measure that gave the best analytical performance was used to provide the best prediction of total solids in the equation above. The sample and reference filter wavelengths, scale, and intercorrection factors for the fat A, fat B, lactose, and protein are shown in Table 3.1.

Table 3.1. MIR wavenumbers, scale, offset, and intercorrection factors for fat B, lactose, protein, and fat A traditional virtual filter wavelengths.

Sample filters	1st wave number	Last wave number	Scale	Offset
Fat B	2838	2864	34.6352	0.00
Lactose	1038	1058	17.6939	0.00
Protein	1531	1551	21.6284	0.00

Fat A	1740	1756	21.8407	0.00

Reference filters	1st wave number	Last wave number	Scale	Offset
Fat B	2800	2824	-34.6352	0.00
Lactose	1286	1300	-17.6939	0.00
Protein	1485	1497	-21.6284	0.00
Fat A	1783	1799	-21.8407	0.00

Intercorrection factors

	Fat B	Lactose	Protein	Fat A
Fat B	1.000	-0.149	-0.057	0.000
Lactose	0.044	1.000	0.016	0.000
Protein	0.064	0.052	1.000	0.000
Fat A	0.000	0.024	0.020	1.000

RESULTS AND DISCUSSION

Calibration

The 34 colored cheese samples produced in one factory that were used for calibration of the MIR produced SEP for fat A, fat B, fat A+B, moisture, protein, and salt of 0.115, 0.110, 0.110, 0.092, 0.074, and 0.034, respectively. The r-squared values were 0.91, 0.92, 0.92, 0.92, 0.95, and 0.85, respectively. Two consecutive measures of each blended cheese sample from the same vial were performed with the MIR. The mean difference (**MD**) and repeatability standard deviation (**S_r**) of the absolute difference between two consecutive measures of each of the 34 blended cheese samples were 0.076 and 0.069, 0.071 and 0.068, 0.072 and 0.068, 0.080 and 0.051, 0.041 and 0.033, and 0.009 and 0.009, respectively for fat A, fat B, fat A+B, moisture, protein, and salt. The relative standard deviations of repeatability (**RSD_r**) were 0.21, 0.20, 0.20, 0.14, 0.14, and 0.52% for fat A, fat B, fat A+B, moisture, protein, and salt, respectively.

Validation

An independent set of 36 colored cheddar cheeses produced in 4 different factories were used for validation of the MIR method. Reference chemistry and NIR results were also available for each sample to include for comparison to the results produced by MIR. The regression analyses of reference moisture values as a function of predicted moisture by NIR (Figure 3.1A) and MIR (Figure 3.1B) both had similar r-squared values of about 0.93. The regression analyses of reference fat values as a function of predicted fat by NIR (Figure 3.2A) and MIR (Figure 3.2B) had very different r-squared values of about 0.70 and 0.93, respectively. For the NIR, each of the 4 factories calibrated their own NIR for fat, tested their own cheese samples by NIR, and reported fat percentages for their cheeses. The poor agreement between fat reference chemistry and NIR predictions could be due to inaccuracy in fat reference chemistry that was used to calibrate their NIRs or lack of robustness of the NIR calibration model. In practice, this is what was seen in our survey of cheese factory analytical performance in the previous cheese yield and composition control study (Margolies et al., 2017).

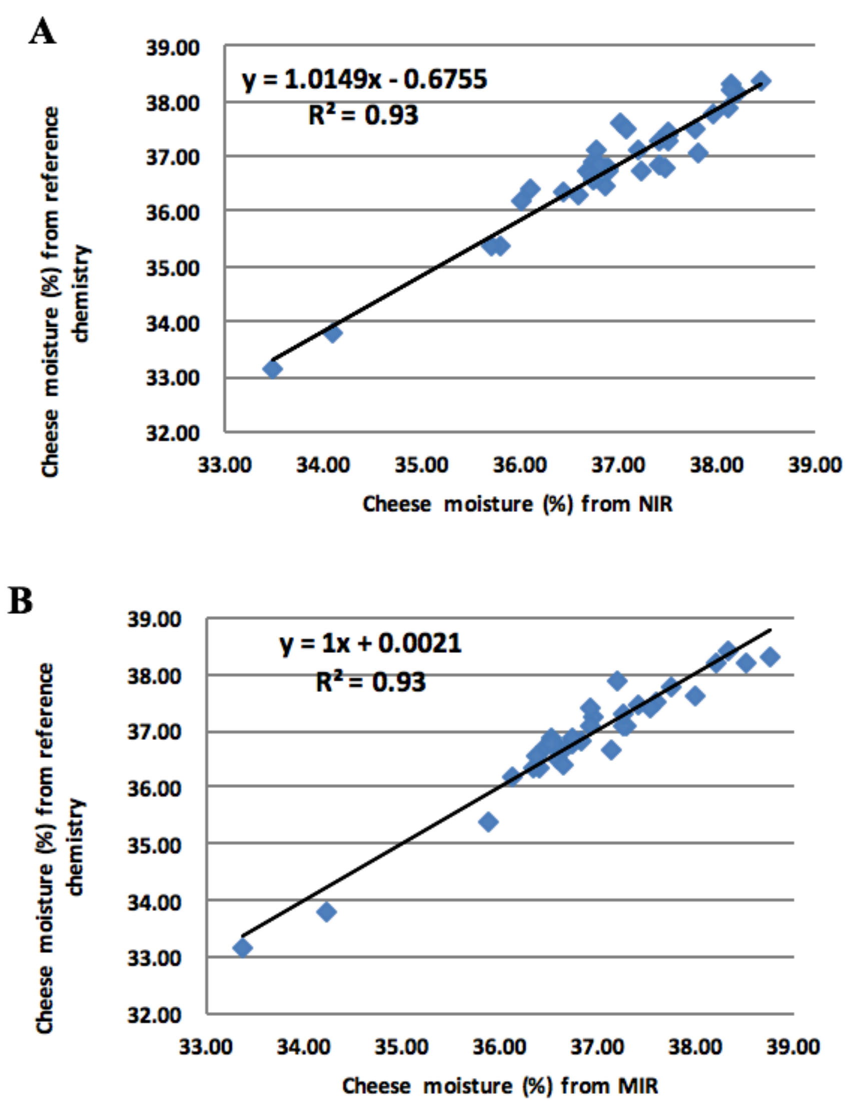

Figure 3.1. Predicted cheese moisture from (A) NIR, and (B) MIR and actual cheese moisture determined by reference chemistry oven-drying total solids.

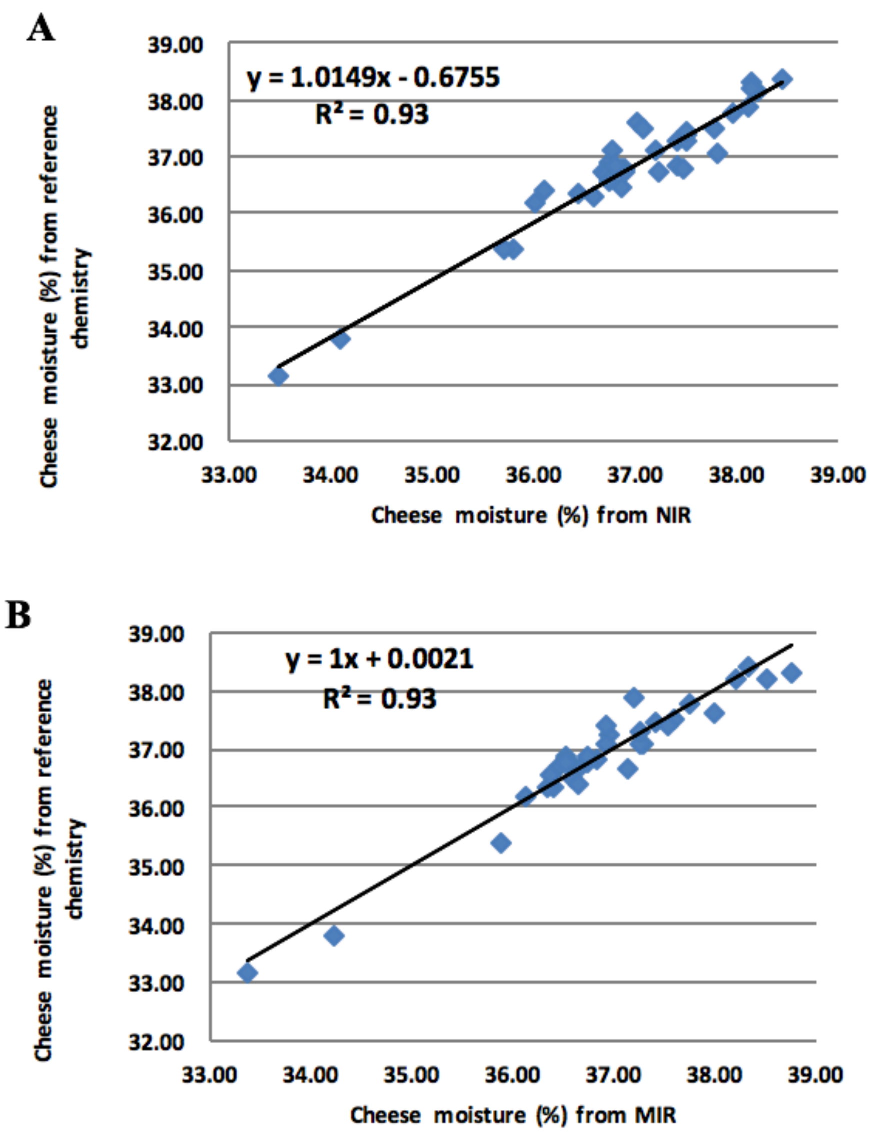

Figure 3.2. Predicted cheese fat from (A) NIR, and (B) MIR and actual cheese fat determined by reference chemistry Mojonnier ether extraction.

The regression analyses of reference salt values as a function of predicted salt by the coulometric method (Figure 3.3A) and MIR (Figure 3.3B) had very different r-squared values of about 0.16 and 0.93, respectively. The large difference in prediction performance between the commonly used method in commercial cheese factories and the MIR was surprising, but the poor performance was consistent with observations of weakness in the quality of cheese analysis data observed in our previous study (Margolies et al., 2017). Protein content of cheese is not routinely measured in most cheese factories; however, protein makes a very important contribution to cheese yield. Thus, we decided to develop a protein prediction with MIR. The regression analyses of reference protein values as a function of predicted protein by MIR (Figure 3.4) had an r-squared value of 0.82. Considering the important impact cheese compositional control has on cheese quality during aging, a method for routine cheese analysis that can achieve better agreement with reference chemistry than current practices is needed. Overall, the regression predictions of moisture, fat, salt, and protein by the MIR instrument appeared to be suitable for routine quality assurance use.

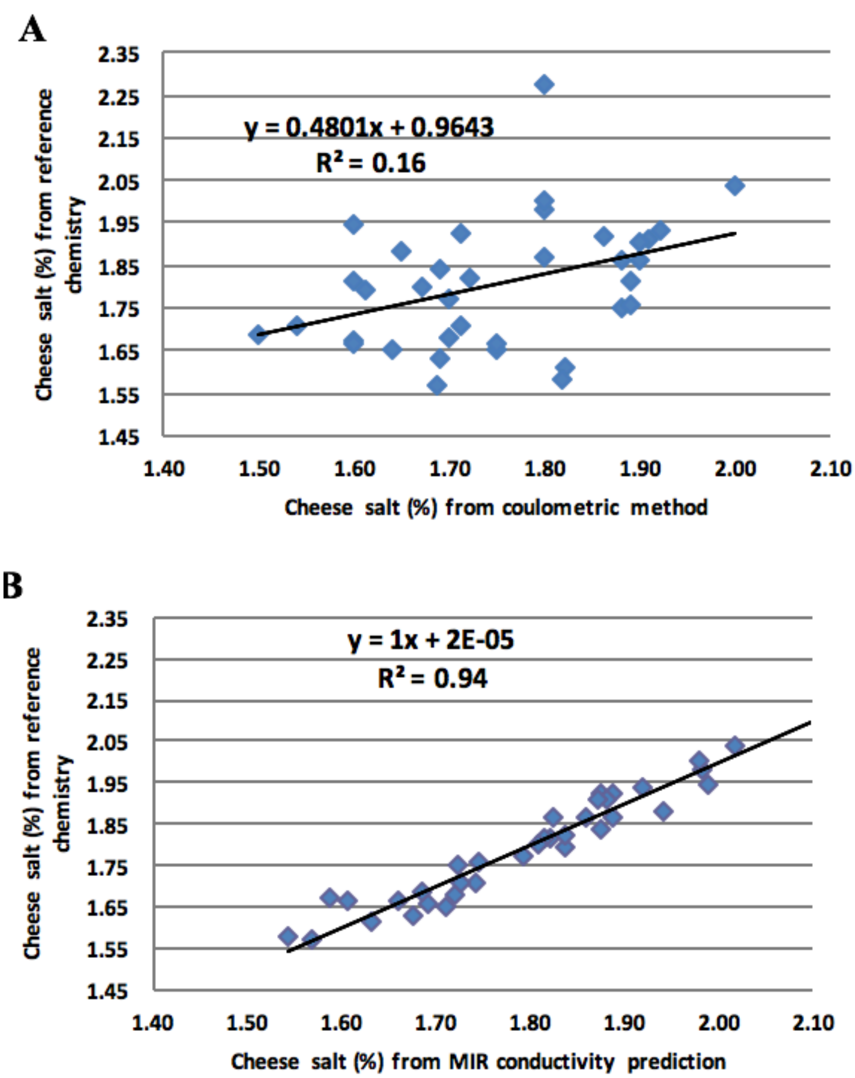

Figure 3.3. Predicted cheese salt from (A) coulometric method, and (B) MIR conductivity sensor and actual cheese salt determined by reference chemistry Volhard silver nitrate titration.

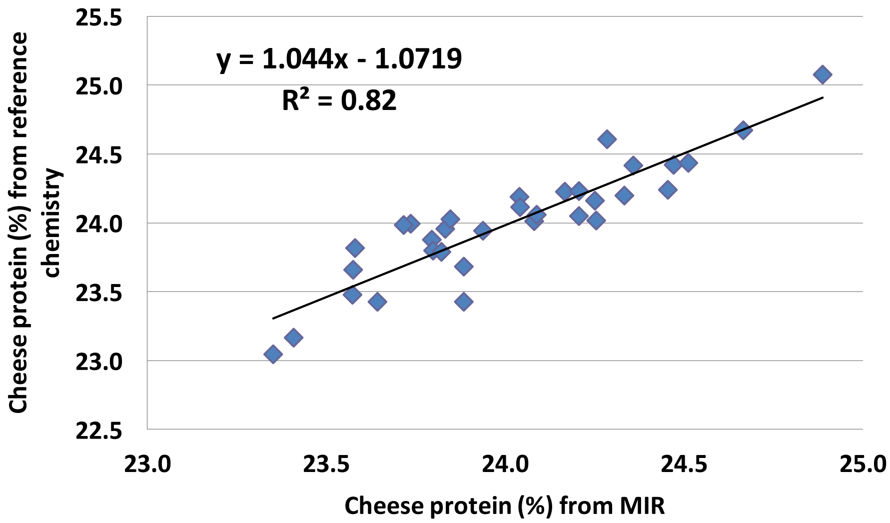

Figure 3.4. Predicted cheese protein from MIR and actual cheese protein determined by reference chemistry Kjeldahl method.

A comparison of mean test results on a factory by factory basis for moisture, fat, and salt are shown in Table 3.2. For moisture, agreement of the NIR and MIR means for all 34 cheeses with mean reference chemistry was the same for MIR and NIR, but standard deviation of the difference (**SDD**) between NIR and reference chemistry was larger (0.14) than the SDD between MIR and reference chemistry (0.09, Table 3.2). For fat, only MIR data for fat A is presented (Table 3.1) because of the 3 MIR approaches for measurement of fat in cheddar cheese, the fat A had the best agreement with reference chemistry (to be discussed later). For fat, both MIR and NIR tested lower on average than the reference chemistry but the NIR results were further from reference chemistry, particularly in factory 1, which has been reporting a problem with low fat recovery in cheese based on their NIR analysis data. It appears that the NIR fat calibration is not satisfactory in this factory. This is consistent with observations reported by Margolies et al. (2017). For salt determination, the MIR gave slightly lower mean results for all 34 cheeses than the reference method on validation (Table 3.2). The SDD between the MIR results and reference chemistry for salt was smaller (0.04) than the SDD between coulometric analysis and reference chemistry (0.14, Table 3.2). This suggests that a further adjustment of the slope and intercept on the MIR salt calibration would bring the MIR results into better agreement with reference chemistry than the coulometric method.

Table 3.2. Comparison of mean moisture and fat values with reference values for MIR versus NIR and coulometric method versus MIR for salt on a cheese factory by factory basis (factory 1, 2, 3, 4 represent the mean of 6, 6, 12, and 12 colored cheddar cheeses, respectively).

		Moisture				
Factory	MIR	Reference	Difference	NIR	Reference	Difference
1	36.91	36.99	-0.08	36.99	36.99	0.00
2	37.50	37.37	0.13	37.22	37.37	-0.15
3	37.11	37.12	-0.01	37.32	37.12	0.20
4	36.15	36.15	0.00	36.15	36.15	0.00
Mean	36.92	36.91	0.01	36.92	36.91	0.01
SDD			0.09			0.14
		Fat				
Factory	MIR (Fat A)	Reference	Difference	NIR	Reference	Difference
1	33.81	34.06	-0.25	33.06	34.06	-0.99
2	33.73	33.75	-0.02	33.50	33.75	-0.25
3	33.43	33.47	-0.04	33.26	33.47	-0.21
4	34.61	34.65	-0.04	34.57	34.65	-0.04
Mean	33.89	33.98	-0.09	33.60	33.98	-0.37
SDD			0.11			0.42
		Salt				
Factory	MIR	Reference	Difference	Coulometric	Reference	Difference
1	1.61	1.66	-0.04	1.72	1.66	0.06
2	1.59	1.69	-0.10	1.82	1.69	0.13
3	1.75	1.85	-0.11	1.76	1.85	-0.10
4	1.76	1.89	-0.12	1.73	1.89	-0.16
Mean	1.68	1.77	-0.09	1.75	1.77	-0.02
SDD			0.04			0.14

The validation performance statistics for the NIR and MIR analysis of the 34 cheeses for moisture and fat is shown in Tables 3.3 and 3.4 Each factory QC laboratory tested their own cheeses with their NIR that was calibrated with cheese produced at their factory using their own reference chemistry and with the coulometric method. The SEP values for moisture and fat on the NIR, 0.30 and 0.45, respectively, were both higher than the values on the MIR, 0.28 and 0.23, for moisture and fat A (which had the best performance of all the fat measurements on the MIR), respectively. The MIR salt predictions followed a similar pattern, with the MIR out-performing the coulometric method with SEP values of 0.036 versus 0.139, respectively. During the time of this study, none of the cheese factories were analyzing their cheese for protein content. The MIR had an SEP value of 0.19 for estimation of protein which suggests MIR could be an easy and effective way for cheese producers to measure protein to determine protein recovery in cheese making, similar to fat recovery. The SEP values for MIR using the sample analysis method described in the present study are very comparable or better than those reported by Holroyd (2011) for NIR, but were achieved with just a single calibration on the MIR performing well on cheddar cheeses from 4 different cheese factories.

Table 3.3. Validation performance of NIR on percent moisture and fat and the coulometric method for salt of 34 full fat cheddar cheeses from 4 different cheese factories.

	N	Reference	NIR[1]	MD[2]	SDD[3]	CV[4]	SEP[5]
Moisture	34	36.82	36.95	0.13	0.29	0.79	0.30
Fat	34	34.01	33.70	-0.30	0.44	1.29	0.45
			Coulometric Method				
Salt	34	1.804	1.750	-0.055	0.137	7.590	0.139

[1]NIR = near infrared
[2]MD = mean difference
[3]SDD = standard deviation of the difference between instrument and reference
[4]CV = coefficient of variation
[5]SEP = standard error of prediction

Table 3.4. Validation performance of MIR on for percent moisture, fat, salt, and protein for 34 full fat cheddar cheeses from 4 different cheese factories.

	N	Reference	MIR[1]	MD[2]	SDD[3]	CV[4]	SEP[5]
Moisture	34	36.82	36.82	0.00	0.28	0.76	0.28
Fat A[6]	34	34.01	33.94	-0.07	0.23	0.67	0.23

Fat B[7]	34	34.01	33.70	-0.31	0.32	0.95	0.32
Fat (AB)[8]	34	34.01	33.77	-0.24	0.29	0.85	0.29
Salt	34	1.804	1.705	-0.100	0.035	1.950	0.036
Protein	34	24.00	23.91	-0.09	0.23	0.94	0.19

[1]MIR = mid infrared
[2]MD = mean difference
[3]SDD = standard deviation of the difference between instrument and reference
[4]CV = coefficient of variation
[5]SEP = standard error of prediction
[6]Fat A = fat prediction based on carbonyl stretch
[7]Fat B = fat prediction based on C-H stretch
[8]Fat (AB) = fat prediction based on combination of carbonyl and C-H stretches

Impact of Annatto Color on MIR Analysis. In addition to the 36 colored cheddar cheese validation samples, an additional 12 non-colored cheddar cheese samples were also tested. It was found that the calibration which was done only with colored cheese samples, did not predict well for the non-colored cheddar cheese (data not shown). Of the four cheese plants that provided colored cheddar cheese, two different annatto color concentrates were used (Material No:70471, Chr. Hansen, Boege Alle 10-12, 2970 Hoersholm, Denmark; Item # 423506, D.D. Williamson Colors, LLC, 815 Sunset Road, Port Washington, WI 53074). The concentrates of the annatto colors were diluted (1:4, v/v) with 0.01% triton water zeroing solution and compared to 0.01% triton water zeroing solution run through the MIR (Figure 3.5). The spectra are shown (Figure 3.5) over a range of wavelengths that include the sample and reference wavelengths for fat A and protein (Table 3.1) because those were the only wavelengths used in the current study to predict cheese composition. The absorbance of the two color concentrates at the sample wavelengths for fat A (1740 to 1756 cm^{-1}) and reference wavelengths for fat A (1783 to 1799 cm^{-1}) were similar and had only a slightly higher intensity than the triton water solution, indicating that the color would have little impact on prediction of fat content of the cheese. However, the absorbance for the color concentrates was much higher at the protein sample wavelengths (1531 to 1551 cm^{-1})

than it was for the protein reference wavelengths (1485 to 1497 cm^{-1}) and the triton water. This demonstrates that the annatto coloring influences the MIR's ability to predict protein content and the calculated solids content of the cheese. Therefore, a separate calibration would be needed to be done for compositional prediction of white cheddar cheese by using white cheddar for calibration.

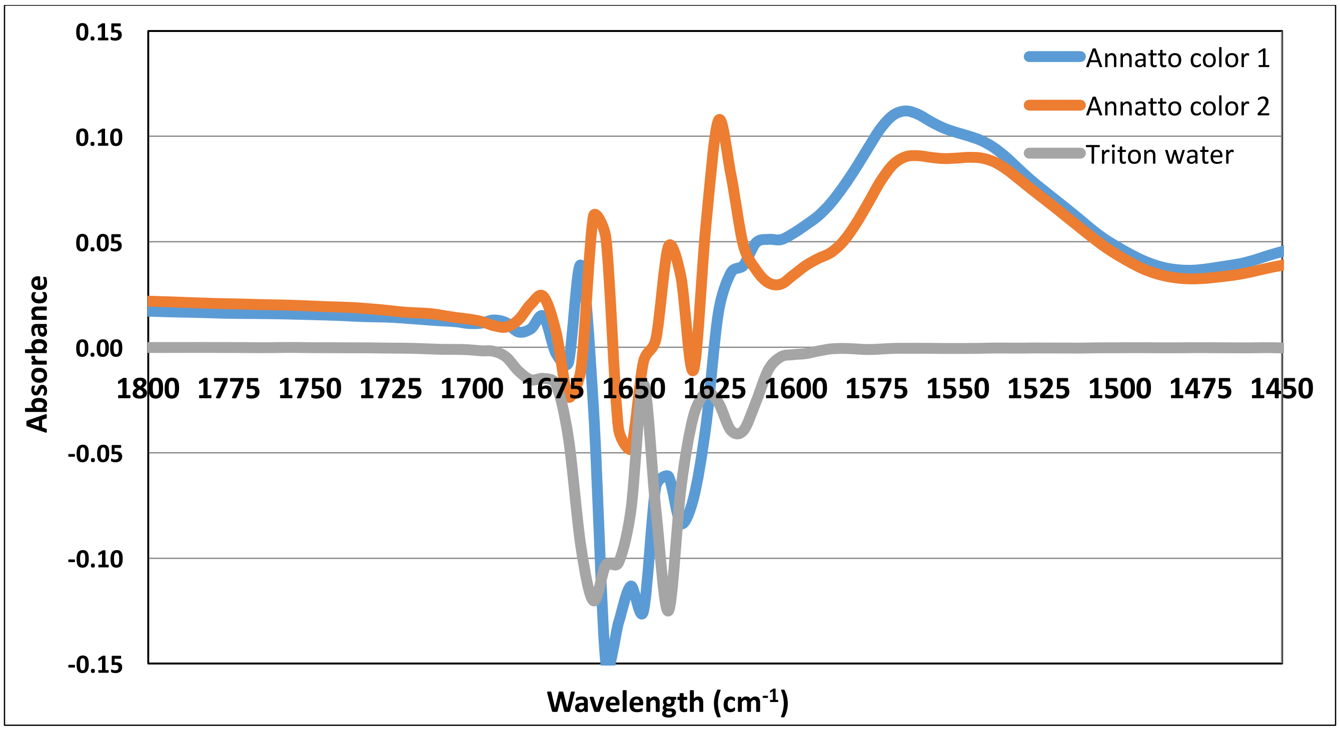

Figure 3.5. MIR spectra of two annatto color concentrates and triton water at the sample and reference wavelengths of fat A and protein.

Practical Aspects of Calibration of NIR and MIR in Commercial Cheese Factories.

The approaches to calibrate NIR and MIR for cheese analysis are very different. For NIR, each cheese variety within each factory requires a PLS calibration model to be developed for each measured parameter. The development of PLS models requires chemical analysis of 200 to 400 cheeses for each cheese type for each parameter to be measured (McKenna, 2001; Barbano and Lynch, 2006). In practice, this is very difficult for a QC laboratory in a cheese factory due to the challenge of maintaining the skilled staff members and equipment required to conduct high quality reference chemistry testing. Additionally, calibrations are generally not easily transferable from NIR instrument to NIR instrument and are typically cheese type and factory specific. Recently, some NIR equipment manufacturers have been able to produce global PLS base calibrations that require less (10 to 20 samples) reference chemistry for a slope and intercept adjustment (Holroyd, 2011). The global model for NIR reduces the amount of reference chemistry that needs to be done by the cheese factory laboratory compared to development of the full PLS model in each factory. How well the global model predicts (i.e., SEP) needs to be determined within each factory.

The MIR instrument used in the current study was a standard MIR milk analyzer that is normally used to test milk, cream, and whey samples in a cheese factory. Because cheese is a solid, the analyst would not normally consider trying to test a cheese on an instrument designed for liquids. The current paper reports a method for liquification of cheese samples so that they can be tested like a milk or whey sample using a MIR milk analyzer. Thus, the MIR method requires additional time for sample preparation compared to NIR. In NIR, however, the consistency of sample grinding from analyst to analyst may influence results (Holroyd, 2011). Instead of developing PLS models on the MIR, we started with an evaluation of the performance of classical filter wavelengths (Kaylegian et al., 2009) used for measurement of fat and protein in milk analysis (Tables 3.1 and 3.4). This approach with MIR creates an opportunity for cheese factories to use a prepared set of liquid cheese calibration samples with reference chemistry done by a laboratory that specializes in calibration sample preparation and high quality reference chemistry. A cheese factory would purchase calibration samples for cheese analysis, just like they purchase samples for calibration of the same instrument for milk and whey analysis. This approach would reduce the need for reference chemistry to be done in the cheese factories and would allow cheese factories to achieve better analytical performance in cheese analysis used for cheese yield evaluation and compositional control.

In our study the MIR was calibrated with 34 cheeses from one cheese factory and more accurately predicted the compositional parameters of the cheeses from three different factories than the NIR that was calibrated in each of those factories. For analysis of milk, a centrally produced calibration set is used across multiple factories and a similar approach could be applied to cheese testing using the MIR, thus saving time and resources normally required to calibrate an NIR, while attaining more accurate analyses.

CONCLUSIONS

A method for blending colored cheddar cheese to form a liquid sample for MIR analysis gave equal or better performance than NIR and coulometric analysis of the same cheddar cheese. The SEP values for moisture and fat on the NIR, 0.30 and 0.45, respectively, were both higher than the SEP values on the MIR, 0.28 and 0.23, for moisture and fat A (which had the best performance of all the possible fat measurement wavelengths on the MIR), respectively. Salt predictions followed a similar pattern, with the MIR out-performing the coulometric method with SEP values of 0.036 and 0.139, respectively. The MIR had an SEP value of 0.19 for estimation of protein which suggests that MIR could be an easy and effective way for cheese producers to measure protein to determine protein recovery in cheese making.

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CHAPTER FOUR

CONCLUSIONS AND FUTURE WORK

A systematic approach based on theoretical cheese yield equations was developed for evaluation of cheese yield performance and fat losses in a cheese factory. Based on observations in commercial cheese factories, sensitivity analysis was done to demonstrate the sensitivity of the evaluation outcome to analytical uncertainty of data used in the evaluation. Uncertainty in the accuracy of milk weight, composition of milk, and composition of cheese were identified as important factors that influence the ability to manage business profitability and consistency of cheese quality. It was demonstrated that an uncertainty of $\pm$ 0.1% milk fat or milk protein in the vat causes a range of theoretical cheddar cheese yield from 10.05 to 10.37% and an uncertainty of yield efficiency of $\pm$ 1.5%. This equates to $\pm$ 1,489 kg (3,283 lbs) of cheese per day in a factory processing 938,935 kg (2.07 million lbs) of milk per day. The same is true for uncertainty in cheese composition, where the impact of running 0.5% low on moisture or fat is about 484 kg (1,067 lbs) of missed revenue opportunity for the day. Missing the moisture target also leads to missing targets such as FDB and salt in the moisture, which are dependent on the cheese moisture. Similar impacts were demonstrated for mozzarella cheese.

A method for blending colored cheddar cheese to form a liquid sample for MIR analysis gave equal or better performance than NIR and coulometric analysis of the same cheddar cheese. The SEP values for moisture and fat on the NIR, 0.30 and 0.45, respectively, were both higher than the SEP values on the MIR, 0.28 and 0.23 for moisture and fat A (which had the best performance of all the fat measurements on the MIR), respectively. Salt predictions followed a similar pattern, with the MIR out-performing the coulometric method with SEP values of 0.036 and 0.139, respectively. The MIR had an SEP value of 0.19 for estimation of protein which suggests that MIR could be an easy and effective way for cheese producers to measure protein to determine protein recovery in cheese making.

In the future, a MIR cheese calibration set could be centrally produced and distributed to several factories for them to calibrate their MIRs, similarly to how MIR calibration for milk is done. The effect of annatto coloring on MIR absorbance should be investigated to determine if it is possible have one calibration set that can successfully predict composition for both colored and non-colored cheeses. The implementation of MIR for cheese analysis will ultimately save cheese manufacturers time and resources by minimizing the amount of time required to calibrate NIR with reference chemistry, and by allowing them to obtain more accurate analytical data thus allowing them to maximize their cheese quality and yields.