

NUTRIENT PROFILE, FUNCTIONAL PROPERTIES, AND
MICROSTRUCTURE OF DRIED WASTE MILK PRODUCTS FOR USE AS A
POTENTIAL ANIMAL FEED

A Dissertation

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DEDICATION

This dissertation is dedicated to my grandfather, Sigmunt Joseph Sarna, who was an inspiration in my life. The stories of his travels throughout the United States of America, Europe, and the Middle East have always inspired me to excel at all things I start and to keep striving for knowledge everyday. I have seen no greater love than the love he had for my grandmother, Mary. I will forever remember how he always opened doors for her. I only hope that I can pass his love and compassion on to my children. I find strength in his memory.

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ABSTRACT

A study was conducted to determine the feasibility of concentrating the wastewater of a butter/powder factory for use as an animal feed. Two concentrated products were evaluated: recovered milk product (RMP), which is the direct factory waste stream; and formulated recovered milk product (FRMP), which is a product made by combining RMP and separator de-sludge in a 3:1 ratio. Three pilot scale dryer systems were used to concentrate the product: a spray dryer, a roller dryer, and a pulse combustion dryer. Dried samples were analyzed for fat, moisture, protein, ash, nitrates, chloride, pH, calcium, phosphorus, sodium and amino acids. Values for total digestible nutrients, nitrogen free extract and lactose were calculated. Functional properties were measured by free-fat, insolubility index, wettability, and particle size distribution. Additionally, the microstructure was examined using environmental scanning electron microscopy (ESEM).

The objectives to this study were to: 1) further concentrate and dry RMP into a powder to reduce hauling cost, improve consistency, and increase the storage life of the product; 2) add other by-products to the RMP to improve the nutrient profile; and 3) compare three drying systems as to the effect to the nutrient profile, functional properties, and microstructure of the dried product.

The protein content in the FRMP was significantly ($P<0.05$) higher than in the RMP. The nitrate (NO_3) concentration in the RMP was significantly ($P<0.05$) higher than the NO_3 concentration in the FRMP. The Mojonnier fat determination test resulted in higher fat content for the products dried on the spray and pulse dryer compared to the Soxhlet fat determination method. The roller drier produced a powder that was significantly ($P<0.05$) higher in free-fat compared to the other two drier systems. The pulse combustion dryer produced the most soluble product as determined by the insolubility index. The available lysine concentration in the product dried on the roller dryer was significantly ($P<0.05$) lower than the available lysine concentrations in the product dried on the spray and pulse combustion dryers. The microstructure of the powders was different for each of the dryers when examined using ESEM.

INTRODUCTION

The enforcement of environmental laws is becoming a high priority for regulatory agencies, especially those agencies involved with water quality (Mozingo, 2001). Publicly owned water treatment facilities have to comply with the Environmental Protection Agency's (EPA) regulations for water discharge into national waterways. These regulations are passed from the Publicly Owned Treatment Works (POTWs) to the industrial discharger.

Although the dairy processing industry does not usually deal with extremely hazardous materials such as arsenic, there are many contaminants that are found in their waste streams that are potentially harmful to the environment. Nitrates and other salts are the most difficult compounds to remove from the waste stream, while fats, proteins, and carbohydrates are easily removed by degradation. Dischargers of industrial wastewater are faced with higher fees and stricter discharge requirements each year.

There are few alternatives for the factory to combat the increasing cost of keeping discharges within regulatory limits. However, some alternatives are to 1) reduce waste in the factory, 2) change cleaning chemicals to reduce salts, 3) change processing conditions, or 4) generate no discharge.

A butter/powder factory in California has taken a unique approach to treating the effluents from their manufacturing processes. This factory is a green-field site, since it treats all the industrial wastewater to meet EPA discharge requirements before it is discharged. This facility uses a falling film evaporator with mechanical vapor recompression to concentrate the factory waste effluent into RMP of approximately 15% total solids that has some animal feed value. This concentrated RMP is hauled to animal feeding operations in the area to be fed to cattle. Sometimes the feeding operations do not want the concentrated feed product. When this occurs the product must be dumped as a high cost waste product, significantly decreasing the profitability of the food manufacturer.

It was hypothesized that the RMP could be further concentrated and dried into a powder to reduce hauling cost, improve consistency, and increase the storage life of the product. It was further hypothesized that other by-products could be added to the RMP to improve the nutrient profile. It was also hypothesized that the type of dryer system used for drying the RMP would affect the nutrient profile, functional properties, and microstructure.

This study examined the nutrient profile of the current feed, recovered milk product (RMP), and two by-products: separator de-sludge and deproteinized milk solids. The nutrient profile was used to decide how best to blend the three products to produce a formulated blend optimized for animal nutritional value and product volumes. Secondly, RMP and the formulated blend were dried using three different systems. These pilot scale dryer systems are 1) traditional spray dryer, 2) traditional roller dryer, and 3) pulse combustion spray dryer.

This research evaluated the nutrient profile based on analytical tests for: fat, moisture, protein, ash, nitrate, chloride, pH, calcium, phosphorus, sodium and amino acids. Calculations were used to determine lactose, total digestible nutrients, and

nitrogen free extract. Functional properties of the dry powders were used to evaluate the three drying systems using analytical tests for: free-fat, wettability, particle size distribution, and insolubility index. Additionally, the microstructure of the powder was examined using environmental scanning electron microscopy (ESEM) to compare and contrast the morphology of the powder particles from each of the drying systems. This was important because the pulse combustion dryer had not been used in the dairy industry at the time of this project.

LITERATURE REVIEW

Regulations for wastewater discharge

In 1972, the passage of the Clean Water Act (CWA) gave the Environmental Protection Agency (EPA) the task of developing effluent limitation guidelines and standards that would provide a minimum, technology-based threshold for ongoing improvements in effluent quality (EPA, 2000). It is estimated that this program has prevented the release of more than a billion pounds of priority toxic pollutants each year. These pollutants are known to contribute to cancer and other chronic illnesses (EPA, 2000). The EPA intends to continue to use the effluent guidelines program to provide even greater protection of human health and the environment (EPA, 2000). However, the EPA has not been enforcing all aspects of the CWA. This lack of enforcement has allowed dischargers' permits to expire (Smith et al., 2000).

In southern California the Los Angeles Regional Water Quality Control Board (LARWQCB) levied about \$200,000 in fines in 1997 and in 1999 the fines totaled \$1.4 million (Mozingo, 2001). Enforcement of the current regulations led to the increase in fines (Mozingo, 2001). Legislation has provided new money to the LARWQCB for enforcement of storm water runoff regulation after receiving pressure from environmental groups. (Mozingo, 2001). The EPA believes that this level of enforcement will be followed throughout the State of California (Mozingo, 2001).

The 2001 California Ocean Plan (Anonymous, 2000b) states that "waste management systems that discharge to the ocean must be designed and operated in a manner that will maintain the indigenous marine life and a healthy and diverse marine community." The objective of the Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters (Smith et al, 2000). Environmental groups across the United States have been aggressively lobbying the EPA and state agencies to enforce the provisions of the Clean Water Act (Mozingo, 2001). It is not likely that these environmental groups will reduce their efforts to keep pollution of water to a minimum.

Wastewater treatment

Generally, wastewater treatment systems are designed to eliminate or minimize contaminants to meet discharge regulations. There are numerous methods for treating wastewater in the dairy foods processing industry. These include, but are not limited to, aerated lagoon systems, diffused air flotation (DAF), anaerobic sludge reactor, membranes, and evaporation. Each of these technologies can be applied separately or in combination. Some dairy foods processing plants use anaerobic sludge reactors to produce methane gas, which is used as an energy source. Other plants discharge directly to a publicly owned treatment works (POTWs). Regardless of the method used, processing the effluent from a dairy foods processing plant increases operational costs.

It is commonly stated that if product is going down the drain then you are paying for it twice. The plant pays to purchase the product and then has to pay a second time to treat the product in the wastewater. This is why the most important

step for a dairy foods processing plant is to reduce the amount of product going into the wastewater.

The main pollutants in the effluent from dairy food processing plants are fat, lactose (carbohydrate), and protein (Baick et al., 1992; Gough et al., 2000). The EPA uses the following factors to calculate the biochemical oxygen demand (BOD₅ in mg/L) for milk products: 0.89 for fat, 1.031 for proteins, and 0.691 for carbohydrates (Anonymous, 1994). These factors are useful in determining the amount of BOD₅ coming into a milk processing facility and in setting limits on the amount of discharge allowed per pound of BOD₅ received. For the California Dairies, Inc.'s plant in Tipton, California those limits were set at a thirty day average of 0.008 kg/100 kg of BOD₅ input, with a maximum of 0.016 kg/100 kg of BOD₅ input daily (Anonymous, 1994).

Henze (1997) states that legislation and control are getting stricter for wastewater discharge. The former attitude in the United States of America that "dilution is the solution to pollution" is no longer an accepted practice. Henze (1997) suggests that wastewater can be viewed as a resource for production of biogas or carbon for denitrification. Development of more stringent water quality standards are being met with development of more sophisticated processing (Stephenson, 1996).

Membrane bioreactor technologies are becoming more energy efficient as compared to traditional methods (Van Dijk and Roncken, 1997). Membrane bioreactors are well suited for applications that require a small footprint and make it possible to recover valuable components of the waste stream (Van Dijk and Roncken, 1997).

Operating costs play a major role in selecting a technology for treating wastewater. Several technologies may achieve the same level of treatment, but investment costs and operating costs will differ, sometimes significantly.

California feed regulations

A review of the Commercial Feed Law and Regulations (California Department of Food and Agriculture, 1997) states that it is unlawful to sell commercial feed deemed to contain a poisonous, deleterious, or nonnutritive substance in amounts that are specified as being unsafe. Section 2683 of the California Commercial Feed Law and Regulations (California Department of Food and Agriculture, 1997) states that before the first delivery of a special mix the manufacturer shall furnish the purchaser a guaranteed analysis stating the following: 1) crude protein (minimum); 2) equivalent crude protein from non-protein nitrogen (maximum); 3) crude fat (minimum); 4) crude fiber (maximum); 5) ash (maximum); 6) sodium (maximum). Additionally, if the mix contains more than nine percent ash, then the minimum and maximum percentage of calcium, minimum percentage of phosphorus, and maximum percentage of sodium must be listed.

The use of non-protein nitrogen may be used in commercial feeds for ruminants and only by approval for other animals (California Department of Food and Agriculture, 1997). Feed containing non-protein nitrogen products shall be labeled with the maximum percent of equivalent crude protein from non-protein nitrogen and shall appear immediately below the guarantee for the minimum percent of crude

protein (California Department of Food and Agriculture, 1997). If the feed contains more than 8.75 percent equivalent crude protein from all forms of non-protein nitrogen, or if the equivalent crude protein from all forms of non-protein nitrogen is in excess of one-third of the total crude protein, the label shall bear a warning statement followed by feeding directions for the safe use of the feed (California Department of Food and Agriculture, 1997). The warning statement shall read "Warning: Excessive consumption may result in adverse toxic reaction. Use only as directed" (California Department of Food and Agriculture, 1997).

The California Commercial Feed Law and Regulations does not currently have a definition for lactose obtained from the ultra-filtration of raw or pasteurized whole milk. However, there is a definition for condensed whey permeate which states that the label must show the minimum percent total whey product solids, crude protein, lactose, maximum percent of ash, and equivalent crude protein from non-protein nitrogen (California Department of Food and Agriculture, 1997).

Lactose in feed

There are six groups of feed nutrients; carbohydrates, fats, proteins, minerals, vitamins, and water (Cullison, 1982). Lactose, or "milk sugar", is the principal carbohydrate in milk (Cullison, 1982; Fox and McSweeney, 1998; Holsinger, 1997; Holsinger, 1988; Larson, 1985; Thelwall, 1997; Mustapha, 1997). Lactose is a disaccharide composed of one molecule of glucose and one molecule of galactose joined in a 1-4 carbon linkage as a β -galactoside, specifically 4-O- β -D-galactopyranosyl-D-glucopyranose (Fox and McSweeney, 1998; Holsinger, 1997; Holsinger, 1988; Larson, 1985; Thelwall, 1997). In solution, lactose exists as an equilibrium mixture of α - and β -lactose (Mustapha, 1997; Holsinger, 1997; Fox, 1998). In solution, α -lactose is about 37% and β -lactose is about 63% (Mustapha, 1997; Holsinger, 1997; Fox, 1998). The solubility of lactose in water is low compared to other sugars (Mustapha, 1997; Holsinger, 1997; Fox, 1998).

There has been little research performed on feeding pure lactose to animals. Bylund (1995) suggests that lactose can be used as fodder, a coarse feed for cattle, and the feed value can be increased if the salts are removed and high-quality proteins are added. Nessmith et al. (1997a) hypothesized that high dietary concentrations of lactose would allow for inclusion of more soybean meal and less spray-dried plasma protein in the diet of weanling pigs. They used lactose concentrations of 0, 20, and 40% in the diets of 8 to 21 day old pigs and altered the protein intake as well. From day 0 to 10 after weaning, increasing lactose increased the average daily gain. From day 10 to 26 there were no subsequent or cumulative effects on growth performance. Therefore, they concluded that relationships among lactose and protein sources have minimal effects on performance of pigs of good health.

In another study performed by Nessmith et al. (1997b), researchers replaced the lactose from whey with crystalline lactose. In two experiments there were no differences between the use of lactose and the use of whey on average daily gain of pigs. They concluded that edible-grade de-proteinized whey and crystalline lactose can replace the lactose provided by high-quality dried whey without affecting pig performance.

Mahan (1992) concluded that adding lactose to the diet of weanling pigs improved gain and feed efficiency. Mahan (1993) suggested that using a highly digestible carbohydrate along with a good protein source in pig starter diets would improve gain and feed efficiency in the weanling pigs. Hansen, et al. (1993) found that lactose seemed to support better growth than cornstarch did in the diets of young weanling pigs.

Another potential use for lactose in the animal feed industry is the production of lactosyl urea. Urea can serve as a cheap source of nitrogen for cattle, but its use is limited because NH_3 is released too quickly leading to toxic concentrations of NH_3 in the blood (Fox, 1998). Reaction of urea with lactose yields lactosyl urea from which NH_3 is released more slowly (Fox, 1998).

Dairy protein in feed

Skim milk powder (SMP) has been used extensively as the main source of protein in milk replacers for calves (Lammers et al., 1998). However, the primary protein source in milk replacers currently is whey (Lammers et al., 1998; Terosky et al., 1997). Research conducted by Lammers et al. (1998) showed that whey protein concentrate (WPC) was better than or equal to SMP as a source of protein. Terosky et al. (1997) suggests that WPC is nutritionally acceptable and more economical than SMP.

It is well established that feeding good quality dried whey improves the performance of 3- to 4-week-old weanling pigs (Hansen, et al., 1993; Mahan, 1992 and 1993). Dried whey is frequently added to weanling pig diets at levels of 20 to 25% and provides a highly digestible source of nutrients (Mahan, 1993). Mahan (1992) found that diets of young weanling pigs containing a 1.30% lysine concentration in combination with lactose resulted in a lower feed intake. Mahan (1992) concluded that the addition of high-quality dried whey in the diets of young weanling pigs resulted in improved gain and feed efficiency. However, Mahan (1992) concluded that the lactose component of the whey was the primary component for improving performance.

Concentration technologies

A French researcher, Nicolas Appert, carried out some of the earliest attempts of condensing milk in the 1790's (Hunziker, 1946). Appert used a water bath over fire to condense the milk to about two-thirds the original volume (Hunziker, 1946). The condensed milk was then cooled and placed in glass bottles, filled to the top and corked, then boiled for two hours (Hunziker, 1946). This milk kept so well that the French Marine Department made use of the product on its warships in the early nineteenth century (Hunziker, 1946).

In 1856, Gail Borden received patents from both the United States and England for "producing concentrated sweet milk by evaporation in vacuum without the admixture of sugar or other foreign matter" (Hunziker, 1946). After some failures, Borden finally formed the New York Condensed Milk Company in Wassaic, New York in 1858 (Hunziker, 1946). Gail Borden is considered to be the father of the commercial condensing industry (Hunziker, 1946).

The general principle of vacuum evaporators is to remove water from milk at reduced temperature. The various designs that are in use in the dairy industry today include the falling film evaporator, the rising film evaporator, and the plate evaporator (Bylund, 1995; Caric', 1994; Kyle and Rich, 1986). Modern evaporators are made up of the calandria, vapor separator, condenser, vacuum production unit, and a system for steam recompression (Caric', 1994; Kyle and Rich, 1986). The calandria is a tube chest where steam is circulated around the outside of the tubes, and the product flows through the inside of the tubes. The vapor separator is a vertical cylinder with a tangential vapor inlet and a central outlet that keeps the drops of concentrated product from being taken away with the vapor (Caric', 1994; Kyle and Rich, 1986). The calandria and the vapor separator make up an effect (Kyle and Rich, 1986). The condenser condenses vapors coming out of the last effect by transferring the heat to a cooling medium (Caric', 1994; Kyle and Rich, 1986). The vacuum production unit removes air from the calandria allowing the boiling point of the milk to be reduced (Bylund, 1995; Caric', 1994; Kyle and Rich, 1986). The steam recompression system can be divided into thermal vapor recompression (TVR) evaporators or mechanical vapor recompression (MVR) evaporators (Caric', 1994; Kyle and Rich, 1986). In TVR evaporators, steam used to heat the first effect is at a low pressure, a thermo-compressor is used to compress the vapors from the first effect to a higher pressure so they can be used to heat steam in the first effect vapor space (Kyle and Rich, 1986). In an MVR evaporator, the vapor from the effect is fed into a turbo fan that compresses the vapor to a high pressure and returns it to the same effect (Kyle and Rich, 1986). The MVR uses very little externally generated steam and is very energy efficient, using up to 80 percent less energy per unit of water evaporated than a TVR evaporator (Kyle and Rich, 1986).

The falling film tubular evaporator is primarily used in the dairy industry today (Caric', 1994; Singh and Newstead, 1992). It was first introduced in 1953 in Germany (Caric', 1994). In this type of evaporator it is very common to see five to seven effects being used (Bylund, 1995; Caric', 1994; Kyle and Rich, 1986). Milk is pumped to the top of the first effect and distributed to the tubes where it flows downward under the influence of gravity and pressure difference to the vapor separator (Kyle and Rich, 1986). As the product is falling, vapors are released (due to the boiling) forcing the liquid against the heating surface (Kyle and Rich, 1986). The concentrated liquid is collected at the bottom of the calandria and pumped to the next effect. This process is repeated for each effect in the system (Kyle and Rich, 1986).

Drying technologies

Drying of milk dates back to the thirteenth century when Marco Polo described dried milk made by the Tartars (Caric' and Kalab, 1987; Hunziker, 1946). This early drying of milk was accomplished in the sun (Caric' and Kalab, 1987). Nicolas Appert, in 1810 in France, dried milk in a pill form using a current of dry air (Caric' and Kalab, 1987; Hunziker, 1946). The first commercial drying of milk was based on a British patent issued in 1855 to Grimwade and this milk contained sodium or potassium carbonates and sucrose (Caric' and Kalab, 1987; Hunziker, 1946). Hunziker (1946) reports the first dried milk on a commercial scale was malted milk,

which was placed on the market in 1887. The first drum drying equipment was designed and put into service in 1902 (Caric' and Kalab, 1987). In 1872 there was a patent issued for spray drying equipment and a procedure by Percy in the United States (Caric' and Kalab, 1987).

Roller process. The roller process was the first form of commercial drying of milk powder throughout the world in the early 1900's (Singh and Newstead, 1992). Product is applied as a thin film upon the smooth surface of a continuously rotating, steam heated metal drum, and the film of dried product is continuously scraped off by a stationary knife located opposite the point of application (Hunziker, 1946). Drying equipment consists of one or two rotating rollers (Caric', 1994) that range in size from 1 to 6 m long and 0.3 to 3 m in diameter (Bylund, 1995). Some of the advantages to using a roller or drum dryer is low initial capital cost, compactness, and simplicity of operation (Hunziker, 1946; Caric', 1994; Bylund, 1995). Drum dryers produce products that are advantageous to some confectionaries and bakeries (Caric', 1994). Drum driers are also used to dry milk and whey products for animal feed blends (Caric', 1994). One disadvantage of using a roller dryer is that products of Maillard-type reactions may cause a scorched flavor in the powder (Caric', 1994). Maillard-type reactions lower the lysine content and therefore make it undesirable to dry milk-based baby foods on a roller dryer because lysine is needed in a baby's diet (Hansen, 1985). Another disadvantage is poor solubility of the powder in water (Caric', 1994).

There are several factors that affect the quality of the product produced and the capacity of drum driers. These factors include steam pressure, speed of drying drum, and the removal of the dried milk film from the drum (Hunziker, 1946). Researchers found that increasing the steam pressure from 60 to 85 pounds and increasing the drum speed from 24 to 36 revolutions per minute (rpm) increased the capacity of a drum drier by 23 percent (Hunziker, 1946). A stationary adjustable knife that extends over the entire length of the drum carries out the removal of dried product from the drum. Hunziker (1946) notes that the knife often allows product to accumulate on the drum due to the uneven heating at different parts of the scraper. He also notes that the product scraped off during the first revolution of the drum is superior in quality compared to that, which is allowed to accumulate on the drum over time.

Caric' and Kalab (1987) prepared micrographs of skim milk powder that were dried on a roller dryer. They found that powder particles from the roller process were irregular in shape and had sharp edges. These researchers also noted that the particles were compact and contained no occluded (or trapped) air.

Spray drying. Spray drying is the most common method of drying milk and milk products (Caric', 1994). Spray drying chambers are both horizontal and vertical, with the vertical dryer being used more frequently (Caric', 1994). Spray drying is based on the principle that filtered ambient air is heated in the range of 150 to 300 °C and introduced into the drying chamber at high velocity (50 m/second) (Caric', 1994; Hunziker, 1946; Bylund, 1995). There are two distinct stages in the drying operation: the constant-rate and falling-rate stages (Harper and Hall, 1981; Kyle and Rich, 1986). In the constant-rate stage water must migrate to the free surface of the particle and little heating of the product occurs because of rapid vaporization of moisture from the surface (Harper and Hall, 1981; Kyle and Rich, 1986). In the falling-rate stage the

water must evaporate from the free surface into the drying medium (Harper and Hall, 1981; Kyle and Rich, 1986). Therefore, the optimum drying condition occurs when the water is being evaporated from the surface at the same rate at which it is arriving at the surface (Kyle and Rich, 1986). Concentrated milk at 45 to 50% total solids is pumped, using a high-pressure pump at ca. 200 bar, through spray nozzles into the hot air flow (Caric', 1994; Hunziker, 1946; Bylund, 1995). The dry powder and air then travels to the bottom of the drying chamber. In single stage drying, the air and powder exit into a cyclone or bag-house where the air is separated from the powder and exhausted to the atmosphere (Bylund, 1995; Caric', 1994; Kyle and Rich, 1986). In multi-stage drying a portion of the powder drops to a fluidized bed for further drying while the majority of the air with a portion of the powder goes through cyclones and bag-houses (Bylund, 1995; Caric', 1994; Kyle and Rich, 1986). In the drying of dairy products a quantity of heat is transferred from the heated air to the milk droplets in order to vaporize the water (Kyle and Rich, 1986). Simultaneously the free water vapor is transferred from the droplets to the air and is removed from the system (Kyle and Rich, 1986). Therefore, factors affecting these transfer processes will affect the rate of drying (Kyle and Rich, 1986). These factors are: 1) the particle (droplet) size; 2) the temperature difference between the particle and the heating source, and 3) the turbulence and velocity of the drying air over the particles (Kyle and Rich, 1986). Spray drying in a stream of hot air is performed mostly at a constant-rate for dryers of milk powder (Harper and Hall, 1981).

Pulse dryer. The pulse-combustion spray dryer is a new technology when compared to the roller process and the conventional spray dryer. The patent for the pulse combustion energy system was issued in 1987 to Lockwood (Lockwood, 1987). The pulse combustion system is similar to the V-1 "Buzz Bomb" jet engine (Lockwood, 1987). The heart of the process is "gas dynamic atomization," where the slurry is pumped at low pressure to an atomizer and then released into a pulsating stream of hot gas (PCS, 2000). The sound pressure, as high as 180 dBA, disperses the slurry into droplets that are dried by the heated air (Hosokawa, 1994). In a pulse-combustion spray dryer, the gas and liquid environments are reversed from a traditional spray dryer (Anonymous, 2000). Instead of accelerating the liquid by high-pressure atomization, the pulse-combustion unit accelerates the gas (Anonymous, 2000). As the liquid, at a low pressure and velocity, enters the hot gas stream, a high-velocity pulse wave instantly atomizes it (Anonymous, 2000). The combustion reaction is assisted at startup and becomes self-sustaining, occurring between 60 and 200 times per second (Hosokawa, 1994). Product particle size is controllable by adjusting the dryer's gas velocity, pulse amplitude, and inlet temperature (PCS, 2000). The pulse-combustion dryer produces finer particles and a narrower particle size distribution than that of a traditional spray dryer (Anonymous, 2000).

Figure 1 is a diagram of the Pulse Combustion Systems burner and atomizer (courtesy of Pulse Combustion Systems, San Rafael, CA). Air (1) is pumped into the pulse combustor's outer shell at low pressure, where it flows through the patented unidirectional air valve (2). The air enters a tuned combustion chamber (3) where fuel (4) is added. The air valve (2) closes. The fuel/air mixture is ignited by a pilot (5) and explodes, creating hot air, pressurized to about 3 psi above combustion fan pressure.

The hot gases rush down the tailpipe (6) toward the atomizer (7). The air valve (2) reopens and allows the next air charge to enter. The fuel valve admits fuel, and the mixture explodes in the hot combustion chamber. This cycle repeats 100 times per second. Just above the atomizer, quench air (8) is blended in to achieve desired product contact temperature. The exclusive atomizer releases the liquid (9) into a carefully balanced gas flow, which dynamically controls atomization, drying, and particle trajectory. The atomized liquid enters a conventional tall-form drying chamber (10) (Pulse Combustion Systems, 2000).

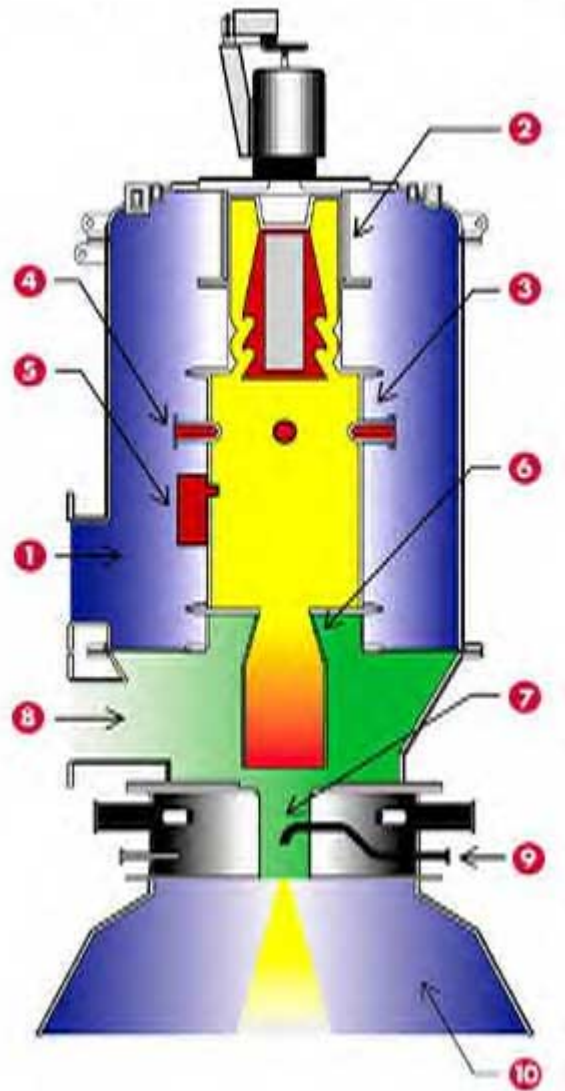


Figure 1. Pulse combustion system burner and atomizer. 1. Combustion air; 2. Rotary valve; 3. Combustion chamber; 4. Natural gas; 5. Short term pilot; 6. Tailpipe; 7. Atomizer; 8. Quench air; 9. Feed material; 10. Drying chamber. (Courtesy of Pulse Combustion Systems, San Rafael, CA, www.pulsedry.com).

Drying lactose

High lactose products become very thermoplastic when they are concentrated, therefore making a product that is sticky and very difficult to handle (Hansen, 1985). The temperature for drying lactose should not exceed 93° C, as β -lactose is formed at higher temperatures (Bylund, 1995). Crystallization of lactose in skim milk powder and whole milk powder causes 'caking' of the powder into a hard mass (Fox, 1995). Some researchers have reported that lactose in a roller-process product is crystalline, whereas in a spray dried product it is amorphous (Choi et al., 1951). The state of lactose has a major effect on the properties of spray-dried whey powder (Fox, 1998). Problems arising from the crystallization of lactose in milk and whey powders may be controlled by pre-crystallizing the lactose (Fox, 1995). This is accomplished by adding finely divided lactose powder to a supersaturated lactose solution (Caric', 1994; Fox, 1995). The objective of crystallization is to produce a large number of similar sized crystals (0.2 mm diameter average) (Caric', 1994). Lactose crystallization will take anywhere from 4 to 30 hours, depending on the degree of crystallization desired (Caric', 1994). The degree of crystallization is determined by the quantity of β -lactose converted to the desired α -lactose form (Bylund, 1995). Crystallization improves the quality and the economy of drying whey powders or lactose (Caric', 1994). Powder containing 85 to 100 percent α -monohydrate lactose will not cake (Mistry et al., 1992).

Lactose in freshly spray-dried milk powder is in the metastable amorphous state (Lai and Schmidt, 1990). Amorphous lactose is very hygroscopic and if the dried milk powder is exposed to high relative humidity and/or high temperatures, the metastable amorphous lactose will proceed through an irreversible transition to the stable crystalline state (Lai and Schmidt, 1990). The quality of the powder will be affected by lumping and caking of the milk powder causing poor reconstitution properties of the milk powder (Caric', 1994; Fox, 1998; Lai and Schmidt, 1990; Mistry et al., 1992). In most milk powders, lactose is the predominant component (Mistry et al., 1992). Skim milk powder contains approximately 50 percent lactose (Caric', 1994; Fox, 1998; Mistry et al., 1992), whole milk powder contains approximately 35 percent lactose (Mistry et al., 1992), and dried whey may contain as much as 70 percent lactose (Mistry et al., 1992). Lactose plays a significant role in micro-structural characteristics and may exist in different forms, which significantly affect the physicochemical and structural properties of the products (Mistry, et al., 1992).

MATERIALS AND METHODS

Recovered milk product

Recovered milk product (RMP) is defined here as concentrated wastewater from a butter/powder processing facility. The wastewater contains the rinses and washes of all the milk tanks, pasteurizers, evaporators, dryers, and butter churns. Wastewater is discharged to storage tanks, if the electrical conductivity (EC) is greater than 1000 μs . If the wastewater has an EC concentration of less than 1000 μs it goes directly to aerobic storage ponds (see appendix B for flow diagram).

The concentration occurred using a Rogers (C.E. Rogers, St. Cloud, MN) mechanical vapor recompression (MVR) evaporator. The typical wastewater flow that was diverted to the storage tanks from the facility was 0.25 to 0.75% total solids. The MVR evaporator removed a sufficient amount of water to make a concentrate of 10.0 to 15% total solids.

De-proteinized milk solids

De-proteinized milk solids were collected from California Dairies, Inc.'s Los Banos cheese/powder facility. The de-proteinized milk solids were obtained from ultrafiltration of pasteurized whole milk with polyethersulfone membranes (PTI, Oxnard, CA). The pore size of the membranes had a 10,000 nominal molecular weight cutoff. Milk was processed through 8 stages of membranes at a temperature of 49° C. The pressure for the stages ranged from 40 to 70 psi. The de-proteinized milk solids were then processed through a 3-stage reverse osmosis unit (APV Americas, Tonawanda, NY) with thin-film composite membranes (PTI, Oxnard, CA) at a temperature of 48° C and a pressure of ca. 550 psi to remove water to a final concentration of 22% total solids. The membranes were designed for a 99.5 percent rejection of sodium chloride. From the reverse osmosis unit the de-proteinized milk solids were then processed through a falling film finishing evaporator (Zimmer Corporation, Baltimore, MD) to obtain a final concentration of ca. 35 to 40% total solids (see appendix B for a flow diagram).

Separator de-sludge

The separator de-sludge product was collected throughout the day at California Dairies, Inc.'s Fresno butter/powder processing factory. This product was discharged during the "de-sludge" cycle while the separators are running product. The de-sludge cycle occurs every 20 to 40 min. when separator bowl opens and milk is forced through the bowl to clean the accumulated sludge out. The separator de-sludge product was collected in a 6,000 gallon tank and was typically 5 to 10% total solids and 1 to 3% fat (see appendix B for a flow diagram).

Collection of evaluation samples

The three dairy plant waste products were evaluated for their feed value using chemical analysis. Two samples for each of the potential ingredients were taken each month during the months of October, November, and December of the same year. The samples were frozen at - 10 °C until the samples were analyzed. The six samples for

each product were composited into one sample. These composite samples were then tested for fat, dry matter, crude protein, ash, nitrate, chloride, pH, calcium, phosphorus, sodium, and amino acids.

Collection of RMP and separator de-sludge

Approximately 1,900 L of RMP were collected at California Dairies, Inc.'s Tipton facility and approximately 410 L of separator de-sludge were collected at California Dairies, Inc.'s Fresno facility. These products were held overnight at ambient temperature (ca. 7° C) then transported (ca. 2 hours) to California Polytechnic Dairy Products Technology Center (DPTC) in San Luis Obispo, California.

Upon arrival at the DPTC a 3:1 blend of RMP:separator de-sludge was prepared by transferring 850 L of RMP to a 1,135 L processing tank. Then 283 L of separator de-sludge were transferred to the same vessel. The product was heated to 46° C and held until used. Nine samples each of the prepared 3:1 formulated blend (FRMP) and the control, RMP, were prepared by evaporating the products to approximately 40% total solids on a batch basis.

One-hundred and thirteen L of product were transferred into a feed tank connected to a Walker single effect, rising film evaporator (Marriott Walker Corporation, Birmingham, MI). The product was drawn from the feed tank into the evaporator by vacuum and allowed to evaporate until the volume was approximately 19 to 23 L. The volume concentration factor was approximately 5 to 1. The finished product was then removed from the evaporator into a 19 L plastic pail. The plastic pail was then sealed with a lid and stored at ambient temperature for one to two days.

Random sample numbers were generated using the random number generator feature in Microsoft Excel (Microsoft Corporation, Seattle, WA). Eighteen different 4 digit numbers were generated. Nine numbers were used to identify the RMP samples, and nine numbers were used to identify the FRMP blend samples (table 1). Three samples from each formulation were randomly selected and assigned to a dryer (table 1).

Roller dryer

Samples were run on a two-drum pilot roller dryer (Blaw-Knox Co., Buflovak Equipment Division, Buffalo, NY) equipped with a Graham variable speed transmission (Model 175BR5, Graham Transmission, Inc., Menomonee Falls, WI) at Clemson University Department of Food Science and Human Nutrition pilot plant located in Clemson, South Carolina. Samples were tempered to ca. 40° C in a water bath prior to drying. The sample was manually poured into the center trough and the dried product was collected in stainless steel pans. The steam for one of the drums was not working properly; therefore the dried product from only one drum was collected for analysis. The drier was operated continuously with no cleanup needed between samples. The blades were adjusted periodically to keep the drums clear of burned product. The speed was set at low speed and no other adjustments were made during the runs. Most of the product came off the drum in the form of a thin ribbon.

Table 1. Sample numbers for recovered milk product (RMP) and formulated recovered milk product (FRMP).

Random number	Formulation	Dryer
6919	FRMP	Spray
5338	FRMP	Spray
6450	FRMP	Spray
8996	FRMP	Pulse
9640	FRMP	Pulse
1124	FRMP	Pulse
5390	FRMP	Roller
0592	FRMP	Roller
2896	FRMP	Roller
4082	RMP	Spray
3020	RMP	Spray
4733	RMP	Spray
3036	RMP	Pulse
7979	RMP	Pulse
3801	RMP	Pulse
6864	RMP	Roller
3625	RMP	Roller
8084	RMP	Roller

Dry product was collected in Ziploc (S.C. Johnson & Son, Inc., Racine, WI) bags. Samples were crushed by hand to break thin ribbons into small particles, and samples were worked for about 10 minutes. All product for one sample was put in a large plastic bag (Arman Plastics, Division of Tyco International, Torrance, CA) and mixed. Split samples were made using a scoop to separate the powder into 6 oz and 18 oz Whirlpak bags (Nasco, Fort Atkinson, WI).

Spray dryer

A Niro Filtermat ((Niro, Inc. – GEA Powder Division, Hudson, WI) pilot spray dryer at California Polytechnic State University Dairy Products Technology Center (DPTC) located in San Luis Obispo, California was used. The spray nozzle assembly consisted of a number 16 core and a number 70 nozzle (except for sample number 6450, a number 76 nozzle was used). The inlet air temperature ranged from 185° C to 212.8° C and the outlet air temperature ranged from 82.2° C to 90.6° C. The dryer chamber and collection system were dry cleaned after each run. The liquid samples were held at ambient temperature (ca. 21 °C) until processed on the dryer.

The dry samples were collected in plastic bags (Cryovac, Charlotte, North Carolina) and stored. Split samples were collected using a scoop into 6 oz or 18 oz Whirlpak bags (Nasco, Fort Atkinson, WI) and stored for analysis.

Pulse dryer

Samples were run on a pilot pulse dryer at Pulse Combustion Systems, LLC Research and Development laboratory located in Payson, Arizona (figures 2 and 3). Each run took approximately one hour and a dry cleanup was done between runs except after sample 1124 (FRMP) and sample 3801 (RMP) when a wet cleanup was performed. Wet cleanups were performed when the main dryer chamber became soiled to ensure the integrity of the dried samples. Product contact temperature, the temperature of the air at the point the product is introduced into the dryer, was between 320° C and 381.7° C. Chamber exit temperature was between 92.8° C and 103.3° C. A peristaltic pump was used for all samples to pump the product to the nozzle at a pressure of 1 to 2 psi (see appendix C for dryer test reports). All samples were heated in a boiling water bath to ca. 40 °C prior to drying (except FRMP sample 9640 which was processed at 21° C) to liquefy the samples.

Dry samples from each run were collected in Ziploc (S.C. Johnson & Son, Inc., Racine, WI) bags marked with the sample identification number. Samples for each run were composited in a large plastic bag (Arman Plastics, Division of Tyco International, Torrance, CA), mixed, then split into 6 oz and 18 oz Whirlpak bags (Nasco, Fort Atkinson, WI) for further analysis.



Figure 2. Photograph of combustion burner for the pilot pulse combustion dryer at Pulse Combustion System's Research laboratory located in Payson, AZ.



Figure 3. Photograph of pilot pulse combustion dryer at Pulse Combustion System's Research laboratory located in Payson, AZ.

Total solids/moisture

Moisture content of the powder samples was determined using a vacuum oven at 100° C for 4 hrs. Total solids content of the liquid samples was determined using the method outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 1980).

Fat determination

Two methods for fat determination were used. Fat was determined by the Mojonnier method (Marshall, 1992) that is typically used for fat determination in milk powder in the United States. Also, fat was determined by the Soxhlet method described in Association of Official Analytical Chemists (AOAC, 1990) that is commonly used for feed analysis.

Free-fat

Free-fat in the powdered products was determined using the free-fat in whole milk powder method from Methods of Analysis for Dry Milk Products (Sorensen et al., 1978) with the following modifications. A 10 g sample of powder was weighed into a 250 ml flask and 50 ml of petroleum ether were added. The sample and ether were agitated for 5 min and allowed to stand for 2 min. The sample was then poured through a 2V Whatman folded filter (Whatman, Ofallon, MO) into a fat cup and the flask was rinsed with 20 ml of petroleum ether. The sample was then filtered through the same filter into another fat cup and the ether was evaporated on a Mojonnier hot plate (135°C) (Meyer-Mojonnier, Charleston, SC). Both cups were then placed in a vacuum oven (135°C) for 5 min and then cooled for 10 min. Percentage free-fat in the sample was determined using the following equation:

$$\% \text{ Free fat} = \frac{(\text{cup} + \text{fat}) - (\text{empty cup})}{\text{sample weight}} \times 100$$

The % free-fat was expressed as a percentage of fat using the following equation:

$$\% \text{ Free fat as a \% of fat} = \frac{\% \text{ Free fat}}{\% \text{ Mojonnier fat}} \times 100$$

Crude protein

Crude protein was determined by the Kjeldahl method (method #:955.04) as described in the Association of Official Analytical Chemists (AOAC, 1990). Nitrogen was multiplied by 6.25 for this study.

Ash

AOAC (1990) method 942.05 was used to determine the ash values. A 2 g sample was weighed into a porcelain crucible and placed in muffle furnace at 600° C for 2 hr. The crucible was removed from the furnace and placed in a desiccator, cooled, and weighed. The residue is the ash and represents the inorganic constituents of the sample. Values were reported as percentage ash.

pH

The pH was measured using a Mettler Autotitrator (Model DC12, Mettler-Toledo, Inc., Hightstown, NJ) in pH mode with a combination electrode. Ten g of powder were reconstituted in 100 ml water and allowed to stand for 30 minutes prior to measurement.

Amino acids analysis

Amino acid analysis was performed by ion exchange chromatography using a Dionex D-300 (Dionex Corporation, Sunnyvale, CA) amino acid analyzer equipped with DDW-10 dual wavelength detector (Lab Alliance, State College, PA) and a Chromjet integrator (Thermo Separation Products, San Jose, CA). The column resin (IC1011-6, Inter Action Chromatography, San Jose, CA) had a diameter of 5 μm . Samples were hydrolyzed using 6 N HCl (Fisher Scientific, Fair Lawn, NJ) for 22 hours in a 110°C oven (Model 17, Precision Scientific Co.). Liquid samples were freeze dried prior to hydrolysis. After hydrolysis samples were cooled and evaporated using a R-114 rotary evaporator equipped with a glass condenser (Buchi, Switzerland) until dry. The dried hydrolysate was then dissolved in 20.0 ml of pH 2.20 sodium citrate buffer (Fisher Scientific, Fair Lawn, NJ). A portion of the dissolved sample was poured into a test tube and centrifuged (IECHN-SII, Damon/IEC Division) at 3500 rpm for 8 minutes. A 1.0 ml aliquot of the supernatant was analyzed on the amino acid analyzer. Amino Acid Standard Solution (Stock No. AA-S-18, Sigma-Aldrich, Saint Louis, MO) was used as a standard.

Cystine and methionine were determined using performic acid oxidation and analyzed on a Dionex Amino Acid Analyzer (Dionex, Sunnyvale, CA) equipped with an Autoion™ 100 controller and Basic Chromatography module. A HP Integrator (HP3394A, Hewlett Packard, Palo Alto, CA) was used to calculate the peak areas. A 80 mg sample was weighed into a 125 ml flat bottom boiling flask. The flask was packed in ice, and 10 to 15 ml of performic acid solution (Fisher Scientific, Fair Lawn, NJ) were added. The samples were then covered and stored in a refrigerator overnight. Two ml of 48% hydrobromic acid were then added to the flask and the contents were evaporated using a R-114 rotary evaporator equipped with a glass condenser (Buchi, Switzerland) until dry. After complete evaporation, 20.0 ml of 6 N HCl (Fisher Scientific, Fair Lawn, NJ) were added to the flask, and an Airless-Ware adapter was placed on the top of the flasks. Samples were then completely frozen in a -80 °C bath. The flasks were flushed with nitrogen gas (National Welder Supply, Charlotte, NC) and evacuated. Samples were then placed in a 110°C convection oven (Model 17, Precision Scientific Co., Winchester, VA) for 22 hours. Samples were removed from the oven and evaporated using a R-114 rotary evaporator with glass condenser (Buchi, Switzerland) until dry. The dry samples were then dissolved in 20.0 ml of pH 2.20 sodium citrate buffer (Fisher Scientific, Fair Lawn, NJ). A portion of the dissolved sample was poured into a test tube and centrifuged (IECHN-SII, Damon/IEC Division) at 3,500 rpm for 8 min, 1.0 ml aliquots were then analyzed in the amino acid analyzer.

Tryptophan was determined using basic hydrolysis and analyzed on a Dionex Amino Acid Analyzer (Dionex, Sunnyvale, CA) equipped with a uvMonitor fixed wavelength (550nm) detector (LCD Analytical, Riviera Beach, FL) and a series 5000 Fisher Recordall (Omniscribe Recorder, Austin, TX). A 100 mg sample was weighed into a Tefzel round bottom tube and 1.8 ml of 4.2 N NaOH (Fisher Scientific, Fair Lawn, NJ) were added. The Tefzel tube was placed inside a Chromaflex spray tube and a Airless-Ware adapter was fastened to the top. This assembled hydrolysis tubes were placed into a -80°C bath until sample was completely frozen. The flasks were then flushed with nitrogen gas (National Welder Supply, Charlotte, NC) and evacuated. Samples were then placed in a 110°C convection oven (Model 17, Precision Scientific Co., Winchester, VA) for 22 hours. The sample tubes were then removed, 2.0 ml of sodium citrate buffer (Fisher Scientific, Fair Lawn, NJ) were added, and the samples were mixed on a vortex mixer. Contents were then poured into a 12 ml Nalgene centrifuge tube containing 1.26 ml of cold (ca. 0°C) 6 N HCl (Fisher Scientific, Fair Lawn, NJ) and then filled to a final volume of 10.0 ml with sodium citrate buffer. The samples were then centrifuged (IECHN-SII, Damon/IEC Division) at 3,500 rpm for 20 min. Samples were stored refrigerated until analysis, but for less than 12 hours, 1.0 ml aliquots were then analyzed in the amino acid analyzer.

Available lysine was determined using the method described by Eklund (1976) and analyzed on a Dionex Amino Acid Analyzer (Dionex, Sunnyvale, CA) equipped with an Autoion™ 100 controller and Basic Chromatography module. An HP Integrator (HP3394A, Hewlett Packard, Palo Alto, CA) was used to calculate the peak areas. One hundred mg samples were weighed into 20x150 mm screw cap culture tubes and 5.0 ml of 0.5 M NaHCO_3 (Fisher Scientific, Fair Lawn, NJ) were added. The tubes were placed in a 35°C rotary incubator and rotated at high speed for 30 min. Then 5 ml of 1% 2,4,6-Trinitro-benzene sulfonic acid (TNBS) solution (Fisher Scientific, Fair Lawn, NJ) were added and samples were rotated at high speed for 2 hrs. The tubes were removed from the incubator and placed under a fume hood where 10.0 ml of concentrated HCl (Fisher Scientific, Fair Lawn, NJ) were added. The tubes were placed in a 110°C convection oven (Model 17, Precision Scientific Co.) for 22 hrs. After removing the tube from the oven, the contents of the tube were transferred into a 250 ml flat bottom boiling flask, the tube was rinsed with de-ionized water and added to the flask. The samples were then evaporated using a R-114 rotary evaporator equipped with a glass condenser (Buchi, Switzerland) until dry. The dry samples were then dissolved in 20.0 ml of pH 2.20 sodium citrate buffer (Fisher Scientific, Fair Lawn, NJ). A 1.0 ml aliquot of each supernatant was analyzed on the amino acid analyzer.

Insolubility index

The insolubility index analysis was conducted according to the method in the American Dairy Products Institute's Standards for Grades of Dry Milk including Methods of Analysis (ADPI, 1990). A 20 g sample of powder was mixed into 200 ml of 23.9°C distilled water using a blender (Model 36BL12, Waring Product Division, Dynamics Corporation of America, New Hartford, CT) set at a speed of 3,000 to 3,500

rpm. After mixing for 5 minutes, the sample was poured into a 50 ml conical centrifuge tube. Samples were centrifuged at 870 rpm using a HN SII centrifuge (International Equipment Company, Needham Heights, MA) for 5 min. The supernatant liquid was siphoned off to within 5 ml of the surface of the sediment. Twenty-five ml of 23.9° C distilled water were added and the samples were gently mixed. The tubes were then filled to the 50 ml mark with distilled water at 23.9° C and again centrifuged for 5 min. Insolubility index was determined by holding the tube in the vertical position and visually determining the sediment level to the nearest graduated scale using back lighting. All samples were analyzed in triplicate.

Phosphorus and calcium

A Spectroflame-EOP (Spectro Analytical Instruments, Kleve, Germany) was used to determine phosphorus and calcium content. This ICP analyzer was supplied argon from National Welders Supply, Charlotte, NC.

Sodium

Sodium content was determined using Atomic absorption spectrophotometry (Perkin-Elmer Corporation, Norwalk, CT) following the method developed by Perkin-Elmer Corporation (1973).

Chloride

Chloride content was determined using a Labconco Digital Chloridometer (Labconco, Kansas City, MO). No sample preparation was necessary for this method.

Nitrate

Nitrate (NO_3^-) was determined using an atomic absorption II auto-analyzer (Alpkem Corporation, Clackamas, OR) following EPA method 353.2. No sample preparation was necessary for this method.

Nitrogen free extract

Nitrogen free extract (NFE) was calculated using the following equation: $\text{NFE} = 100 - (\text{protein}) - (\text{fiber}) - (\text{fat}) - (\text{ash})$ as described in Perry et al. (1999). Values were reported as a %NFE on a dry matter basis.

Total digestible nutrients

Total digestible nutrients (TDN) were calculated using the following equation: $\text{TDN} = (0.8 \text{ NFE}) + (0.75 \text{ protein}) + (0.45 \text{ fiber}) + (0.9)(2.25 \text{ fat})$ as described in Forage Analysis Methods (National Forage Association, 1993). The digestion factors used are for forage feeds and not particularly for dairy protein, these factors were used because these are common factors for feed laboratories.

Lactose

Percent lactose concentrations were calculated in the liquid and dry samples by subtracting the dry matter values for protein, fat, and ash from 100 percent. Values were reported as percent lactose on a dry matter basis.

Environmental scanning electron microscopy

The microstructure of powder was evaluated using an Environmental Scanning Electron Microscope (ElectroScan Corporation, Wilmington, MA) at the Louisiana State University Department of Chemical Engineering located in Baton Rouge, Louisiana. A magnification of 250x was used on the powder samples. This magnification was thought to give the best field to observe several particles. A 20kv electron beam was used with back scatter electron detection (BSED). Images were collected using Image Acquisition and Archiving System Version 1.01 (ElectroScan Corporation, Wilmington, MA). Sample preparation was the same as used by Thompson and McGregor (1998). Black double stick tape was placed on an aluminum specimen stub, and then a small portion of sample was placed on the tape.

Real time effects of powder hydration were also evaluated using the ESEM. For hydration, prepared aluminum specimen stubs with samples were placed on Styrofoam. The Styrofoam was then placed in an airtight container with a small amount of water (ca. 100 ml). The container was then placed in a 65° C incubator for 30 minutes. The samples were removed from the container and placed in a desiccator until they were viewed on the ESEM (ca. 1 hr).

Wettability

Wettability values were determined as described in Methods of Analysis for Dry Milk Products (Sorensen et al., 1978). A 13 g sample and 100 ± 1 g of water adjusted to 40 ± 1° C were weighed in separate containers. Using the apparatus as described in the method A 6a (Sorensen et al., 1978) the sample was gently dropped into the water. The amount of time, in seconds, that it took for all particles to be wetted was recorded.

Determination of particle size distribution by sieving

Particle size distribution was determined using the method described in Methods of Analysis for Dry Milk Products (Sorensen et al., 1978) with U.S. Standard ASTM specification sieves (20.32 cm (8 in.)) #40, #100, and #200 mesh screens and collection pan (Fisher Scientific Company, Fair Lawn, NJ) with the following modifications. A 50 g sample was weighed into a plastic screw top container and 1 g of Syloid 244 was weighed into the same plastic screw top container. The lid was then placed on the container and the sample was shaken by hand for 1 min. The Syloid 244 was added to the sample to reduce the stickiness of the sample to improve the performance. The sample was then poured onto the top sieve (#40) of the sieve stack. The sieve stack was then placed on the Rotap shaker (Model RX-29, W.S. Tyler, Mentor, OH) and the timer was set to shake the sample for 15 min. Results were reported as percentage on #40 mesh, percentage on #100 mesh, percentage on #200 mesh, and percentage thru #200 mesh. The 1 g of Syloid was subtracted from the amount of sample in the collection pan.

Particle size analysis by infra-red

A Coulter Particle Characterization analyzer (Coulter LS 230, Coulter Corporation, Miami, FL) equipped with a dry powder module (Coulter Corporation, Miami, FL) was used. Due to the stickiness and clumping of the powder Syloid 244 (source unknown) was added to the sample at three different ratio levels; 1 part Syloid:99 parts sample (1%), 2 parts Syloid:98 parts sample (2%), and 3 parts Syloid:97 parts sample (3%). The sieve attachment (Coulter Corporation, Miami, FL) with a #40 mesh screen was used to input the sample. A 49.5 g sample and 0.5 g of Syloid 244 were weighed into a snap-cap vial (Capitol Vials, Charlotte, NC) then shaken by hand for one minute for the 1:99 ratio samples. For 2% Syloid samples 24.5 g of sample and 0.5 g of Syloid were weighed into a snap-cap vial and for the 3% Syloid samples 24.25 g of sample and 0.75 g Syloid were weighed into a snap-cap vial (see appendix D for analyzer test reports).

Statistical analysis

A completely randomized two-factor factorial experimental design model with three replicates was used to statistically evaluate the results from the analytical testing. The blend factor had two treatments: RMP and FRMP; the dryer factor had three treatments: pulse combustion, roller, and spray. The linear statistical model for this design is $Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \epsilon_{ijk}$ where Y_{ijk} is the observation of the i th blend, the j th dryer, and the k th replication. μ is the overall mean effect, τ_i is the effect of the i th blend, β_j is the effect of the j th dryer treatment, $(\tau\beta)_{ij}$ is the effect of the interaction between the i th blend and the j th dryer treatment, and ϵ_{ijk} is the random experimental error with mean zero and variance of σ_i^2 .

The data were analyzed using SAS[®] System for Microsoft[®] Windows[™], Release 8.01 (SAS Institute Inc, Cary, North Carolina, 1999). Levene's test for equal variances was performed. For Levene's tests in which significance was detected at the 0.05 level, gplots were produced and outliers were identified. The outliers were examined and a determination was made based on experience with the testing procedures and dairy powders to remove the outliers. An unbalanced experiment was created when the outliers were removed from the data set. The mixed model procedure was used specifying an error term of sample nested in blend*dryer treatment for analytical tests with unbalanced data. Analysis of variance (ANOVA) was performed for analytical tests with balanced data. General linear model (GLM), correlation, and least squared means were determined. To detect differences in means, the pdiff option was used. For unbalanced data, degrees of freedom were determined using the Satterthwaite's method. Significant differences were determined at $\alpha = 0.05$ level of significance. See appendix A for detailed results.

RESULTS AND DISCUSSION

Ingredient evaluation

The dry matter (DM), fat, pH, crude protein, ash, and lactose results from the analysis of the three milk by-products are presented in tables 2 and 3. Separator de-sludge had the highest fat content and the highest crude protein content at 22.2 % and 30.9 % on a dry basis, respectively. These results can be compared to the average component testing of raw milk when converted to a dry basis (table 5). There is some similarity to the raw milk since separator de-sludge is produced when the milk separator forces milk or water into the separator bowl to clean the separator bowl, this occurs about three times an hour for each milk separator. The separator de-sludge also had the highest concentration of total amino acids (table 4). Available lysine was not tested on the evaluation samples because it was not determined to be important until the concentration and drying of the products was completed. For this project the separator de-sludge was rated as the product with the highest feed value because of the higher protein concentration.

Table 2. Dry matter (DM), fat, pH, crude protein, ash, and lactose results for composite samples of liquid recovered milk product (RMP), de-proteinized milk solids (DPMS), and separator de-sludge.

Ingredient	DM	Fat ¹	pH	Crude Protein ¹	Ash ¹	Lactose ^{1,2}
	<u>%</u>	<u>%</u>	<u>pH</u>	<u>%</u>	<u>%</u>	<u>%</u>
RMP	11.76	18.9	9.45	19.8	32.9	28.4
DPMS	35.95	7.9	5.72	3.0	9.0	80.1
De-sludge	6.95	22.2	6.74	30.9	9.9	37.0

¹Expressed on a dry basis.

²Lactose=100%- (%Fat + %Crude Protein + %Ash).

Table 3. Nitrate (NO₃), chloride (Cl), calcium (Ca), phosphorus (P), and sodium (Na) results for composite samples of recovered milk product (RMP), de-proteinized milk solids (DPMS), and separator de-sludge.

Ingredient	NO ₃	Ca ¹	P ¹	Na ¹	Cl
	<u>ppm</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>
RMP	6.3	1.3	1.80	9.8	0.15
DPMS	1.7	0.4	1.03	0.8	0.82
De-sludge	17.6	1.2	1.07	0.8	0.06

¹Expressed on a dry basis.

The recovered milk product (RMP) had the greatest ash concentration at 32.9 % (table 2) and the greatest sodium concentration at 9.8 % (table 3). Since the RMP contains the products of the chemicals that are used for cleaning dairy equipment, namely sodium hydroxide and phosphoric acid, it is possible that these cleaning chemicals contribute to the high ash concentration and the high sodium concentration in the RMP. RMP has lower amino acid concentration than the separator de-sludge (table 4). The protein concentration for the RMP was 19.8 % (table 2) and the fat concentration was 18.9 % (table 2). Lactose concentration of the RMP was calculated at 28.4 %. For the purpose of this study it was determined that the RMP had good feed value because of the protein, fat, and lactose concentrations.

The values for the de-proteinized milk solids are listed in tables 2, 3, and 4. This product was expected to be high in lactose concentration; the calculated lactose concentration was 80.1 %. When compared to the other ingredients, the protein concentration in the de-proteinized milk solids was relatively low at 3.0 % and the fat content was higher than expected at 7.9 %. The high fat content was possibly due to faulty membrane seals in the ultrafiltration unit and is not considered typical. The amino acid concentration was low in the de-proteinized milk solids (table 4). These low concentrations of amino acids were expected since the protein concentration was low. The chloride concentration in the de-proteinized milk solids was high, which may be due to cleaning procedures used at the processing plant. For the purpose of this study it was determined that the de-proteinized milk solids had a low feed value because of low protein concentration and high lactose concentration.

After reviewing the data for all three potential ingredients it was decided that the ultra-filtered milk de-proteinized milk solids would add very little nutritional value to a blended feed for this project. Therefore, in order to maximize the protein concentration, a blend of separator de-sludge and RMP using all the separator de-sludge produced in a day was formulated. California Dairies, Inc., at the time of this project, was producing about 28,390 liters of RMP and 9,460 liters of separator de-sludge each day. Therefore, a 3 to 1 mixture was created using three parts RMP and one part separator de-sludge to make the formulation. The ultra-filtered milk de-proteinized milk solids was not used in this project because of the low protein concentration and the high carbohydrate concentration.

Liquid raw material and blend evaluation

Recovered milk product (RMP) and separator de-sludge, were blended together in a ratio of 3 parts RMP to 1 part separator de-sludge. The resulting blend is referred to as formulated recovered milk product (FRMP). The average results of the two raw ingredients and the FRMP for fat, crude protein, ash, and lactose are listed below in table 6.

The results from nitrate (NO₃), chloride (Cl), calcium (Ca), phosphorus (P), and sodium (Na) analysis on the two raw ingredients and the blend are presented in table 7. The RMP had the greatest NO₃ concentration (99.6 ppm), while the separator de-sludge had the lowest concentration (7.8 ppm). These NO₃ concentrations are lower than historical data for this processing facility. The Na concentration in the de-

sludge (8.86%) was greater in the raw ingredient than historical data for this processing facility. There is no explanation for these differences.

Table 4. Amino acid analysis for composite samples of recovered milk product (RMP), de-proteinized milk solids (DPMS), and separator de-sludge (% amino acid per 100 g dry matter).

Amino acids	RMP	DPMS	De-sludge
	<u>%</u>	<u>%</u>	<u>%</u>
Aspartic acid	1.86	0.04	2.49
Threonine	0.91	0.02	1.42
Serine	0.99	0.02	1.71
Glutamic acid	4.19	0.13	5.65
Proline	2.26	0.04	3.34
Glycine	0.55	0.04	0.68
Alanine	0.93	0.02	1.13
Cystine	0.24	0.01	0.34
Valine	1.48	0.02	1.94
Methionine	0.71	0.01	0.96
Isoleucine	1.18	0.02	1.63
Leucine	2.11	0.02	2.81
Tyrosine	1.11	0.0	1.61
Phenylalanine	1.09	0.0	1.55
Histidine	0.64	0.01	0.97
Lysine	1.24	0.03	2.35
Arginine	0.43	0.02	1.07
Tryptophan	0.26	0.0	0.38
Total amino acids ¹	22.18	0.43	32.03

¹Total amino acids may not equal individual amino acids due to rounding.

Table 5. Year 2000 average raw milk components from infra-red milk analyzer data on a dry basis for California Dairies, Inc.'s members.

Period	Fat	Protein	Lactose	Ash ¹
	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>
1 st Qtr	29.8	26.1	39.3	4.8
2 nd Qtr	29.0	26.0	40.3	4.6
3 rd Qtr	29.0	26.1	39.9	4.9
4 th Qtr	29.7	26.5	39.0	4.8

¹%Ash= 100% - %Fat - %Protein - %Lactose.

Source: California Dairies, Inc., 2001 daily infrared milk analyzer data for payment purposes.

Table 6. Dry matter (DM), fat, crude protein, ash, and lactose results for liquid recovered milk product (RMP), separator de-sludge, and liquid formulated recovered milk product.

Ingredient	DM	Fat ¹	Crude Protein ¹	Ash ¹	Lactose ^{1,2}
	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>
RMP	6.3	18.9	16.0	37.0	28.1
De-sludge	5.4	20.7	40.1	6.9	32.3
FRMP	6.3	19.6	18.9	30.2	31.3

¹Reported on a dry basis.

²Lactose=100%- (%Fat + %Protein + %Ash).

Table 7. Nitrate (NO₃), chloride (Cl), calcium (Ca), phosphorus (P), and sodium (Na) results for liquid recovered milk product (RMP), separator de-sludge, and formulated recovered milk product (FRMP).

Ingredient	Ca ¹	P ¹	Na ¹	Cl ¹	NO ₃ ¹
	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>ppm</u>
RMP	0.76	2.08	11.13	1.61	99.6
De-sludge	1.05	0.92	0.33	0.80	7.8
FRMP	0.83	1.80	8.86	1.47	69.0

¹Reported on a dry basis.

The amino acid profiles for the two raw ingredients used and the formulated blend are presented in table 8. Since the separator de-sludge had a higher concentration of protein than the other two ingredients, it follows that the total amino acid concentration would be greater for the separator de-sludge.

Blend treatment effects

Each of the two treatments, recovered milk product (RMP) and formulated recovered milk product (FRMP), were dried on three different types of dryers. Samples were collected and analyzed for chemical and functional properties and the results were statistically analyzed for the blend treatment effect. The two raw ingredients were blended together to improve the feed value of the standard recovered milk product (RMP), the blended product is referred to as formulated recovered milk product (FRMP). The FRMP was formulated to have a higher protein concentration than the RMP.

The mean results from Mojonnier fat, Soxhlet fat, and free-fat for both the RMP and the FRMP are presented in table 9. There were no significant differences (P<0.05) between the Mojonnier fat values of the two treatments. There were also no significant differences (P<0.05) between the Soxhlet fat values. This was expected because the two ingredients had similar fat content. The two methods of fat

determination were performed on the samples to evaluate each of the methods appropriateness for this product. The Mojonnier test is typically used to evaluate dairy products, whereas the Soxhlet method is used for fat determination in feeds. From the data collected, the Mojonnier fat determination was consistently greater than the Soxhlet fat determination.

Table 8. Amino acid profile of liquid recovered milk product (RMP), liquid separator de-sludge and the liquid formulated recovered milk product (FRMP).

Amino acids ¹	RMP	De-sludge	FRMP
	%	%	%
Aspartic acid	1.39	3.12	1.23
Threonine	0.65	1.73	0.65
Serine	0.57	2.14	0.66
Glutamic acid	2.09	8.09	2.48
Proline	0.93	3.79	0.69
Glycine	0.42	0.80	0.41
Alanine	0.62	1.32	0.67
Cystine	0.13	0.32	0.15
Valine	0.86	2.52	0.98
Methionine	0.39	1.38	0.44
Isoleucine	0.64	1.98	0.78
Leucine	1.13	3.75	1.34
Tyrosine	0.61	1.84	0.75
Phenylalanine	0.65	1.89	0.78
Histidine	0.41	1.23	0.44
Lysine	0.77	3.14	0.95
Available lysine	0.30	3.02	0.65
Arginine	0.30	1.43	0.48
Tryptophan	0.14	0.52	0.33
Total amino acids ²	12.70	40.99	14.21

¹Results reported as a % of dry matter per 100 g

²Total amino acids may not equal individual amino acid due to rounding; available lysine is not included in total.

The differences in the two fat determination methods suggest that both the buyer and the seller should agree upon the method used to evaluate this product for fat content. Since the manufacturer of this product is a dairy plant, the ingredient specifications would be developed using appropriate methods for dairy powders. However, the buyer of this product will most likely use the method appropriate for analyzing feeds. Since the two methods yield different results there will be disagreement if the feed manufacturer is comparing to the dairy plant analysis.

Table 9. Mojonnier fat, Soxhlet fat, and free-fat of recovered milk product (RMP) and formulated recovered milk product (FRMP) treatments.

Treatment	Mojonnier fat ¹		Soxlet fat ¹		Free-fat ²	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
RMP ²	27	16.19 ^a	26	13.83 ^a	26	42.81 ^a
FRMP	26	15.92 ^a	27	13.81 ^a	26	37.56 ^a

¹Reported on a dry matter basis.

²Free-fat is reported as a percent (%) of Mojonnier fat on a dry basis.

^aMeans in a column, followed by same letter superscript do not differ significantly (P<0.05).

Similar to the fat content, the free-fat content was not significantly different (P<0.05) in the two treatments. Free-fat is the portion of the fat that is on the surface of the powder particles and can be important to the keeping quality of a powdered product (Hansen, 1985).

The mean moisture content of the FRMP was significantly greater (P<0.05) than the mean moisture content of the RMP, 7.31% vs. 5.37% (table 10). One explanation for this difference could be due to the higher protein concentration in the FRMP (table 11). The protein in the FRMP may have bound more water molecules and when both treatments were subjected to the same drying conditions the water molecules in the FRMP required more energy for evaporation.

Table 10. Moisture, pH, and insolubility index of recovered milk product (RMP) and formulated recovered milk product (FRMP) treatments.

Treatment	Moisture		pH		Insolubility index	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>pH</u>	<u>n</u>	<u>ml</u>
RMP ¹	27	5.37 ^a	27	8.97 ^a	26	9.18 ^a
FRMP	24	7.31 ^b	26	7.42 ^b	26	6.37 ^b

^{a,b}Means in a column, followed by same letter superscript do not differ significantly (P<0.05).

The RMP was significantly higher (P<0.05) in pH than FRMP (table 10). This was expected because the liquid RMP had a higher pH value (9.45) than the liquid separator de-sludge (6.74). Standardization of pH level may be important because differences in pH could affect the functional properties. For example, a higher pH may cause more Maillard reactions and therefore increase the insolubility index.

The insolubility index for the FRMP is significantly less (P<0.05) than the insolubility index for the RMP, 6.37 ml vs. 9.18 ml, respectively (table 10). Good quality skim milk powder from modern spray dryers typically has an insolubility index of less than 0.1 ml (Hansen, 1985) and the standard for skim milk powder is 1.25 ml maximum (ADPI, 1990). This indicates that both products are much less soluble than skim milk powder; however the insolubility index may be improved by adjusting

drying parameters such as outlet temperature. Poor solubility can be caused by poor quality milk, excessive heat treatment, or situations that result in complex formations of casein, whey proteins, and lactose (Hansen, 1985). The recovered milk product used in this project has been subjected to caustic washes, acid, and high temperatures. The abuse that this product has been subjected to has likely formed some complexes of proteins and lactose that contribute to the poor insolubility. For example, an alkaline solution (pH 13 – 14) is used in the cleaning cycles to remove the fat and proteins which is then followed by an acid rinse (pH 2.0) to remove the minerals. On the other hand, the separator de-sludge has had little heat treatment and no chemical addition. The quality of the two raw ingredients is likely the reason for the difference in the insolubility index between the two treatments.

The protein concentration in the FRMP was significantly greater ($P>0.05$) than the protein concentration in the RMP (table 11). As mentioned previously, one of the goals of this project and the basis for using the separator de-sludge was to increase the protein concentration in the formulated product. From the data presented this goal was achieved.

The ash and total digestible nutrients (TDN) concentrations for both treatments were not significantly different ($P<0.05$) (table 11). The lactose and nitrogen free extract (NFE) concentrations were significantly different ($P<0.05$) in the two treatments. The RMP had a greater concentration of lactose (34.15%) and NFE (34.15%).

Table 11. Protein, ash, nitrogen free extract (NFE), total digestible nutrients (TDN), and lactose of recovered milk product (RMP) and formulated recovered milk product (FRMP) treatments.

Treatment	Protein ¹		Ash		NFE ^{1,4}		TDN ^{1,5}		Lactose ^{1,6}	
	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%
RMP ²	25	15.52 ^a	27	34.14 ^a	25	34.15 ^a	25	71.75 ^a	25	34.15 ^a
FRMP	27	19.43 ^b	26	34.35 ^a	25	30.29 ^b	25	71.06 ^a	25	30.29 ^b

¹Reported on a dry basis.

⁴NFE calculation based on %NFE = 100% - (%Fat + %Protein +%Ash).

⁵TDN calculation based on %TDN = (0.8*NFE) + (0.75*protein) + (0.45*fiber) + (0.9*2.25*fat), fiber content was 0 in all samples.

⁶Lactose reported as %Lactose = 100% - (%Fat + %Protein +%Ash).

^{a,b}Means in a column, followed by same letter superscript do not differ significantly ($P<0.05$).

There were significant differences ($P<0.05$) between the blend treatments for the mean calcium (Ca), phosphorous (P), soluble chloride (Cl), and nitrate (NO₃) concentrations (table 12). These differences can mainly be attributed to the differences in the two raw ingredients. There was no significant difference ($P<0.05$) in the Na content of the two blend treatments. Ca content was slightly lower in the

raw RMP compared to the FRMP (table 7) and this was also true for the finished products where the Ca was significantly lower ($P<0.05$) in the RMP at 0.72% (table 12) as compared to 0.95% in the FRMP. Soluble Cl was significantly higher in the RMP (1.63%) (table 12) than in the FRMP (1.54%). Referring back to table 7, the soluble Cl was also slightly higher in the raw ingredient RMP (1.61%) versus the raw FRMP (1.47%). In the raw ingredients the Na concentration was 2.27% higher in the RMP than in the FRMP (table 7). However, the mean Na concentrations of the two products after processing were not significantly different ($P<0.05$) (table 12). The P concentrations (table 12) in the finished RMP (1.86%) were not significantly different ($P<0.05$) than the P concentrations in the FRMP (2.15%). NO_3 concentrations in the finished RMP were significantly higher ($P<0.05$) than the concentration in the FRMP, some of this difference can be related back to the high NO_3 concentration in the raw RMP (table 7). High NO_3 concentration (>3000 ppm) in feed have been associated with abortion and death in cattle, therefore the use of nitric acid in the dairy plant has to be strictly controlled for this feed product.

Table 12. Calcium (Ca), phosphorus (P), sodium (Na), chloride (Cl), and nitrate (NO_3) of recovered milk product (RMP) and formulated recovered milk product (FRMP) treatments.

Treatment	Ca ¹		P ¹		Na ¹		Cl ¹		NO ₃ ¹	
	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%	<u>n</u>	ppm
RMP ²	26	0.72 ^a	25	1.86 ^a	25	9.24 ^a	27	1.63 ^a	26	347.84 ^a
FRMP	27	0.95 ^b	27	2.15 ^a	27	9.62 ^a	27	1.54 ^b	27	69.85 ^b

¹Reported on a dry basis.

²Means in same column, followed by same letter do not differ significantly ($P<0.05$).

The mean results from the particle size analysis by sieving for the RMP and FRMP treatments are listed in table 13. There was no significant difference ($P<0.05$) between the two treatments for any of the screen sizes. This indicates that the FRMP and the RMP behaved similarly in each of the dryers. Particle size can be effected by the nozzle pressure and product viscosity (Caric, 1994). With nozzle atomization, the mean particle size is inversely proportional to the pressure applied and directly proportional to the product viscosity (Caric, 1994). The spray dryer and the pulse dryer were compared (table 14) because these driers produced similar particles. A large amount of the powder particles for both blend treatments for the pulse and spray dryer were smaller than 75 μm (#200 mesh) .

Table 13. Particle size analysis by sieving of recovered milk product (RMP) and formulated recovered milk product (FRMP) treatments.

Treatment	On #40		On #100		On #200		Thru #200	
	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%
RMP	8	22.82 ^a	8	17.43 ^a	8	19.99 ^a	8	39.76 ^a
FRMP	8	21.52 ^a	8	20.67 ^a	8	20.13 ^a	8	37.68 ^a

^aMeans in a column, followed by same letter superscript do not differ significantly (P<0.05).

Table 14. Particle size analysis by sieving of recovered milk product (RMP) and formulated recovered milk product (FRMP) treatments, using only the spray dryer and pulse dryer treatment results.

Treatment	On #40		On #100		On #200		Thru #200	
	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%
RMP ¹	6	2.90 ^a	6	13.80 ^a	6	30.47 ^a	6	52.83 ^a
FRMP	6	9.27 ^a	6	14.50 ^a	6	26.57 ^a	6	49.67 ^a

^aMeans in a column, followed by same letter superscript do not differ significantly (P<0.05).

Particle size analysis using an infra-red Coulter LS 230 (Coulter Corporation, Miami, FL) was performed in duplicate on the samples from the pulse dryer and spray dryer. The samples from the roller dryer had particles that were too large to go through the particle analyzer therefore they were not analyzed. The mean result (by volume) for all samples was 68.37 μm , the mean result (by volume) for all FRMP samples was 60.15 μm and the mean result (by volume) for all RMP samples was 76.59 μm (table 15). There were no significant differences (P<0.05) in any of the size ranges. These results compare with the sieve analysis that also showed no significant differences between (P<0.05) the two treatments.

The results from the infra-red particle size analyzer with the size ranges comparable to the sieve analysis are presented in table 16. The two methods gave similar results, but the larger particles were harder to measure on the infra-red particle size analyzer. Therefore, the main differences between the two methods (infra-red vs. sieve) for this powder are in the greater than 150 μm range.

The RMP was significantly lower (P<0.05) in all amino acids, except lysine where there was no significant difference (P<0.05) between the two treatments (table 17). There were also no significant differences (P<0.05) between the two treatments for available lysine. Since the FRMP was significantly higher (P<0.05) in total protein it was expected that the amino acids would be higher in the FRMP compared to the RMP. Also, the original ingredient evaluation showed that all amino acids in the RMP were lower than all the amino acids in the separator de-sludge (table 4). This was also true for the raw ingredient evaluation (table 8).

Table 15. Infra-red particle size analysis of recovered milk product (RMP) and formulated recovered milk product (FRMP) treatments.

Particle size μm	FRMP ^{1,2}		RMP ^{1,2}	
	\underline{n}	$\underline{\%}$	\underline{n}	$\underline{\%}$
<10	12	4.03 ^a	12	3.51 ^a
11 – 20	12	12.19 ^a	12	8.06 ^a
21 – 30	12	19.42 ^a	12	13.93 ^a
31 – 40	12	20.38 ^a	12	15.72 ^a
41 – 50	12	16.38 ^a	12	13.77 ^a
51 – 60	12	5.62 ^a	12	8.29 ^a
61 – 70	12	2.42 ^a	12	3.81 ^a
71 – 80	12	2.13 ^a	12	2.85 ^a
81 – 90	12	1.90 ^a	12	2.71 ^a
91 – 100	12	1.68 ^a	12	2.57 ^a
>100	12	13.87 ^a	12	24.79 ^a

^aMeans in a row followed by same letter superscript are not significantly different ($P < 0.05$).

¹Columns may not add exactly to 100% due to rounding.

²Means are percent volume.

Table 16. Particle size analysis by sieving of recovered milk product (RMP) and formulated recovered milk product (FRMP) treatments (spray and pulse dryer treatments only).

Treatment	On #100 >150 μm		On #200 76-150 μm		Thru #200 <75 μm	
	\underline{n}	$\underline{\%}$	\underline{n}	$\underline{\%}$	\underline{n}	$\underline{\%}$
RMP ¹	12	0.68 ^a	12	29.36 ^a	12	69.82 ^a
FRMP	12	0.88 ^a	12	16.59 ^a	12	82.41 ^a

^aMeans in a column, followed by same letter superscript do not differ significantly ($P < 0.05$).

Table 17. Amino acids analysis of recovered milk product (RMP) and formulated recovered milk product (FRMP) treatments.

Amino acids	RMP		FRMP	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
Aspartic acid	0	1.40 ^a	9	1.65 ^b
Threonine	9	0.66 ^a	9	0.82 ^b
Serine	9	0.61 ^a	9	0.83 ^b
Glutamic acid	9	2.75 ^a	9	3.60 ^b
Proline	9	1.06 ^a	9	1.46 ^b
Glycine	9	0.46 ^a	9	0.50 ^b
Alanine	9	0.74 ^a	9	0.80 ^b
Cystine	9	0.15 ^a	9	0.21 ^b
Valine	9	0.99 ^a	9	1.25 ^b
Methionine	9	0.34 ^a	9	0.41 ^b
Isoleucine	9	0.75 ^a	9	0.94 ^b
Leucine	9	1.33 ^a	9	1.70 ^b
Tyrosine	9	0.59 ^a	9	0.76 ^b
Phenylalanine	9	0.71 ^a	9	0.85 ^b
Histidine	9	0.31 ^a	9	0.39 ^b
Lysine	9	0.56 ^a	9	0.58 ^a
Avail. Lysine	9	0.14 ^a	9	0.12 ^b
Arginine	9	0.29 ^a	9	0.40 ^b
Tryptophan	9	0.19 ^a	9	0.23 ^b
Total amino acids ²	9	13.89 ^a	9	17.38 ^b

¹Percent (%) reported on a dry basis per 100 g dry matter.

²Total amino acid number may not equal sum of all amino acids due to rounding.

^aMeans in same row followed by same letter are not significantly different (P>0.05).

Dryer treatment effects

The three dryer treatments that were used in this project were a nozzle spray dryer, a two-drum roller dryer, and a pulse combustion spray dryer. The nozzle spray dryer is one of the most common spray dryers used in the dairy industry. The roller dryer is most often used for drying whey for animal feed because it is economical and easy to operate. The pulse combustion spray dryer is not currently used in the food industry, but has some potential for various products. A goal of this research project was to compare and contrast the pulse combustion dryer with the spray dryer and the roller dryer because, the pulse combustion dryer had not been used in the dairy industry at the time of this research.

The mean results for the Mojonnier fat, Soxhlet fat, and free-fat for the dryer treatment effects are presented in table 18. There were no significant differences (P<0.05) in the Mojonnier fat values among the three dryer treatments. However, the Soxhlet fat value for the pulse combustion dryer is significantly less (P<0.05) than the

Soxhlet fat values for the other two dryer treatments. It is interesting to note that the mean Soxhlet fat tests were lower than the Mojonnier fat for the spray dryer and pulse dryer treatments but higher than the Mojonnier fat for the roller dryer treatment. One observation is that the performance between the two methods may be based on particle surface area. The pulse dryer treatment has the highest percentage of smaller particles (although not significantly higher ($P < 0.05$) than the spray dryer) whereas the roller dryer had larger particles. Another possibility is the difference in wettability of the samples. The roller dryer samples are the only samples that became completely wetted with 1 min; the other two dryer treatment samples did not perform well (results on wettability are not reported because of all samples took too long to wet). It would require more research with this product to determine if there really are differences and, if so, what is causing the differences between methods for this product or even dairy products in general.

Table 18. Mojonnier fat, Soxhlet fat, and free-fat of spray dryer, roller dryer, and pulse dryer treatments.

Treatment	Mojonnier Fat ¹		Soxhlet Fat ¹		Free-fat ³	
	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%
Spray ²	18	16.53 ^a	18	14.55 ^a	17	37.21 ^a
Pulse	17	17.04 ^a	17	10.95 ^b	17	34.10 ^a
Roller	18	14.60 ^a	18	15.96 ^a	18	49.29 ^b

¹ Reported on a dry basis.

² Free-fat is reported as a percent (%) of Mojonnier fat on a dry basis.

^{a,b} Means in a column, followed by same letter superscript do not differ significantly ($P < 0.05$).

There was a significant difference ($P < 0.05$) in the percentage of fat as free-fat between the roller dryer (49.29%) and the pulse (34.10%) and the spray dryer treatments (37.21%). Hansen (1985) had seen the same increase in free-fat with the roller dryer in whole milk powders. In fact, whole milk processed on a roller dryer is preferred by chocolate manufacturers because of the higher free-fat that makes it easier to give the chocolate a distinct buttery flavor (Hansen, 1985). As mentioned in the previous section, free-fat content can adversely affect the keeping quality of a powder and is directly responsible for poor wettability when powder is mixed in cold water (Hansen, 1985, Litmand and Ashworth, 1956; Buma, 1971; De Vilder et al., 1977).

The mean moisture content for the spray dryer was significantly higher ($P < 0.05$) from the other two dryer treatments (table 19). The moisture content was not controlled during the drying process because the sample size was too small (ca. 19 L) to make adjustments. The target for this product was a moisture content in the 3.5% to 4.0% range. Although, the dryers were not controlled specifically to meet this moisture content (i.e. samples were not evaluated during the runs for moisture content) it appears that the pulse dryer performed the best. Typical commercial milk powders

are produced in the 3.0 % to 4.0 % moisture range with the maximum allowed moisture of 4.0 % in most milk powders (ADPI, 1991). Therefore, all analysis numbers were converted to a dry matter basis to remove the effect of the moisture level. With a larger run and more experience with drying the RMP it is likely that the moisture levels for all the dryer treatments could be adjusted to be in the range of the typical moisture content for commercial dairy powders.

The pH for the spray dryer treatment (pH 7.83) was significantly lower ($P<0.05$) than the pulse dryer treatment (pH 8.53) and the roller dryer treatment (pH 8.22) (table 19). This was unexpected since it was thought that the dryer treatments would not have an effect on the pH of the product, only the raw ingredients would affect the pH. The only difference in the processing between the three treatments was the amount of time elapsed from the initial preparation of the concentrated liquid samples (prior to drying). The spray dryer treatment was performed in week 1 immediately after the samples were prepared on the evaporator. The roller dryer treatment was performed in week 2 and the pulse dryer treatment was performed in week 3. Typically, dairy products develop acid over time, therefore lowering the pH. There may have been some phenomenon with age thickening of the concentrated liquid samples to form complexes that increased the pH values. It was noted that the samples formed a gel structure when cooled, but heating to ca. 40 °C easily reversed this.

Table 19. Moisture, pH, and insolubility index of spray dryer, roller dryer, and pulse dryer treatments.

Treatment	Moisture		pH		Insolubility index	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>pH</u>	<u>n</u>	<u>ml</u>
Spray ¹	16	9.76 ^a	17	7.83 ^a	17	7.78 ^a
Pulse	17	3.86 ^b	18	8.53 ^b	18	4.99 ^b
Roller	18	5.38 ^b	18	8.22 ^b	17	10.69 ^c

¹Means in a column, followed by same letter superscript do not differ significantly ($P<0.05$).

The insolubility index was significantly different ($P<0.05$) between all three dryer treatments (table 19). The pulse dryer had the lowest, or best, insolubility index at 4.99 ml, followed by the spray dryer at 7.78 ml. The roller dryer produced the least soluble product (10.69 ml), which is typical of roller dryers (Caric, 1994; Hunziker, 1946; Masters, 1985). The insolubility index for both the spray dryer and the pulse dryer were higher than is typical for skim milk powder (<0.1 ml) as mentioned previously. It is likely with more experience in drying the product that the insolubility index could be decreased for both the spray dryer and the pulse dryer. However, from the data in table 19, the pulse dryer seems to perform better than the spray dryer and roller dryer with respect to insolubility index on the two recovered milk products. From a feed value perspective, if the dry product is used in a dry mix the insolubility index would not likely make a difference in the value of the product. There may be a

difference in the feed value if the dry product was reconstituted to liquid form, as the less soluble product would not stay in solution.

The protein concentrations were statistically significantly different ($P < 0.05$) between the spray dryer and the other two treatments, with the spray dryer having a higher protein concentration (17.94%) vs. the pulse dryer treatment (17.15%) and the roller dryer treatment (17.33%) (table 20). From a practical point of view these may not be different when formulating a feeding ration.

The ash, nitrogen free extract (NFE), total digestible nutrients (TDN) and lactose content of the powders did not differ significantly ($P < 0.05$) between the three dryer treatments (table 20).

Table 20. Protein, ash, nitrogen free extract (NFE), total digestible nutrients (TDN), and lactose of the spray dryer, roller dryer, and pulse dryer treatments.

Treatment	Protein ¹		Ash		NFE ^{1,2,3}		TDN ^{1,2,4}		Lactose ^{1,2,5}	
	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%
Spray	18	17.94 ^a	17	33.78 ^a	17	31.72 ^a	17	72.33 ^a	17	31.72 ^a
Pulse	17	17.15 ^b	18	34.63 ^a	16	31.18 ^a	16	72.33 ^a	16	31.18 ^a
Roller	17	17.33 ^b	18	34.31 ^a	17	33.75 ^a	17	69.56 ^a	17	33.75 ^a

¹Reported on a dry basis.

²Mojonnier fat value was used in all calculations for %fat value.

³%NFE = 100% - (%Fat + %Protein + %Ash).

⁴%TDN = (0.8*NFE) + (0.75*protein) + (0.45*fiber) + (0.9*2.25*fat), fiber content was assumed 0 in all samples.

⁵%Lactose = 100% - (%Fat + %Protein + %Ash).

^{a,b}Means in a column, followed by same letter superscript do not differ significantly ($P < 0.05$).

The mean calcium, phosphorus, sodium, and chloride concentrations for the spray, pulse, and roller dryer treatments (table 21) were not significantly different ($P < 0.05$). There was no significant difference ($P < 0.05$) between the pulse dryer (234.62 ppm), the spray dryer (256.58 ppm), and the roller dryer (135.92 ppm) treatments for the nitrate (NO₃) concentrations (table 21). It does appear, however, that the spray dryer and the pulse dryer had the highest NO₃ concentrations and the roller dryer had the lowest NO₃ concentration (table 21). A possible explanation for some of this difference maybe the fact that compounds of combustion of natural gas are in direct contact with the powder particles in both the spray dryer and pulse dryer. Natural gas combustion creates oxides of nitrogen (NO_x), which is an air pollutant that is regulated in California. Commercial milk dryers in California must meet stringent NO_x emission limits (<30 ppm / mmBTU natural gas) (San Joaquin Valley Air Pollution Control District, 2000). However, since the pilot dryers used in this

project are not subjected to low NOx requirements it is not known what the NOx limits are for the burners on these pilot dryers.

Table 21. Calcium (Ca), phosphorus (P), sodium (Na), chloride (Cl), and nitrate (NO₃) analysis of spray dryer, roller dryer, and pulse dryer treatments.

Treatment	Ca ¹		P ¹		Na ¹		Cl ¹		NO ₃ ¹	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>ppm</u>
Spray	18	0.83 ^a	18	2.03 ^a	18	9.90 ^a	18	1.57 ^a	18	256.58 ^a
Pulse	18	0.90 ^a	17	2.19 ^a	17	10.22 ^a	18	1.62 ^b	17	234.62 ^a
Roller	17	0.78 ^a	17	1.79 ^a	17	8.16 ^a	18	1.56 ^b	18	135.32 ^a

¹Reported on a dry basis.

^{a,b}Means in a column, followed by same letter superscript do not differ significantly (P<0.05).

The mean results, in percent, for the particle size analysis using sieves are listed in table 22. There were no significant differences between the spray dryer (3.05%) and the pulse dryer (2.77%) for percent powder sample left on the #40 mesh sieve. The mean result for the roller dryer (60.70%) was significantly higher (P<0.05) than both the spray and the pulse dryer. Because the powder from a roller dryer is usually processed through some type of hammer mill to pulverize the sheets of product as they come off the roller dryer, the particles are usually larger than particles from a spray dryer. Therefore, it was not surprising that the majority of the powder particles (60.70%) from the roller dryer were too large to go through the 425 μm screen (#40 mesh). The pulse dryer and the spray dryer were not significantly different (P<0.05) for any of the mesh sizes (table 22). The roller dryer treatment was significantly different (P<0.05) from both the spray dryer treatment and the pulse dryer treatment for all sieve sizes.

The infra-red particle size analyzer shows no significant differences (P<0.05) between the pulse dryer treatment and the spray dryer treatment (table 23 and table 24).

Table 22. Particle size analysis by sieving for the spray dryer, pulse combustion dryer, and roller dryer treatments.

Treatment	On #40		On #100		On #200		Thru #200	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
Spray	5	3.05 ^a	5	11.00 ^a	5	33.63 ^a	5	52.32 ^a
Pulse	5	2.77 ^a	5	11.35 ^a	5	23.48 ^a	5	62.40 ^a
Roller	6	60.70 ^b	6	34.80 ^b	6	3.07 ^b	6	1.43 ^b

^{a,b}Means in a column, followed by same letter superscript do not differ significantly (P<0.05).

Table 23. Infra-red particle size analysis by sieve size for the spray dryer and pulse combustion dryer treatments.

Treatment	On #100 >150 μm		On #200 76-150 μm		Thru #200 <75 μm	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
Spray	12	0.50 ^a	12	27.09 ^a	12	72.26 ^a
Pulse	12	1.06 ^a	12	18.87 ^a	12	79.97 ^a

^aMeans in a column, followed by same letter superscript do not differ significantly ($P < 0.05$).

Table 24. Infra-red particle size analyzer results by % volume for the spray dryer and pulse combustion dryer treatments.

Particle size <u>μm</u>	Spray		Pulse	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
<10	12	3.44 ^a	12	4.10 ^a
11 – 20	12	9.09 ^a	12	11.16 ^a
21 – 30	12	14.05 ^a	12	19.30 ^a
31 – 40	12	16.04 ^a	12	20.05 ^a
41 – 50	12	14.28 ^a	12	15.87 ^a
51 – 60	12	7.74 ^a	12	6.17 ^a
61 – 70	12	4.20 ^a	12	2.03 ^a
71 – 80	12	3.56 ^a	12	1.42 ^a
81 – 90	12	3.33 ^a	12	1.28 ^a
91 – 100	12	3.07 ^a	12	1.18 ^a
>100	12	21.20 ^a	12	17.46 ^a

^aMeans in a row, followed by same letter superscript do not differ significantly ($P < 0.05$).

The amino acid analyses for each of the dryer treatments are listed in table 25. There were no significant differences ($P < 0.05$) between the dryer treatments for the total amino acid percent. The roller dryer had a significantly lower ($P < 0.05$) available lysine content (0.05%) than the other two dryers (pulse combustion, 0.18% and the spray, 0.15%). It is well documented that roller dryers cause a much higher degree of Maillard reactions due to excessive heat and these Maillard reactions bind the amino acid lysine and lactose in such a way that it is not available for use (van den Bruel et al, 1971; Hansen, 1985). Researchers agree that available lysine is easily improved by adding lysine back to the dried product (van den Bruel et al., 1971; Mahan, 1992;

Mahan, 1993; Hansen et al., 1993). There were no significant differences ($P<0.05$) between dryer treatments for all other amino acids (table 25).

Table 25. Effect of spray dryer, roller dryer, and pulse dryer on mean results for amino acids.

Amino acids ¹	Spray		Pulse		Roller	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
Aspartic acid	6	1.54 ^a	6	1.51 ^a	6	1.52 ^a
Threonine	6	0.75 ^a	6	0.73 ^a	6	0.75 ^a
Serine	6	0.73 ^a	6	0.71 ^a	6	0.73 ^a
Glutamic acid	6	3.22 ^a	6	3.15 ^a	6	3.16 ^a
Proline	6	1.28 ^a	6	1.23 ^a	6	1.27 ^a
Glycine	6	0.47 ^a	6	0.48 ^a	6	0.48 ^a
Alanine	6	0.77 ^a	6	0.78 ^a	6	0.77 ^a
Cystine	6	0.20 ^a	6	0.17 ^a	6	0.18 ^a
Valine	6	1.14 ^a	6	1.09 ^a	6	1.13 ^a
Methionine	6	0.38 ^a	6	0.40 ^a	6	0.36 ^a
Isoleucine	6	0.85 ^a	6	0.83 ^a	6	0.85 ^a
Leucine	6	1.53 ^a	6	1.50 ^a	6	1.51 ^a
Tyrosine	6	0.68 ^a	6	0.67 ^a	6	0.68 ^a
Phenylalanine	6	0.78 ^a	6	0.81 ^a	6	0.77 ^a
Histidine	6	0.33 ^a	6	0.36 ^a	6	0.36 ^a
Lysine	6	0.55 ^a	6	0.61 ^a	6	0.55 ^a
Available Lysine	6	0.15 ^a	6	0.18 ^a	6	0.05 ^b
Arginine	6	0.35 ^a	6	0.36 ^a	6	0.32 ^a
Tryptophan	6	0.21 ^a	6	0.20 ^a	6	0.22 ^a
Total Amino Acids ²	6	15.76 ^a	6	15.59 ^a	6	15.61 ^a

¹Percent (%) reported on a dry basis per 100 g.

²Total amino acid number may not equal sum of all amino acids due to rounding.

^{a,b}Means in a row, followed by same letter superscript are not significantly different ($P<0.05$).

Interactions from the effect of blend/dryer

Data were statistically analyzed to evaluate the blend/dryer interaction to determine if there were significant differences ($P<0.05$) between the six blend/dryer treatments. Three samples of each blend treatment were run on each dryer treatment for a total of six runs per dryer. Each dryer was operated using the same parameters for each of the six samples. The samples were then analyzed in triplicate for Mojonnier fat, Soxhlet fat, moisture, pH, free-fat, insolubility index, protein, ash, calcium, phosphorus, sodium, chloride, and nitrate. Samples from the pulse dryer and spray dryer treatments were analyzed in duplicate for particle size on an infra-red particle size analyzer. All samples were also analyzed for particle size by sieve analysis and amino acid analysis was also performed.

There were no significant interactions ($P < 0.05$) between the six blend/dryer treatments for Mojonnier fat, Soxhlet fat, or free-fat (table 26). There were no significant differences ($P < 0.05$) between the interactions for moisture content. The pH for the three RMP/dryer interactions was significantly higher ($P < 0.05$) than the pH for the three FRMP/dryer interactions as seen in the batch effects. However, within the three RMP/dryer interactions the RMP/spray dryer interaction had the lowest pH (pH 8.42) which was significantly less than the other two RMP/dryer interactions. Within the FRMP/dryer interactions the FRMP/pulse dryer interaction had a significantly higher pH than the FRMP/roller dryer and FRMP/spray dryer interactions.

There were some significant differences ($P < 0.05$) in the insolubility index between the blend /dryer interactions (table 27). The RMP/roller dryer, FRMP/roller dryer, and RMP/spray dryer interactions had the poorest insolubility index and were not significantly different ($P < 0.05$) from each other. The FRMP/pulse dryer interaction had the best insolubility index (1.14 ml) and was significantly lower ($P < 0.05$) from all other blend/dryer interactions. The FRMP/spray dryer interaction and the RMP/Spray dryer interaction were not significantly different ($P < 0.05$) from each other. From the data in table 27 it can be inferred that the FRMP dried on the pulse dryer performed the best with regards to solubility.

The mean results for protein, ash, NFE, TDN, and lactose for the six blend/dryer interactions are listed in table 28. There were no significant differences ($P < 0.05$) between the blend/dryer interactions for protein, ash, NFE, and lactose. The TDN result for the RMP/roller dryer interaction was significantly lower ($P < 0.05$) than the RMP/spray dryer and RMP/pulse dryer interactions, but not significantly different ($P < 0.05$) from the FRMP/dryer interactions (table 28).

Table 26. Mojonnier fat, Soxhlet fat, and free-fat for the blend/dryer interactions.

Treatment	Mojonnier Fat ¹		Soxhlet fat		Free-fat ²	
	<u>n</u>	%	<u>n</u>	%	<u>n</u>	%
RMP/Spray	9	16.84 ^a	9	15.53 ^a	9	39.13 ^a
RMP/Pulse	9	17.80 ^a	8	11.29 ^a	8	33.28 ^a
RMP/Roller	9	13.93 ^a	9	14.68 ^a	9	56.02 ^a
FRMP/Spray	9	16.22 ^a	9	13.56 ^a	9	35.26 ^a
FRMP/Pulse	8	16.28 ^a	9	10.62 ^a	9	34.88 ^a
FRMP/Roller	9	15.27 ^a	9	17.25 ^a	9	42.55 ^a

¹Report on a dry basis.

²Free-fat is reported as a percent (%) of Mojonnier fat on a dry basis.

^aMeans in a column, followed by same letter superscript do not differ significantly ($P < 0.05$).

Table 27. Moisture, pH, and insolubility index for the blend/dryer interactions.

Treatment	Moisture		pH		Insolubility index	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>pH</u>	<u>n</u>	<u>ml</u>
RMP/Spray	9	9.30 ^a	9	8.42 ^a	8	9.03 ^{abc}
RMP/Pulse	9	2.29 ^a	9	9.26 ^b	9	8.83 ^{ab}
RMP/Roller	9	4.50 ^a	9	9.23 ^b	9	9.67 ^{bc}
FRMP/Spray	7	10.22 ^a	8	7.25 ^c	9	6.53 ^a
FRMP/Pulse	8	5.43 ^a	9	7.79 ^d	9	1.14 ^d
FRMP/Roller	9	6.26 ^a	9	7.21 ^c	8	11.72 ^c

^{a,b,c,d}Means in a column, followed by same letter superscript do not differ significantly (P<0.05).

Table 28. Protein, ash, nitrogen free extract (NFE), total digestible nutrients (TDN), and lactose for the blend/dryer interactions.

Treatment	Protein ¹		Ash		NFE ^{1,4}		TDN ^{1,5}		Lactose ^{1,6}	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
RMP/Spray	9	16.32 ^a	9	31.89 ^a	9	34.95 ^a	9	74.30 ^a	9	34.95 ^a
RMP/Pulse	8	15.11 ^a	9	34.23 ^a	8	32.84 ^a	8	73.69 ^a	8	32.84 ^a
RMP/Roller	8	15.13 ^a	9	36.29 ^a	8	34.65 ^a	8	67.26 ^b	8	34.65 ^a
FRMP/Spray	9	19.57 ^a	8	35.68 ^a	8	28.49 ^a	8	70.36 ^{ab}	8	28.49 ^a
FRMP/Pulse	9	19.18 ^a	9	35.02 ^a	8	29.52 ^a	8	70.97 ^{ab}	8	29.52 ^a
FRMP/Roller	9	19.54 ^a	9	32.34 ^a	9	32.86 ^a	9	71.85 ^{ab}	9	32.86 ^a

¹Reported on a dry basis.

²Mojonnier fat value was used in all calculations for %fat value.

³%NFE = 100% - (%Fat + %Protein + %Ash).

⁴%TDN = (0.8*NFE) + (0.75*protein) + (0.45*fiber) + (0.9*2.25*fat), fiber content was assumed 0 in all samples.

⁵%Lactose = 100% - (%Fat + %Protein + %Ash).

^{a,b}Means in a column, followed by same letter superscript do not differ significantly (P<0.05).

There was no blend/dryer effect for Ca, P, Cl, and NO₃ at P<0.05 (table 29). The Na concentration for the RMP/roller dryer treatment was significantly less (P<0.05) than all other treatments. The RMP/spray dryer, RMP/pulse dryer, and FRMP/roller dryer treatments were not significantly different (P<0.05) in Na concentration. The Na concentration for the RMP/pulse treatment was significantly greater (P<0.05) than the Na concentration of the FRMP/spray dryer treatment and the FRMP/pulse dryer treatment (table 29).

Table 29. Calcium (Ca), phosphorus (P), sodium (Na), chloride (Cl), and nitrate (NO₃) concentrations for the blend/dryer interactions.

Treatment	Ca ¹		P ¹		Na ¹		Cl ¹		NO ₃ ¹	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>ppm</u>
RMP/Spray	9	0.78 ^a	9	2.04 ^a	9	10.52 ^{ab}	9	1.61 ^a	9	446.90 ^a
RMP/Pulse	9	0.83 ^a	8	2.21 ^a	8	11.08 ^a	9	1.70 ^a	8	374.07 ^a
RMP/Roller	8	0.56 ^a	8	1.32 ^b	8	6.10 ^c	9	1.57 ^a	9	222.54 ^a
FRMP/Spray	9	0.88 ^a	9	2.01 ^a	9	9.28 ^b	9	1.53 ^a	9	66.26 ^a
FRMP/Pulse	9	0.98 ^a	9	2.18 ^a	9	9.36 ^b	9	1.54 ^a	9	95.17 ^a
FRMP/Roller	9	0.99 ^a	9	2.25 ^a	9	10.23 ^{ab}	9	1.55 ^a	9	48.11 ^a

¹Reported on a dry basis.

^{a,b,c}Means in a column, followed by same letter superscript do not differ significantly (P<0.05).

There were no blend/dryer effects for the “On #40”, “On #100”, and “On #200” category results (P<0.05). There were some significant differences between the blend/dryer interactions for the “Thru #200” category results. The RMP/roller dryer and FRMP/roller dryer treatments were significantly lower (P<0.05) than the other four blend/dryer interactions. The RMP/pulse dryer interaction had the greatest volume by weight of particles that were less than 75 μm, but this number was not significantly different (P<0.05) from the FRMP/spray dryer interaction. However, it was significantly different (P<0.05) from the other four interactions (RMP/spray dryer, RMP/roller dryer, FRMP/pulse dryer, and FRMP/roller dryer).

Table 30. Particle size analysis by sieving for the blend/dryer interactions.

Treatment	On #40		On #100		On #200		Thru #200	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
RMP/Spray	3	3.80 ^a	3	15.20 ^a	3	37.07 ^a	3	43.93 ^a
RMP/Pulse	2	0.60 ^a	2	4.30 ^a	2	21.30 ^a	2	73.80 ^b
RMP/Roller	3	64.07 ^a	3	32.80 ^a	3	1.60 ^a	3	1.53 ^c
FRMP/Spray	2	2.30 ^a	2	6.80 ^a	2	30.20 ^a	2	60.70 ^{ab}
FRMP/Pulse	3	4.93 ^a	3	18.40 ^a	3	25.67 ^a	3	51.00 ^a
FRMP/Roller	3	57.33 ^a	3	36.80 ^a	3	4.53 ^a	3	1.33 ^c

^{a,b,c}Means in a column, followed by same letter superscript do not differ significantly (P<0.05).

The mean results for the particle size analysis by the infra-red analyzer compared to the three sieve sizes are presented in table 31. The results as a percentage of volume for a range of particle sizes from <10 µm to 100 µm are given in table 32. The infra-red analyzer did not generate any useful information for this study, but it does offer the ability to look at a wide range of particle sizes and is not limited to the sieve sizes.

The amino acid profile for the six blend/dryer interactions are given in table 33. Phenylalanine, lysine, and arginine are the only amino acids that had differences between the blend/dryer interactions. The RMP/roller dryer and RMP/spray dryer interactions were significantly lower ($P<0.05$) than the other four blend/dryer interactions for phenylalanine. The lysine content in the FRMP/pulse interaction was significantly higher ($P<0.05$) than all other blend/dryer interactions. The arginine concentrations in the RMP/dryer interactions were significantly lower ($P<0.05$) than the arginine concentrations in the FRMP/dryer interactions. The FRMP/pulse dryer and FRMP/spray dryer interactions were significantly higher ($P<0.05$) in arginine content than the FRMP/roller dryer interaction.

Environmental scanning electron microscopy analysis

All eighteen samples were examined by an environmental scanning electron microscope (ESEM). Hydrated samples from each blend/dryer treatment were also examined. Figures 4 and 6 are micrographs from the ESEM for skim milk powder processed on an industrial spray dryer (nozzle atomization). In figure 4, small indentations can be seen (A) in the particles and there is wrinkling (B) on some of the particles. These observations are consistent with observations by Caric (1994) who indicated that wrinkles were caused by large temperature differences between the hot air and the powder particles. Figure 6 shows powdered skim milk with particles that are not as wrinkled.

Figures 5 and 7 are ESEM micrographs of hydrated skim milk powder processed on an industrial spray dryer (nozzle atomization). The star shaped structures are similar to lactose crystals isolated by McKenna (1997). Therefore, it is likely that the structures in figures 5 and 7 are lactose crystals that have started to form due to the hydration of the sample.

Figures 8, 10, and 11 are ESEM micrographs of different samples of the formulated recovered milk product (FRMP) that have been dried using a spray dryer. The particles in figures 8, 10, and 11 appear to be similar to each other with broken fragments visible in figure 8 (A) and figure 11 (A). These fragments are typical in milk powders when occluded air in the particle makes the particle fragile. Verhey (1972a, 1972b, and 1973) studied the formation of occluded air (or vacuoles) in milk powder samples. He concluded that air is incorporated into the liquid just prior to atomization and that disc atomizers incorporate more air than nozzle atomizers. Verhey also concluded that vacuoles are only formed in droplets that contain air bubbles that do not dissolve prior to the particle becoming solid. Powders in figures 4, 6, 8, 10, and 11 were all dried on a nozzle spray dryer.

Table 31. Particle size analysis by sieving, showing sieve sizes, for the blend/spray dryer and blend/pulse combustion dryer interactions.

Treatment	On #100 >150 μm		On #200 76-150 μm		Thru #200 <75 μm	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
RMP/Spray ¹	3	0.65 ^a	3	39.86 ^a	3	59.33 ^a
RMP/Pulse	2	0.70 ^a	2	18.87 ^a	2	80.30 ^a
FRMP/Spray	2	0.34 ^a	2	14.32 ^a	2	85.19 ^a
FRMP/Pulse	3	1.42 ^a	3	18.87 ^a	3	79.64 ^a

^aMeans in a column, followed by same letter superscript do not differ significantly (P<0.05).

Table 32. Mean results from infra-red particle size analyzer for formulated recovered milk product (FRMP) dried on spray dryer and pulse combustion dryer and for recovered milk product (RMP) dried on spray dryer and pulse combustion dryer.

Particle size <u>μm</u>	Spray/FMRP		Spray/RMP		Pulse/FMRP		Pulse/RMP	
	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>	<u>n</u>	<u>%</u>
<10	6	3.84 ^a	6	3.05 ^a	6	4.23 ^a	6	3.98 ^a
11 – 20	6	12.36 ^a	6	5.83 ^a	6	12.02 ^a	6	10.30 ^a
21 – 30	6	18.60 ^a	6	9.50 ^a	6	20.24 ^a	6	18.36 ^a
31 – 40	6	20.22 ^a	6	11.86 ^a	6	20.53 ^a	6	19.57 ^a
41 – 50	6	17.28 ^a	6	11.27 ^a	6	15.47 ^a	6	16.27 ^a
51 – 60	6	6.93 ^a	6	8.55 ^a	6	4.30 ^a	6	8.03 ^a
61 – 70	6	3.22 ^a	6	5.18 ^a	6	1.62 ^a	6	2.43 ^a
71 – 80	6	2.92 ^a	6	4.20 ^a	6	1.33 ^a	6	1.50 ^a
81 – 90	6	2.60 ^a	6	4.07 ^a	6	1.20 ^a	6	1.35 ^a
91 – 100	6	2.27 ^a	6	3.87 ^a	6	1.10 ^a	6	1.27 ^a
>100	6	9.77 ^a	6	32.63 ^a	6	17.97 ^a	6	16.95 ^a

^aMeans in a row, followed by same letter superscript do not differ significantly (P<0.05).

Table 33. Amino acids analysis for the blend/dryer interactions.

Amino acids ¹	F/P	F/R	F/S	R/P	R/R	R/S
	***** n=3 *****					
	%	%	%	%	%	%
Aspartic acid ²	1.57 ^a	1.68 ^a	1.70 ^a	1.45 ^a	1.37 ^a	1.38 ^a
Threonine	0.78 ^a	0.85 ^a	0.83 ^a	0.67 ^a	0.65 ^a	0.66 ^a
Serine	0.80 ^a	0.86 ^a	0.84 ^a	0.62 ^a	0.60 ^a	0.63 ^a
Glutamic acid	3.51 ^a	3.67 ^a	3.62 ^a	2.79 ^a	2.65 ^a	2.82 ^a
Proline	1.41 ^a	1.51 ^a	1.47 ^a	1.04 ^a	1.03 ^a	1.09 ^a
Glycine	0.48 ^a	0.52 ^a	0.49 ^a	0.47 ^a	0.45 ^a	0.45 ^a
Alanine	0.78 ^a	0.82 ^a	0.81 ^a	0.78 ^a	0.72 ^a	0.74 ^a
Cystine	0.19 ^a	0.22 ^a	0.23 ^a	0.15 ^a	0.15 ^a	0.16 ^a
Valine	1.18 ^a	1.31 ^a	1.27 ^a	1.01 ^a	0.96 ^a	1.01 ^a
Methionine	0.40 ^a	0.43 ^a	0.42 ^a	0.39 ^a	0.30 ^a	0.34 ^a
Isoleucine	0.90 ^a	0.96 ^a	0.94 ^a	0.76 ^a	0.73 ^a	0.76 ^a
Leucine	1.67 ^a	1.74 ^a	1.70 ^a	1.33 ^a	1.29 ^a	1.36 ^a
Tyrosine	0.73 ^a	0.78 ^a	0.76 ^a	0.60 ^a	0.58 ^a	0.60 ^a
Phenylalanine	0.82 ^a	0.88 ^a	0.86 ^a	0.79 ^a	0.66 ^b	0.69 ^b
Histidine	0.40 ^a	0.40 ^a	0.36 ^a	0.31 ^a	0.32 ^a	0.31 ^a
Lysine	0.64 ^a	0.56 ^b	0.53 ^b	0.57 ^b	0.54 ^b	0.57 ^b
Available Lysine	0.19 ^a	0.04 ^c	0.12 ^a	0.18 ^a	0.06 ^a	0.19 ^a
Arginine	0.44 ^a	0.35 ^b	0.41 ^a	0.28 ^c	0.29 ^c	0.29 ^c
Tryptophan	0.24 ^a	0.23 ^a	0.23 ^a	0.16 ^a	0.21 ^a	0.19 ^a
Total amino acids ³	16.94 ^a	17.77 ^a	17.47 ^a	14.17 ^a	13.50 ^a	14.05 ^a

F/P = Formulated Recovered milk product (FRMP) * Pulse dryer effect

F/R = Formulated Recovered milk product (FRMP) * Roller dryer effect

F/S = Formulated Recovered milk product (FRMP) * Spray dryer effect

R/P = Recovered milk product (RMP) * Pulse dryer effect

R/R = Recovered milk product (RMP) * Roller dryer effect

R/S = Recovered milk product (RMP) * Spray dryer effect

¹Percent (%) reported on a dry basis.

²Total amino acid number may not equal sum of all amino acids due to rounding.

^{a,b,c}Means in a row, followed by same letter superscript are not significantly different (P<0.05).

It can also be seen in figures 8, 10, and 11 that the particles have dimples or folds consistent with observations made by Caric (1994) and similar to particles in figure 4. From these observations it can be noted that the microstructure of FRMP is similar to typical spray dried skim milk powder.

One benefit of using the ESEM is the simple sample preparation without damaging the sample. Therefore, it is possible to view a sample that is partially hydrated. Figure 9 is a micrograph of the FRMP that was dried on the spray dryer and then hydrated in a humid atmosphere for 30 minutes just prior to examination on the

ESEM. White specks can be seen on the surface of the hydrated product (A), these are thought to be lactose crystals that are just starting to develop. Figures 5 and 7 show lactose crystals that have developed when skim milk powder was hydrated by the same method used above. Since the skim milk powder has a higher lactose content (ca. 54%), as compared to the FRMP (ca. 30%), the lactose crystals in the FRMP are much smaller.

The roller dried samples were similar, flat particles with jagged edges (figures 12, 14, 15, 28, 30, and 31). These observations are similar to observations made by Caric (1994). During the roller drying process the dry product is scraped off the drum in a thin sheet. It was expected that the microstructure of this product would be quite different from the other two dryers.

Figures 16 through 19 and 24 through 27 are micrographs of FRMP and RMP, respectively, that were dried on the pulse combustion dryer. The particles in figures 16, 18, 19, 24, 26, and 27 are spherical with one or two indentations (A) that look like two particles were stuck together for a brief time. The RMP particles in figures 24, 26, and 27 are more wrinkled (or rough) than the FRMP particles seen in figures 16, 18, and 19. These differences in the microstructure could be due to the lower moisture levels between the different treatments, 5.43% (FRMP) vs. 2.29% (RMP). Researchers (Caric (1994), Verhey (1972a, 1972b, and 1973)) have observed that the higher contact temperature (or inlet temperature) will increase the evaporation rate of water from the particles, which tends to form wrinkles. It is also important to note that the individual particles from the pulse combustion dryer are all of a similar morphology which indicates that the particles were all subjected to similar drying conditions. When comparing the morphology of the individual particles from a spray dryer to the morphology of the individual particles from the pulse dryer, one can see that the spray dryer produces a lot more variation in the particle morphology. Caric (1994) suggested that the different morphology of individual particles in the same sample was due to different drying conditions within the dryer. These differences in structure may affect functional characteristics.

Figures 9, 13, and 17 are all micrographs of formulated recovered milk product (FRMP) after hydration. Figures 21, 25, and 29 are all micrographs of recovered milk product (RMP) after hydration. In comparing the microstructure after hydration of the two treatments (FRMP vs. RMP) it appears that the FRMP has absorbed more water than the RMP. This is suggested because the particles in figures 9, 13, and 17 are not very prominent whereas, in figures 21, 25, and 29 the original particles are clearly defined. This observation agrees with the differences noted earlier in the insolubility index, 6.37 ml for FRMP vs. 9.18 ml for RMP, which indicates that the FRMP samples dissolve better than the RMP samples.

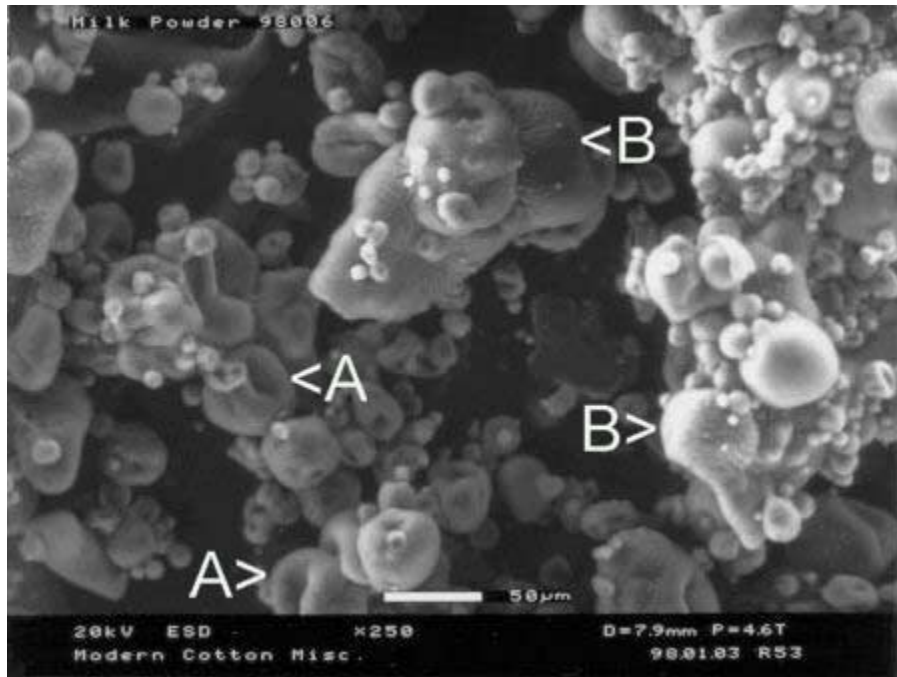


Figure 4. ESEM micrograph of skim milk powder processed on a spray dryer. A. Particle with indentation. B. Particle with wrinkles.

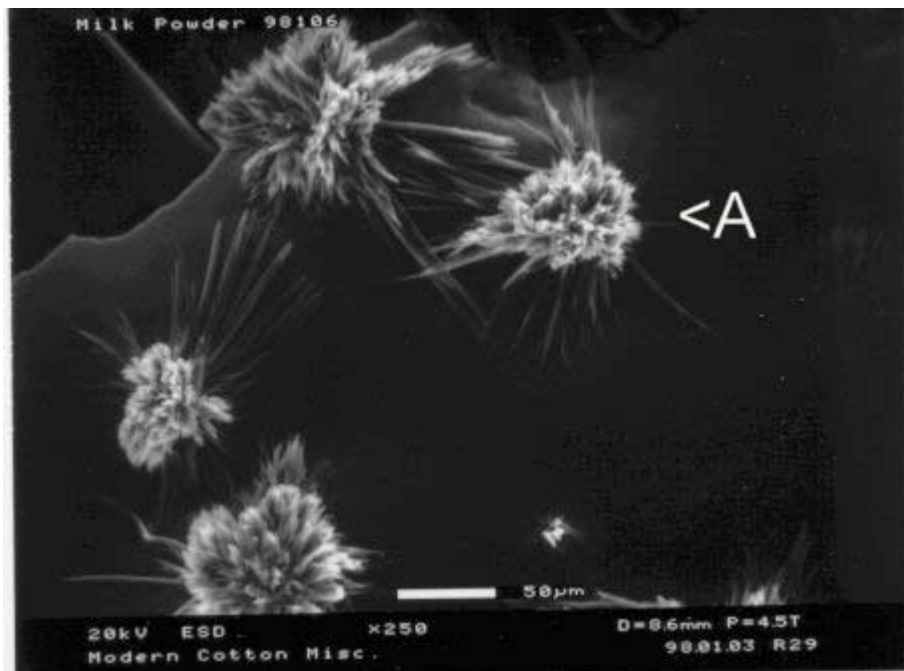


Figure 5. ESEM micrograph of hydrated skim milk powder processed on a spray dryer. A. Lactose crystal.

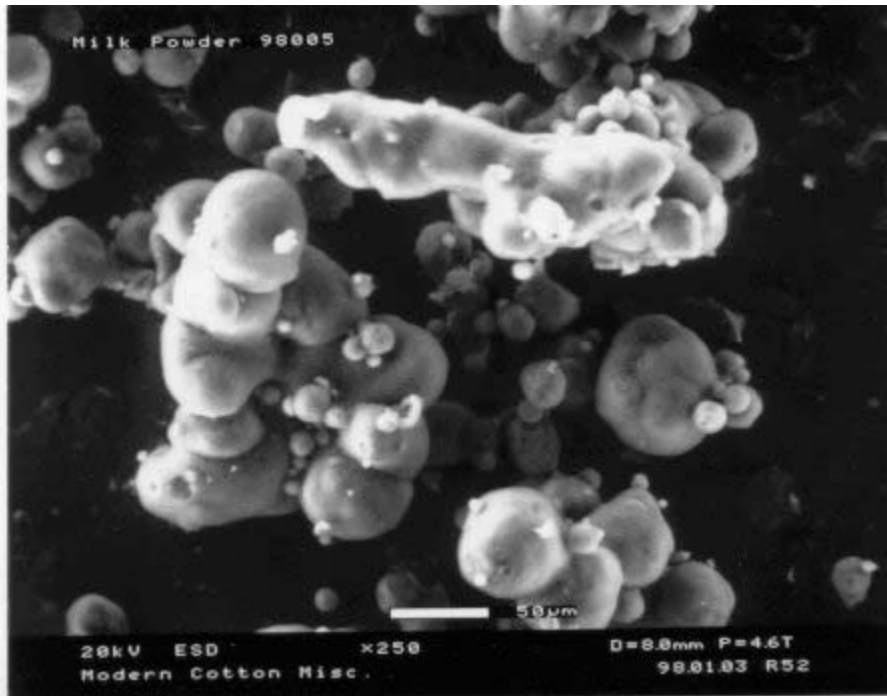


Figure 6. ESEM micrograph of skim milk powder processed on a spray dryer.

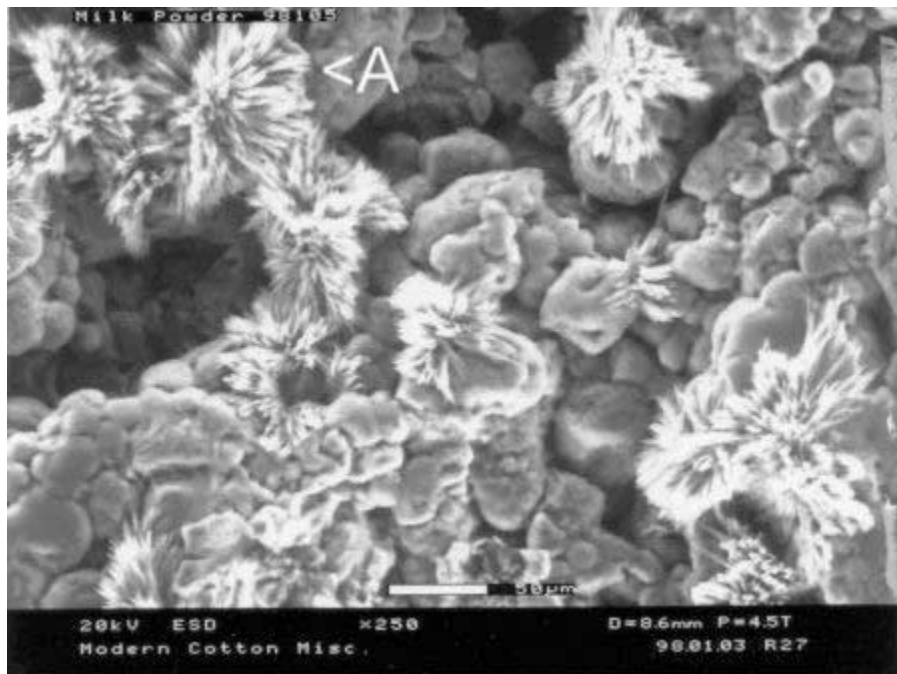


Figure 7. ESEM micrograph of hydrated skim milk powder processed on a spray dryer. A. Lactose crystal.

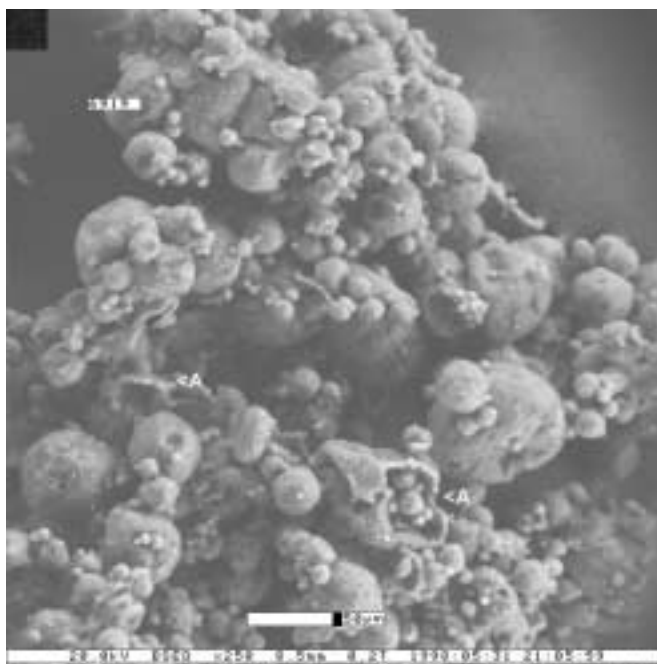


Figure 8. ESEM micrograph of formulated recovered milk product processed on the spray dryer (sample #6919). A. Particle fragment.

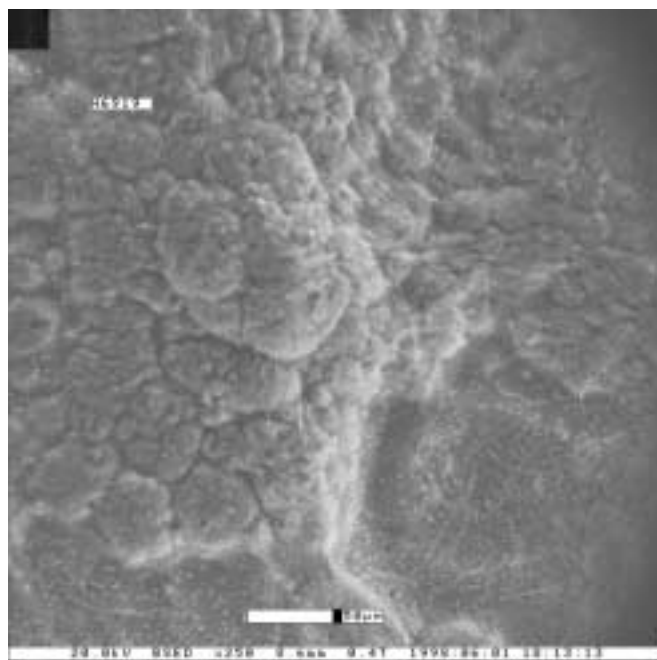


Figure 9. ESEM micrograph of hydrated formulated recovered milk product processed on the spray dryer (sample #6919).

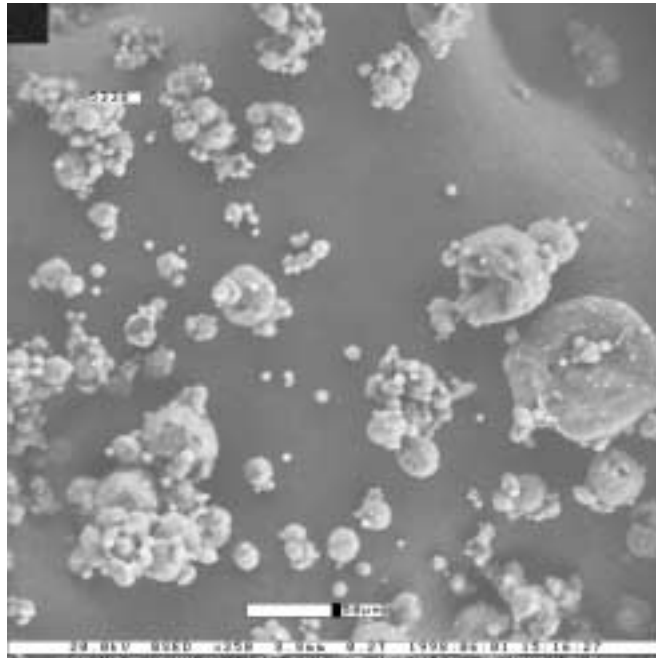


Figure 10. ESEM micrograph of formulated recovered milk product processed on the spray dryer (sample #5338).

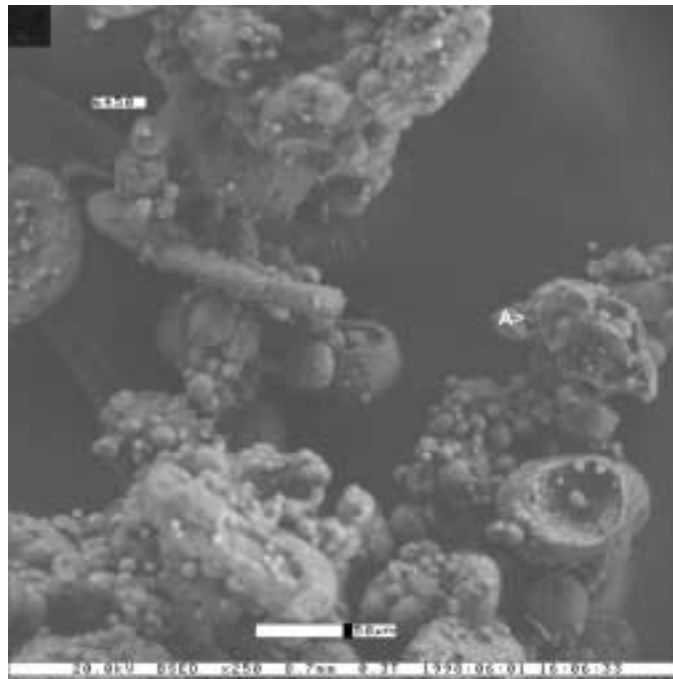


Figure 11. ESEM micrograph of formulated recovered milk product processed on the spray dryer (sample #6450). A. Particle fragment.

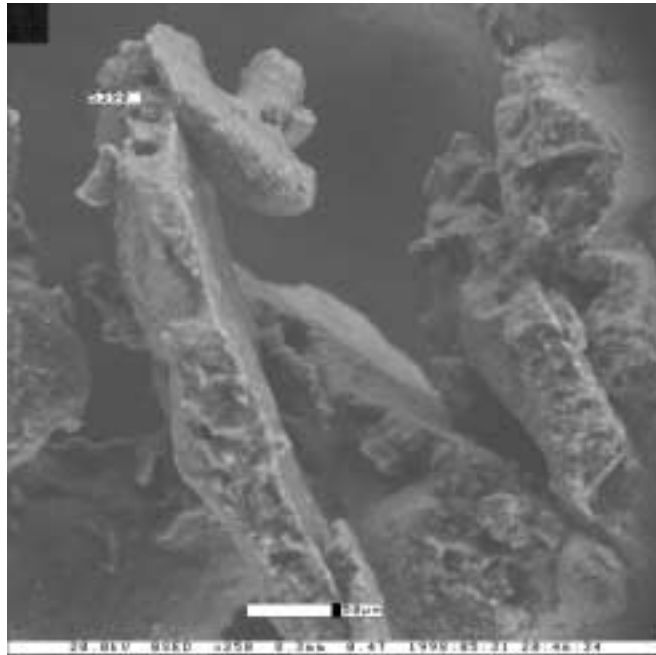


Figure 12. ESEM micrograph of formulated recovered milk product processed on the roller dryer (sample #5390).

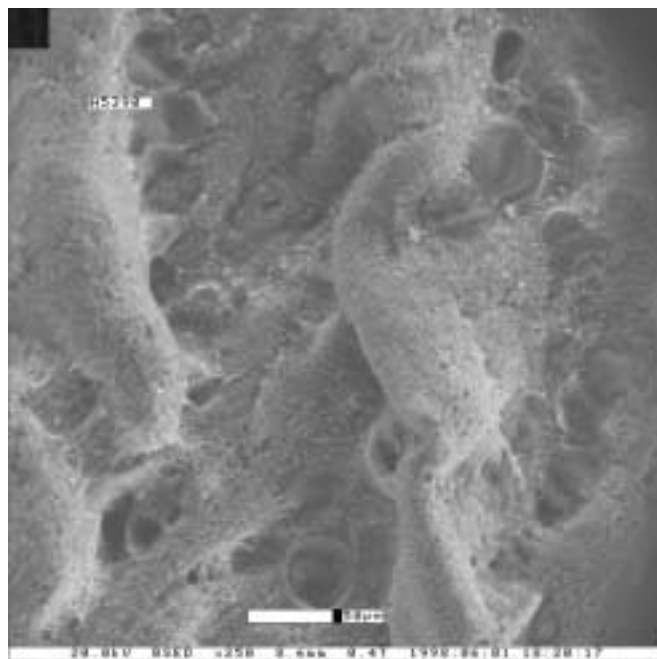


Figure 13. ESEM micrograph of hydrated formulated recovered milk product processed on the roller dryer (sample #5390).

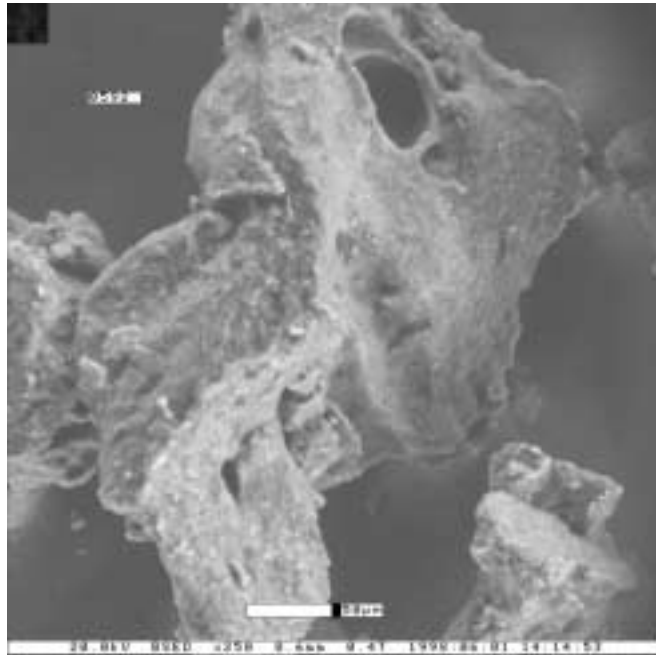


Figure 14. ESEM micrograph of formulated recovered milk product processed on the roller dryer (sample #0592).

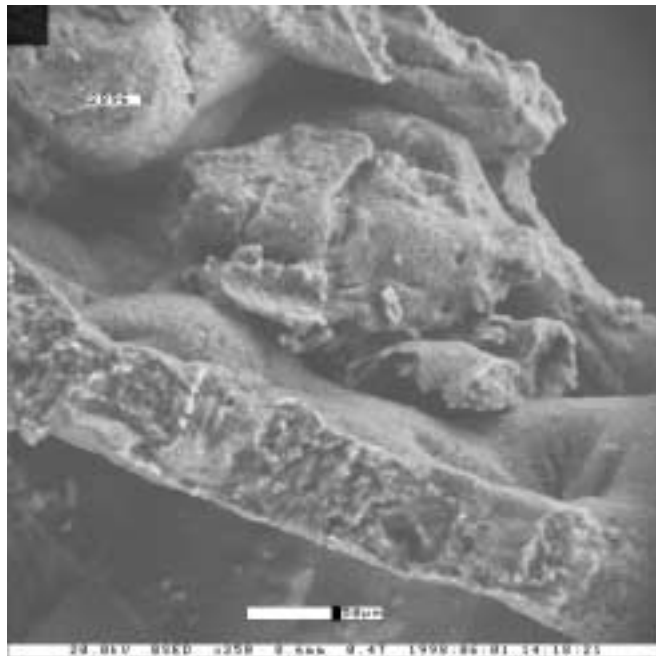


Figure 15. ESEM micrograph of formulated recovered milk product processed on the roller dryer (sample #2896).

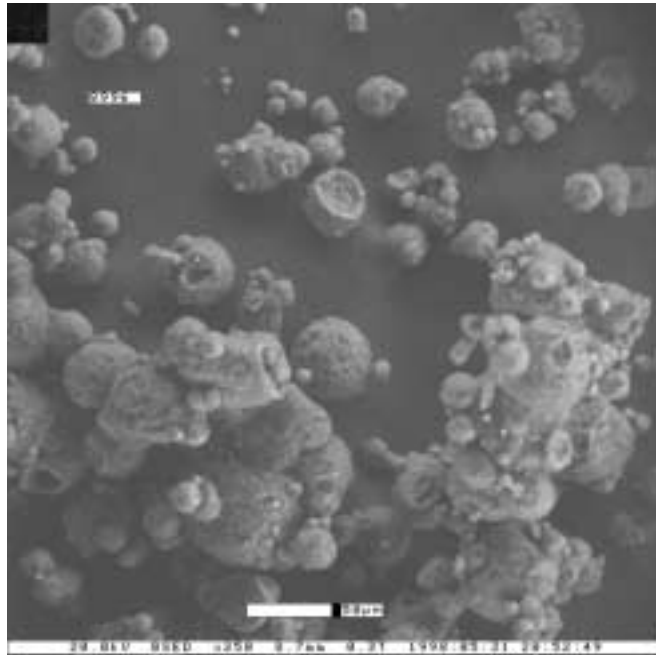


Figure 16. ESEM micrograph of formulated recovered milk product processed on the pulse dryer (sample #8996).

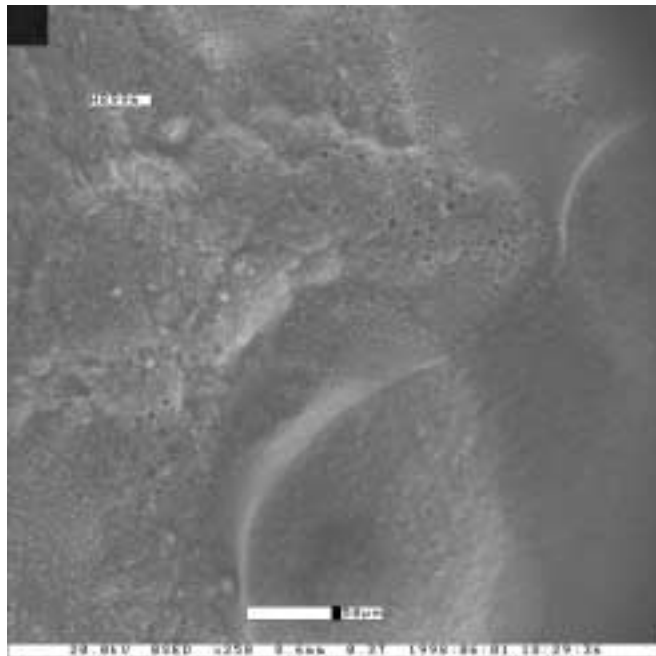


Figure 17. ESEM micrograph of hydrated formulated recovered milk product processed on the pulse dryer (sample #8996).

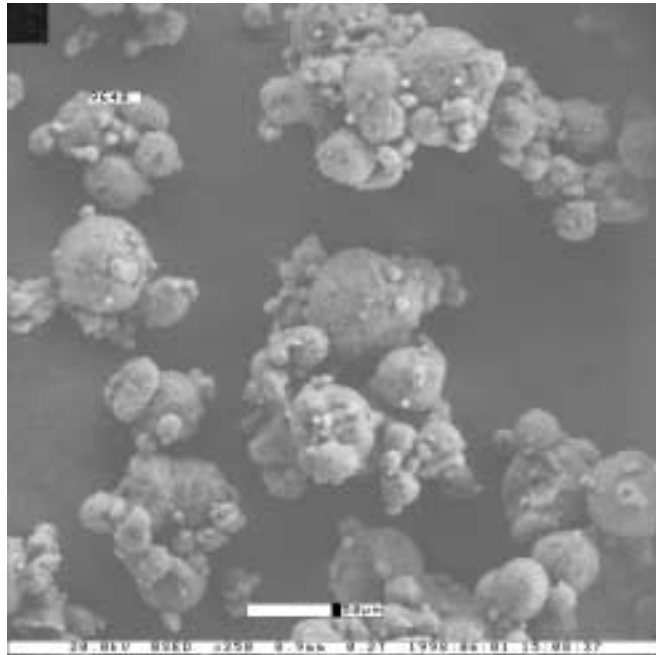


Figure 18. ESEM micrograph of formulated recovered milk product processed on the pulse dryer (sample #9640).

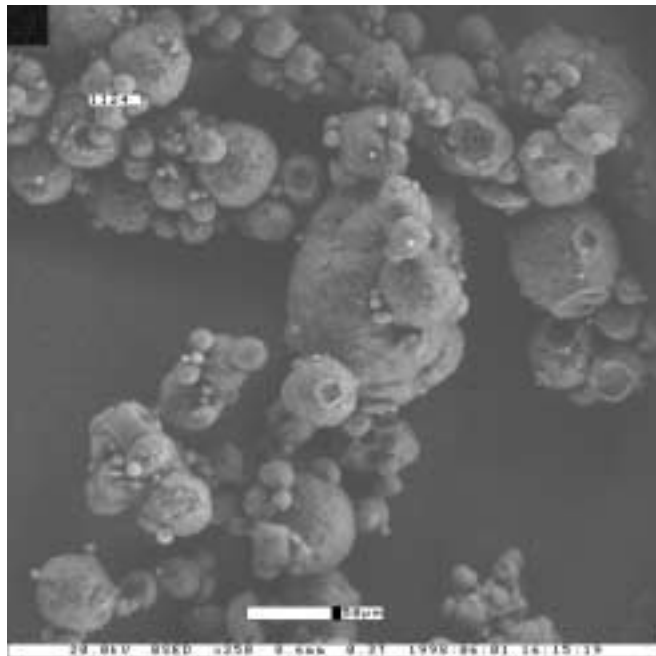


Figure 19. ESEM micrograph of formulated recovered milk product processed on the pulse dryer (sample #1124).

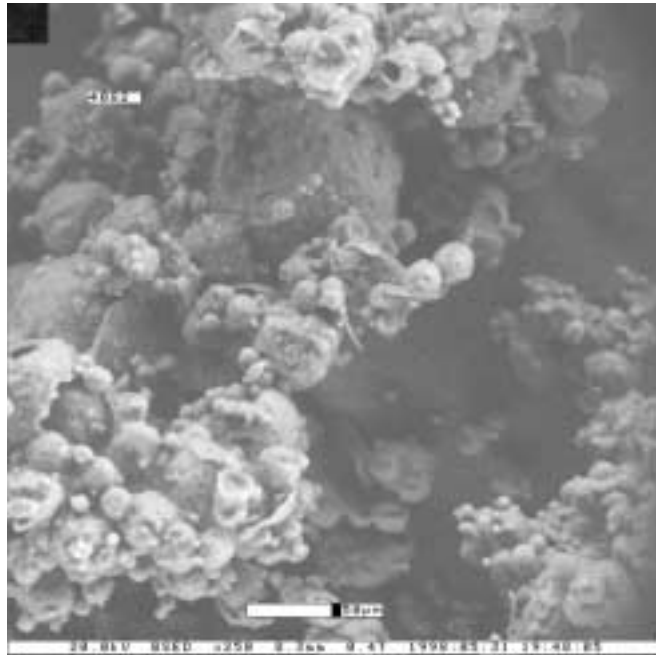


Figure 20. ESEM micrograph of recovered milk product processed on the spray dryer (sample #4082).

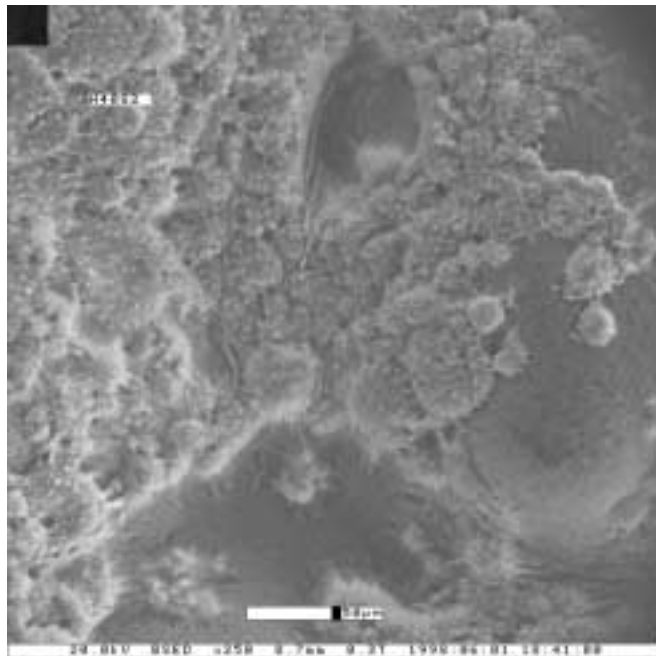


Figure 21. ESEM micrograph of hydrated recovered milk product processed on the spray dryer (sample #4082).

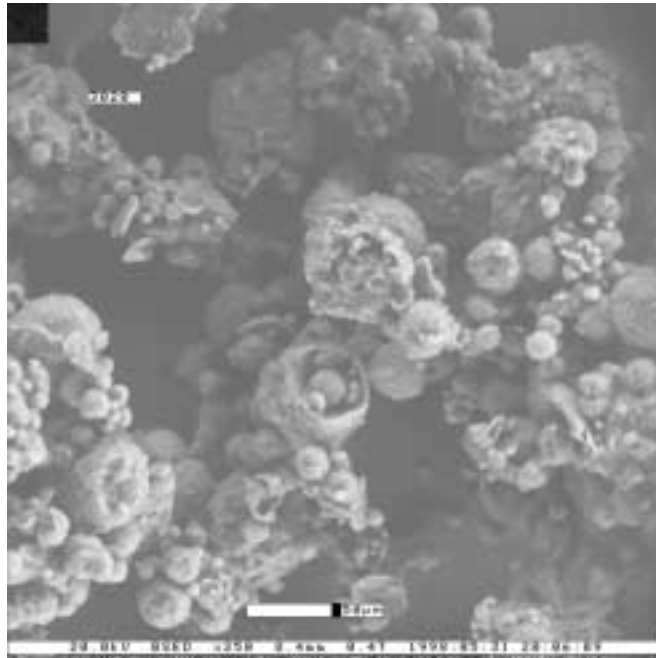


Figure 22. ESEM micrograph of recovered milk product processed on the spray dryer (sample #3020).

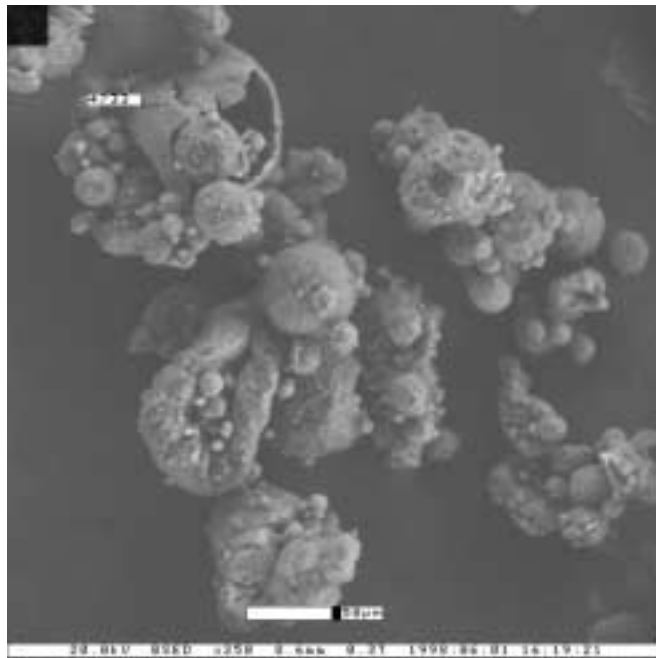


Figure 23. ESEM micrograph of recovered milk product processed on the spray dryer (sample #4733).

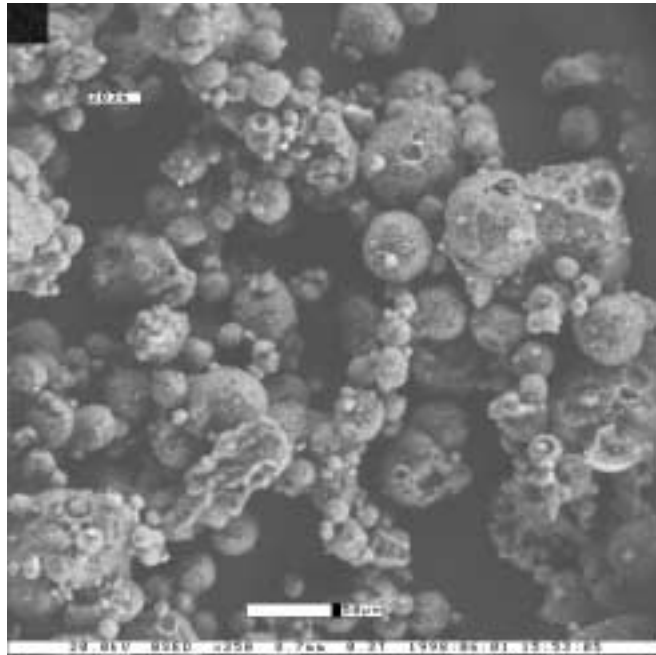


Figure 24. ESEM micrograph of recovered milk product processed on the pulse dryer (sample #3036).

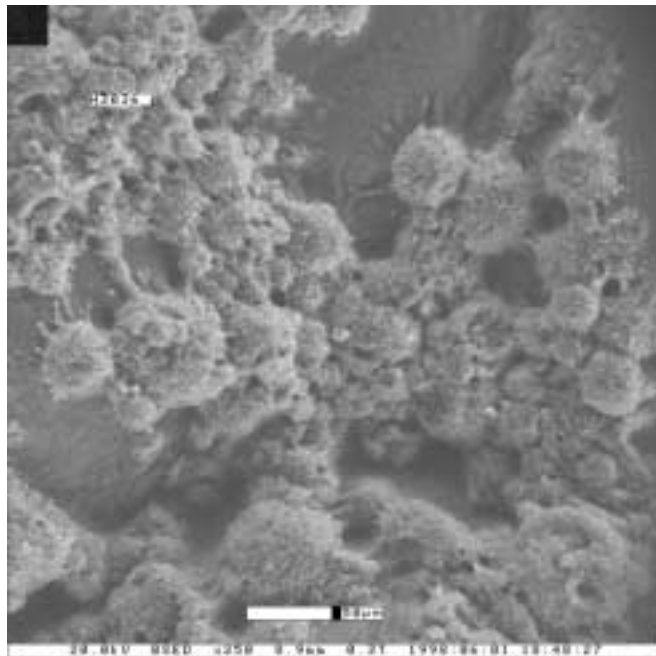


Figure 25. ESEM micrograph of hydrated recovered milk product processed on the pulse dryer (sample #3036).

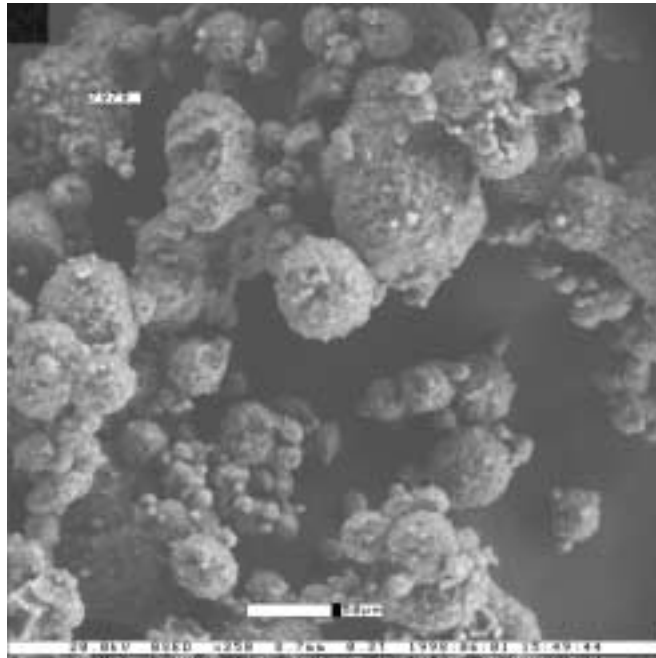


Figure 26. ESEM micrograph of recovered milk product processed on the pulse dryer (sample #7979).

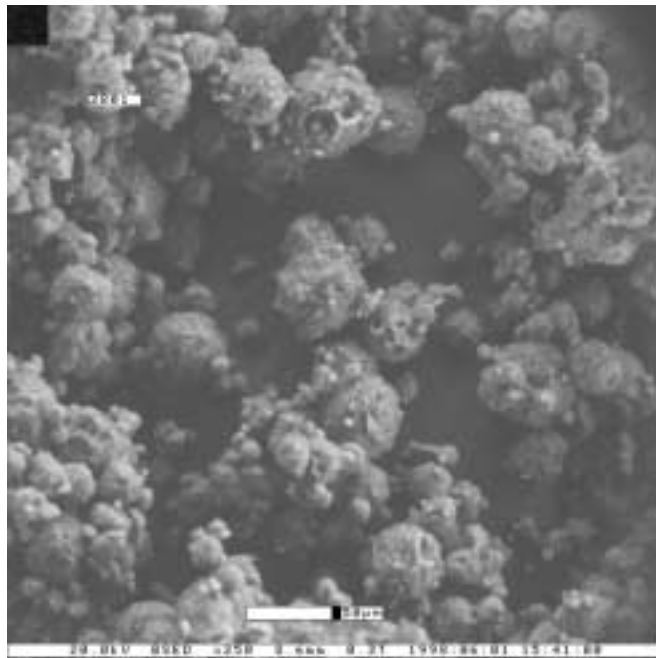


Figure 27. ESEM micrograph of recovered milk product processed on the pulse dryer (sample #3801).

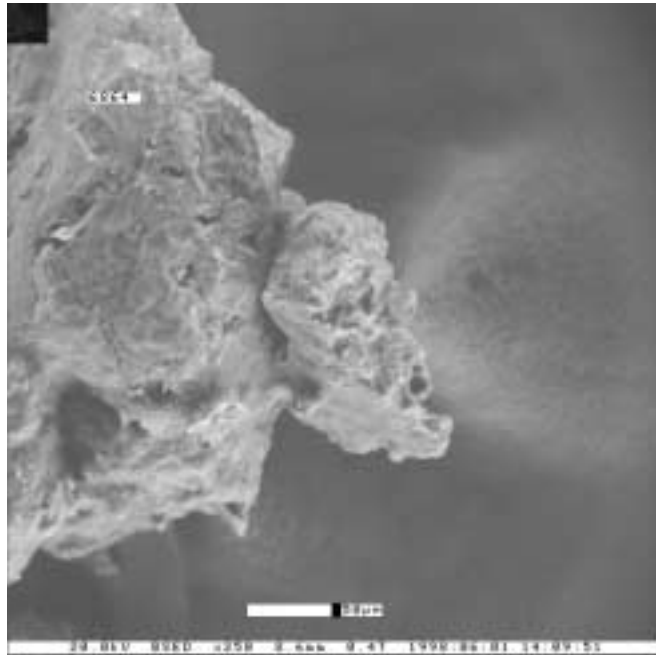


Figure 28. ESEM micrograph of recovered milk product processed on the roller dryer (sample #6864).

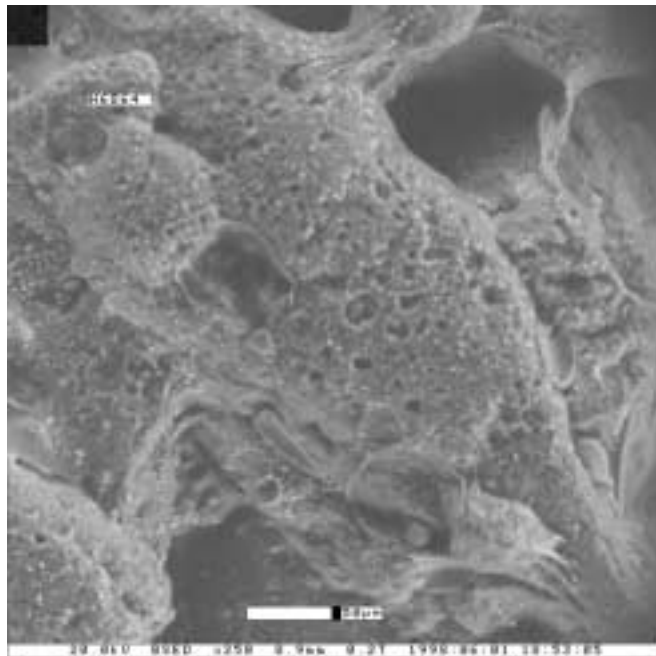


Figure 29. ESEM micrograph of hydrated recovered milk product processed on the roller dryer (sample #6864).

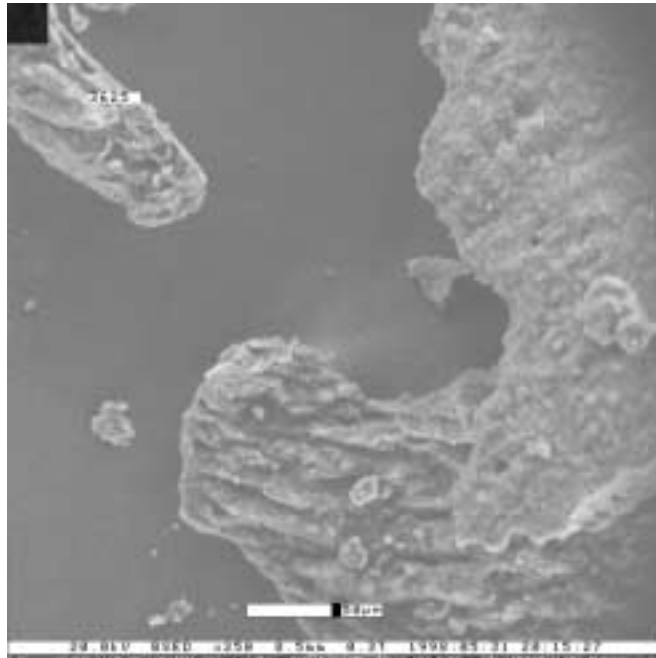


Figure 30. ESEM micrograph of recovered milk product processed on the roller dryer (sample #3625).

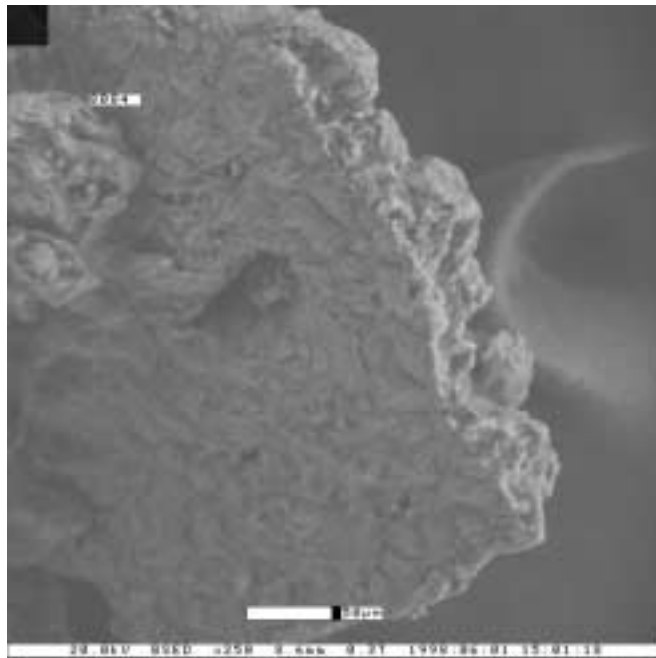


Figure 31. ESEM micrograph of recovered milk product processed on the roller dryer (sample #8084).

CONCLUSIONS AND RECOMMENDATIONS

In the dairy industry the control of wastewater is becoming more important as regulatory agencies focus more attention on water quality. An objective of this research was to improve the feed quality of an existing wastewater flow, recovered milk product (RMP), from a dairy butter/powder factory by adding other waste streams from nearby facilities and processing the blend into a powder. A second objective of this research was to evaluate three drying systems to determine if they had an effect on the quality of the finished product or the microstructure.

Three waste by-products were evaluated in this investigation, recovered milk product (RMP), separator de-sludge, and whole milk ultrafiltration de-proteinized milk solids. It was determined from fat, protein, and amino acid analysis that the best by-product was the separator de-sludge. It was also determined that the whole milk ultrafiltration de-proteinized milk solids by-product did not provide any added nutritional feed value for this research. RMP was used as a control and a blend was formulated using one part, by volume, of separator de-sludge and three parts, by volume, of RMP. The resulting blend is referred to as formulated recovered milk product (FRMP) in this investigation.

The main findings of this investigation can be summarized as follows:

1. The control, RMP, and the blend, FRMP, had poor solubility as compared to typical skim milk powder standards using insolubility index. The FRMP had a significantly ($P<0.05$) lower insolubility index than the RMP. This may not have any affect on feed quality if the product is used as a dry feed.
2. The protein content in the FRMP was significantly ($P<0.05$) different, apparently higher, than in the RMP. The total amino acid concentration was also significantly ($P<0.05$) different, apparently higher, in the FRMP than in the RMP.
3. The nitrate (NO_3) concentration in the RMP was significantly ($P<0.05$) different, apparently higher, than the NO_3 concentration in the FRMP. This is likely due to the higher concentration of cleaning compounds in the RMP.
4. There were no significant differences ($P<0.05$) in the particle size analysis between RMP and FRMP.
5. Since this product is a feed it is expected that the fat determination test of choice would be the Soxhlet method, whereas for a dairy powder for human consumption the method of choice would be the Mojonnier method. The Mojonnier method test resulted in higher fat content for the spray dried and pulse dried products compared to the Soxhlet fat determination. However, the Soxhlet fat results were higher than the

Mojonnier results for the roller dried products. The fat determination methods are not equal for measuring fat in the recovered milk products.

6. Free-fat concentration was greater ($P<0.05$) in the roller-dried powder than in the spray dried or pulse dried powders. This may be an important quality factor when determining which dryer to use for the recovered milk products. Higher free-fat may be desirable in some applications. For example, a dry feed mix may be more appropriate for a high free-fat product because this product would not reconstitute as well with water.
7. The pulse dryer produced a powder that was closest to the targeted range of 3.5 to 4.0% moisture content without any control. The moisture content of the pulse-dried samples was significantly ($P<0.05$) less than the spray-dried samples. The mean moisture content for the roller dried product was 1.52% higher than the mean moisture content of the product dried on the pulse dryer, but this was not statistically significant ($P<0.05$) in this study.
8. The pulse dryer produced the most soluble product as determined by the insolubility index. The overall mean of the insolubility index for the pulse dryer treatment was significantly ($P<0.05$) less than the other two dryer treatments. Furthermore, the insolubility index of the pulse dried FRMP was significantly ($P<0.05$) less than the other five-blend/dryer treatments.
9. The available lysine in the roller-dried product was significantly ($P<0.05$) less than the available lysine concentration in the products from the spray dryer and pulse dryer.
10. The microstructure of the powders was different for each of the dryers. The roller dryer produced a particle with a morphology that was definitely different from both the pulse dryer and spray dryer. The pulse dryer produced particles that had similar morphology indicating all particles were subjected to the same drying conditions.

In conclusion, adding the separator de-sludge to the existing recovered milk product (RMP) improved the nutritional value of the RMP by increasing the protein content. From a nutritional analysis, adding the separator de-sludge to the RMP did not have any adverse effects when compared with the control RMP. The FRMP was a more soluble product and therefore higher quality from a functional perspective for reconstitution purposes.

Recommendations

In this study, the Soxhlet fat determination method and the Mojonnier fat determination method were used to measure fat content in the powders. More research to study the reasons for the differing results between the two methods would be appropriate.

In this study, the pulse dryer out performed, or equaled, the spray dryer performance with respect to the functional properties. Further investigation into the capabilities of the pulse combustion spray dryer in the dairy industry is needed to determine if the pulse combustion dryer can produce a skim milk powder or whole milk powder with improved functional qualities.

More research is needed in the area of converting waste effluents from food factories into usable and consistent feed for animals. One of the next steps in developing this product would be to test animal performance, intake, and palatability of the feed. Research in this area will help develop economical methods of keeping the environment clean and improving overall water quality.

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APPENDIX A: STATISTICAL ANALYSIS

The Mixed Procedure

Dependent Variable Mojonnier fat
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	12	0.11	0.7472
dryer	2	12	3.37	0.0691
batch*dryer	2	12	1.08	0.3708

Dependent Variable Soxhlet fat
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	12	0.00	0.9789
dryer	2	12	12.75	0.0011
batch*dryer	2	12	2.62	0.1133

Least Squares Means

Effect	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	10.9505	0.7242	12.1	15.12	<.0001
dryer	Roller	15.9628	0.7224	12	22.10	<.0001
dryer	Spray	14.5452	0.7224	12	20.14	<.0001

Differences of Least Squares Means

Effect	dryer	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	Roller	-5.0123	1.0229	12.1	-4.90	0.0004
dryer	Pulse	Spray	-3.5947	1.0229	12.1	-3.51	0.0042
dryer	Roller	Spray	1.4175	1.0216	12	1.39	0.1905

Dependent Variable moisture
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	12	10.19	0.0078
dryer	2	12	33.85	<.0001
batch*dryer	2	12	1.13	0.3550

Least Squares Means

Effect	batch	dryer	Estimate	Standard Error	DF	t Value	Pr > t
batch	FRMP		7.3055	0.4300	12	16.99	<.0001
batch	RMP		5.3648	0.4299	12	12.48	<.0001
dryer		Pulse	3.8615	0.5266	12	7.33	<.0001
dryer		Roller	5.3817	0.5265	12	10.22	<.0001
dryer		Spray	9.7623	0.5266	12	18.54	<.0001

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	Estimate	Standard Error	DF
batch	FRMP		RMP		1.9407	0.6080	12
dryer		Pulse		Roller	-1.5202	0.7447	12
dryer		Pulse		Spray	-5.9008	0.7447	12
dryer		Roller		Spray	-4.3806	0.7447	12

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	t Value	Pr > t
batch	FRMP		RMP		3.19	0.0078
dryer		Pulse		Roller	-2.04	0.0638
dryer		Pulse		Spray	-7.92	<.0001
dryer		Roller		Spray	-5.88	<.0001

Dependent Variable pH
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	12	154.82	<.0001
dryer	2	12	10.35	0.0024
batch*dryer	2	12	3.98	0.0471

Least Squares Means

Effect	batch	dryer	Estimate	Standard Error	DF	t Value	Pr > t
batch	FRMP		7.4183	0.08813	12	84.18	<.0001
batch	RMP		8.9689	0.08811	12	101.79	<.0001
dryer		Pulse	8.5256	0.1079	12	79.01	<.0001
dryer		Roller	8.2222	0.1079	12	76.19	<.0001
dryer		Spray	7.8330	0.1079	12	72.56	<.0001
batch*dryer	FRMP	Pulse	7.7900	0.1526	12	51.05	<.0001
batch*dryer	FRMP	Roller	7.2144	0.1526	12	47.27	<.0001
batch*dryer	FRMP	Spray	7.2504	0.1527	12	47.48	<.0001
batch*dryer	RMP	Pulse	9.2611	0.1526	12	60.68	<.0001
batch*dryer	RMP	Roller	9.2300	0.1526	12	60.48	<.0001
batch*dryer	RMP	Spray	8.4156	0.1526	12	55.14	<.0001

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	Estimate	Standard Error	DF
batch	FRMP		RMP		-1.5506	0.1246	12
dryer		Pulse		Roller	0.3033	0.1526	12
dryer		Pulse		Spray	0.6926	0.1526	12
dryer		Roller		Spray	0.3893	0.1526	12
batch*dryer	FRMP	Pulse	FRMP	Roller	0.5756	0.2158	12
batch*dryer	FRMP	Pulse	FRMP	Spray	0.5396	0.2159	12
batch*dryer	FRMP	Pulse	RMP	Pulse	-1.4711	0.2158	12
batch*dryer	FRMP	Pulse	RMP	Roller	-1.4400	0.2158	12
batch*dryer	FRMP	Pulse	RMP	Spray	-0.6256	0.2158	12
batch*dryer	FRMP	Roller	FRMP	Spray	-0.03594	0.2159	12
batch*dryer	FRMP	Roller	RMP	Pulse	-2.0467	0.2158	12
batch*dryer	FRMP	Roller	RMP	Roller	-2.0156	0.2158	12
batch*dryer	FRMP	Roller	RMP	Spray	-1.2011	0.2158	12
batch*dryer	FRMP	Spray	RMP	Pulse	-2.0107	0.2159	12
batch*dryer	FRMP	Spray	RMP	Roller	-1.9796	0.2159	12
batch*dryer	FRMP	Spray	RMP	Spray	-1.1652	0.2159	12

Effect	batch	dryer	batch	dryer	Estimate	Standard Error	DF
batch*dryer	RMP	Pulse	RMP	Roller	0.03111	0.2158	12
batch*dryer	RMP	Pulse	RMP	Spray	0.8456	0.2158	12
batch*dryer	RMP	Roller	RMP	Spray	0.8144	0.2158	12

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	t Value	Pr > t
batch	FRMP		RMP		-12.44	<.0001
dryer		Pulse		Roller	1.99	0.0702
dryer		Pulse		Spray	4.54	0.0007
dryer		Roller		Spray	2.55	0.0254
batch*dryer	FRMP	Pulse	FRMP	Roller	2.67	0.0205
batch*dryer	FRMP	Pulse	FRMP	Spray	2.50	0.0279
batch*dryer	FRMP	Pulse	RMP	Pulse	-6.82	<.0001
batch*dryer	FRMP	Pulse	RMP	Roller	-6.67	<.0001
batch*dryer	FRMP	Pulse	RMP	Spray	-2.90	0.0134
batch*dryer	FRMP	Roller	FRMP	Spray	-0.17	0.8705
batch*dryer	FRMP	Roller	RMP	Pulse	-9.48	<.0001
batch*dryer	FRMP	Roller	RMP	Roller	-9.34	<.0001
batch*dryer	FRMP	Roller	RMP	Spray	-5.57	0.0001
batch*dryer	FRMP	Spray	RMP	Pulse	-9.31	<.0001
batch*dryer	FRMP	Spray	RMP	Roller	-9.17	<.0001
batch*dryer	FRMP	Spray	RMP	Spray	-5.40	0.0002
batch*dryer	RMP	Pulse	RMP	Roller	0.14	0.8878
batch*dryer	RMP	Pulse	RMP	Spray	3.92	0.0020
batch*dryer	RMP	Roller	RMP	Spray	3.77	0.0027

Dependent Variable insolubility index
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	12	13.42	0.0032
dryer	2	12	19.91	0.0002
batch*dryer	2	12	14.54	0.0006

Least Squares Means

Effect	batch	dryer	Estimate	Standard			Pr > t
				Error	DF	t Value	
batch	FRMP		6.4672	0.5223	12	12.38	<.0001
batch	RMP		9.1734	0.5223	12	17.56	<.0001
dryer		Pulse	4.9889	0.6389	11.9	7.81	<.0001
dryer		Roller	10.6952	0.6400	12	16.71	<.0001
dryer		Spray	7.7768	0.6400	12	12.15	<.0001
batch*dryer	FRMP	Pulse	1.1444	0.9036	11.9	1.27	0.2295
batch*dryer	FRMP	Roller	11.7237	0.9066	12.1	12.93	<.0001
batch*dryer	FRMP	Spray	6.5333	0.9036	11.9	7.23	<.0001
batch*dryer	RMP	Pulse	8.8333	0.9036	11.9	9.78	<.0001
batch*dryer	RMP	Roller	9.6667	0.9036	11.9	10.70	<.0001
batch*dryer	RMP	Spray	9.0202	0.9066	12.1	9.95	<.0001

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	Estimate	Standard	
						Error	DF
batch	FRMP		RMP		-2.7062	0.7386	12
dryer		Pulse		Roller	-5.7063	0.9044	12
dryer		Pulse		Spray	-2.7879	0.9044	12
dryer		Roller		Spray	2.9184	0.9051	12
batch*dryer	FRMP	Pulse	FRMP	Roller	-10.5793	1.2800	12
batch*dryer	FRMP	Pulse	FRMP	Spray	-5.3889	1.2779	11.9
batch*dryer	FRMP	Pulse	RMP	Pulse	-7.6889	1.2779	11.9
batch*dryer	FRMP	Pulse	RMP	Roller	-8.5222	1.2779	11.9
batch*dryer	FRMP	Pulse	RMP	Spray	-7.8757	1.2800	12
batch*dryer	FRMP	Roller	FRMP	Spray	5.1904	1.2800	12
batch*dryer	FRMP	Roller	RMP	Pulse	2.8904	1.2800	12
batch*dryer	FRMP	Roller	RMP	Roller	2.0570	1.2800	12
batch*dryer	FRMP	Roller	RMP	Spray	2.7035	1.2821	12.1
batch*dryer	FRMP	Spray	RMP	Roller	-3.1333	1.2779	11.9
batch*dryer	FRMP	Spray	RMP	Spray	-2.4868	1.2800	12
batch*dryer	RMP	Pulse	RMP	Roller	-0.8333	1.2779	11.9
batch*dryer	RMP	Pulse	RMP	Spray	-0.1868	1.2800	12
batch*dryer	RMP	Roller	RMP	Spray	0.6465	1.2800	12

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	Estimate	Standard Error	DF
batch	FRMP		RMP		3.9094	0.1841	11.9
dryer		Pulse		Roller	-0.1953	0.2260	12
dryer		Pulse		Spray	-0.8008	0.2252	11.9
dryer		Roller		Spray	-0.6055	0.2252	11.9

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	t Value	Pr > t
batch	FRMP		RMP		21.24	<.0001
dryer		Pulse		Roller	-0.86	0.4043
dryer		Pulse		Spray	-3.56	0.0040
dryer		Roller		Spray	-2.69	0.0199

Dependent Variable Calcium
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	12.1	11.19	0.0058
dryer	2	12.1	1.15	0.3505
batch*dryer	2	12.1	2.10	0.1656

Least Squares Means

Effect	batch	Estimate	Standard Error	DF	t Value	Pr > t
batch	FRMP	0.9478	0.04718	11.9	20.09	<.0001
batch	RMP	0.7236	0.04763	12.3	15.19	<.0001

Differences of Least Squares Means

Effect	batch	batch	Estimate	Standard Error	DF	t Value	Pr > t
batch	FRMP	RMP	0.2242	0.06704	12.1	3.34	0.0058

Dependent Variable Phosphorus
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	12.1	4.67	0.0515
dryer	2	12.1	3.10	0.0815
batch*dryer	2	12.1	5.69	0.0181

Least Squares Means

Effect	batch	dryer	Estimate	Standard Error	DF	t Value	Pr > t
batch*dryer	FRMP	Pulse	2.1822	0.1598	11.7	13.65	<.0001
batch*dryer	FRMP	Roller	2.2511	0.1598	11.7	14.08	<.0001
batch*dryer	FRMP	Spray	2.0100	0.1598	11.7	12.57	<.0001
batch*dryer	RMP	Pulse	2.2100	0.1649	13	13.40	<.0001
batch*dryer	RMP	Roller	1.3353	0.1649	13	8.10	<.0001
batch*dryer	RMP	Spray	2.0433	0.1598	11.7	12.78	<.0001

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	Estimate	Standard Error	DF
batch*dryer	FRMP	Pulse	FRMP	Roller	-0.06889	0.2261	11.7
batch*dryer	FRMP	Pulse	FRMP	Spray	0.1722	0.2261	11.7
batch*dryer	FRMP	Pulse	RMP	Pulse	-0.02782	0.2297	12.3
batch*dryer	FRMP	Pulse	RMP	Roller	0.8470	0.2297	12.3
batch*dryer	FRMP	Pulse	RMP	Spray	0.1389	0.2261	11.7
batch*dryer	FRMP	Roller	FRMP	Spray	0.2411	0.2261	11.7
batch*dryer	FRMP	Roller	RMP	Pulse	0.04107	0.2297	12.3
batch*dryer	FRMP	Roller	RMP	Roller	0.9158	0.2297	12.3
batch*dryer	FRMP	Roller	RMP	Spray	0.2078	0.2261	11.7
batch*dryer	FRMP	Spray	RMP	Pulse	-0.2000	0.2297	12.3
batch*dryer	FRMP	Spray	RMP	Roller	0.6747	0.2297	12.3
batch*dryer	FRMP	Spray	RMP	Spray	-0.03333	0.2261	11.7
batch*dryer	RMP	Pulse	RMP	Roller	0.8748	0.2332	13
batch*dryer	RMP	Pulse	RMP	Spray	0.1667	0.2297	12.3
batch*dryer	RMP	Roller	RMP	Spray	-0.7081	0.2297	12.3

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	t Value	Pr > t
batch*dryer	FRMP	Pulse	FRMP	Roller	-0.30	0.7659
batch*dryer	FRMP	Pulse	FRMP	Spray	0.76	0.4612
batch*dryer	FRMP	Pulse	RMP	Pulse	-0.12	0.9055
batch*dryer	FRMP	Pulse	RMP	Roller	3.69	0.0030
batch*dryer	FRMP	Pulse	RMP	Spray	0.61	0.5507
batch*dryer	FRMP	Roller	FRMP	Spray	1.07	0.3077
batch*dryer	FRMP	Roller	RMP	Pulse	0.18	0.8610
batch*dryer	FRMP	Roller	RMP	Roller	3.99	0.0017
batch*dryer	FRMP	Roller	RMP	Spray	0.92	0.3766
batch*dryer	FRMP	Spray	RMP	Pulse	-0.87	0.4004
batch*dryer	FRMP	Spray	RMP	Roller	2.94	0.0121
batch*dryer	FRMP	Spray	RMP	Spray	-0.15	0.8853
batch*dryer	RMP	Pulse	RMP	Roller	3.75	0.0024
batch*dryer	RMP	Pulse	RMP	Spray	0.73	0.4814
batch*dryer	RMP	Roller	RMP	Spray	-3.08	0.0092

Dependent Variable Sodium
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	12.1	0.28	0.6070
dryer	2	12.1	3.36	0.0689
batch*dryer	2	12.1	7.32	0.0083

Least Squares Means

Effect	batch	dryer	Estimate	Standard Error	DF	t Value	Pr > t
batch*dryer	FRMP	Pulse	9.3644	0.8234	11.7	11.37	<.0001
batch*dryer	FRMP	Roller	10.2267	0.8234	11.7	12.42	<.0001
batch*dryer	FRMP	Spray	9.2822	0.8234	11.7	11.27	<.0001
batch*dryer	RMP	Pulse	11.0910	0.8496	13	13.05	<.0001
batch*dryer	RMP	Roller	6.1904	0.8496	13	7.29	<.0001
batch*dryer	RMP	Spray	10.5156	0.8234	11.7	12.77	<.0001

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	Estimate	Standard Error	DF
batch*dryer	FRMP	Pulse	FRMP	Roller	-0.8622	1.1644	11.7
batch*dryer	FRMP	Pulse	FRMP	Spray	0.08222	1.1644	11.7
batch*dryer	FRMP	Pulse	RMP	Pulse	-1.7265	1.1831	12.3
batch*dryer	FRMP	Pulse	RMP	Roller	3.1741	1.1831	12.3
batch*dryer	FRMP	Pulse	RMP	Spray	-1.1511	1.1644	11.7
batch*dryer	FRMP	Roller	FRMP	Spray	0.9444	1.1644	11.7
batch*dryer	FRMP	Roller	RMP	Pulse	-0.8643	1.1831	12.3
batch*dryer	FRMP	Roller	RMP	Roller	4.0363	1.1831	12.3
batch*dryer	FRMP	Roller	RMP	Spray	-0.2889	1.1644	11.7
batch*dryer	FRMP	Spray	RMP	Pulse	-1.8088	1.1831	12.3
batch*dryer	FRMP	Spray	RMP	Roller	3.0918	1.1831	12.3
batch*dryer	FRMP	Spray	RMP	Spray	-1.2333	1.1644	11.7
batch*dryer	RMP	Pulse	RMP	Roller	4.9006	1.2015	13
batch*dryer	RMP	Pulse	RMP	Spray	0.5754	1.1831	12.3
batch*dryer	RMP	Roller	RMP	Spray	-4.3252	1.1831	12.3

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	t Value	Pr > t
batch*dryer	FRMP	Pulse	FRMP	Roller	-0.74	0.4737
batch*dryer	FRMP	Pulse	FRMP	Spray	0.07	0.9449
batch*dryer	FRMP	Pulse	RMP	Pulse	-1.46	0.1695
batch*dryer	FRMP	Pulse	RMP	Roller	2.68	0.0195
batch*dryer	FRMP	Pulse	RMP	Spray	-0.99	0.3429
batch*dryer	FRMP	Roller	FRMP	Spray	0.81	0.4336
batch*dryer	FRMP	Roller	RMP	Pulse	-0.73	0.4787
batch*dryer	FRMP	Roller	RMP	Roller	3.41	0.0050
batch*dryer	FRMP	Roller	RMP	Spray	-0.25	0.8084
batch*dryer	FRMP	Spray	RMP	Pulse	-1.53	0.1515
batch*dryer	FRMP	Spray	RMP	Roller	2.61	0.0222
batch*dryer	FRMP	Spray	RMP	Spray	-1.06	0.3110
batch*dryer	RMP	Pulse	RMP	Roller	4.08	0.0013
batch*dryer	RMP	Pulse	RMP	Spray	0.49	0.6352
batch*dryer	RMP	Roller	RMP	Spray	-3.66	0.0032

Dependent Variable Nitrate
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num	Den	F Value	Pr > F
	DF	DF		
batch	1	12	35.92	<.0001
dryer	2	12	2.59	0.1164
batch*dryer	2	12	1.65	0.2333

Least Squares Means

Effect	batch	Estimate	Standard Error	DF	t Value	Pr > t
batch	FRMP	69.8470	32.7995	12	2.13	0.0546
batch	RMP	347.83	32.7998	12	10.60	<.0001

Differences of Least Squares Means

Effect	batch	batch	Estimate	Standard Error	DF	t Value	Pr > t
batch	FRMP	RMP	-277.99	46.3858	12	-5.99	<.0001

Dependent Variable Ash
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num	Den	F Value	Pr > F
	DF	DF		
batch	1	12	0.02	0.8785
dryer	2	12	0.13	0.8751
batch*dryer	2	12	2.83	0.0985

Dependent Variable Lactose
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num	Den	F Value	Pr > F
	DF	DF		
batch	1	12	4.68	0.0513
dryer	2	12	0.77	0.4835
batch*dryer	2	12	0.59	0.5671

Least Squares Means

Effect	batch	dryer	Standard			
			Estimate	Error	DF	t Value Pr > t
batch	FRMP		30.2895	1.2598	12	24.04 <.0001
batch	RMP		34.1454	1.2598	12	27.10 <.0001
dryer		Pulse	31.1804	1.5432	12	20.21 <.0001
dryer		Roller	33.7521	1.5429	12	21.88 <.0001
dryer		Spray	31.7199	1.5429	12	20.56 <.0001
batch*dryer	FRMP	Pulse	29.5198	2.1824	12	13.53 <.0001
batch*dryer	FRMP	Roller	32.8578	2.1815	12	15.06 <.0001
batch*dryer	FRMP	Spray	28.4908	2.1824	12	13.05 <.0001
batch*dryer	RMP	Pulse	32.8410	2.1824	12	15.05 <.0001
batch*dryer	RMP	Roller	34.6464	2.1824	12	15.88 <.0001
batch*dryer	RMP	Spray	34.9489	2.1815	12	16.02 <.0001

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	Standard		
					Estimate	Error	DF
batch	FRMP		RMP		-3.8560	1.7817	12
dryer		Pulse		Roller	-2.5717	2.1822	12
dryer		Pulse		Spray	-0.5395	2.1822	12
dryer		Roller		Spray	2.0322	2.1819	12
batch*dryer	FRMP	Pulse	FRMP	Roller	-3.3380	3.0857	12
batch*dryer	FRMP	Pulse	FRMP	Spray	1.0290	3.0864	12
batch*dryer	FRMP	Pulse	RMP	Pulse	-3.3212	3.0864	12
batch*dryer	FRMP	Pulse	RMP	Roller	-5.1266	3.0864	12
batch*dryer	FRMP	Pulse	RMP	Spray	-5.4291	3.0857	12
batch*dryer	FRMP	Roller	FRMP	Spray	4.3669	3.0857	12

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	t Value	Pr > t
batch	FRMP		RMP		-2.16	0.0513
dryer		Pulse		Roller	-1.18	0.2614
dryer		Pulse		Spray	-0.25	0.8089
dryer		Roller		Spray	0.93	0.3700
batch*dryer	FRMP	Pulse	FRMP	Roller	-1.08	0.3006
batch*dryer	FRMP	Pulse	FRMP	Spray	0.33	0.7446
batch*dryer	FRMP	Pulse	RMP	Pulse	-1.08	0.3031
batch*dryer	FRMP	Pulse	RMP	Roller	-1.66	0.1226
batch*dryer	FRMP	Pulse	RMP	Spray	-1.76	0.1040
batch*dryer	FRMP	Roller	FRMP	Spray	1.42	0.1825

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	Estimate	Standard	
						Error	DF
batch*dryer	FRMP	Roller	RMP	Pulse	0.01682	3.0857	12
batch*dryer	FRMP	Roller	RMP	Roller	-1.7886	3.0857	12
batch*dryer	FRMP	Roller	RMP	Spray	-2.0911	3.0851	12
batch*dryer	FRMP	Spray	RMP	Pulse	-4.3501	3.0864	12
batch*dryer	FRMP	Spray	RMP	Roller	-6.1556	3.0864	12
batch*dryer	FRMP	Spray	RMP	Spray	-6.4581	3.0857	12
batch*dryer	RMP	Pulse	RMP	Roller	-1.8055	3.0864	12
batch*dryer	RMP	Pulse	RMP	Spray	-2.1079	3.0857	12
batch*dryer	RMP	Roller	RMP	Spray	-0.3025	3.0857	12

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	t Value	Pr > t
batch*dryer	FRMP	Roller	RMP	Pulse	0.01	0.9957
batch*dryer	FRMP	Roller	RMP	Roller	-0.58	0.5729
batch*dryer	FRMP	Roller	RMP	Spray	-0.68	0.5108
batch*dryer	FRMP	Spray	RMP	Pulse	-1.41	0.1841
batch*dryer	FRMP	Spray	RMP	Roller	-1.99	0.0693
batch*dryer	FRMP	Spray	RMP	Spray	-2.09	0.0583
batch*dryer	RMP	Pulse	RMP	Roller	-0.58	0.5075
batch*dryer	RMP	Roller	RMP	Spray	-0.10	0.9235

Dependent Variable

Nitrogen free extract

Degrees of Freedom Method

Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num	Den	F Value	Pr > F
	DF	DF		
batch	1	12	4.68	0.0513
dryer	2	12	0.77	0.4835
batch*dryer	2	12	0.59	0.5671

Dependent Variable

Total digestible nutrients

Degrees of Freedom Method

Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num	Den	F Value	Pr > F
	DF	DF		
batch	1	12	0.29	0.5975
dryer	2	12	2.12	0.1625
batch*dryer	2	12	4.39	0.0370

Dependent Variable Free-fat as a percentage of fat (Mojo)
 Degrees of Freedom Method Satterthwaite

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	12	2.12	0.1715
dryer	2	12	6.58	0.0118
batch*dryer	2	12	1.48	0.2657

Least Squares Means

Effect	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	34.1003	3.1300	12	10.89	<.0001
dryer	Roller	49.2850	3.1262	12	15.76	<.0001
dryer	Spray	37.2118	3.1300	12	11.89	<.0001

Differences of Least Squares Means

Effect	dryer	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	Roller	-15.1847	4.4238	12	-3.43	0.0050
dryer	Pulse	Spray	-3.1115	4.4264	12	-0.70	0.4955
dryer	Roller	Spray	12.0732	4.4238	12	2.73	0.0183

Dependent Variable #40 mesh
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	10	0.30	0.5969
dryer	2	10	282.20	<.0001
batch*dryer	2	10	1.87	0.2042

Least Squares Means

Effect	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	2.7667	2.1336	10	1.30	0.2238
dryer	Roller	60.7000	1.9083	10	31.81	<.0001
dryer	Spray	3.0500	2.1336	10	1.43	0.1833

Differences of Least Squares Means

Effect	dryer	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	Roller	-57.9333	2.8625	10	-20.24	<.0001
dryer	Pulse	Spray	-0.2833	3.0173	10	-0.09	0.9270
dryer	Roller	Spray	57.6500	2.8625	10	20.14	<.0001

Dependent Variable #100 mesh
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	10	1.01	0.3376
dryer	2	10	25.92	0.0001
batch*dryer	2	10	3.84	0.0580

Least Squares Means

Effect	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	11.3500	2.8779	10	3.94	0.0028
dryer	Roller	34.8000	2.5740	10	13.52	<.0001
dryer	Spray	11.0000	2.8779	10	3.82	0.0034

Differences of Least Squares Means

Effect	dryer	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	Roller	-23.4500	3.8611	10	-6.07	0.0001
dryer	Pulse	Spray	0.3500	4.0699	10	0.09	0.9332
dryer	Roller	Spray	23.8000	3.8611	10	6.16	0.0001

Dependent Variable #200 Mesh
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	10	0.00	0.9523
dryer	2	10	61.95	<.0001
batch*dryer	2	10	2.15	0.1672

Least Squares Means

Effect	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	23.4833	2.1096	10	11.13	<.0001
dryer	Roller	3.0667	1.8869	10	1.63	0.1352
dryer	Spray	33.6333	2.1096	10	15.94	<.0001

Differences of Least Squares Means

Effect	dryer	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer	Pulse	Roller	20.4167	2.8303	10	7.21	<.0001
dryer	Pulse	Spray	-10.1500	2.9834	10	-3.40	0.0067
dryer	Roller	Spray	-30.5667	2.8303	10	-10.80	<.0001

Dependent Variable Thru #200 mesh
 Degrees of Freedom Method Satterthwaite

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
batch	1	10	0.16	0.6938
dryer	2	10	58.15	<.0001
batch*dryer	2	10	4.67	0.0370

Least Squares Means

Effect	batch	dryer	Estimate	Standard Error	DF	t Value	Pr > t
dryer		Pulse	62.4000	4.5962	10	13.58	<.0001
dryer		Roller	1.4333	4.1110	10	0.35	0.7346
dryer		Spray	52.3167	4.5962	10	11.38	<.0001
batch*dryer	FRMP	Pulse	51.0000	5.8138	10	8.77	<.0001
batch*dryer	FRMP	Roller	1.3333	5.8138	10	0.23	0.8232
batch*dryer	FRMP	Spray	60.7000	7.1205	10	8.52	<.0001
batch*dryer	RMP	Pulse	73.8000	7.1205	10	10.36	<.0001
batch*dryer	RMP	Roller	1.5333	5.8138	10	0.26	0.7973
batch*dryer	RMP	Spray	43.9333	5.8138	10	7.56	<.0001

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	Estimate	Standard Error	DF
dryer		Pulse		Roller	60.9667	6.1665	10
dryer		Pulse		Spray	10.0833	6.5001	10
dryer		Roller		Spray	-50.8833	6.1665	10
batch*dryer	FRMP	Pulse	FRMP	Roller	49.6667	8.2220	10
batch*dryer	FRMP	Pulse	FRMP	Spray	-9.7000	9.1925	10
batch*dryer	FRMP	Pulse	RMP	Pulse	-22.8000	9.1925	10
batch*dryer	FRMP	Pulse	RMP	Roller	49.4667	8.2220	10
batch*dryer	FRMP	Pulse	RMP	Spray	7.0667	8.2220	10
batch*dryer	FRMP	Roller	FRMP	Spray	-59.3667	9.1925	10
batch*dryer	FRMP	Roller	RMP	Pulse	-72.4667	9.1925	10
batch*dryer	FRMP	Roller	RMP	Roller	-0.2000	8.2220	10
batch*dryer	FRMP	Roller	RMP	Spray	-42.6000	8.2220	10
batch*dryer	FRMP	Spray	RMP	Pulse	-13.1000	10.0699	10
batch*dryer	FRMP	Spray	RMP	Roller	59.1667	9.1925	10
batch*dryer	FRMP	Spray	RMP	Spray	16.7667	9.1925	10
batch*dryer	RMP	Pulse	RMP	Roller	72.2667	9.1925	10
batch*dryer	RMP	Pulse	RMP	Spray	29.8667	9.1925	10
batch*dryer	RMP	Roller	RMP	Spray	-42.4000	8.2220	10

Differences of Least Squares Means

Effect	batch	dryer	batch	dryer	t Value	Pr > t
dryer		Pulse		Roller	9.89	<.0001
dryer		Pulse		Spray	1.55	0.1519
dryer		Roller		Spray	-8.25	<.0001
batch*dryer	FRMP	Pulse	FRMP	Roller	6.04	0.0001
batch*dryer	FRMP	Pulse	FRMP	Spray	-1.06	0.3162
batch*dryer	FRMP	Pulse	RMP	Pulse	-2.48	0.0325
batch*dryer	FRMP	Pulse	RMP	Roller	6.02	0.0001
batch*dryer	FRMP	Pulse	RMP	Spray	0.86	0.4102
batch*dryer	FRMP	Roller	FRMP	Spray	-6.46	<.0001
batch*dryer	FRMP	Roller	RMP	Pulse	-7.88	<.0001
batch*dryer	FRMP	Roller	RMP	Roller	-0.02	0.9811
batch*dryer	FRMP	Roller	RMP	Spray	-5.18	0.0004
batch*dryer	FRMP	Spray	RMP	Pulse	-1.30	0.2225
batch*dryer	FRMP	Spray	RMP	Roller	6.44	<.0001
batch*dryer	FRMP	Spray	RMP	Spray	1.82	0.0981
batch*dryer	RMP	Pulse	RMP	Roller	7.86	<.0001
batch*dryer	RMP	Pulse	RMP	Spray	3.25	0.0087
batch*dryer	RMP	Roller	RMP	Spray	-5.16	0.0004

Analysis for chloride

The GLM Procedure

Dependent Variable: Chloride

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	0.39652326	0.02332490	8.43	<.0001
Error	36	0.09965706	0.00276825		
Corrected Total	53	0.49618033			

R-Square	Coeff Var	Root MSE	CLDM Mean
0.799152	3.324369	0.052614	1.582682

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.11788635	0.11788635	42.59	<.0001
dryer	2	0.03852780	0.01926390	6.96	0.0028
batch*dryer	2	0.04826096	0.02413048	8.72	0.0008
sample(batch*dryer)	12	0.19184815	0.01598735	5.78	<.0001

Source	Type III Expected Mean Square
batch	Var(Error) + 3 Var(sample(batch*dryer)) + Q(batch, batch*dryer)
dryer	Var(Error) + 3 Var(sample(batch*dryer)) + Q(dryer, batch*dryer)
batch*dryer	Var(Error) + 3 Var(sample(batch*dryer)) + Q(batch*dryer)
sample(batch*dryer)	Var(Error) + 3 Var(sample(batch*dryer))

Tests of Hypotheses for Mixed Model Analysis of Variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
* batch	1	0.117886	0.117886	7.37	0.0188
* dryer	2	0.038528	0.019264	1.20	0.3335
batch*dryer	2	0.048261	0.024130	1.51	0.2602
Error	12	0.191848	0.015987		

Error: MS(sample(batch*dryer))

* This test assumes one or more other fixed effects are zero.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
sample(batch*dryer)	12	0.191848	0.015987	5.78	<.0001
Error: MS(Error)	36	0.099657	0.002768		

Least Squares Means

Standard Errors and Probabilities Calculated Using the Type III MS for sample(batch*dryer) as an Error Term

batch	CI LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	H0:LSMean1= LSMean2 Pr > t
FRMP	1.53595817	0.02433360	<.0001	0.0188
RMP	1.62940506	0.02433360	<.0001	

Amino acid analysis for dried RMP and FRMP:

Class Level Information

Class	Levels	Values
sample	18	592 1124 2896 3020 3036 3625 3801 4082 4733 5338 5390 6450 6864 6919 7979 8084 8996 9640
batch	2	FRMP RMP
dryer	3	Pulse Roller Spray
Number of observations	18	

The GLM Procedure

Dependent Variable: Asparatic acid

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.32274537	0.06454907	8.66	0.0011
Error	12	0.08940610	0.00745051		
Corrected Total	17	0.41215148			

R-Square	Coeff Var	Root MSE	ASP Mean
0.783075	5.665782	0.086316	1.523467

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.28063238	0.28063238	37.67	<.0001
dryer	2	0.00225730	0.00112865	0.15	0.8610
batch*dryer	2	0.03985569	0.01992785	2.67	0.1095

Least Squares Means

Batch	ASP LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	H0:LSMean1= LSMean2 Pr > t
FRMP	1.64832987	0.02877211	<.0001	<.0001
RMP	1.39860452	0.02877211	<.0001	

Dependent Variable: Threonine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.12089801	0.02417960	12.39	0.0002
Error	12	0.02341616	0.00195135		
Corrected Total	17	0.14431417			
R-Square	Coeff Var	Root MSE	THR Mean		
0.837742	5.956241	0.044174	0.741643		

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.11367857	0.11367857	58.26	<.0001
dryer	2	0.00183623	0.00091812	0.47	0.6357
batch*dryer	2	0.00538321	0.00269160	1.38	0.2889

Least Squares Means

batch	THR LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	H0:LSMean1= LSMean2 Pr > t
FRMP	0.82111317	0.01472468	<.0001	<.0001
RMP	0.66217323	0.01472468	<.0001	

Dependent Variable: Serine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.22074836	0.04414967	17.82	<.0001
Error	12	0.02973276	0.00247773		
Corrected Total	17	0.25048112			

R-Square	Coeff Var	Root MSE	SER Mean
0.881297	6.879935	0.049777	0.723507

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.21516777	0.21516777	86.84	<.0001
dryer	2	0.00151124	0.00075562	0.30	0.7427
dryer*batch	2	0.00406936	0.00203468	0.82	0.4632

Least Squares Means

batch	SER LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	H0:LSMean1= LSMean2 Pr > t
FRMP	0.83284011	0.01659227	<.0001	<.0001
RMP	0.61417356	0.01659227	<.0001	

Dependent Variable: Glutamic acid

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3.29288583	0.65857717	22.40	<.0001
Error	12	0.35273240	0.02939437		
Corrected Total	17	3.64561822			

R-Square	Coeff Var	Root MSE	GLN Mean
0.903245	5.400570	0.171448	3.174625

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	3.20326478	3.20326478	108.98	<.0001
dryer	2	0.01909484	0.00954742	0.32	0.7288
batch*dryer	2	0.07052621	0.03526310	1.20	0.3350

Least Squares Means			Standard Error	H0:LSMEAN=0	H0:LSMean1=LSMean2
batch	GLN LSMEAN			Pr > t	Pr > t
FRMP	3.59647699		0.05714928	<.0001	<.0001
RMP	2.75277289		0.05714928	<.0001	

Dependent Variable: Proline

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.76901503	0.15380301	45.40	<.0001
Error	12	0.04065259	0.00338772		
Corrected Total	17	0.80966763			

R-Square	Coeff Var	Root MSE	PRO Mean
0.949791	4.622633	0.058204	1.259111

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.74857814	0.74857814	220.97	<.0001
dryer	2	0.01057961	0.00528981	1.56	0.2496
batch*dryer	2	0.00985728	0.00492864	1.45	0.2718

Least Squares Means			Standard Error	H0:LSMEAN=0	H0:LSMean1=LSMean2
batch	PRO LSMEAN			Pr > t	Pr > t
FRMP	1.46304179		0.01940136	<.0001	<.0001
RMP	1.05518067		0.01940136	<.0001	

Dependent Variable: DMGLY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.00997222	0.00199444	3.13	0.0488
Error	12	0.00764142	0.00063678		
Corrected Total	17	0.01761364			

R-Square	Coeff Var	Root MSE	GLY Mean
0.566165	5.293164	0.025235	0.476739

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.00730985	0.00730985	11.48	0.0054
dryer	2	0.00033808	0.00016904	0.27	0.7712
batch*dryer	2	0.00232429	0.00116214	1.83	0.2032

Least Squares Means			Standard Error	H0:LSMEAN=0 Pr > t	H0:LSMean1=LSMean2 Pr > t
batch	GLY LSMEAN				
FRMP	0.49689140		0.00841153	<.0001	0.0054
RMP	0.45658741		0.00841153	<.0001	

Dependent Variable: Alanine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.02460883	0.00492177	1.60	0.2331
Error	12	0.03687318	0.00307276		
Corrected Total	17	0.06148201			

R-Square	Coeff Var	Root MSE	ALA Mean
0.400261	7.163801	0.055433	0.773786

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.01557888	0.01557888	5.07	0.0439
dryer	2	0.00028318	0.00014159	0.05	0.9551
batch*dryer	2	0.00874677	0.00437338	1.42	0.2788

Least Squares Means			Standard Error	H0:LSMEAN=0 Pr > t	H0:LSMean1=LSMean2 Pr > t
batch	ALA LSMEAN				
FRMP	0.80320576		0.01847751	<.0001	0.0439
RMP	0.74436723		0.01847751	<.0001	

Dependent Variable: Cystine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.01745285	0.00349057	5.44	0.0076
Error	12	0.00769732	0.00064144		
Corrected Total	17	0.02515017			

R-Square	Coeff Var	Root MSE	CYS Mean
0.693945	13.89617	0.025327	0.182257

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.01434409	0.01434409	22.36	0.0005
dryer	2	0.00199312	0.00099656	1.55	0.2512
batch*dryer	2	0.00111564	0.00055782	0.87	0.4439

Least Squares Means			H0:LSMean1=LSMean2	
batch	CYS LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	Pr > t
FRMP	0.21048622	0.00844225	<.0001	0.0005
RMP	0.15402760	0.00844225	<.0001	

Dependent Variable: Valine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.34814966	0.06962993	13.66	0.0001
Error	12	0.06118350	0.00509862		
Corrected Total	17	0.40933316			

R-Square	Coeff Var	Root MSE	DMVAL Mean
0.850529	6.369814	0.071405	1.120985

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.31365306	0.31365306	61.52	<.0001
dryer	2	0.00804246	0.00402123	0.79	0.4766
batch*dryer	2	0.02645414	0.01322707	2.59	0.1158

Least Squares Means			H0:LSMean1=LSMean2	
batch	DMVAL LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	Pr > t
FRMP	1.25298932	0.02380155	<.0001	<.0001
RMP	0.98898046	0.02380155	<.0001	

Dependent Variable: Methionine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.03928521	0.00785704	4.61	0.0141
Error	12	0.02046689	0.00170557		
Corrected Total	17	0.05975211			

R-Square	Coeff Var	Root MSE	MET Mean
0.657470	10.91835	0.041299	0.378250

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.02335303	0.02335303	13.69	0.0030
dryer	2	0.00401930	0.00200965	1.18	0.3410
batch*dryer	2	0.01191289	0.00595644	3.49	0.0638

Least Squares Means			H0:LSMean1=LSMean2	
batch	MET LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	Pr > t
FRMP	0.41426892	0.01376620	<.0001	0.0030
RMP	0.34223031	0.01376620	<.0001	

Dependent Variable: Isoleucine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.16998431	0.03399686	16.85	<.0001
Error	12	0.02421475	0.00201790		
Corrected Total	17	0.19419906			

R-Square	Coeff Var	Root MSE	ILE Mean
0.875310	5.338961	0.044921	0.841381

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.16210458	0.16210458	80.33	<.0001
dryer	2	0.00111093	0.00055547	0.28	0.7640
batch*dryer	2	0.00676879	0.00338440	1.68	0.2279

Least Squares Means			H0:LSMean1=LSMean2	
batch	ILE LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	Pr > t
FRMP	0.93627986	0.01497367	<.0001	<.0001
RMP	0.74648197	0.01497367	<.0001	

Dependent Variable: Leucine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.64168983	0.12833797	34.03	<.0001
Error	12	0.04525936	0.00377161		
Corrected Total	17	0.68694919			

R-Square	Coeff Var	Root MSE	LEU Mean
0.934115	4.056252	0.061413	1.514045

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.62742463	0.62742463	166.35	<.0001
dryer	2	0.00304250	0.00152125	0.40	0.6768
batch*dryer	2	0.01122270	0.00561135	1.49	0.2647

Least Squares Means			H0:LSMean1=LSMean2	
batch	LEU LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	Pr > t
FRMP	1.70074463	0.02047115	<.0001	<.0001
RMP	1.32734445	0.02047115	<.0001	

Dependent Variable: Tyrosine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.12780796	0.02556159	24.78	<.0001
Error	12	0.01237749	0.00103146		
Corrected Total	17	0.14018545			

R-Square	Coeff Var	Root MSE	TYR Mean
0.911706	4.769682	0.032116	0.673343

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.12466027	0.12466027	120.86	<.0001
dryer	2	0.00062136	0.00031068	0.30	0.7454
batch*dryer	2	0.00252634	0.00126317	1.22	0.3281

Least Squares Means			H0:LSMean1=LSMean2	
batch	TYR LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	Pr > t
FRMP	0.75656290	0.01070544	<.0001	<.0001
RMP	0.59012287	0.01070544	<.0001	

Dependent Variable: Phenylalanine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.12392736	0.02478547	7.13	0.0026
Error	12	0.04171661	0.00347638		
Corrected Total	17	0.16564396			

R-Square	Coeff Var	Root MSE	PHE Mean
0.748155	7.532037	0.058961	0.782801

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.09152362	0.09152362	26.33	0.0002
dryer	2	0.00511998	0.00255999	0.74	0.4993
batch*dryer	2	0.02728376	0.01364188	3.92	0.0488

Least Squares Means

batch	dryer	PHE LSMEAN	Standard Error	LSMEAN Pr > t	Number
FRMP	Pulse	0.82409186	0.03404107	<.0001	1
FRMP	Roller	0.87664801	0.03404107	<.0001	2
FRMP	Spray	0.86158360	0.03404107	<.0001	3
RMP	Pulse	0.78823742	0.03404107	<.0001	4
RMP	Roller	0.65727822	0.03404107	<.0001	5
RMP	Spray	0.68896763	0.03404107	<.0001	6

Least Squares Means for effect batch*dryer

Pr > |t| for H0: LSMean(i)=LSMean(j)

i/j	1	2	3	4	5	6
1		0.2964	0.4512	0.4707	0.0047	0.0158
2	0.2964		0.7597	0.0912	0.0007	0.0021
3	0.4512	0.7597		0.1535	0.0011	0.0037
4	0.4707	0.0912	0.1535		0.0186	0.0615
5	0.0047	0.0007	0.0011	0.0186		0.5228
6	0.0158	0.0021	0.0037	0.0615	0.5228	

Dependent Variable: Histidine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.02923685	0.00584737	5.02	0.0103
Error	12	0.01398345	0.00116529		
Corrected Total	17	0.04322030			

R-Square	Coeff Var	Root MSE	HIS Mean
0.676461	9.745197	0.034136	0.350289

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.02530801	0.02530801	21.72	0.0006
dryer	2	0.00293748	0.00146874	1.26	0.3185
batch*dryer	2	0.00099135	0.00049568	0.43	0.6630

Least Squares Means H0:LSMean1=

batch	DMHIS LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	LSMean2 Pr > t
FRMP	0.38778526	0.01137877	<.0001	0.0006
RMP	0.31279191	0.01137877	<.0001	

Dependent Variable: Lysine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.02277418	0.00455484	4.05	0.0219
Error	12	0.01348467	0.00112372		
Corrected Total	17	0.03625885			

R-Square	Coeff Var	Root MSE	DMLYS Mean
0.628100	5.901146	0.033522	0.568059

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.00147940	0.00147940	1.32	0.2736
dryer	2	0.01253612	0.00626806	5.58	0.0194
batch*dryer	2	0.00875865	0.00437933	3.90	0.0496

Least Squares Means

batch	dryer	LYS LSMEAN	Standard Error	LSMEAN Pr > t	Number
FRMP	Pulse	0.64220679	0.01935392	<.0001	1
FRMP	Roller	0.55688205	0.01935392	<.0001	2
FRMP	Spray	0.53228488	0.01935392	<.0001	3
RMP	Pulse	0.56855393	0.01935392	<.0001	4
RMP	Roller	0.54186160	0.01935392	<.0001	5
RMP	Spray	0.56656334	0.01935392	<.0001	6

Least Squares Means for effect batch*dryer
Pr > |t| for H0: LSMean(i)=LSMean(j)

i/j	1	2	3	4	5	6
1		0.0089	0.0017	0.0196	0.0032	0.0172
2	0.0089		0.3865	0.6773	0.5932	0.7297
3	0.0017	0.3865		0.2098	0.7325	0.2343
4	0.0196	0.6773	0.2098		0.3487	0.9432
5	0.0032	0.5932	0.7325	0.3487		0.3846
6	0.0172	0.7297	0.2343	0.9432	0.3846	

Dependent Variable: Arginine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.07323298	0.01464660	16.41	<.0001
Error	12	0.01071266	0.00089272		
Corrected Total	17	0.08394564			

R-Square	Coeff Var	Root MSE	ARG Mean
0.872386	8.677568	0.029878	0.344318

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.05880300	0.05880300	65.87	<.0001
dryer	2	0.00521814	0.00260907	2.92	0.0925
batch*dryer	2	0.00921184	0.00460592	5.16	0.0242

Least Squares Means

batch	dryer	DMARG	LSMEAN	Standard Error	LSMEAN Pr > t	Number
FRMP	Pulse	0.44429246		0.01725033	<.0001	1
FRMP	Roller	0.34897330		0.01725033	<.0001	2
FRMP	Spray	0.41115762		0.01725033	<.0001	3
RMP	Pulse	0.27811465		0.01725033	<.0001	4
RMP	Roller	0.29304506		0.01725033	<.0001	5
RMP	Spray	0.29032635		0.01725033	<.0001	6

Least Squares Means for effect batch*dryer
Pr > |t| for H0: LSMean(i)=LSMean(j)

i/j	1	2	3	4	5	6
1		0.0021	0.1994	<.0001	<.0001	<.0001
2	0.0021		0.0255	0.0132	0.0407	0.0333
3	0.1994	0.0255		0.0001	0.0004	0.0003
4	<.0001	0.0132	0.0001		0.5520	0.6257
5	<.0001	0.0407	0.0004	0.5520		0.9131
6	<.0001	0.0333	0.0003	0.6257	0.9131	

Dependent Variable: Tryptophan

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.01376521	0.00275304	5.19	0.0091
Error	12	0.00636593	0.00053049		
Corrected Total	17	0.02013114			

R-Square	Coeff Var	Root MSE	TRP Mean
0.683777	10.99874	0.023032	0.209410

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.01057095	0.01057095	19.93	0.0008
dryer	2	0.00122226	0.00061113	1.15	0.3486
batch*dryer	2	0.00197200	0.00098600	1.86	0.1981

Least Squares Means

batch	TRP LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	H0:LSMean1= LSMean2 Pr > t
FRMP	0.23364382	0.00767749	<.0001	0.0008
RMP	0.18517631	0.00767749	<.0001	

Dependent Variable: Available lysine

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.06771491	0.01354298	11.59	0.0003
Error	12	0.01402593	0.00116883		
Corrected Total	17	0.08174084			

R-Square	Coeff Var	Root MSE	ALYS Mean
0.828410	26.35906	0.034188	0.129702

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	0.00393808	0.00393808	3.37	0.0913
dryer	2	0.05927176	0.02963588	25.36	<.0001
batch*dryer	2	0.00450506	0.00225253	1.93	0.1880

Least Squares Means

dryer	ALYS LSMEAN	Standard Error	LSMEAN Pr > t	Number
Pulse	0.18431954	0.01395724	<.0001	1
Roller	0.05041210	0.01395724	0.0036	2
Spray	0.15437307	0.01395724	<.0001	3

Least Squares Means for effect dryer
 Pr > |t| for H0: LSMean(i)=LSMean(j)

i/j	1	2	3
1		<.0001	0.1551
2	<.0001		0.0002
3	0.1551	0.0002	

Dependent Variable: Total amino acids

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	58.34415781	11.66883156	18.71	<.0001
Error	12	7.48405480	0.62367123		
Corrected Total	17	65.82821261			

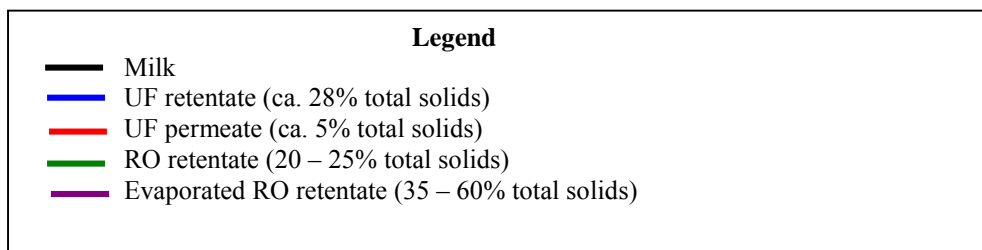
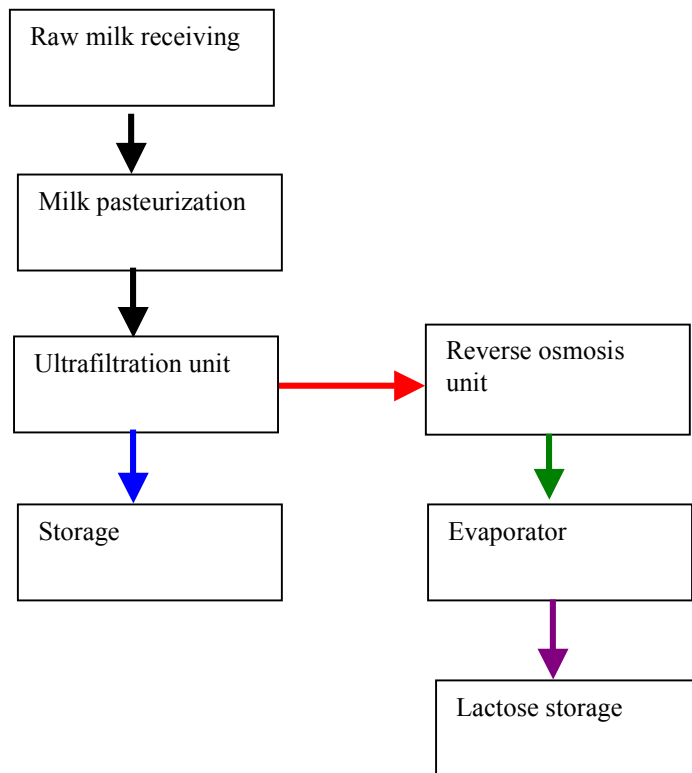
R-Square	Coeff Var	Root MSE	Total AA Mean
0.886309	4.951581	0.789729	15.94902

Source	DF	Type III SS	Mean Square	F Value	Pr > F
batch	1	56.55998624	56.55998624	90.69	<.0001
dryer	2	0.14521363	0.07260682	0.12	0.8911
batch*dryer	2	1.63895794	0.81947897	1.31	0.3048

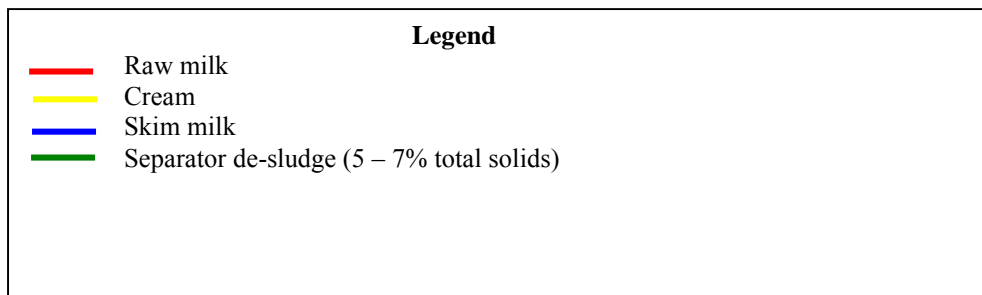
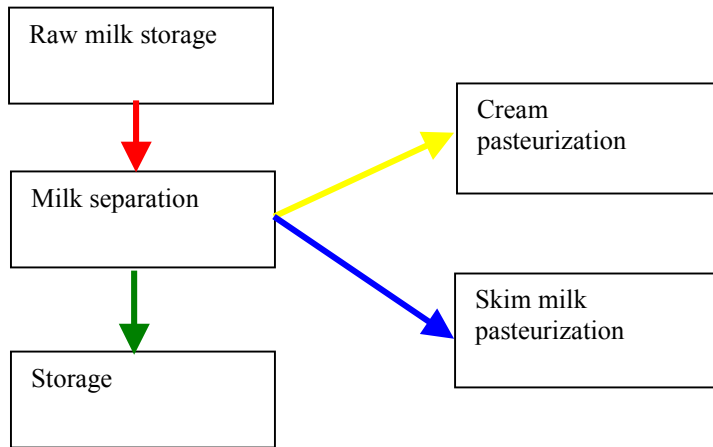
Least Squares Means

batch	Total AA LSMEAN	Standard Error	H0:LSMEAN=0 Pr > t	H0:LSMean1=LSMean2 Pr > t
FRMP	17.7216511	0.2632429	<.0001	<.0001
RMP	14.1763887	0.2632429	<.0001	

Flow diagram for de-proteinized milk solids:



Flow diagram for separator de-sludge:





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Pulse Drying Test Report

April 26, 2001

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 1184 Ave. 120
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 USA
 Tel 559-752-5210
 Fax 559-752-5201

Test Results for RMP-rmp 1124, Run Number 115-6-1

Percent Solids in Feed(Brix) 37%

System Setpoints

Contact Temperature **709 F (376.1 C)**
 Chamber Exit Temperature **199 F (92.8 C)**
 Cyclone Temperature **186 F (85.6 C)**
 Pump Used **Peristaltic**

Dryer Data

Feed Pressure **1PSI**
 Overall Performance **Excellent**
 Collection Efficiency (Cyclone Recovery) **34%**
 Collection Efficiency (Total System) **85%**
 System Losses **15%**
 Thermal Efficiency **N/A: Runtime < 1 Hr.**
 Problems **Chamber Wall Sticking
 Rewetting**

Powder Characteristics

Tapped Bulk Density **n/a g/cc**
 Untapped Bulk Density **n/a g/cc**
 Percent Moisture **3.80%**
 Flowability **Med**
 Flavor Retention
 Color Retention **Excellent**
 Off-flavor or Scorching
 Browning **No**

Notes:
this run produced moderate chamber wall sticking, which would not blow down completely. Over all this was a very productive run.



Pulse Combustion Systems LLC
 135 Eye Street, Suite B
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 Tel 415.457.6500
 Fax 208.723.3727

Pulse Drying Test Report

April 26, 2001

California Dairies, Inc.
 Ron Thompson
 1184 Ave. 120
 Tipton CA 93274
 USA
 Tel 559-752-5210
 Fax 559-752-5201

Test Results for RMP-3036, Run Number 115-7-1

Percent Solids in Feed(Brix) **37%**

System Setpoints

Contact Temperature **703 F (372.8 C)**
 Chamber Exit Temperature **218 F (103.3 C)**
 Cyclone Temperature **209 F (98.3 C)**
 Pump Used **Peristaltic**

Dryer Data

Feed Pressure **1PSI**
 Overall Performance **Excellent**
 Collection Efficiency (Cyclone Recovery) **50%**
 Collection Efficiency (Total System) **85%**
 System Losses **15%**
 Thermal Efficiency **N/A: Runtime < 1 Hr.**
 Problems **Chamber Wall Sticking**

Powder Characteristics

Tapped Bulk Density **n/a g/cc**
 Untapped Bulk Density **n/a g/cc**
 Percent Moisture **2.96%**
 Flowability **High**
 Flavor Retention
 Color Retention **Excellent**
 Off-flavor or Scorching
 Browning **No**

Notes:
This run yielded some chamber wall sticking, that blew down well, with only a small amount remaining on the wall. The rest of the run looked good.



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Test Results for RMP-7979, Run Number 115-8-1

Percent Solids in Feed(Brix) 37%

System Setpoints

Contact Temperature 705 F (373.9 C)
 Chamber Exit Temperature 218 F (103.3 C)
 Cyclone Temperature 209 F (98.3 C)
 Pump Used Peristaltic

Powder Characteristics

Tapped Bulk Density n/a g/cc
 Untapped Bulk Density n/a g/cc
 Percent Moisture 3.50%
 Flowability High
 Flavor Retention
 Color Retention Excellent
 Off-flavor or Scorching
 Browning No

Dryer Data

Feed Pressure 2PSI
 Overall Performance
 Collection Efficiency (Cyclone Recovery) . . . 11%
 Collection Efficiency (Total System) 86%
 System Losses 14%
 Thermal Efficiency N/A: Runtime < 1 Hr.
 Problems Chamber Wall Sticking
 Rewetting

Notes:
This run was mostly blow down material. The capture efficiency was not reel good due to the chamber wall hang-up. Still, this is not a big concern because a production dryer will have air sweeps.



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Test Results for RMP-8996, Run Number 115-10-1

Percent Solids in Feed(Brix) 37%

System Setpoints

Contact Temperature F (C)
 Chamber Exit Temperature F (C)
 Cyclone Temperature F (C)
 Pump Used Peristaltic

Dryer Data

Feed Pressure 1PSI
 Overall Performance Excellent
 Collection Efficiency (Cyclone Recovery) ... 36%
 Collection Efficiency (Total System) 92%
 System Losses 8%
 Thermal Efficiency N/A: Runtime < 1 Hr.
 Problems Chamber Wall Sticking
 Rewetting

Powder Characteristics

Tapped Bulk Density n/a g/cc
 Untapped Bulk Density n/a g/cc
 Percent Moisture 3.60%
 Flowability High
 Flavor Retention
 Color Retention Excellent
 Off-flavor or Scorching No
 Browning No

Notes:
 This was the last run of this product and yielded roughly the same results as the previous runs.

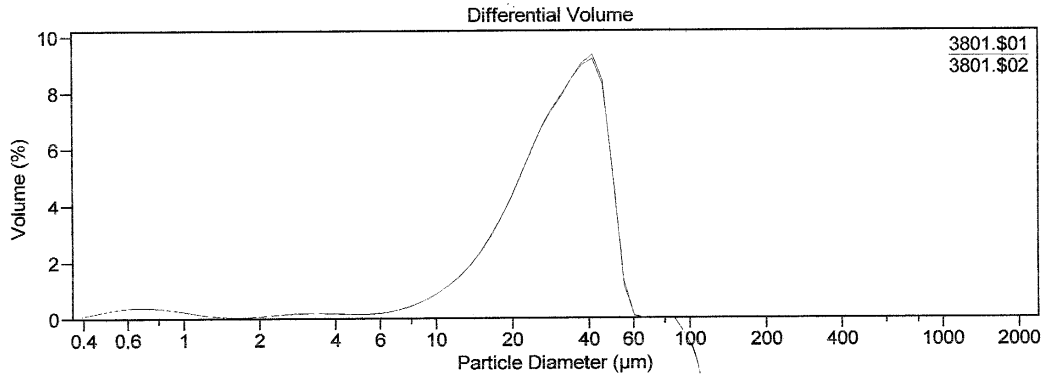
APPENDIX D: COULTER PARTICLE SIZE ANALYZER REPORTS



LS Particle Size Analyzer

22 Aug 2001

D.P.T.C.



Volume Statistics (Arithmetic) 3801.\$01

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	29.26 µm	S.D.:	12.84 µm
Median:	29.78 µm	C.V.:	43.9%
D(1,0):	0.605 µm		
Mode:	41.67 µm		

% <	10	25	50	75	90
Size µm	12.18	20.36	29.78	39.30	45.92

Volume Statistics (Arithmetic) 3801.\$02

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	29.31 µm	S.D.:	12.83 µm
Median:	29.77 µm	C.V.:	43.8%
D(1,0):	0.606 µm		
Mode:	41.67 µm		

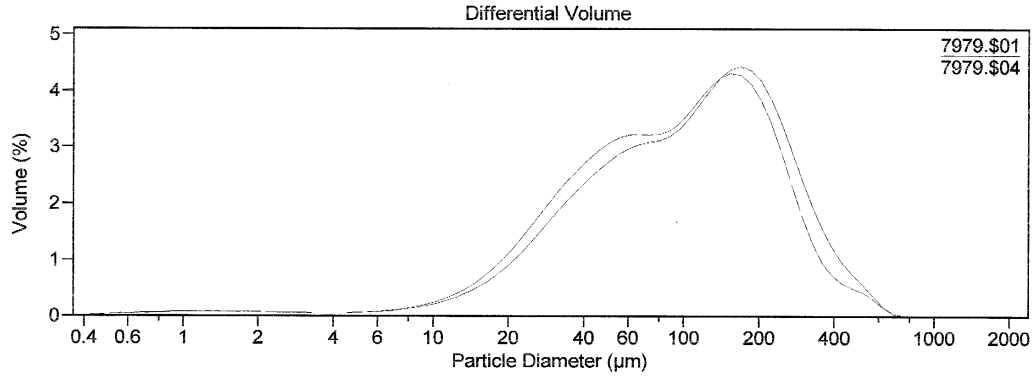
% <	10	25	50	75	90
Size µm	12.34	20.39	29.77	39.28	46.02



LS Particle Size Analyzer

D.P.T.C.

22 Aug 2001



Volume Statistics (Arithmetic) 7979.\$01

Calculations from 0.375 µm to 2,000 µm

Volume 100.0%
 Mean: 136.6 µm S.D.: 108.8 µm
 Median: 109.9 µm C.V.: 79.7%
 D(1,0): 0.744 µm
 Mode: 168.8 µm

% <	10	25	50	75	90
Size µm	27.87	52.15	109.9	191.8	282.3

Volume Statistics (Arithmetic) 7979.\$04

Calculations from 0.375 µm to 2,000 µm

Volume 100.0%
 Mean: 121.4 µm S.D.: 99.84 µm
 Median: 95.16 µm C.V.: 82.2%
 D(1,0): 0.743 µm
 Mode: 153.8 µm

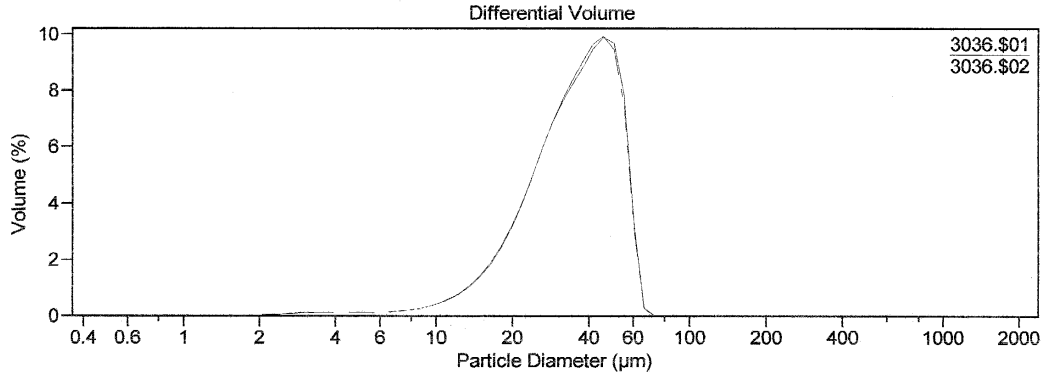
% <	10	25	50	75	90
Size µm	25.21	45.81	95.16	170.8	249.7



LS Particle Size Analyzer

22 Aug 2001

D.P.T.C.



Volume Statistics (Arithmetic) 3036.\$01

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	35.85 µm	S.D.:	13.16 µm
Median:	35.91 µm	C.V.:	36.7%
D(1,0):	6.368 µm		
Mode:	45.75 µm		

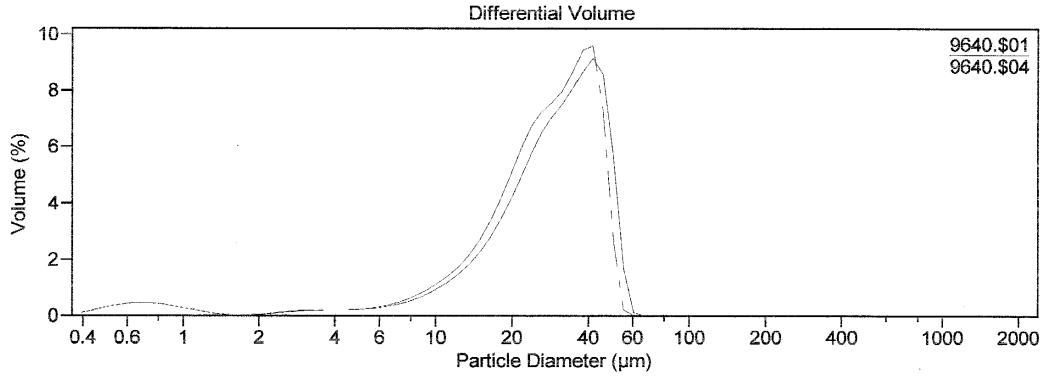
% <	10	25	50	75	90
Size µm	18.47	26.04	35.91	46.19	53.48

Volume Statistics (Arithmetic) 3036.\$02

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	35.68 µm	S.D.:	13.05 µm
Median:	35.77 µm	C.V.:	36.6%
D(1,0):	6.874 µm		
Mode:	45.75 µm		

% <	10	25	50	75	90
Size µm	18.39	25.96	35.77	45.85	53.12



Volume Statistics (Arithmetic) 9640.\$01

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	29.30 µm	S.D.:	13.36 µm
Median:	29.80 µm	C.V.:	45.6%
D(1,0):	0.603 µm		
Mode:	41.67 µm		

% <	10	25	50	75	90
Size µm	11.20	19.99	29.80	39.82	46.63

Volume Statistics (Arithmetic) 9640.\$04

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	28.59 µm	S.D.:	11.42 µm
Median:	28.56 µm	C.V.:	39.9%
D(1,0):	5.547 µm		
Mode:	41.67 µm		

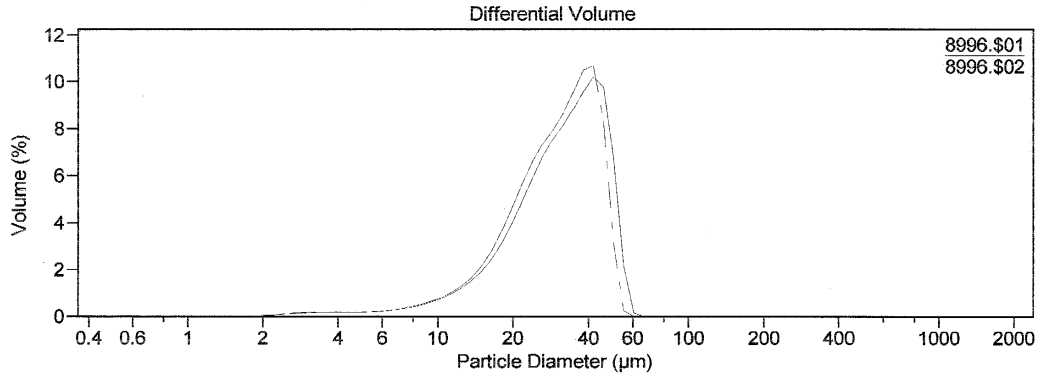
% <	10	25	50	75	90
Size µm	13.24	20.01	28.56	37.80	43.75



LS Particle Size Analyzer

22 Aug 2001

D.P.T.C.



Volume Statistics (Arithmetic) 8996.\$01

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	31.78 µm	S.D.:	12.05 µm
Median:	32.06 µm	C.V.:	37.9%
D(1,0):	5.565 µm		
Mode:	41.67 µm		

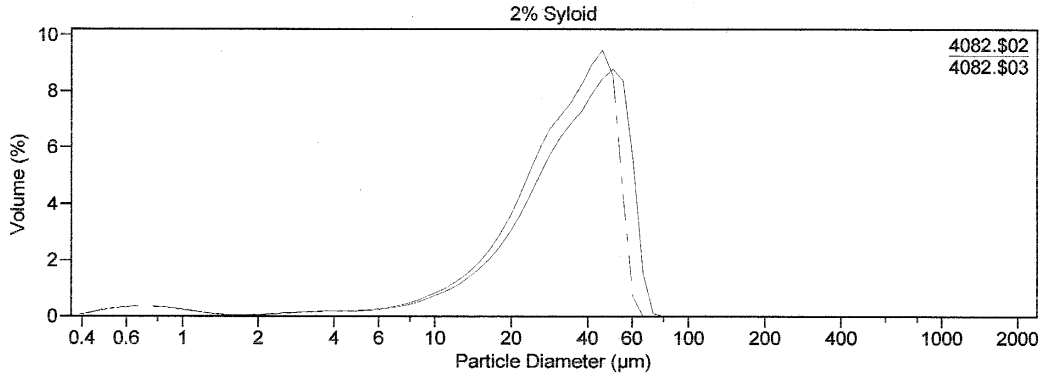
% <	10	25	50	75	90
Size µm	15.62	22.97	32.06	41.30	47.51

Volume Statistics (Arithmetic) 8996.\$02

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	30.04 µm	S.D.:	11.09 µm
Median:	30.40 µm	C.V.:	36.9%
D(1,0):	5.584 µm		
Mode:	41.67 µm		

% <	10	25	50	75	90
Size µm	15.18	21.90	30.40	38.89	44.53



Volume Statistics (Arithmetic) 4082.\$02

Calculations from 0.375 µm to 2,000 µm

Volume 100.0%
 Mean: 34.89 µm S.D.: 15.98 µm
 Median: 35.23 µm C.V.: 45.8%
 D(1,0): 0.611 µm
 Mode: 50.23 µm

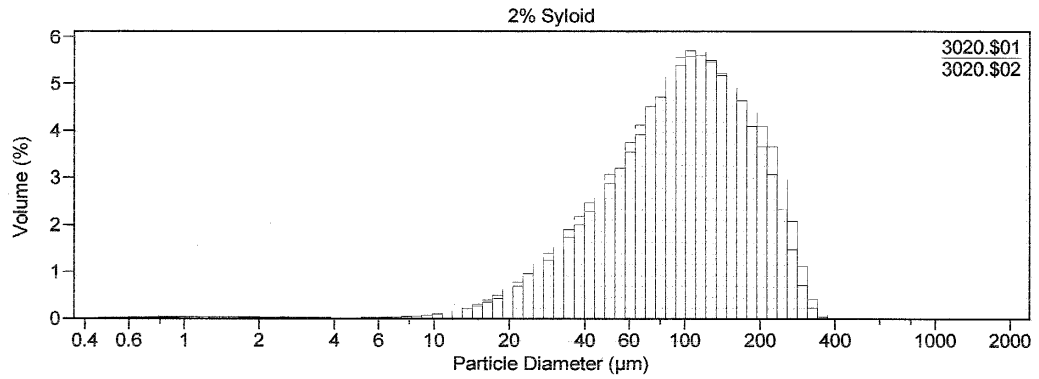
% <	10	25	50	75	90
Size µm	13.34	23.37	35.23	47.53	55.97

Volume Statistics (Arithmetic) 4082.\$03

Calculations from 0.375 µm to 2,000 µm

Volume 100.0%
 Mean: 31.57 µm S.D.: 14.08 µm
 Median: 32.11 µm C.V.: 44.6%
 D(1,0): 0.611 µm
 Mode: 45.75 µm

% <	10	25	50	75	90
Size µm	12.43	21.71	32.11	42.79	49.89



Volume Statistics (Arithmetic) 3020.\$01

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	114.4 µm	S.D.:	67.94 µm
Median:	101.5 µm	C.V.:	59.4%
D(1,0):	0.738 µm		
Mode:	116.3 µm		

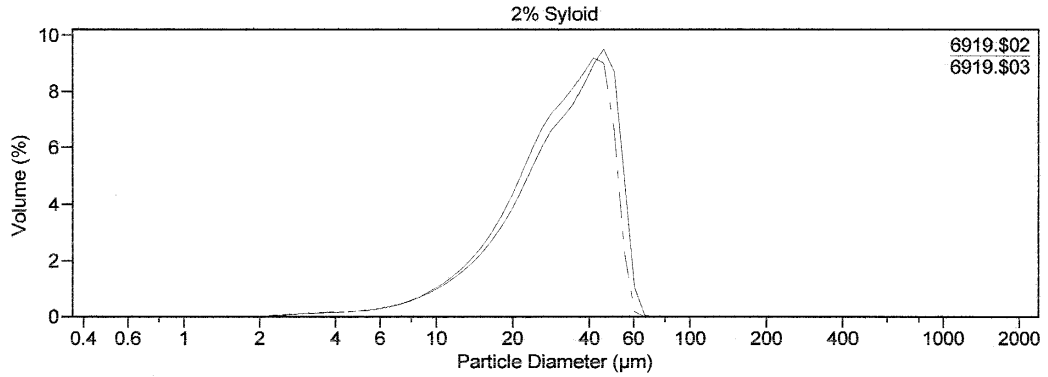
% <	10	25	50	75	90
Size µm	36.42	61.24	101.5	156.6	214.9

Volume Statistics (Arithmetic) 3020.\$02

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	107.7 µm	S.D.:	64.08 µm
Median:	96.04 µm	C.V.:	59.5%
D(1,0):	0.734 µm		
Mode:	105.9 µm		

% <	10	25	50	75	90
Size µm	34.32	57.80	96.04	146.3	201.8



Volume Statistics (Arithmetic) 6919.\$02

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	32.49 µm	S.D.:	13.37 µm
Median:	32.52 µm	C.V.:	41.2%
D(1,0):	6.708 µm		
Mode:	45.75 µm		

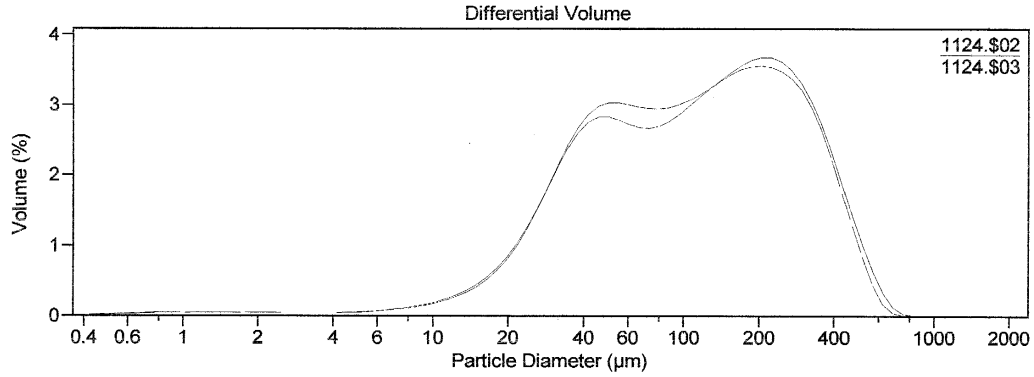
% <	10	25	50	75	90
Size µm	14.31	22.20	32.52	43.29	50.45

Volume Statistics (Arithmetic) 6919.\$03

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	30.80 µm	S.D.:	12.43 µm
Median:	30.70 µm	C.V.:	40.3%
D(1,0):	7.264 µm		
Mode:	41.67 µm		

% <	10	25	50	75	90
Size µm	14.03	21.31	30.70	40.73	47.49



Volume Statistics (Arithmetic) 1124.\$02

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	155.0 µm	S.D.:	129.6 µm
Median:	116.2 µm	C.V.:	83.6%
D(1,0):	0.748 µm		
Mode:	203.5 µm		

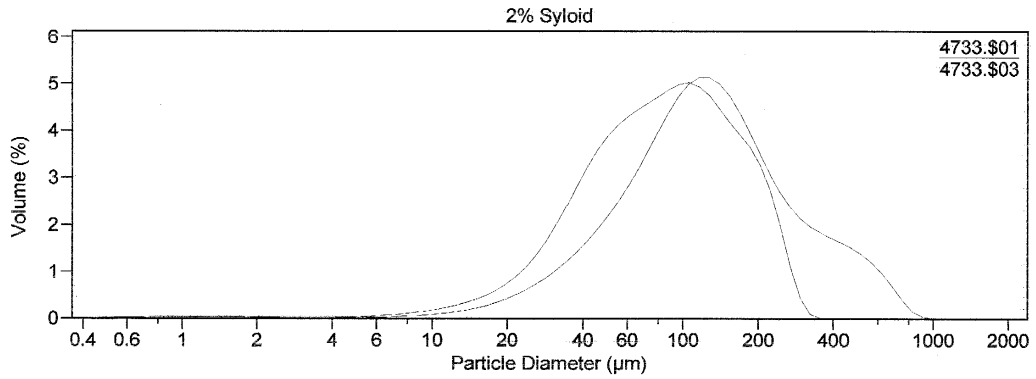
% <	10	25	50	75	90
Size µm	28.73	50.32	116.2	227.5	344.9

Volume Statistics (Arithmetic) 1124.\$03

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	148.8 µm	S.D.:	123.3 µm
Median:	109.6 µm	C.V.:	82.9%
D(1,0):	0.761 µm		
Mode:	203.5 µm		

% <	10	25	50	75	90
Size µm	29.42	50.26	109.6	218.2	332.7



Volume Statistics (Arithmetic) 4733.\$01

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	98.74 µm	S.D.:	62.44 µm
Median:	84.57 µm	C.V.:	63.2%
D(1,0):	0.737 µm		
Mode:	105.9 µm		

% <	10	25	50	75	90
Size µm	30.87	49.73	84.57	136.1	192.3

Volume Statistics (Arithmetic) 4733.\$03

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	166.8 µm	S.D.:	141.6 µm
Median:	122.5 µm	C.V.:	84.9%
D(1,0):	0.774 µm		
Mode:	127.6 µm		

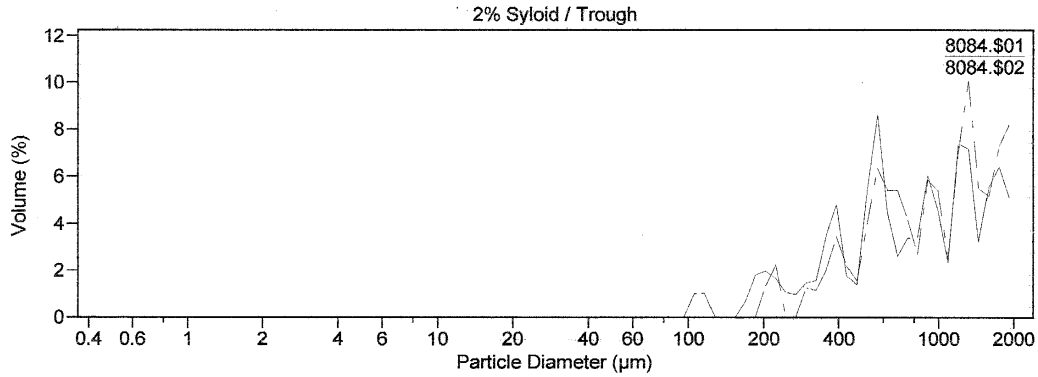
% <	10	25	50	75	90
Size µm	42.91	73.62	122.5	205.6	365.7



LS Particle Size Analyzer

22 Aug 2001

D.P.T.C.



Volume Statistics (Arithmetic) 8084.\$01

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	900.3 µm	S.D.:	515.3 µm
Median:	812.2 µm	C.V.:	57.2%
D(1,0):	197.5 µm		
Mode:	567.8 µm		

% <	10	25	50	75	90
Size µm	280.6	498.2	812.2	1,296	1,698

Volume Statistics (Arithmetic) 8084.\$02

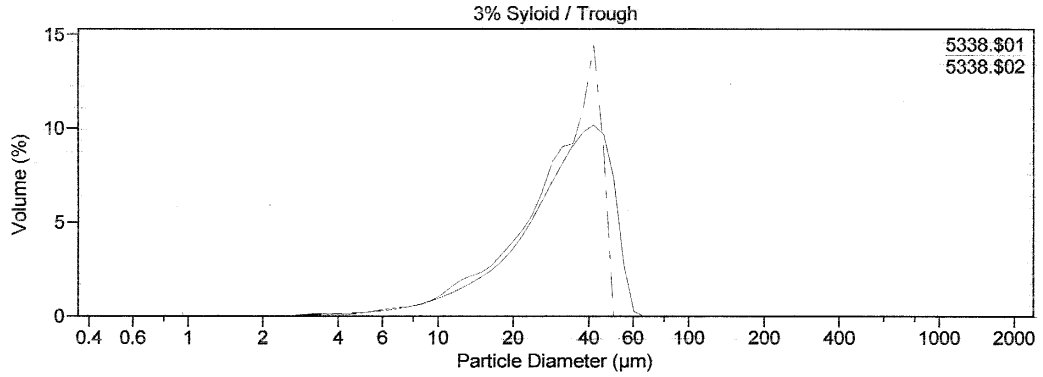
Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	1,027 µm	S.D.:	501.9 µm
Median:	967.0 µm	C.V.:	48.9%
D(1,0):	363.0 µm		
Mode:	1,315 µm		

% <	10	25	50	75	90
Size µm	394.6	591.2	967.0	1,404	1,782



D.P.T.C.



Volume Statistics (Arithmetic) 5338.\$01

Calculations from 0.375 µm to 2,000 µm

Volume:	100.0%			
Mean:	32.08 µm	S.D.:	12.32 µm	
Median:	32.65 µm	C.V.:	38.4%	
D(1,0):	8.633 µm			
Mode:	41.67 µm			

% <	10	25	50	75	90
Size µm	14.78	22.99	32.65	41.74	48.12

Volume Statistics (Arithmetic) 5338.\$02

Calculations from 0.375 µm to 2,000 µm

Volume:	100.0%			
Mean:	29.86 µm	S.D.:	10.84 µm	
Median:	30.89 µm	C.V.:	36.3%	
D(1,0):	8.743 µm			
Mode:	41.67 µm			

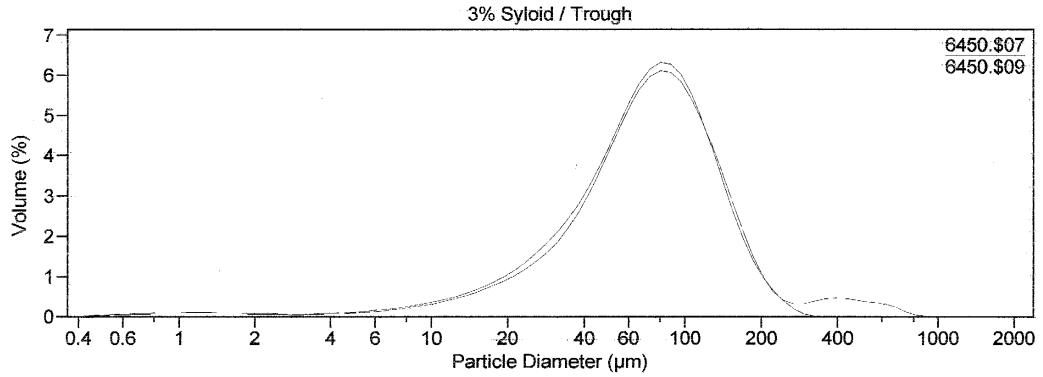
% <	10	25	50	75	90
Size µm	13.96	21.72	30.89	39.21	43.34



LS Particle Size Analyzer

D.P.T.C.

22 Aug 2001



Volume Statistics (Arithmetic) 6450.\$07

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	77.67 µm	S.D.:	46.94 µm
Median:	70.95 µm	C.V.:	60.4%
D(1,0):	0.729 µm		
Mode:	80.08 µm		

% <	10	25	50	75	90
Size µm	23.23	43.70	70.95	103.6	140.3

Volume Statistics (Arithmetic) 6450.\$09

Calculations from 0.375 µm to 2,000 µm

Volume	100.0%		
Mean:	94.41 µm	S.D.:	89.62 µm
Median:	75.01 µm	C.V.:	94.9%
D(1,0):	0.735 µm		
Mode:	80.08 µm		

% <	10	25	50	75	90
Size µm	25.91	47.19	75.01	111.7	159.8

VITA

Ronald I. Thompson was born in Fortuna, California on June 2, 1966. After graduating from Big Valley High School, Bieber, California in 1984 he entered California Polytechnic State University, San Luis Obispo, in September 1984. He graduated with a bachelor of science degree in dairy science with a concentration in dairy products technology in December of 1988.

In July of 1989, Ronald entered the master's program in dairy science at Louisiana State University. He began working as a research associate in charge of the creamery and dairy store operations while completing his master's degree under the guidance of Dr. John U. McGregor in the department of dairy science.

In November of 1992, Ronald accepted the position of Quality Assurance Manager with California Milk Producers in Artesia, California.

In January of 1997, Ronald entered the Doctor of Philosophy program in dairy science at Louisiana State University under the guidance of Dr. John U. McGregor while remaining employed by California Milk Producers. In May of 1999, Ronald was promoted to Vice President of Quality Assurance for California Milk Producers. In August of 1999 California Milk Producers merged with two other cooperatives in California to form California Dairies, Inc. At that time Ronald was promoted to Vice President of Regulatory and Quality Assurance for California Dairies, Inc.

Ronald lives in Tulare, California with his wife, Maricruz, and their two children, Eric and Jacqueline.