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FREEZE CONCENTRATION OF DAIRY PRODUCTS PHASE 2

RP2782- 02

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and used to formulate products such as ice cream, cream cheese, milk chocolate and other products for consumer evaluation. Freeze-concentrated skim milk powder was reconstituted and compared against fresh skim milk as well as skim milk reconstituted from commercial liquid concentrate and nonfat dry milk powder for organoleptic quality and consumer acceptability.

RESULTS The Niro PDU was successfully installed at Galloway West and brought up to 3-A processing standards. The GRAS status of freeze-concentrated milk ingredients was affirmed by an expert safety panel. The semi-commercial unit was used to freeze concentrate skim milk and whey protein concentrate. Continuous runs of up to 510-hours were achieved. Projected energy costs are higher for freeze concentration than they are for other concentration technologies currently in use by the dairy industry. However, a full evaluation of the operating, cleaning and energy utilization costs that differentiate freeze concentration from other evaporation technologies indicate that commercial-scale freeze concentration should be more economical than current evaporation technologies. This is due primarily to the lower product losses incurred with freeze concentration. Consumer evaluations documented that the functional and organoleptic properties of freeze-concentrated skim milk are as good as or better than those of fresh skim milk, current skim milk concentrates or nonfat dry milk powders. The semi-commercial scale production undertaken on the PDU did encounter problems with inconsistent product quality (primarily involving product oxidation) but these were not considered to be serious obstacles to commercial-scale production. The results suggest that, once commercialized, freeze-concentrated milk powders and concentrates should fill significant added-value market niches in both domestic and international markets.

ABSTRACT

The primary objective of Phase II of the investigation into the freeze concentration of dairy streams was to establish the commercial feasibility of freeze concentration on a semi-commercial scale. A Niro Process Development Unit (PDU) was installed, brought to 3A sanitation standards, and used to freeze-concentrate skim milk and whey protein concentrate in semi-commercial quantities. It was determined that freeze concentration should prove to be highly competitive against Thermal Vapor Recompression (TVR) and Mechanical Vapor Recompression (MVR) concentration technologies currently in use by the dairy industry even though freeze concentration is ultimately more energy intensive. The economic savings that accrue from freeze concentration are the result of both the long (30-day) periods during which freeze concentration can be operated continuously and the insignificant product losses associated with freeze concentration compared to those incurred by MVR and TVR. Operating costs for freeze concentration are highly elastic to electrical energy costs. Opportunities for obtaining incremental operating efficiencies were identified and quantified. Ice crystallization patterns that were observed during the freeze concentration of milk followed a sinusoidal pattern not found in the freeze concentration of other food substances, although the impact of this discovery upon production efficiencies remains to be elucidated. An expert panel concluded that freeze-concentrated milk product should be Generally Recognized As Safe (GRAS) by the Food and Drug Administration. Evaluations by expert and consumer sensory panels confirmed that the organoleptic quality of freeze-concentrated milk met the quality of fresh skim milk and exceeded those of conventionally concentrated and powdered skim milks when reconstituted as a beverage or when used as an ingredient in the development of cream cheese, frozen dessert, sour cream, salad dressings, whipped toppings and other products. The organoleptic and functional qualities of freeze-concentrated milk products indicate that such products should open up considerable domestic and export market opportunities for the dairy industry.

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EXECUTIVE SUMMARY

Freeze concentration is a process for removing water from food systems by crystallizing the water as ice and subsequently removing the ice crystals from the food system. Initial calculations indicated that the removal of water from foods by crystallization should be more energy efficient than its removal by evaporation. In addition, freeze concentration offers the advantage of minimizing the heat-abuse of sensitive milk components (such as proteins and flavors) and consequently an opportunity for producing dairy ingredients with enhanced functional and organoleptic qualities. Freeze concentration is already used commercially for concentrating juice, beer and coffee products.

The feasibility of freeze-concentrating milk was demonstrated on a pilot-plant scale during Phase I of a project undertaken by a consortium comprised of the Electric Power Research Institute (EPRI), Dairy Research Foundation, and Niro (formerly Grenco). The U.S. Department of Energy joined the consortium for phase II. The objective of the Phase II study was to prove the technical feasibility of, the economics of, and the market opportunities for the semi-commercial scale freeze concentration of milk.

The technical feasibility of freeze concentration of dairy products was affirmed on a single-stage Niro pilot plant unit. Skim milk was concentrated to a 40% maximum over a 40-hour period; whole milk was concentrated to a 44% maximum (46.5 hours); whey protein concentrate was concentrated to a 46.5% maximum (24- hours); whey permeate was concentrated to a 51% maximum (26-hours); and sweet whey was concentrated to a 52% maximum (59-hours).

A two-stage, semi-commercial scale Niro process development unit (PDU) was installed and evaluated at Galloway West during 1992. Tests were undertaken using whey protein concentrate and skim milk as the primary feed streams and operating procedures were developed for the unit. Skim milk was concentrated to an average of 32.28% solids over a 510-hour period of continuous production. Whey protein concentrate was concentrated to a 41.2% solids content over a 98-hour period of continuous production.

It was discovered that the milk streams developed considerable viscosity as they were concentrated, particularly in the samples with elevated casein content (i.e., whole and skim milks). In-line homogenization was evaluated with partial success as a means for reducing the viscosity of the milk streams. Concern also developed that lactose crystals in the milk stream could cause metal abrasion in the system and thereby reduce the shelf-stability of the milk products. The removal of lactose crystals from skim milk was investigated but proven to be impractical using a commercial decanter. The value of lactose removal to process optimization remains in question.

Several modifications were made in the PDU design in order to accommodate dairy ingredients and to resolve product contamination issues that developed early in the product trials.

Data collected during Phase II of the study were used to project the economic value of full-scale commercial freeze concentration of milk products. The results indicate that commercial freeze concentration of milk is both more energy-intensive and more economical than current evaporation technologies. The energy requirements for freeze concentration, which includes a pasteurization step, are higher than for either Thermal Vapor Recompression (TVR) or Mechanical Vapor Recompression (MVR). The differential operating costs for freeze concentration are also highly elastic to electrical energy costs. It was estimated that electrical energy costs would account for approximately 89% of the operating costs that differentiate freeze concentration from either TVR or MVR under full-scale commercial operations. Conversely, the economic advantages of freeze concentration stem from the ability of the freeze concentration unit to be operated continuously for 30-days or more, to minimize down-time and clean-up costs, and to incur only insignificant product losses during cleaning. Product losses associated with clean-up operations account for between 43% and 67% of the operating costs that differentiate TVR and MVR from freeze concentration. A summary of the projected operating costs which will differentiate commercial-scale freeze concentration from MVR and TVR concentration are provided in Table S-1.

Phase II also established that milk ingredients produced by freeze concentration should be considered Generally Recognized as Safe (GRAS) by the Food & Drug Administration and that the unit could produce dairy products to 3-A Standards of sanitation.

Table S-1.
Annual Operational Costs - Commercial scale FC vs. MVR and TVR.

	TVR		MVR		FC	
	$	%	$	%	$	%
Electricity	19,110	0.90	92,820	26.31	322,140	88.60
Steam	122,850	56.30	27,300	7.02	27,300	7.50
Losses	260,000	37.53	260,000	58.46	11,528	3.20
Cleaning	33,539	5.27	33,539	8.21	2,694	0.70
Total	435,499	100.00	413,659	100.00	363,662	100.00
Production (Total lbs. solids processed)						
	33,776,203		33,776,203		33,158,095	
Cost/lb. solids						
	$0.01289		$0.01225		$0.01097	

The fact that freeze concentration occurs at freezing temperatures and within a closed system would suggest that the technology should produce dairy ingredients of superior organoleptic and functional qualities. This was demonstrated in a number of studies. A University of Georgia study concluded that a skim milk beverage of equal quality to "fresh" commercial samples could be reconstituted from freeze-concentrated skim milk powder. This finding has enormous implications for export markets where the transportation and storage advantages of milk powders are advantageous. A separate study evaluated the organoleptic properties of freeze-concentrated whey protein concentrate and skim milk ingredients in a number of food formulations. It was found that consumers preferred the flavor and textural properties of lowfat ice cream, cream cheese, white sauce and milk chocolate products formulated with freeze-concentrated ingredients over those formulated with conventionally concentrated and spray-dried dairy ingredients.

In conclusion, Phase II demonstrated that freeze concentration can produce concentrated and powdered milk products of superior quality to those produced using conventional concentration technologies and, in the case of skim milk, of equal quality to fresh skim milk. The enhanced product qualities documented for freeze- concentrated milk ingredients should prove to be of great value to the domestic and export market opportunities of American dairy producers. While commercial-scale freeze concentration will be more energy-intensive than either MVR or TVR concentration technologies currently in use, it ultimately should prove to be more economical to dairy processors than either MVR or TVR due to the minimal product losses associated with freeze concentration. The results of Phase II indicate that freeze concentration should offer both economic and product-quality advantages over the concentration technologies currently in use by dairy processors.

1

INTRODUCTION

The dairy industry is the food industry's largest user of energy for evaporation purposes. Whey, nonfat dry milk (NFDM), and other dairy products combined require the evaporation of an estimated 6.7 x 10^{10} lbs. of water per year, using approximately 3.15 x 10^{13} Btu's of energy in the process (see Table 1-1). The dairy industry is also highly energy-intensive in one other sense: the extensive transportation networks required to distribute fluid milk.

Freeze concentration has been proposed as an alternative technology to conventional evaporation technologies that offers both energy and economic savings to dairy processors, as well as the opportunity for the dairy industry to shift its reliance from fossil fuels to more environmentally clean electrical energy. Given this premise, energy savings from freeze concentration could be realized for two reasons:

1. The energy required to form ice crystals (i.e., the heat of fusion) is less than that required for the evaporation of water (heat of vaporization). It requires 143.4 Btu's/lb. to crystallize water, compared to 970 Btu's/lb. to evaporate water.

2. Transportation costs incurred from shipping liquid milk from producers to processors and to customers represent a major cost-factor for the industry. Freeze concentration offers a technology that can concentrate milk to 25% of its volume without any degradation to product quality. Current evaporation technologies are unable to achieve the product quality attainable using freeze concentration.

Freeze concentration offers the potential for considerable operating efficiencies and capital savings compared to other evaporation technologies currently in use by dairy processors. Over 65 billion pounds of water are removed from dairy products annually through thermal concentration. Estimated Btu's of energy required to evaporate 1000 lbs. of water range from 450,000 Btu's for traditional Thermal Vapor Recompression (TVR) evaporators to 200,000 Btu's for Mechanical Vapor Recompression evaporators (MVR) (Figure 1-1). Current estimates for freeze concentration (at a rate of 700 lbs of water removal per hour) indicate that freeze concentration requires 289,600 Btu's to remove 1,000 lbs. of water but that this value could decrease as low as 144,000 Btu's in an ideal system with a water removal rate of 42,000 lbs per hour as improved technologies are implemented. The ideal system would be competitive with the current evaporative technologies with additional benefits of superior quality dairy products with significantly reduced product loss and clean-up costs. Furthermore, this technology is environmental friendly as its byproduct is pure water.

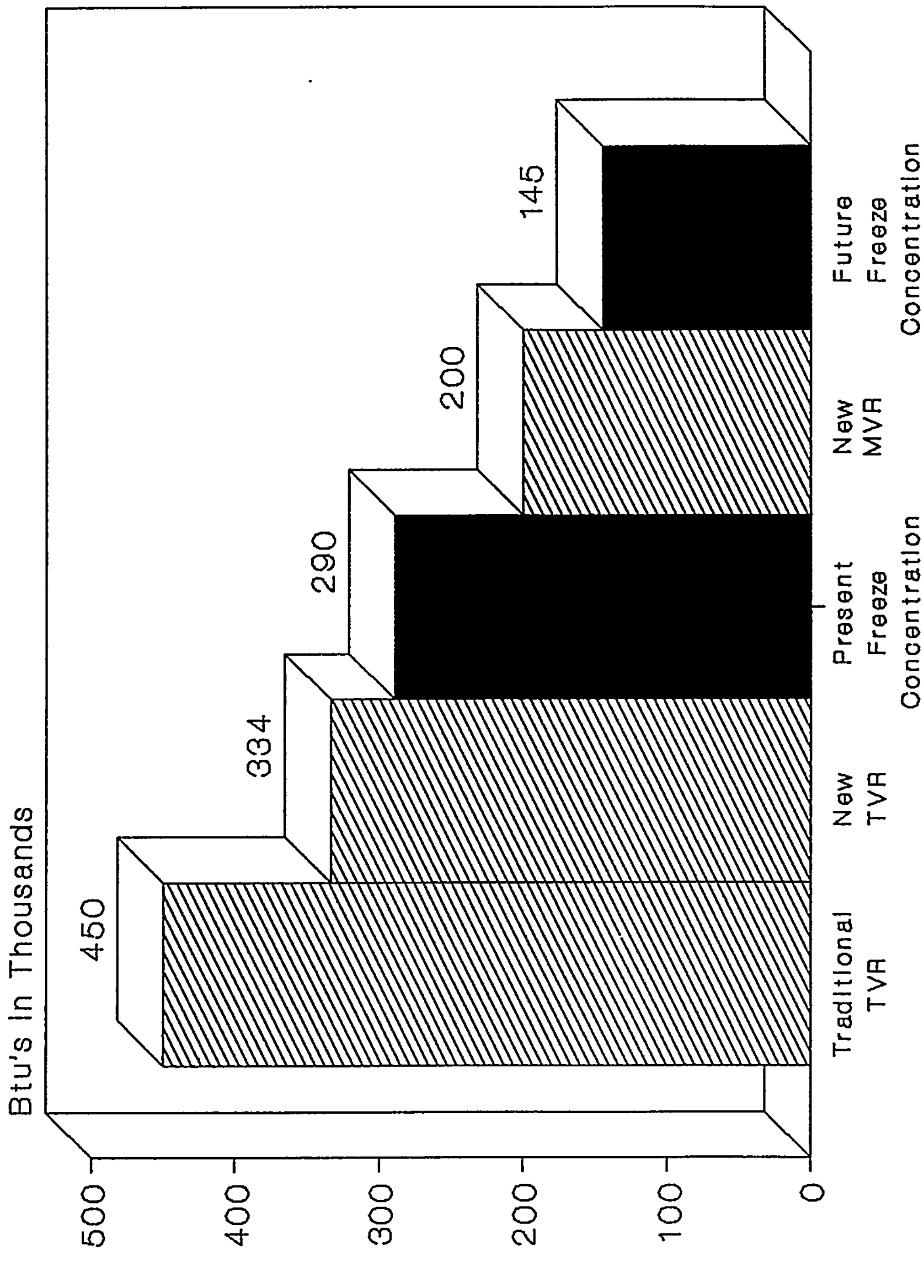

Figure 1-1
Energy Utilization per 1,000 Pounds of Water Removal in TVR, MVR and FC Plants

Table 1-1
Evaluation Needs of Selected Food Products

Food Products	Water Evaporation Per Year 10^9 lbs.	Btu's Per Year 10^{12} Btu's	1,000,000 lbs.Water Evaporation Per Day Plants
Whey	44.00	21.20	120
NFDM	14.00	6.20	38
Other Dairy Products	8.92	4.10	24
Cane Sugar	32.52	15.10	89
Beet Sugar	49.87	21.40	137
Molasses	8.29	2.40	23
Corn Steep Liquor	11.86	3.95	32
Tomato Paste	4.34	1.89	12
Total	173.80	76.24	475

(Source: Freeze Concentration of Dairy Products, Phase 1 - EPRI CU-6292 Project #2782-1 March 1989)

In 1985 the Dairy Research Foundation (then DRINC) and the Electric Power Research Institute (EPRI) joined under EPRI contract # RP 2782-1 to look at the feasibility of using freeze concentration technology in the dairy industry. This was considered Phase I of the program that would lead to the wide-spread adoption of the technology if its initial evaluation was favorable. A joint venture was subsequently developed between DRINC, EPRI and Niro (then Grenco - a freeze concentration equipment company) to implement Phase I. Phase I was concluded in 1987. The research, conducted by the DRF, concluded that implementation of freeze concentration technology for water removal alone could yield 14,500 billion Btu's in annual energy savings to the dairy industry. This estimate was based upon 147 freeze concentration units operating at full capacity with an energy consumption of 1.625 billion kWh. It was projected that the utilization of freeze concentration for just ten percent of the dairy industry's product concentration needs could save up to 3.4 x 10^{12} Btu's/yr. of fossil fuel with an increased electrical usage of 1.3 x 10^8 kWh./yr. By replacing a 100,000 lb./hr. triple-effect evaporator with current freeze concentration technology, an annual operating savings of $559,000 in product losses and clean-up costs along with the superior tasting product, could be realized. Furthermore, instead of fossil fuels, the plant would use 9.6 x 10^6 kWhs. of electricity a year.

In order for the dairy industry to accept a new process such as freeze concentration, it has to be demonstrated that the process can either serve existing dairy markets with overall cost reductions or create and/or expand present markets with new products. Examples include:

1. An estimated 148.5 billion pounds of fluid milk were produced nationwide in 1992 at an average wholesale price of $12.00/100 lbs. as fluid Grade A milk or for further processing applications. Freeze concentration could yield considerable savings in transportation costs to producers and/or processors by reducing the transportable volume of milk between production centers and processing plants. Using a hypothetical trucking charge of $0.30/100 lbs. mile and an average shipment radius of ten miles, freeze concentrating 25% of the milk supply could generate $3.7 billion in annual transportation savings.

2. Given the propositions stated in (1), freeze concentration could expand the effective marketing and distribution radius for fluid milk producers, both domestically and internationally.

3. Milk ingredients with enhanced organoleptic qualities can be used to manufacture added-value consumer products, such as high-quality cheeses, ice creams and other dairy products, that offer enhanced profit margins to producers.

4. Milk ingredients with enhanced functional performance could be manufactured using freeze concentration for non-dairy applications. Enhanced functional properties would promote the use of milk ingredients such as nonfat dry milk solids, caseinate, and whey proteins by the bakery products, salad dressings, condiments, confectionery, dessert toppings, coffee whitener, processed meat, and other processed food industry segments. Enhancement of the functional properties of dairy-based ingredients would better protect the dairy industry from competitive pressures by either a) foreign sources of dairy ingredients, such as the EEC and New Zealand, or b) non-dairy ingredients such as soy proteins, gums and fat-based stabilizers while opening export opportunities for domestically produced ingredients.

5. A more efficient separation of fluid milk products into their constituent components, such as dairy protein ingredients or even pharmaceuticals, could return higher profits to both dairy processors and producers. For example, the milk protein isolate lactoferrin, which is being commercially extracted from milk in Europe by DMV International, is reported to have a market value of $200 to $300 per pound. Human growth hormone, the production of which is in the process of being bio-genetically engineered into cows, carries a wholesale market value of $1.2 million

per ounce. Freeze concentration could prove to be an important step for improving the extraction economics for such components.

Phase I

In order to pursue further the technical feasibility of freeze concentration, the Dairy Research Foundation formed a consortium of investors in 1986 to commercialize freeze concentration for the dairy industry. Partners included the Electrical Power Research Institute (EPRI) and Niro Process Technology B.V. (formerly Grenco Process Technology), a manufacturer of freeze concentration equipment. Phase I, undertaken between 1985 and 1987, proved that a variety of milk products could be freeze concentrated to very high quality standards economically and with the promise of considerable energy savings to the processor. The technology has been protected under U.S. process patent No. 4,959,234. Results of this research are summarized in (Tables 1-2 and 1-3). These results of Phase I encouraged the consortium to invest in a second phase of research.

Table 1-3
Phase I: Test Conclusions - Summary

Product	Steady State Operating Temp./C.	Conc. T.S.	Max. Viscosity	Visual Precipitate	Relative Quality
Whole Milk	-2.6	41.0	130 cps	Yes-Lactose Microscopic Observation	4
Skim Milk	-3.0	40.0	300 cps	Yes-Lactose/ Ash/Protein Microscopic Observation	5
Sweet Whey	-4.0	44.9	296 cps	Yes-Lactose	4
WPC	-4.0	41.6	140 cst	Visible	N/A
Permeate	-6.5	53.1	145 cst	Yes-Lactose/ Ash	N/A
Acid Whey	-5.0	39.6	130 cst	Yes-Lactose/ Ash/Protein	N/A

Table 1-4
Phase 1: Cost Comparison - Summary

Concentration Process	Capacity Lbs.Water Removal/hr	Capital Cost $	Annual Cost $ Utility & Cleaning $	Cost $/100 lbs. Water Removal	Cost $/lbs. Solids
		Milk Fluids			
Current Thermal	45,000	900,000	909,650	2.89	0.028
Best Thermal	49,800	1,340,000	610,820	1.75	0.017
MVR	49,800	1,356,000	345,660	0.90	0.010
Current FC	10,000	1,100,000	109,700	1.32	0.013
Future FC	42,000	2,080,000	144,600	0.41	0.004
		Whey Fluids			
Current Thermal	45,000	1,100,000	790,650	2.51	0.037
Best Thermal	49,800	1,540,000	464,200	1.33	0.020
MVR	49,800	1,765,000	202,600	0.58	0.009
Current FC	10,000	1,100,000	98,900	1.19	0.018
Future FC	42,000	2,090,000	123,700	0.35	0.005

Phase II

Phase II represents the commercial scale-up phase of the Dairy Research Foundation's ongoing efforts to delineate the economic, energy conserving, and product-quality benefits of freeze concentration to the dairy industry. Phase II was a jointly funded effort between EPRI, the Dairy Research Foundation, the U.S. Department of Energy (DOE), Niro Process Technology and the Galloway West Company.

This report summarizes the results of studies undertaken between September, 1991 and December, 1992 that collectively comprise Phase II of the project. Phase II addressed both pilot plant testing and commercialization issues as part of the following test objectives:

I. Pilot plant

1. Establish maximum concentrations for six fluid streams on a laboratory scale.
2. Document crystal-growth profiles as a function of residence times and ice production.
3. Evaluate the efficacy of single stage versus two stage freeze concentration.
4. Confirm the sanitary integrity of the freeze concentration process under steady-state operating conditions and evaluate the compliance of existing NIRO equipment to accepted sanitation standards.

II. Process Development Unit (PDU)

1. Install a multistage commercial freeze concentration PDU into a manufacturing environment and optimize its operation against the manufacturer's specifications for the unit.
2. Evaluate one or more milk product streams on the PDU and provide data for the modeling of the commercial scale unit. Modify the equipment as needed and develop operator manuals for the freeze concentration of milk products.
3. Obtain regulatory approval for the PDU system.
4. Test the suitability of freeze concentrated milk products for further spray drying and finished product applications. Establish the potential value of other by-products such as melt water or lactose.
5. Conduct preliminary market research on freeze concentrated milk products. Initiate a promotional program to communicate the potential benefits of freeze concentration.

2

TECHNICAL DISCUSSION

Principles and Description of Freeze Concentration

One of the developing technologies within the field of separation is freeze crystallization. This refers to the process wherein heat is removed from a solution to form crystals of solvent (in the case of dairy products, the solvent is water and the crystals are ice). Removal of the crystals from the slurry followed by washing the mother liquor from the crystal surface, using pure water as the washing medium, accomplishes the separation of the water solvent. Left behind is a concentrated solution of dissolved solids. The final processing step is the melting of the washed crystals to recover pure solvent containing trace amounts of total dissolved solids from the original solutions. The desired end-product of freeze concentration can be either the melted solvent, as is the case in desalination, or the concentrated mother liquor, as is the case in the concentration of milk and other edible liquids.

Advantages of Freeze Concentration

Theoretically, freeze concentration should offer several advantages when compared to traditional thermal concentration technologies.

1. Low energy consumption relating to the basic differences in the heat of fusion of ice (143.4 Btu's/lb.) as compared to the heat of vaporization of water (970 Btu's/lb.).

2. Minimal loss of solids--as low as 50 to 200 ppm--implying not only efficient process recovery of dairy solids but also minimum environmental by-product liabilities.

3. The absence of any heat-related abuse of the volatile flavor, aroma and other functional components in the concentrate. This is a critical feature for preserving the original "fresh" qualities of processed dairy and dairy ingredient-containing foods.

4. The absence of heat damage, fouling or scale-up of the process that would result in expensive down-time losses for equipment dismantling and cleaning.

5. Low rates of corrosion to the equipment due to low process temperatures.

A schematic diagram for a single-stage freeze concentration process is shown in (Figure 2-1).

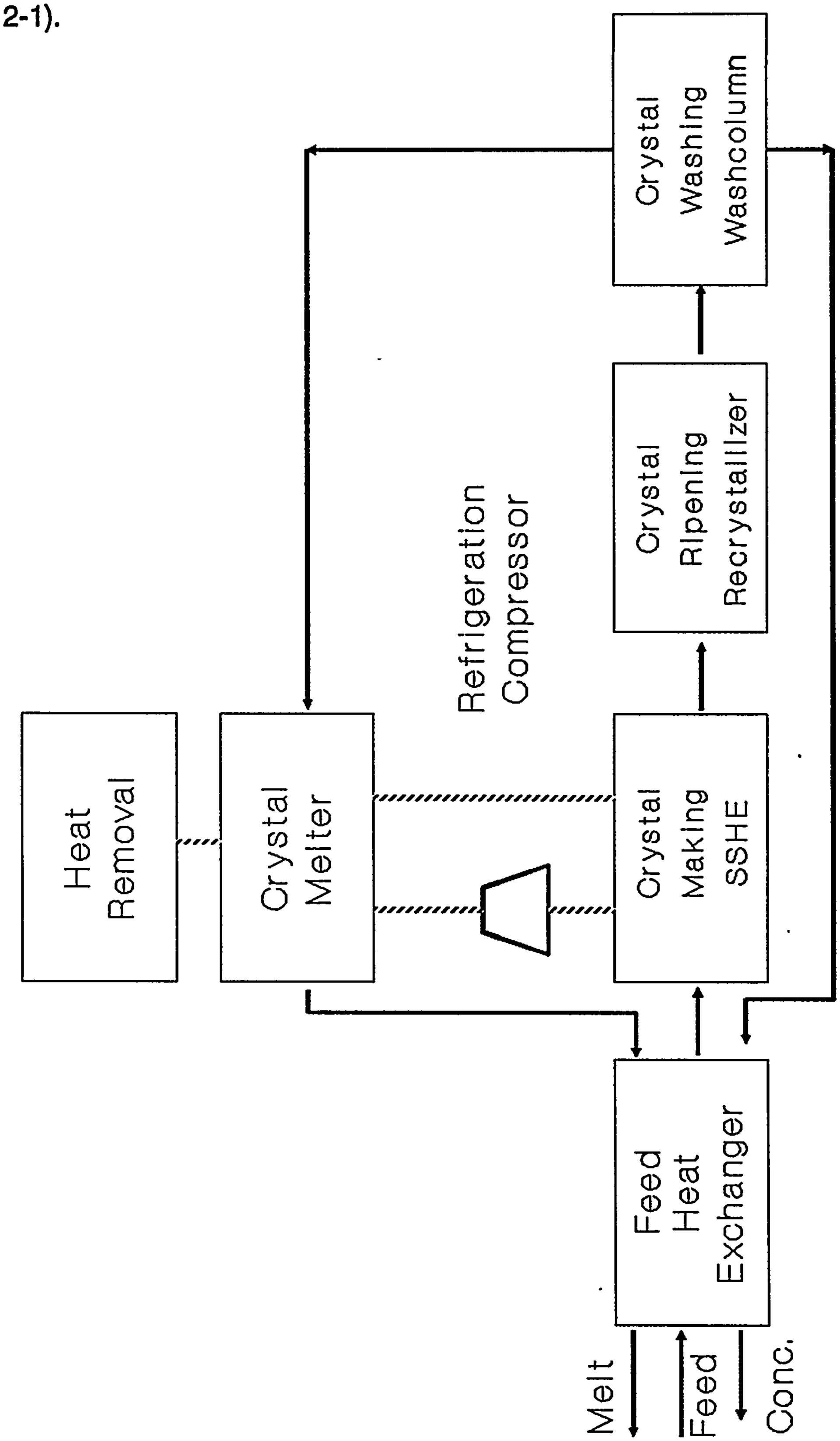

Figure 2-1
General Process Schematic for the Freeze Concentration Process

This representation is applicable to both direct and indirect contact freezing. In the latter, heat transfer surfaces in the freezer and melter physically separate the fluid being concentrated from the refrigerant. In a direct contact system the two fluids are not separated.

With high solids concentrates extremely small ice crystals are formed in the freezer. At the temperatures required for freezing, the concentrates are quite viscous. Because of this condition separation of ice from concentrate is difficult. Therefore, a system promoting rapid crystal growth prior to separation is necessary (the Recrystallizer). The ice is washed by a portion of the pure melt water produced by the process. The ice is then transferred to a melter where the heat removed in the freezer, after being elevated in temperature by a compressor or absorption refrigeration cycle, is re-applied to the ice to accomplish the melting.

Components of the Freeze Concentration Process

There are three essential components to the Niro freeze concentration process.

* Recrystallizer
* Scraped Surface Heat Exchanger (SSHE)
* Washcolumn

The first two components make up the crystallization section where ice crystals are formed and allowed to grow. The third is the separation component where ice crystals are removed and discharged as pure water. The formation of large, pure ice crystals is essential for the efficient operation of the washcolumn.

Recrystallizer

The feed (in this case, a dairy product) passes through a heat exchanger and enters a recrystallizer where sufficient heat is removed to form ice crystals. The recrystallizer is simply a mixing vessel equipped with an internal filter. The filter support is a wedge-wire cylindrical or flat plate-type filter. This allows the passage of liquid through the filter medium (ice crystals) and the support structure (wedge wire) for the production of a crystal-free liquid stream. The support structure is continuously scraped. This provides for the formation of a new filter medium layer and prevents blockage of the filter support.

Scraped Surface Heat Exchanger (SSHE)

This unit provides the heat removal necessary for ice crystal production using Freon R22 as the refrigerant. The heat exchange surface is kept free of ice build-up by a set of rotating stainless steel knives, much like an ice cream freezer. The SSHE receives a supply of crystal-free liquor from the recrystallizer filter and returns the ice slurry to the recrystallizer. The SSHE provides a steady source of ice nuclei to the recrystallizer. The nuclei provides templates for ice crystal growth. These small crystals melt in the recrystallizer, removing heat, and induce water to recrystallize into the larger existing crystals.

Washcolumn

In the Niro process the separation section is a washcolumn (see Figure 2-2). The washcolumn functions as a type of continuous filter press while washing the ice crystals to remove any product clinging to the surface of the crystal. Since the crystal itself is pure, water removal from the outside layers of the crystal provides for very pure water discharge (less than 50 ppm total solids).

The washing action is unique in that the wash water comes in contact with but is not mixed into the concentrated product (i.e., there is no recycling).

The slurry (ice crystals and concentrated product) enters the washcolumn (Figure 2-2,D) above the filter plate where it is mechanically compressed and forces the liquid through the filter and back to the SSHEs. The compressed ice bed with product filling the spaces between the spherical crystals is forced upward into a rotating scraper. The scraper continuously removes the ice which is entrained in a recirculation flow and passed through a tubular heat exchanger where the ice crystals are remelted.

By controlling the pressure in this wash water circuit it is possible to control the amount of water forced counter-current to the flow of ice crystals in the wash column. This counter-current flow of wash water produces a sharp separation within the ice bed which is called the wash front.

The wash front is formed at a point in the ice bed where the water comes into contact with the colder crystals coming from the recrystallizer (Figure 2-2, A). The crystals from the recrystallizer enter at the freezing point of the product within that recrystallizer, which is usually a few degrees below the freezing point of pure water. This means that pure water will freeze instantly onto the surface of these crystals, forcing the product being concentrated away from the growing crystals' surfaces. This also means that the wash water is now ice, which is carried out of the recrystallizer with the other ice crystals and removed at (Figure 2-2, B).

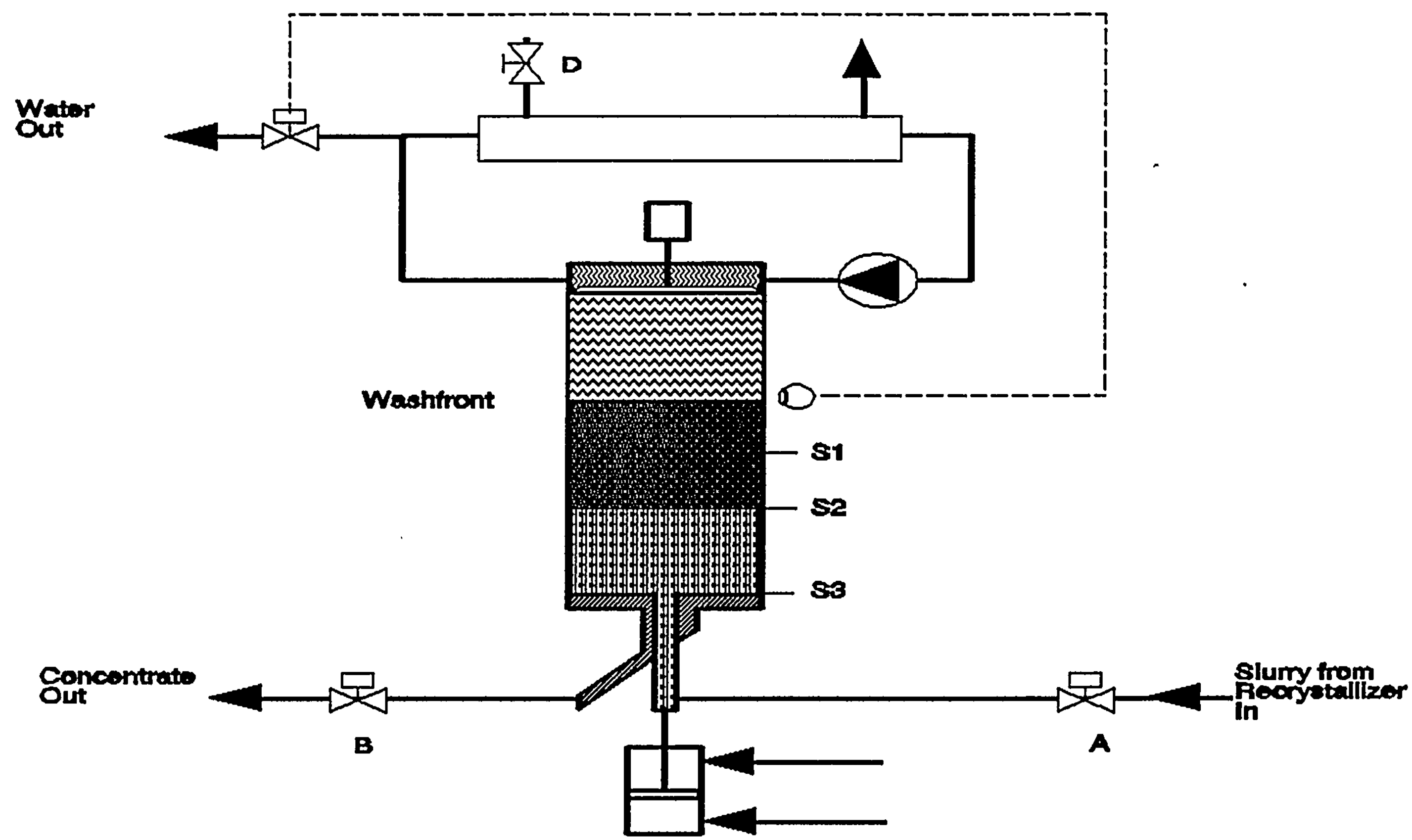

Figure 2-2. NIRO piston type washcolumn

The wash column, recrystallizer, and SSHEs all operate as pressurized, closed, flooded systems, thus eliminating all contact with the outside environment. Because of work input by pumps and compressors and imperfect heat exchange between hot and cold fluids in the heat exchangers, there is more heat available in the melter than can be absorbed by the melting ice. Consequently, a heat rejection system is required to remove this excess heat from the system. It is expected that these process inefficiencies will be addressed as commercialization efforts progress.

Ice Crystallization

Ice-crystal size and growth rates are key production parameters as they have a direct bearing on the superficial velocity of liquids through the packed ice-crystal bed in the washcolumn. Liquid velocity is a direct function of ice crystal diameter. The superficial velocity of a liquid through a packed bed is given in Equation 2-1:

$$V = \frac{E^3}{180} \times \frac{dp^2}{(1-E)^2} \times \frac{O^2}{1} \times \frac{1}{u} \times \frac{dP}{dz} \qquad \text{(eq. 21)}$$

in which:

V = superficial liquid velocity (m/s)
E = volume fraction of liquid (l)
dp = particle diameter of crystals (m)
O = shape factor of the crystals (l)
u = dynamic viscosity (Ns/m^2)
$\frac{dP}{dz}$ = pressure drop along the packed bed (N/m^3)

Niro has developed a linear computer model for ice crystal growth based upon data collected from numerous commercial installations. The Equation 2-2. is basically a linear growth velocity equation of the form.

$$v = K \times \Delta C \qquad \text{(eq. 2-2)}$$

where:

v = growth velocity
K = mass transfer coefficient
ΔC = driving force for growth

The Gibbs-Thomson formula (Equation 2-3) gives a relation between the driving force, ΔC, and ice crystal diameters:

$$\Delta C = \frac{C_w}{Teq} \times a \times \left(\frac{1}{L_B} - \frac{1}{L} \right) \qquad \text{(eq. 2-3)}$$

where:

C_w = weight fraction of water in the solution
Teq = equilibrium temperature of solution
L = crystal diameter
L_B = bulk diameter-i.e., the size at which neither growth nor melt occurs.
a = constant

A value can be calculated for each crystal size and assuming the bulk diameter is known, a value for the driving force and, finally, for the growth velocity can be calculated.

In actual practice it is possible to obtain a crystal size distribution for a specific product, concentration, and ice production rate and then fit this data through iterative calculations with the computer model to obtain the bulk diameter and growth velocities. This information can then be used to develop an empirical formula that can relate the growth velocity and bulk diameter to the ice production rate, viscosity, concentration and crystal residence time.

Niro has assumed that the residence time of a crystal has the greatest influence on the process and has chosen an equation of the form as described in Equation 2-4.

$$f(x,y) = A \times (X)^B \times (Y)^L \qquad \text{(eq. 2-4)}$$

where:

A, B and L are empirical constants
X is the residence time of ice crystals in the vessel
Y is the residence time based upon ice production

Multiple-Stage Processing

Limitations to single-stage processing that needed to be studied and addressed, if possible, in Phase II of the commercialization studies are as follows:

1. The heat of crystallization has to be removed in the scraped surface heat exchanger at the lowest temperature level in the process.

2. Ice crystals grow under unfavorable conditions - high-solids concentrations and high viscosity. The latter is caused by both the high solids content and by the low temperatures. This results in reduced water mobility and increased residence times for the ice crystals. This, in turn, requires larger recrystallizer vessels that are less efficient.

3. The result of the above two conditions is that smaller ice crystals must be removed under the most adverse conditions which detrimentally affect process efficiencies.

4. Pumping and mixing must also be done under high-viscosity conditions, decreasing process efficiencies.

One way to address these shortcomings is to incorporate multiple sequential stages for improved concentration efficiencies. A two-stage configuration was chosen for both the commercial and laboratory scale production research undertaken in Phase II of this project.

There are two other concentration technologies against which freeze concentration must prove itself to be economically competitive.

Thermal Vapor Recompression

Most concentration systems in the dairy industry consist of multiple-effect evaporators. These are based upon the principle that the vapor removed from a thin film of milk in a vacuum drying system contains considerable latent heat of vaporization. This heat is recaptured by cycling it to another higher-vacuum drying step (a second effect) for which it provides the heat of vaporization. The vapor given off by the second effect can then be cycled to a third effect and so on, resulting in a multiple effect drying system. Evaporators with up to seven effects are in use in the dairy industry, however the trade-off remains one of capital costs versus operating efficiencies.

The thermal efficiency of a multi-effect evaporator can be increased by compressing vapor prior to using it as the heating medium for a subsequent effect. This can be done by passing the vapor from the first effect to a thermal recompression jet (essentially a venturi valve) and combining it with high-pressure steam. The high steam pressure is converted to kinetic energy and the mixture ejects at a high velocity through the venturi nozzle and is compressed to a higher pressure (see Figure 2-3).

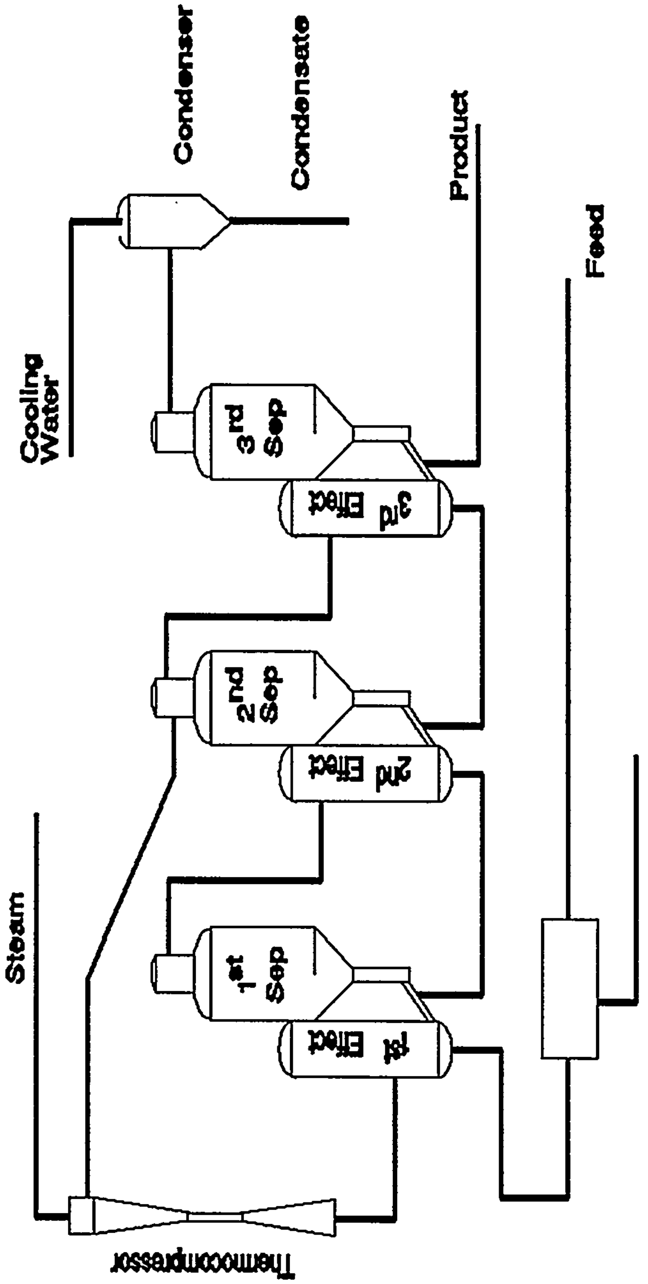

Figure 2-3. Thermal Vapor Recompression (TVR)Evaporation

With thermal recompression a single effect evaporator can be just as economical as a double effect evaporator. The system requires steam generation but very little electricity to operate. Thermal vapor recompression evaporators are very popular in part because they improve processing efficiencies for a lower capital cost.

Mechanical Vapor Recompression

The efficiency of an evaporator can further be increased if the vapor is recompressed mechanically rather than through thermal recompression. Mechanical vapor recompression (MVR) uses a turbo fan to compress vapor to very high pressures. MVR represents the most advanced technology commercially available for concentrating dairy products.

A schematic diagram of a MVR process is provided in (Figure 2-4). Advantages of mechanical recompression include:

1. Reduced energy consumption

2. Use of both electrical and steam energy

3. Relatively low operating temperatures (around 145°F.)

4. Simplicity of operation.

An exception to point-4 is that the compressor requires relatively high maintenance inputs. The limitations inherent to compressors in general imposes some severe process limitations on MVR concentration. Negative factors to MVR concentration include:

1. High capital investment requirements: MVR units are relatively expensive, a factor that has weighed against their acceptance by the dairy industry.

2. Operating expenses: The low processing temperatures at which MVR operates requires extensive heat transfer areas, contributing to the high capital cost and operating costs of MVR units.

3. Long residence times: The long residence times and circulation areas are required because of the small amount of water that can be removed in a single pass. A typical residence time is 30-minutes. Since final product quality is a function of both temperatures and time, this can adversely affect the product in addition to reducing product throughput efficiencies.

4. Heat generation: Steam (hence, a steam-generation capability) is still required for start-up and preheating steps.

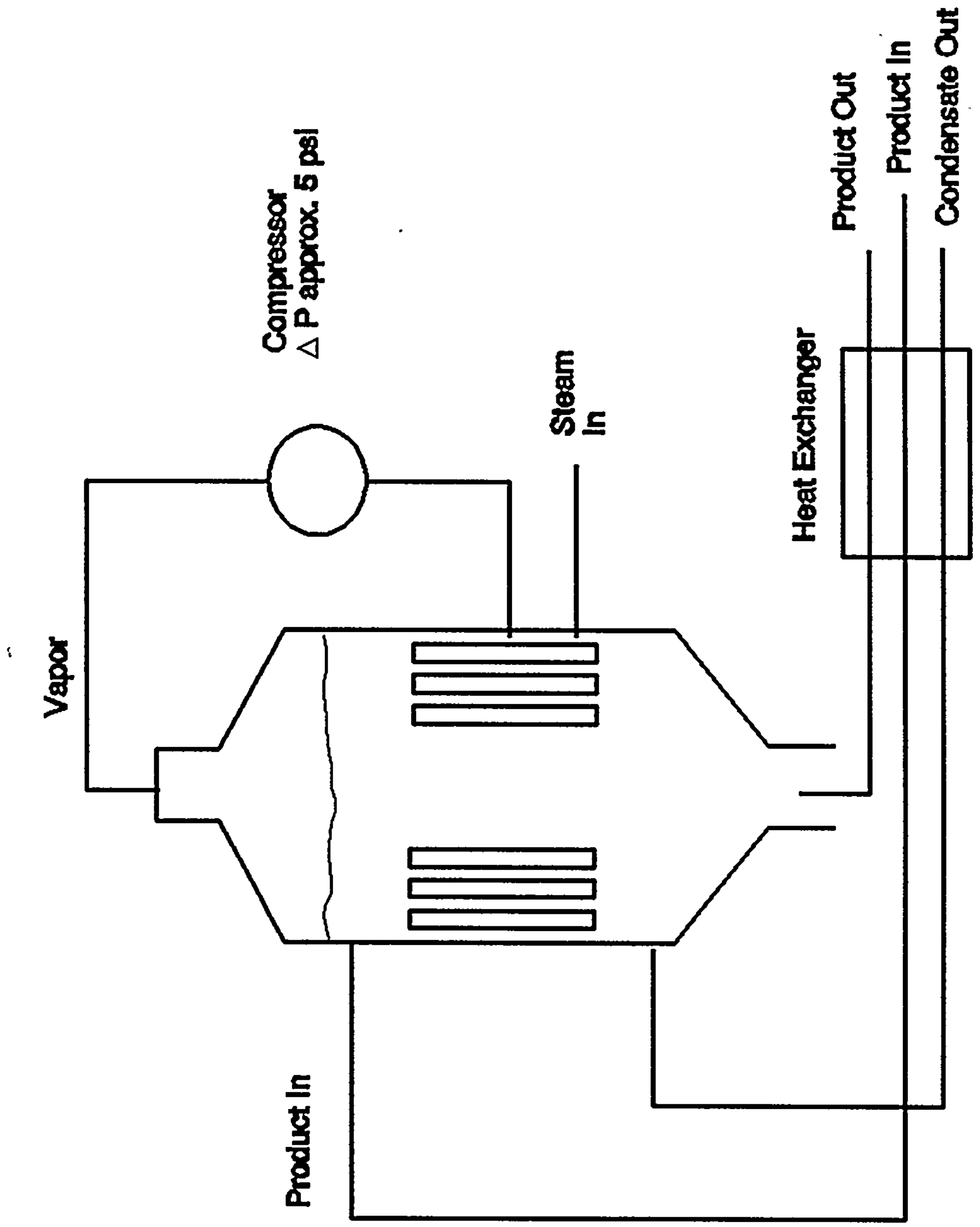

Figure 2-4. Mechanical vapor recompression (MVR) Evaporation

Comparative operating efficiencies between freeze concentration and MVR concentration were evaluated by comparing Phase II freeze concentration data to industrial data for MVR and TVR concentration. This is discussed in Chapter 5. The data was compiled, analyzed and provided by Niro.

Spray Drying

Non-fat and whole milk, sweet whey, and whey protein concentrate from freeze-concentrated dairy stock were run on a DDL/Anhydro laboratory spray dryer No.1. This unit is a small scale drying plant suitable for the capacity of the systems encountered at the Dairy Research Foundation laboratory facility. The operating characteristics of each product can be easily studied on this unit, and any appropriate modifications can be established before scale-up to larger commercial dryers. A schematic of the DDL/Anhydro spray dryer is provided in (Figure 2-5). The dryer is operated in the two-fluid nozzle/mixed air flow set-up mode for our products. After pre-treating the concentrated dairy steam (35-50% total solids) through a 200 micron cloth filter and homogenizing at 500/1500 psi at 57°C, the feed is pumped (120 psi) to the nozzle in the center of the drying chamber. Compressed air at 120 psi is used as the atomizing agent.

Pre-filtered hot air is introduced at 200°C through the drying chamber ceiling. Practically instantaneous evaporation takes place between the hot air and the atomized fluid.

The mixture of dry material and drying air goes through a conical bottom outlet which leads to a cyclone, where the drying air is exhausted and the powder is collected.

The spray dryer was used to dry freeze-concentrated milk products for making comparative evaluations of the milk powders functional and organoleptic qualities against conventionally concentrated milk powders.

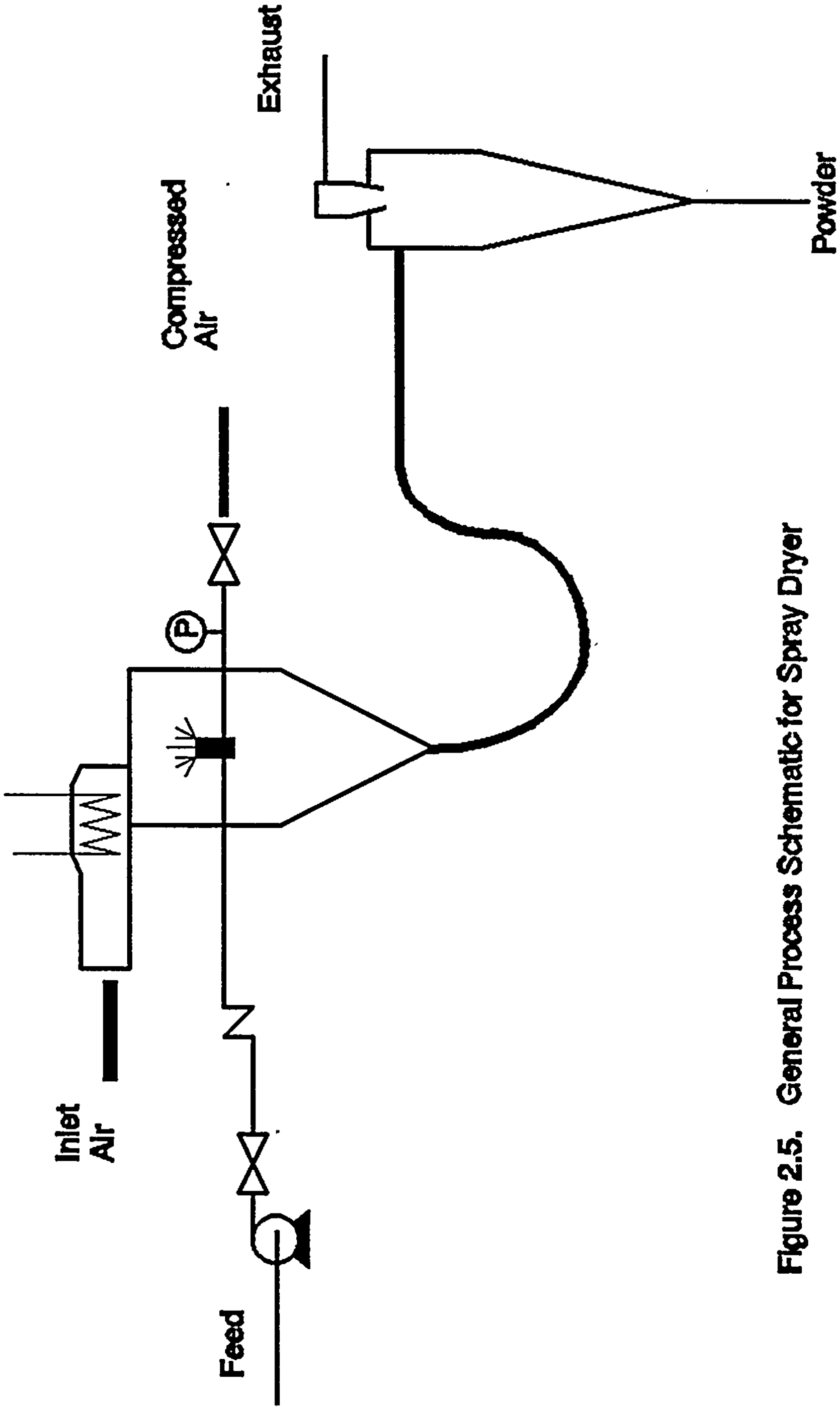

Figure 2.5. General Process Schematic for Spray Dryer

3

PILOT PLANT TESTS

Evaluation of Single-Stage Processing

Whole milk, skim milk, permeate, whey protein concentrate and sweet- and acid whey were processed on a single-stage Niro/Grenco pilot plant unit to confirm maximum attainable concentrations from the product streams under steady state conditions through the single-stage process configuration. During this period, both a two-stage pilot plant unit and a two-stage Niro Process Development Unit (PDU) were configured. The PDU was configured for planned installation at the Galloway West Company, Fond Du Lac, Wisconsin for semi-commercial scale-up trials. Comparative runs were made between single- and two-stage processing for both skim and whole milk.

A secondary objective was to identify any factors that might preclude the semi-commercial scale-up of these product streams on the PDU. Baseline data was collected on ice crystal growth to provide a point of comparison against which future product runs could be compared. In previous runs undertaken during Phase I of the project, it was concluded that very small ice crystals produced under high-solids conditions could compromise the operating efficiency of freeze concentration.

The product variables tracked during both pilot plant and PDU operation were total solids, temperature, viscosity, pH and precipitate contents of concentrate; and the conductivity and pH contents of the wash water being produced. The total solids were measured using a CEM moisture balance and the viscosity was measured using an Ostwald U-tube viscometer at the freezing temperature of the product. Product freezing temperature was measured using a milk cryoscope while percent precipitate (insoluble solids) were measured using a standard spin test. A conductivity meter was used to measure conductivity of wash water.

Ice Crystallization and Crystal Size

Crystal size distribution is an important limiting factor in freeze concentration process efficiencies. This can limit the process in two ways:

1. Separation: Poor crystal size distribution makes washing more difficult which, in turn, results in smaller capacities or lower final product concentrations.

2. Recrystallization: Poor crystal size distribution results in greater pressure drops over the filters, limiting final concentration levels.

Ice crystal nucleation takes place in the SSHE where a large temperature difference establishes dendritic shaped crystals. These are supplied to the recrystallizer, an ideal mixing vessel, where they intermix with already existing (larger) crystals. The small crystals, which have a slightly higher freezing temperature than the larger crystals, will melt in favor of the large crystals which will grow or "ripen." Because there is continuous circulation of an ice-free flow (provided by the filter in the recrystallizer), large, pure and spherical crystals are obtained.

However, crystal size distribution still depends largely on process parameters. Recent studies documented that it was possible to predict crystal size distribution profiles for a given set of operating conditions but it was not possible to characterize the effect of a separate parameter because individual parameters are hard to quantify.

Ice crystals were measured using a microscope with an attached camera that, in turn, was attached to a fabricated chamber designed to capture part of the slurry flow from the recrystallizer.

Results of Pilot Plant Tests

Product Runs

Skim milk (16 runs), whole milk (10 runs), sweet whey (8 runs), acid whey (3 runs), whey protein concentrate (5 runs), and whey permeate (4 runs) were run through the single-stage configured Niro pilot plant unit. Maximum steady state concentrations achieved were 40% for skim milk (at 40-hrs.); 44% for whole milk (at 30-hrs.); 46.5% for whey protein concentrate (at 24-hrs.); 51% for whey permeate (at 26-hrs.); and 52% for sweet whey (at 59-hrs.)--(see Table 3-1). Concentration-versus-time profiles for each of the six product streams are attached in Appendix A, Figures A-I to A-V.

Steady state conditions were not achieved for acid whey due to mechanical difficulties which caused the runs to be aborted.

High viscosity proved to be the limiting factor for the freeze concentration of both skim milk and whole milk (see Figure 3-1). Butterfat separation in the wash column also interfered with proper wash-column operation during the whole milk trials.

The highest concentrates were obtained in those product streams with the highest lactose and whey protein concentrations. This suggests that casein (milk protein) and not whey protein or lactose crystallization is probably the limiting factor in achieving higher concentration. Skim milk contains the highest level of casein, whey protein

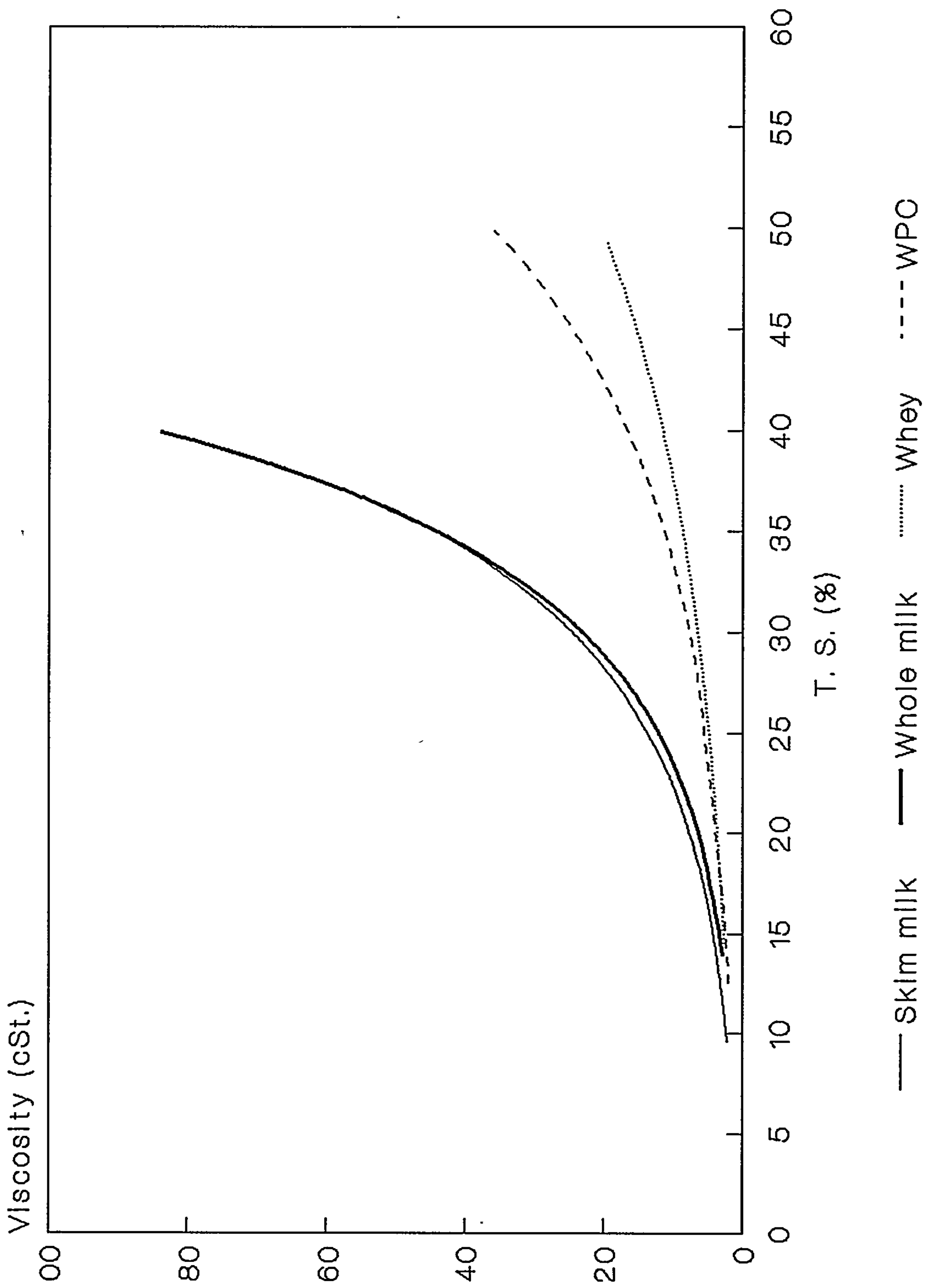

Figure 3-1
Viscosity Development for Four Product Streams

concentrate contains the highest level of whey proteins, and permeate contains the highest level of lactose of all five dairy fluids. Apparently, skim and whole milk represent a separate physico-chemical system different from that of the other milk product streams. This is supported by the observations that the freezing points for skim and whole milk were higher than for the other product streams at elevated concentrations (Figure 3-2). This data warrants additional research to explore the glassy transition state (Tg) dynamics of the various product streams under freeze concentration.

Table 3-1
Maximum Concentration Achieved for Single-Stage Processing

Product	Max. Conc. (w/w)	Viscosity cst.	Limiting Factor	Remarks
Whole Milk	44.0	150.0	High viscosity Lactose ppt.	Fat in WC,
Skim Milk	40.0	150.0	High viscosity Lactose ppt.	Fat in WC,
Permeate	51.0	55.0	δp-filter	
Sweet Whey	52.0	55.0	-	
Acid Whey*	50.0	20.0	-	
WPC	46.5	125.0	δp-filter	

* incomplete run

These observations ran counter to a basic premise of the Phase II proposal that lactose crystallization would prove to be a limiting factor in the freeze concentration of milk. Consequently, further work directed toward controlling lactose crystallization was de-emphasized.

Ice Crystal Growth

Attempts to study ice crystal growth in skim and whole milk did not work well with the pilot plant freeze concentration unit. This was attributed to two problems:

1. The limitations of the pilot plant unit which precluded achieving prolonged steady-state production.

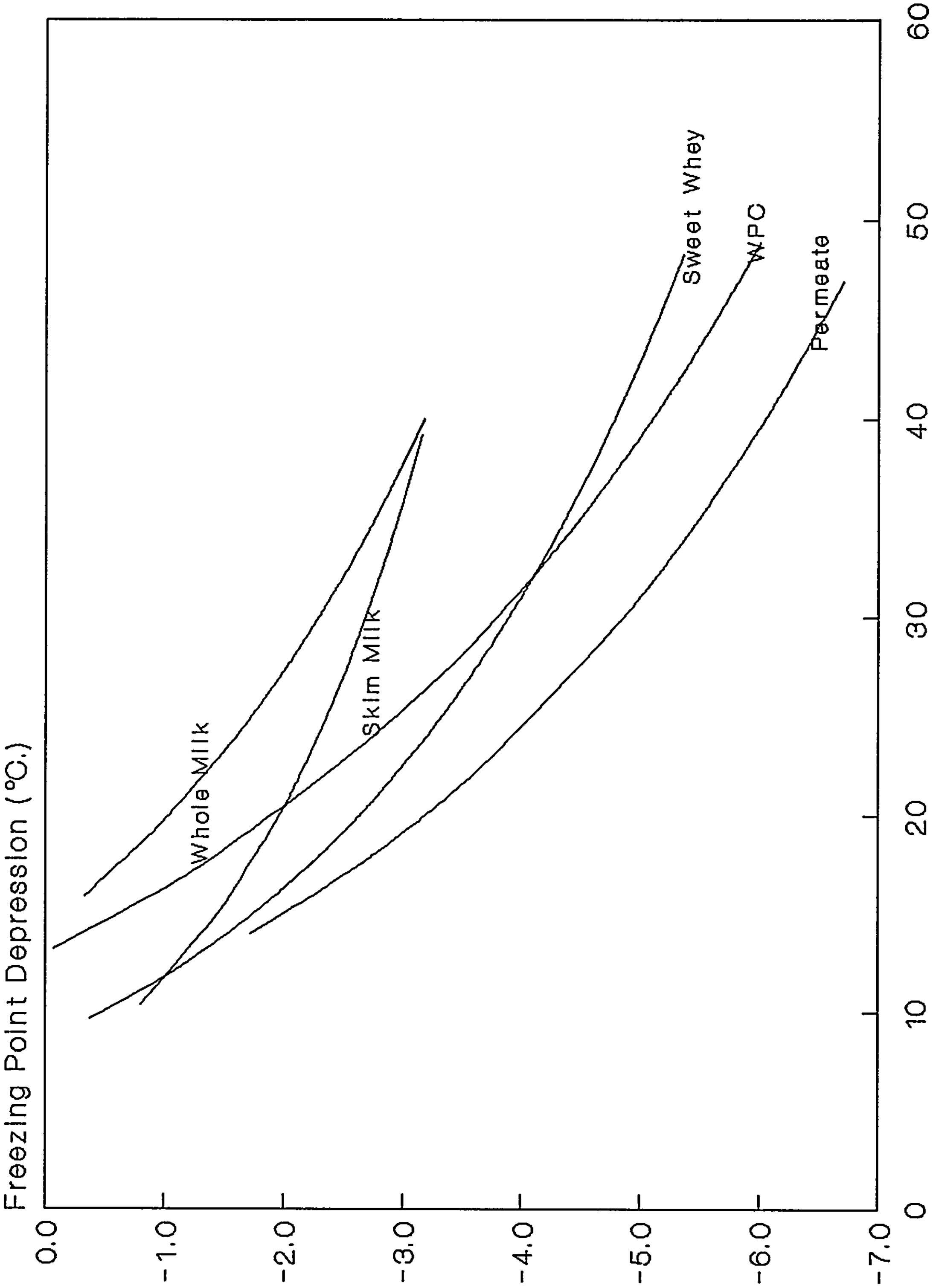

Figure 3-2
Freezing Point Depressions for Five Products Streams

2. Technical problems in maintaining clear photographs. It was determined that large crystal sizes and high protein concentrations interfered with light transmission through the photo cell so that the outer edges of the crystals could not be easily discerned.

Typically, about 10-20 crystals per photo are required in order to determine crystal size distributions. The pilot plant capacity limits taking samples large enough to meet the photography needs without seriously affecting operating conditions.

Limited data was obtained from Niro on ice crystal diameters from the freeze concentration of orange juice. This was done to provide a comparative benchmark for future trials to be conducted on skim milk (Figure 3-3).

Further attempts were made to obtain ice-crystallization data using the commercial scale Process Development Unit (PDU) referred to in subsequent sections.

Two-Stage Configuration

A two-stage configuration was developed for both the Niro pilot plant and PDU systems. Two W-6 freeze concentration units were connected through the recrystallizer columns by a line containing the slurry pump (SP1) as shown in Figure (3-4).

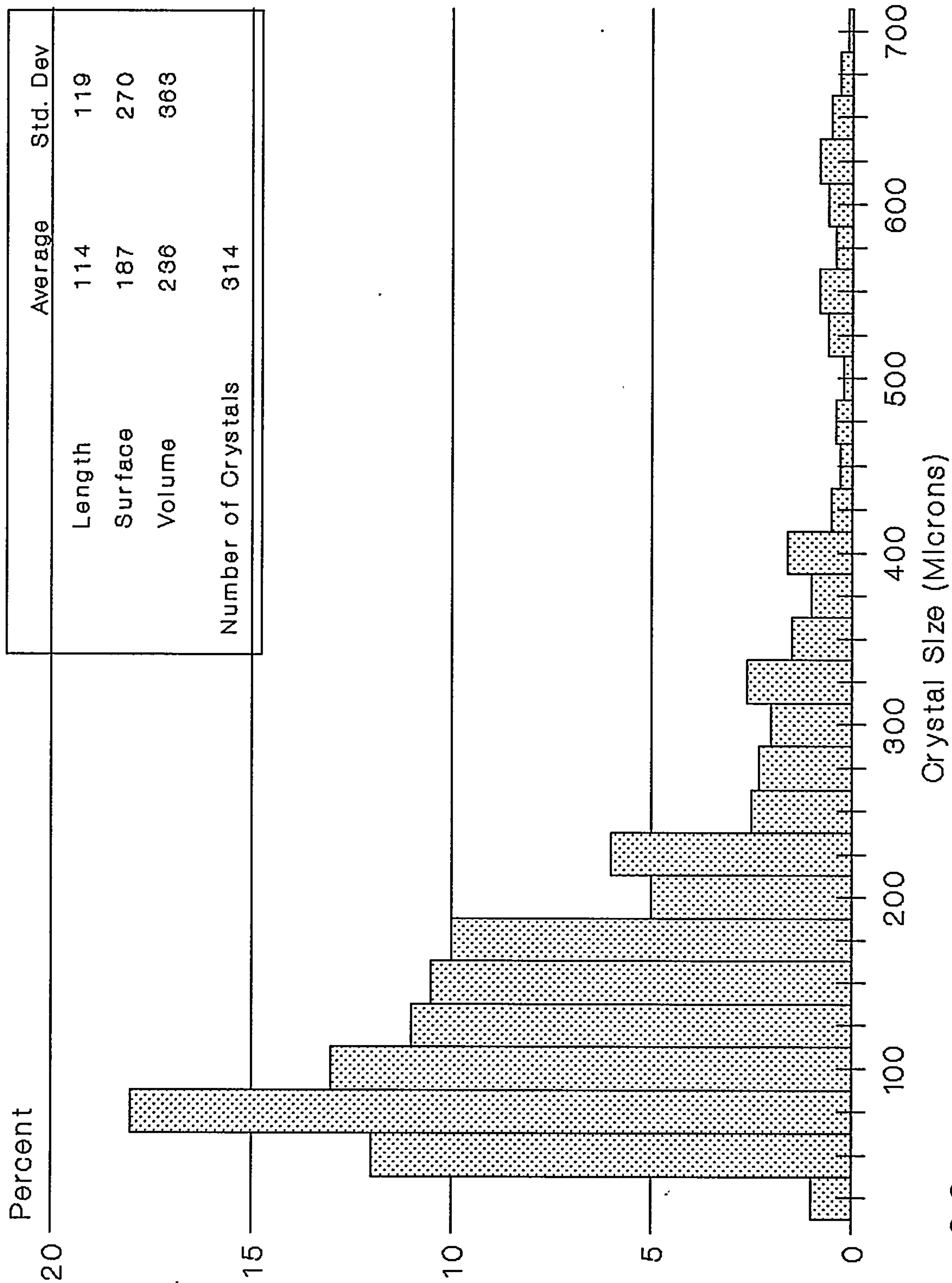

Figure 3-3
Typical Ice Crystal Distribution During Orange Juice Freeze Concentration

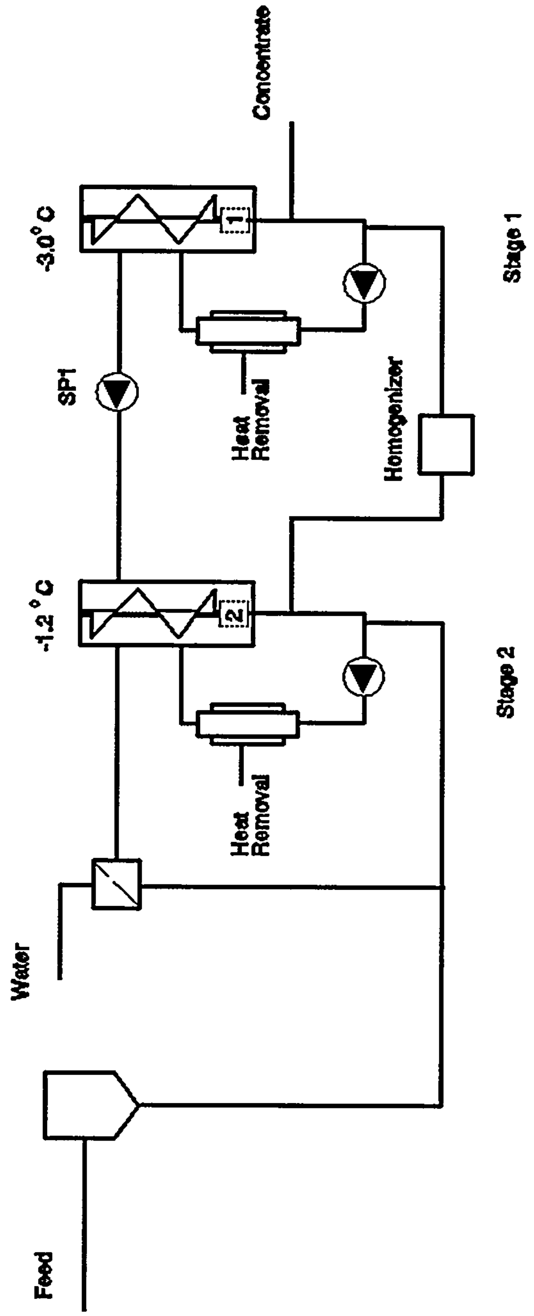

Figure 3.7 . Flow diagram of two stage systemwith homogenizer

Single-Stage vs. Two-Stage Processing

The effect of staging was not fully demonstrated during the pilot study due to the makeshift arrangement of connecting two freeze concentration units to simulate the effects of a two-stage unit. Comparative runs were undertaken with whole milk and skim milk. Although a higher concentration was achieved with a two-stage processing of whole milk (Figure 3-5), this was not the case with skim milk (Figure 3-6). Numerous problems were encountered during repeated runs of skim milk that were attributed to poor flow dynamics which created lumpy build-up behind the recrystallizer filter and by limitations of the small slurry pump connecting the two recrystallizers. There was no evidence to suggest that there was anything inherently wrong with the two-stage configuration. The advantages of multi-stage systems have been proven commercially in non-dairy systems. The advantages of two-stage freeze concentration for dairy products need to be further elucidated on a commercial scale.

Viscosity Reduction

In order to address the viscosity limitations of whole and skim milk, the effect of homogenization on viscosity reduction of the whole milk and skim milk concentrates was investigated on the premise that homogenization would disrupt the colloidal matrices in the milk streams.

A standard two-stage dairy homogenizer was connected to the high concentration stream as indicated in Figure (3-7). Homogenization pressure was applied at 2500 psi after steady state conditions were achieved. Unfortunately, the heat generated during homogenization melted ice crystals and resulted in fluctuating concentrations. It was then decided to take samples of milk concentrates from production at steady state and measure viscosities pre- and post-homogenization under controlled temperatures (4°C).

The data obtained indicated that homogenization dropped viscosities 50% for whole milk and 18% for skim milk. This test indicated that, given good temperature control, homogenization on a similar process could be of future benefit for improving freeze concentration efficiencies for whole and skim milk streams.

Conclusion

The pilot plant work revealed a better understanding of the technology and led to new modifications in the filter design, its locations in the crystallizer, elimination of the holding vessel, and the use of a thickener. All these steps were incorporated into the PDU structure. Proper evaluation of crystallization processes was not possible on the pilot plant unit so further testing was undertaken on the PDU unit.

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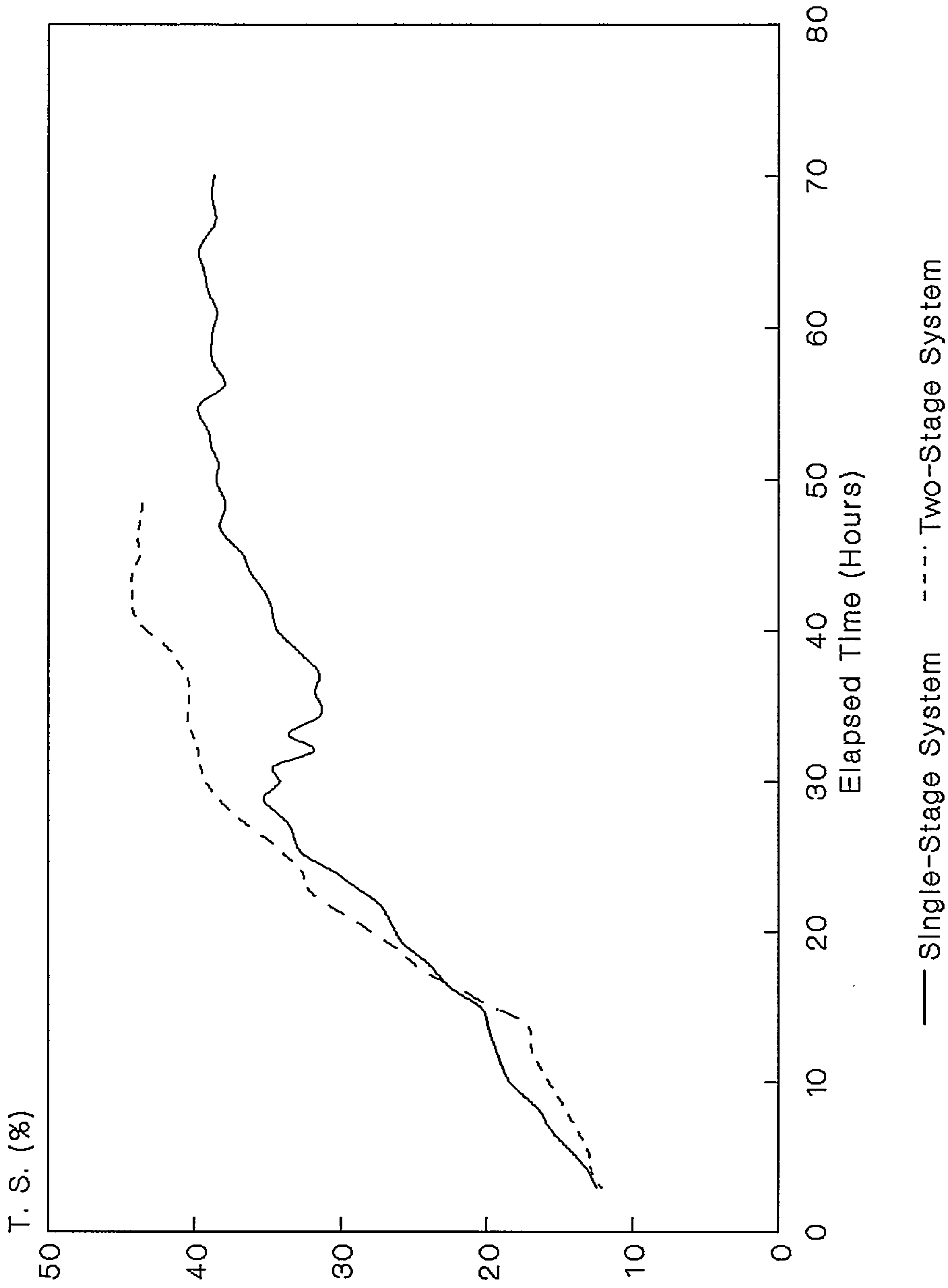


Figure 3-5
Whole Milk Concentrations - Comparison Between Two Systems

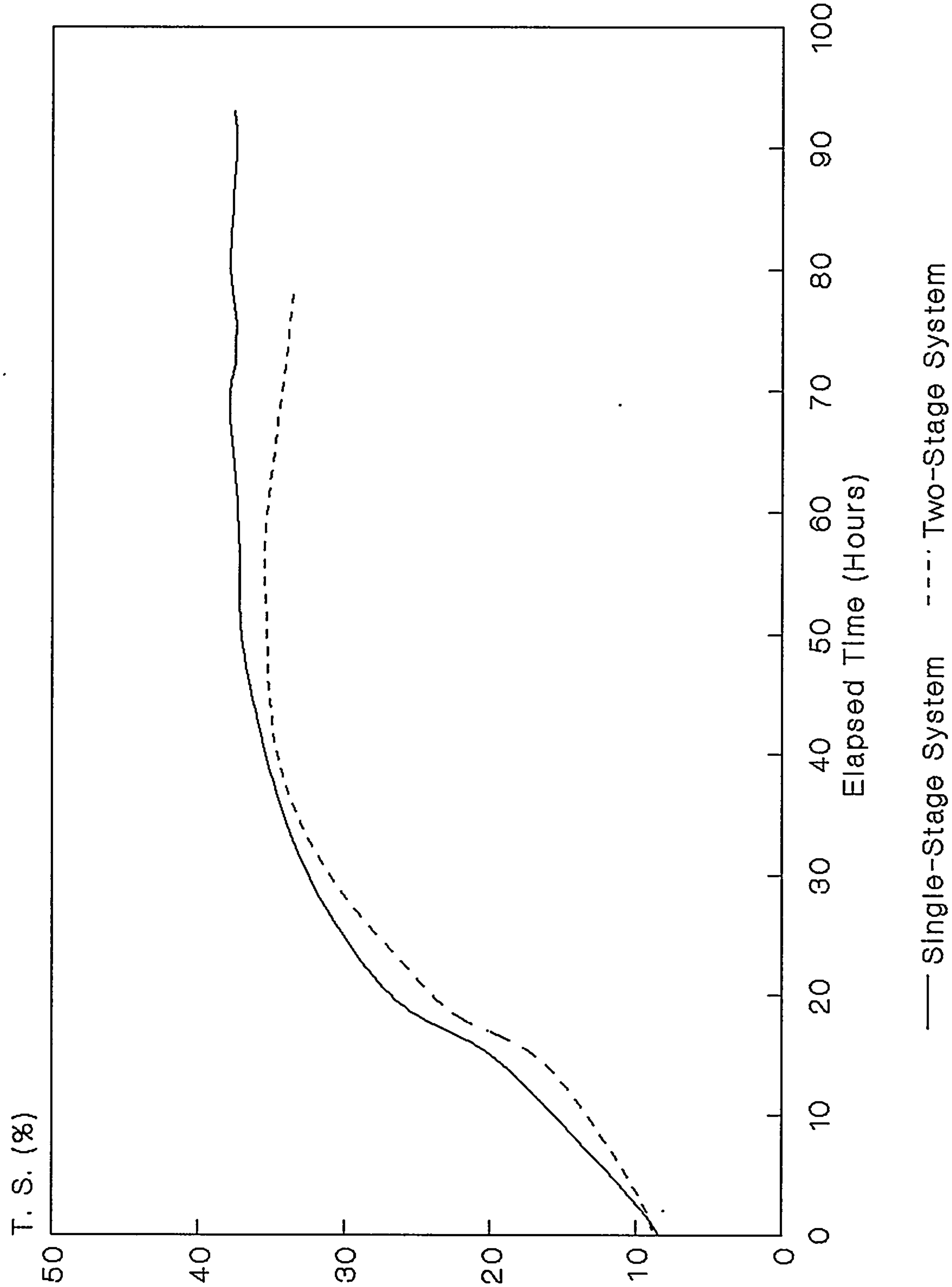


Figure 3-6
Skim Milk Concentrations - Comparison Between Two Systems

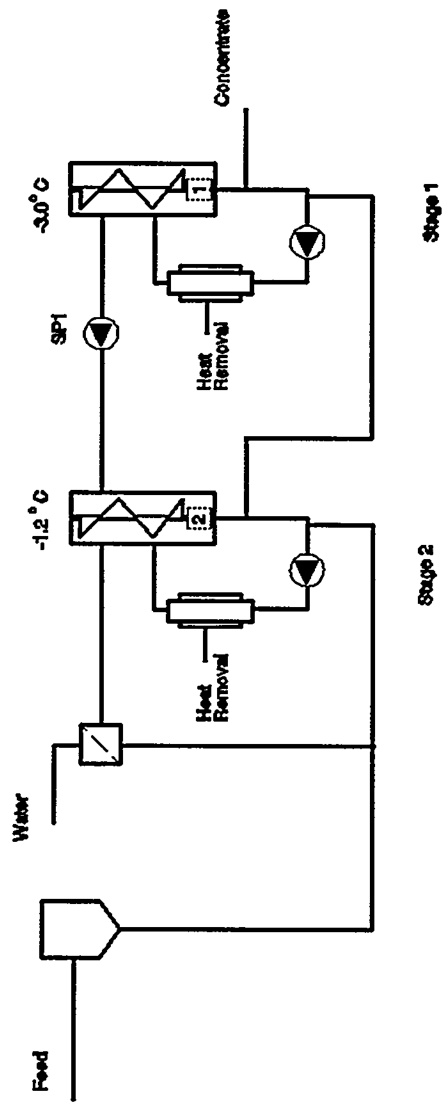


Figure 3.4. Flow diagram of two stage system

On the basis of the pilot plant results, it was decided that two fluid milk streams would be used as the test models for the PDU runs: skim milk (representing a high-casein model) and whey protein concentrate (representing a high-albumen, high-lactose model). The two milk streams were also deemed to be the most likely to offer added-value benefits for the dairy industry. The various runs were intended to determine the process parameters for optimum performance of the freeze concentration of these two products.

4

SEMI-COMMERCIAL PROCESS EVALUATION

Niro PT Process Development Unit (PDU) Evaluations

On the basis of data accumulated during the Phase I and Phase II pilot plant trials, a two-stage PDU crystallization and separation unit, developed by Niro Process Technology B.V. (formerly Grenco P.T.), was configured for use in the commercial scale-up portion of the Phase II trials. Major objectives of this phase were as follows:

* Install, shake-down and establish operating specifications for the two-stage Niro PDU unit. Operate the installed PDU unit to perform to manufacturer's performance specifications.

* Modify the PDU, as needed, in order to obtain regulatory confirmation that the unit conforms to dairy process sanitation standards.

* Develop operating manuals for the Niro PDU freeze concentration unit.

* Characterize fluid runs on the PDU and attempt to surpass the performance specifications obtained from pilot plant runs. Establish maximum operating times and down-time requirements.

* Collect operating data that will permit Niro engineers to model the processing of fluid milk streams and optimize equipment efficiencies and configurations.

* Collect energy utilization data on the two-stage Niro PDU to establish a point of comparison between the PDU freeze crystallization unit's energy requirements as compared to those of competitive technologies.

* Monitor ice crystal formation in the PDU and develop working models for the crystallization process.

Configuration

A schematic diagram of the two-stage Niro PDU is presented in Figure 4-1 and a fully annotated process flow diagram is presented in Appendix B.

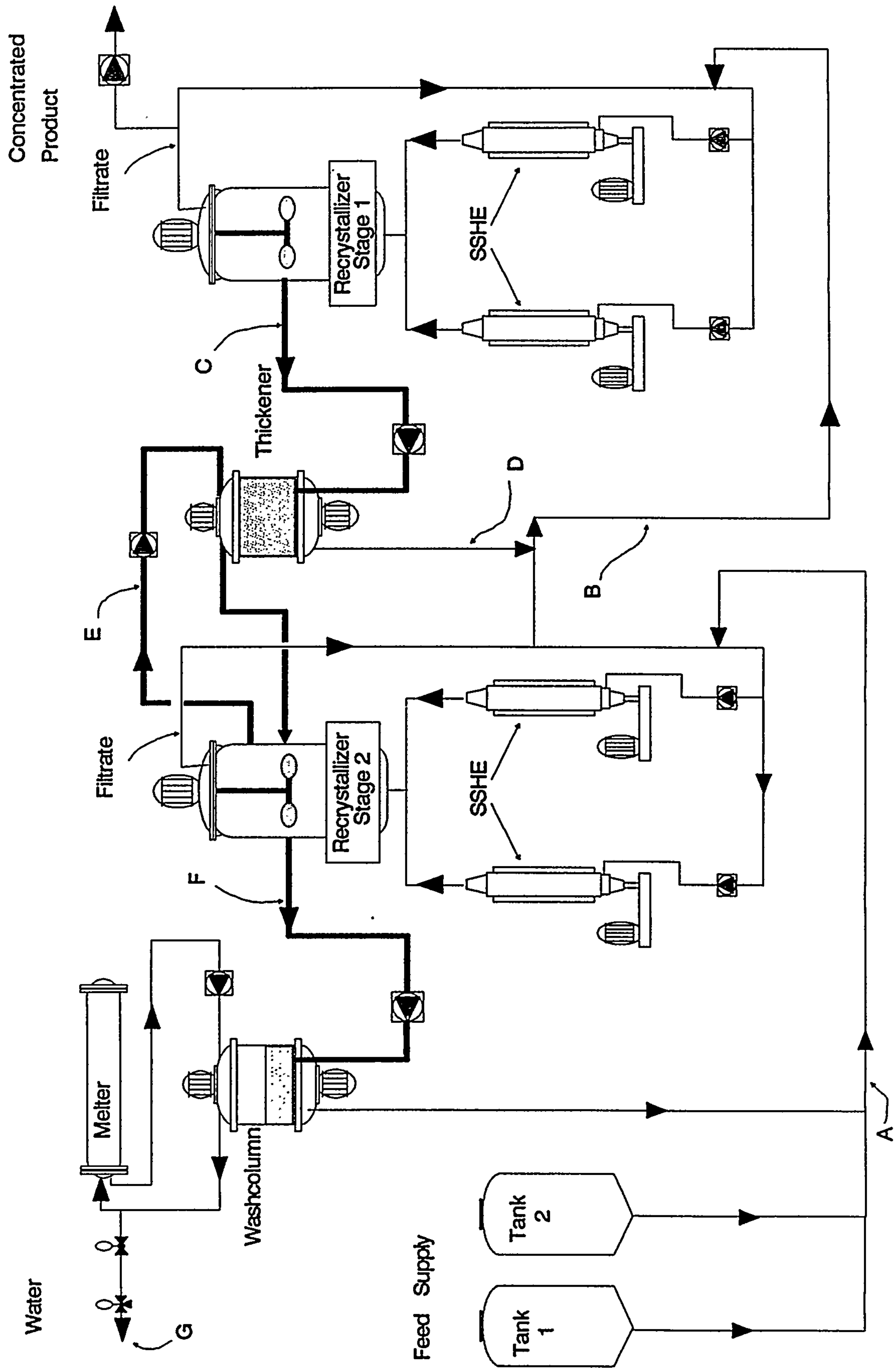


Figure 4-1. Schematic diagram of the two stage PDU

In two-stage processing, the feed enters the system through the freezer units or scraped surface heat exchangers (SSHE) via line A. The stream is mixed with filtrate from stage 2 before entering the SSHE's, whereupon part of the water is converted in to ice crystals. This stream of ice and concentrated product enters the recrystallizer where the small crystals formed in the SSHE will melt and recrystallize onto the surface of the larger crystals already in the recrystallizer. This ripening process is what produces the pure ice crystal that is later separated and discharged as pure water. The recrystallizer is equipped with a filter which provides a crystal-free stream for recirculation over the SSHEs and the "feed" for stage 1.

The concentrate produced in stage 2 enters stage 1 through line B where it passes through the SSHEs for the final concentration step. The concentrated product is removed from the filtrate stream of stage 1. This completes the path followed by the product from the time it enters the system until it can be discharged as concentrate. The ice travels in a countercurrent flow to the product.

The ice produced in stage 1 is pumped to stage 1 through line C. This stream contains approximately 70% liquid concentrate, most of which is returned to stage 1 via the 'thickener' through line D. The thickener is simply a means to filter this concentrate from the ice and return it to stage 1 while allowing the ice crystals to be transported to stage 2. The flow from line E carries the ice from the thickener into stage 2.

The flow in line F carries all of the ice produced in stages 1 and 2 to the wash column whereupon it is separated and discharged as pure water at point G. The waste heat in the discharge gas of the refrigeration unit is used to melt the ice providing additional energy savings.

Since the system operates at freezing temperatures there is no chance for heat damage to the product other than what has been incurred by cornal pasteurization. This eliminates the need for a daily shutdown to clean the system. The feed supply is the only part of the process that operates above freezing temperatures. Therefore, two tanks are installed so that they can be alternately cleaned while the system remains in operation. The sanitary design of the whole process, including dual feed tanks, provides that the system can operate for extended periods without loss of production time. This reduces product loss, cleaning supply usage, and waste disposal.

Performance Specifications

The configuration chosen provided sufficient quantities of concentrate for further product evaluations. The requirement was to provide a minimum dewatering capacity of 350 kg. (770 lbs.) per hour for two dairy streams: skim milk and whey protein concentrate.

Niro guaranteed that for whole milk the Niro PDU would be configured to yield a targeted 40% (by weight) product concentration from an 11% (by weight) feed stream. In addition, solids loss in the melt water would be less than 0.1% by weight. These were based upon the following specifications for whole milk:

-Feed concentration: Min. 10 Wt.% - Max. 12 Wt.%

-Feed temperature: Max. 4°C (37°F)

-Insoluble solids in feed: Less-than 0.5% vol/vol

-Freezing temperature at product concentration: Min. -2.5°C (27.5°F)

-Viscosity of product: Max. 70 mm^2/s at 40 (weight%)
Max. 20 mm^2/s at 30 (weight%)

-Design condenser water temperature: Inlet: 25°C (77°F)
Outlet: 32°C (90°F)

-Flow rate condenser water: Approx. 14 m^3/h (61 gpm)

-Power requirements for the PDU were approximately 180 KW for the connected motor and 108 KW consumption at design conditions.

-The PDU uses R22 refrigerant. The estimated refrigeration load is 61 KW (86°F/-16°F).

The PDU is constructed of 316 grade stainless steel utilizing guidelines set forth by the 3-A Standards Committee. Since the objective was to run the PDU for extended runs of a week or more without shut-down or cleaning, careful consideration had to be given to detailed construction of the PDU.

The PDU installation and initial performance test was done by Niro technicians according to Niro specifications.

Installation and Process Modifications

The PDU was installed at Galloway West between June 1 and August 15, 1991. Installation and shake-down trials took six months. The first three months were marked by mechanical difficulties but no bacterial difficulties. Modifications were made in the second three months during which operating modifications had to be made to address a bacterial contamination problem.

The primary equipment problems addressed were as follows:

Scraped Surface Heat Exchanger

Plastic Knives: Plastic knives in the original heat exchangers were unable to produce ice crystals at the desired rate. When the ice making temperature of slurry was reduced, the plastic knives broke and created more operational problems, it was then a decision was made to replace them with stainless steel knives. This required a design change in which the original "hooks" on the shaft (to which the blades were attached) were removed. The shafts were polished and new screw cavities were drilled on them so that the metal blades could be attached to the shaft by using a screw mechanism. Though the wear on these new stainless steel knives was more than ideal, it was expected to improve with time as further refinement of the heat exchanger design was made.

Knives Connectors: The sealing threads of the stainless steel screws on the modified shafts created a microbial contamination problem. This was eliminated when the additional gaskets were placed on the screws and the screws were fastened with proper torque.

After spot checking the PDU following each run, and examining it in detail approximately once per month, it was determined that the main wear parts on the PDU are the SSHE knives and the filter knives. The estimated lifetime of these knives is one year for a standard filter and six months for a modified filter design.

Shafts: The new modifications also resulted in unexpected cracks and leaks in the center hollow cores of the shafts and thus product contamination problem reappeared. Finally the problem was resolved when Niro replaced the problem shafts with the brand new shafts with the factory installed blades that practically met the 3A Standards.

Pressure Transmitter: An in-line membrane of the pressure transmitter cracked. The cause was not determined and the transmitter was replaced.

Bearing Bushes: The PVDF bearing bushes which were shrink-fit when assembled came loose. This was determined to be attributable to the higher cleaning temperatures required in the system. New tempered bearing bushes were provided and the problem disappeared.

Recrystallizer

Filters: A new recrystallizer with a modified filter design was installed during the first week of July, 1992. The original flat recrystallizer filter was replaced with a standard cylindrical filter. Given that the new design did not meet 3A Standards, the new recrystallizer received a temporary one-year permit to produce Grade-A milk by the Wisconsin Department of Agriculture. The new recrystallizer design was more efficient and delivered approximately 3.5% greater concentration than did the previous design.

Washcolumn

Deposits: A powdery substance was discovered beneath the filter and on top of the inner cylinder of the washcolumn. This was determined to be due to salting-out of the hard water and a cleaning agent. The washcolumn velocity was adjusted and the problem disappeared.

Sheet Packing: The sheet packing would not stay in its groove. This was attributed to a USDA-requested design change made two years prior to installation at Galloway West. New gaskets were designed.

Vacuum-Brazed Connections: Although these are made of gold, some oxidation was detected, possibly due to the alloy materials. Niro is working on alternatives.

Water Quality

Fond Du Lac's water quality was very poor. The water had high levels of rust, silica, total hardness, dissolved solids, chloride, and coliform. A water filter and softener were installed.

Line Integrity

The 3-A certified positive pumps developed leaks on the "O"-ring seal shortly after installation. This was resolved. Welds in some of the connecting lines were poor, with more than 10 holes discovered close to the welds. Corrosion was also discovered in the balance tanks and had to be addressed. Mechanical seals leaked, which was attributed to rust particles sticking to the flushing chambers. A grease which dissolved the EPDM "O"-rings was replaced by a silicon-based grease.

Bacterial Contamination

Problems with Coliform bacteria and Enterobacter Cloacae contamination developed during the second half of the PDU installation phase. Sources of these organisms are typically water, animal products, sewage, hospital environments, or poor human sanitary practices. The behavior of these organisms was studied at 0°C and 32°C. It was determined that such organisms may initially survive at 0°C but will gradually die off. Since PDU operating conditions are below freezing, outgrowth of these organisms should not prove to be a problem (Figures 4-2 and 4-3).

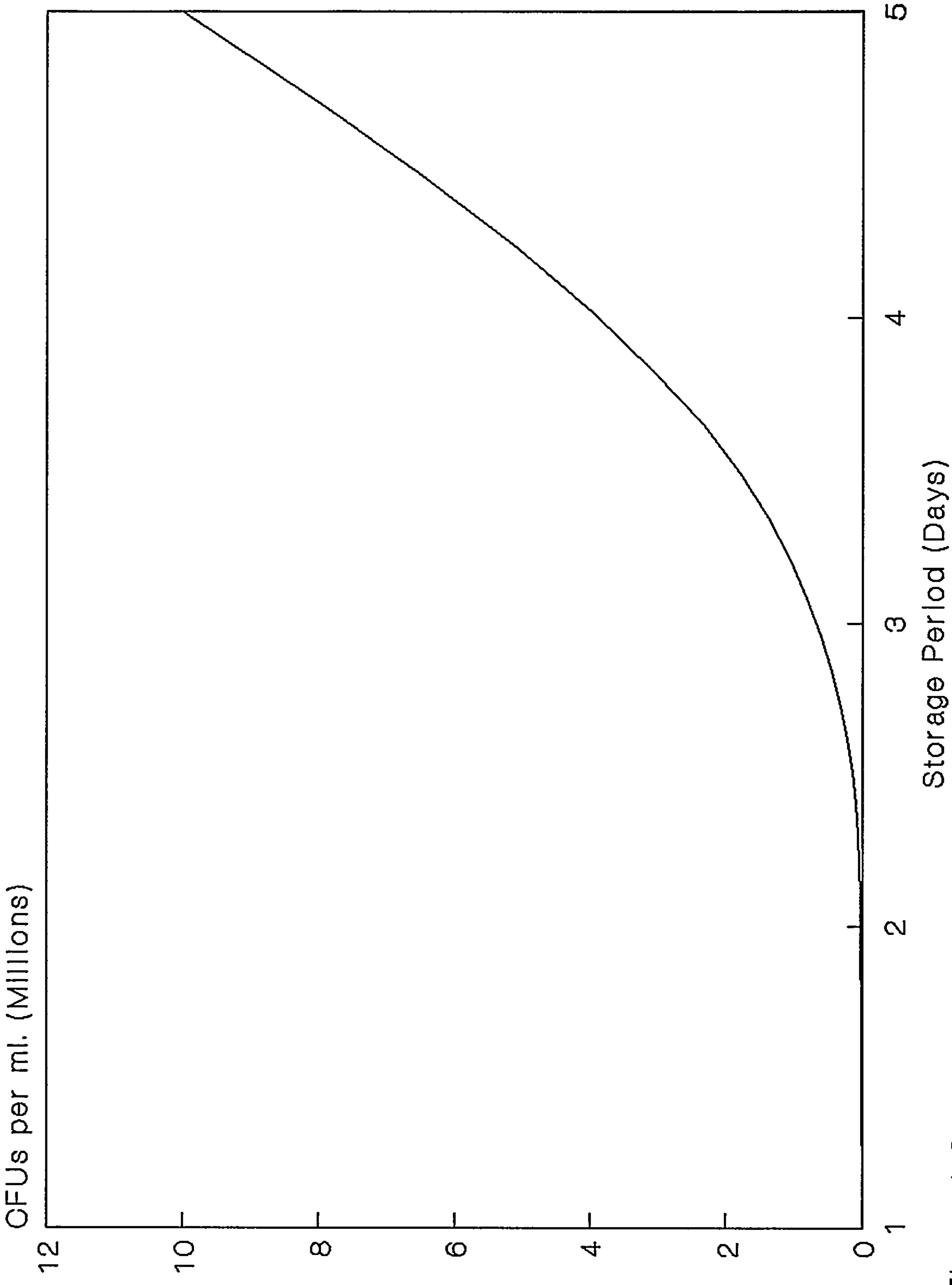


Figure 4-2
Enterobacter Cloacae Growth In Freeze Concentrated Skim Milk Samples Stored at 32°C.

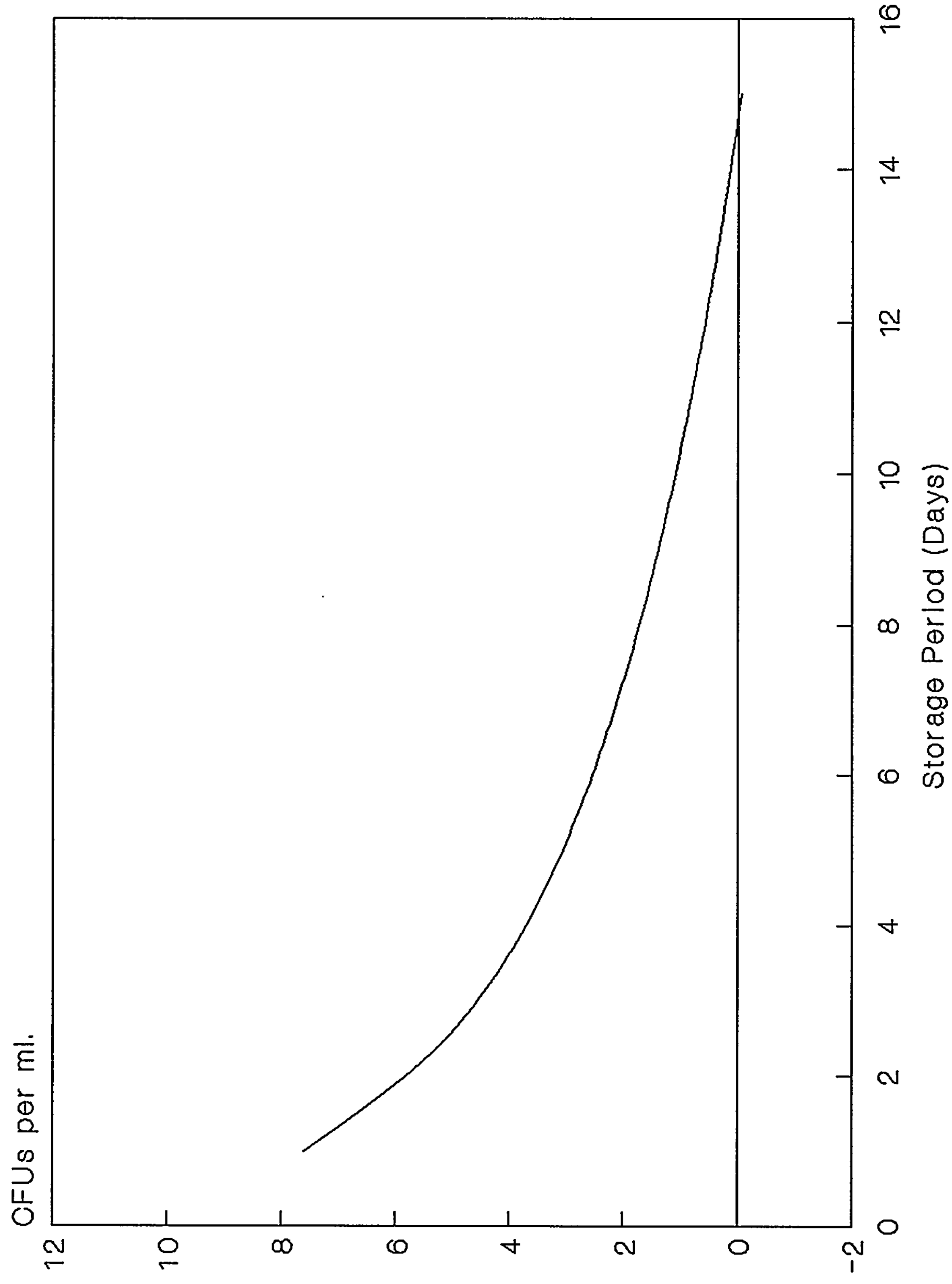


Figure 4-3
<u>Enterobacter Cloacae</u> Growth In Freeze Concentrated Skim Milk Samples Stored at 0 °C.

In addition to the problem points addressed in the preceding section on "INSTALLATION," possible problem areas were corrected at each point to insure that the unit would meet all subsequent inspections. The redesigned ice filter did not perform as expected. A petition was submitted to the USDA and Wisconsin Department of Agriculture to install the recrystallizer with the standard filter design. After a thorough inspection of the installed recrystallizer before and after the production run, USDA officials confirmed the cleanability of the system and subsequently granted a waiver from current 3-A Standards. The following steps were taken to eliminate Coliform organisms from the process:

* Changing the water supply: A water softener was installed to remove rust and decrease water hardness. This improved mechanical seal performance. All seal flushing water should be deionized and bacteria free.

* Chlorinated water was used to flush the seals and reduce incidental contamination.

* The extra sampling valve between the two stages was removed and replaced by a piece of stainless steel line. A hole in the pipe fitting was discovered inside the insulation at this valve.

* The pressure sensors that developed cracks were replaced.

* A thorough clean-up and sanitation of the plant was completed prior to the start of Run #10.

Coliform counts were carefully monitored during three extended runs conducted on two lots of skim milk and one on whey protein concentrate. One run operated on a steady basis for 510 hours (approximately 21 days).

As a consequence of processing and equipment adjustments made, the resulting average Coliform count for milk concentrate fell to 67.5 and the average count for whey protein concentrate was 185.5. It was noted that whenever counts in the skim feed were high, they were also high in the concentrate that followed. It was also concluded that no apparent growth in bacterial populations occurred during extended runs (see Figure 4-4).

Sanitation and Regulatory Approval

The PDU was inspected by the USDA and the Wisconsin Department of Agriculture during the initial design stage, unit construction, testing, and finally during installation and start-up at Galloway West. The PDU system was granted Grade A certification (Appendix C).

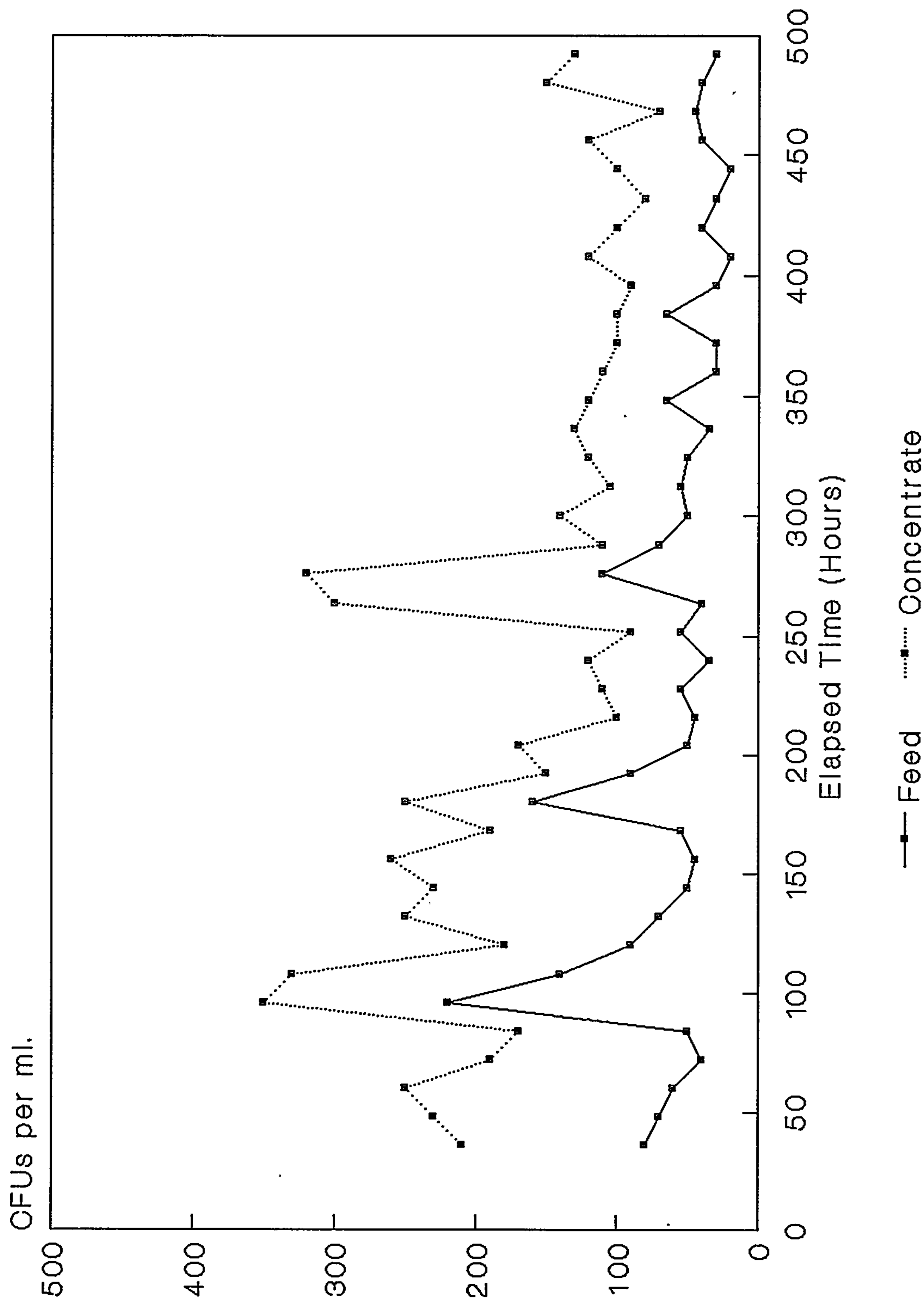


Figure 4-4
Bacterial Counts of Skim Milk During Extended Run

Operating Procedures

Operating procedures were established for the PDU and operator manuals were prepared by Niro.

A typical test can be broken-down into the following operations:

Preparing Unit for Production

The unit is generally stored filled with water to protect the gaskets and seals. The system has a hold-up volume of approximately 6500 liters (1700 gallons), including the balance tank. The first operation in this step is to drain the water and sanitize prior to filling with product.

Charging PDU with Product

Once the PDU is properly sanitized and drained, the product is pumped into the system and air-purged via valves at the top of the two recrystallizers. It is important to purge the system completely during this stage. The washcolumn remains filled with the sanitizer since it will not be started at this point.

Ice Production for Start-up

Once the unit is filled with product and purged the components can be put into operation and the product can begin cooling. The objective is to cool the product down to its equilibrium temperature or freezing point and then produce approximately 30% ice in each recrystallizer before starting the ice removal. Maximum ice percentage is favorable for crystal growth but fluid mechanics limit the flow of this slurry when there is 30 to 35% ice by weight.

Ice Making Operation

The product is recirculated from the recrystallizer through the SSHEs by positive displacement pumps. The filter in the recrystallizer provides a crystal-free stream to the positive displacement pumps.

The refrigerant temperature is controlled by adjusting the desired temperature on the suction valve controller in the control panel. The operator can then adjust this temperature to achieve the desired cooling rate, generally around 10°C (18°F) colder than the product temperature. The ice percentage is calculated from comparison of the concentrations of the filtrate stream and slurry stream with the amount of ice melted. A standard start-up would cool the product down from 4°C (40°F) and produce 30% ice in each recrystallizer within four hours.

Ice removal from the washcolumn can begin once the recrystallizer reaches 30% ice. While the system is removing ice, the feed product replaces the discharged water resulting in a net input of solids into the system. The remaining liquid in the system increases in total solids. Ice removal continues until the desired production solids level is achieved.

During concentration, the freezing point of the product will decrease due to the increasing solids concentration. The operator must lower the refrigerant temperature in order to maintain sufficient ice production. This is observed by the ice percentage readings: Constant ice percentages indicate that ice production rates are in balance with ice removal rates.

The concentration period depends on the feed concentration, desired product concentration, and ice removal rates. Final product concentration in multi-stage units is generally limited by the viscosity of the product at its freezing point. The ice removal rate is limited by viscosity and crystal-growth rates and would decrease as concentration increases. Ice removal is usually set at the desired rate for the final production specifications. For start-up the system should be taken to maximum concentration whereafter the concentration should be reduced in order to obtain maximum textural improvement as the feedstream viscosity increases.

Concentrate Production

Once the desired end-product concentration has been attained the product output pump is started and production rates are adjusted so that solids-in equals solids-out. The system is then free to stabilize to steady-state values.

Ice-production and ice-removal rates can be controlled to maintain a constant ice percentage in each recrystallizer. Product removal rates can also be controlled to maintain a constant product concentration.

All components of the system beyond the feed-balance tanks, are held below freezing temperature (in reference to water) while the heat-exchange surfaces are continuously swept. This reduces microbiological activity. Consequently, the system does not require periodic cleaning. However, as in all traditional dairies, the balance tanks and feed supply system are cleaned daily to prevent contamination.

Production can in principle continue virtually indefinitely limited only by equipment maintenance requirements. Careful monitoring of bacterial counts in both the feed and end-product material will ensure the safety of the system.

Shut-Down and Drain

When production has been completed the refrigeration can be shut down (or capacity reduced) to allow the ice concentration to drop. When ice percentages drop below 5%, the unit is shut down and remaining product is pumped back to supply tanks.

Cleaning

The freeze concentration process is not a typical plug-flow type process and does not fit into standard CIP procedures. The system must be flooded and Cleaned-in-Place as if in operation with cleaning solution. To achieve the necessary velocities in the system, the motors are equipped with a dual speed setting for normal operation and high-speed CIP.

The system was drained to collect majority of milk solids. Then it was rinsed with water to remove any remaining dairy solids prior to CIP operation. This rinse was generally low enough in residual milk solids that it was discharged directly into the drain. The system is filled with a 0.5% caustic solution, heated externally, to a maximum of 60°C (140°F) and circulated for 1 to 4 hours. This is followed by a water rinse and then a 25 ppm chlorine sanitizer run for 30-minutes before filling with product.

Operating Results

Skim Milk

The longest run on the PDU was conducted March 6, 1992 with skim milk . The run lasted 510-hours and produced an average 32.3% total solids with a range of 8.8% to 37.3%. The average ice concentration in stage 1 was 29.6% with a standard deviation of 6.2% T.S. Pressures in the stage 2 crystallizer were normal during most of the run. The system operated at 2.3 bar pressure. The wash-water (melt) output was 315.8 liters/hour with an average conductivity reading of 0.4 millisiemens. Feed viscosity ranged from 66 to 319 cst while lactose precipitation was at maximum 12.2%.

Whey Protein Concentrate

The WPC run of July 26, 1992 lasted 98-hours. During 70-hours of steady state production, 1,400 gallons of concentrate averaging 41.2% total solids, were produced. The maximum concentration achieved was 43.0%. The maximum viscosity of concentrate reached 200 cst. at 42.5% total solids and maximum lactose precipitation occurred was 6.70%. The dewatering rate during the steady state period was 518 liters per hour with a range of 300 to 554 liters per hour. Average conductivity of the wash-water was 0.9 millisiemens.

Lactose Crystallization

Lactose crystallization in the feed stream is perceived to be a major wear factor on the PDU system particularly with respect to the SSHE blades. Lactose crystallization could prove to be a major production bottleneck for extended runs as SSHE blades currently must be replaced every 30 days. Metal abrasion by the lactose crystals could also result in metal contamination of the milk product and undesirable metal-catalyzed oxidative deterioration of the product. Reduced lactose crystallization could significantly extend the shelf-life of both the SSHE blades and freeze-concentrated products.

A decanting technique was explored as a means of decreasing the lactose content of the feed stream. A lactose decanter provided by Centrico Inc was installed into stage 2 of the PDU during the second week of November, 1992. It was anticipated that operation of the decanter should drop lactose/protein ratios from more than 1.0 to 0.7 or less.

The total system was tested with skim milk as the feed during a 198-hour production run. Decanting was initiated during an 18-hour period when steady-state conditions had been reached. Maximum concentration achieved during the run was 39.4% total solids at which time lactose precipitation attained 10.2% and subsequently increased to 13.0%. Only small amounts of lactose were removed via decanting. There was an insignificant change in the total solids content of the concentrate prior to and following the period that decanting was in effect (Table 4-1), and lactose/protein ratios did not fall below 1.33 (Table 4-2). Other lactose removal techniques need to be evaluated if lactose removal continues to be considered a desirable objective.

Table 4-1
Lactose Decantation

		% Total Solids		
Date	**Time**	**Pre-lactose Removal**	**Post-lactose Removal**	**Difference**
11/19	10:30am	38.7	38.3	0.5
11/19	12:30pm	38.7	38.9	0.8
11/19	2:30pm	37.4	36.2	1.2
11/20	11:30am	37.3	37.3	0.0
11/20	4:30pm	38.7	38.3	0.4
11/21	11:15am	37.5	37.3	0.2
11/21	2:15pm	38.1	38.1	0.0
11/21	4:15pm	38.1	38.0	0.1

Table 4-2
Lactose: Protein Ratio During Lactose Decantation

Sample No.	Time	% T.S. Samples*	% Lactose	% Protein	L/P
1	12:00pm	10.00	5.20	3.78	1.38
2	6:00pm	10.00	5.19	3.78	1.37
3	10:00pm	10.00	5.14	3.81	1.35
4	2:00am	10.00	5.14	3.80	1.35
5	6:00am	10.00	5.10	3.83	1.33
6	9:00am	10.00	5.10	3.83	1.33

* Concentrate samples were diluted to 10% T.S. to run laboratory analysis

Conclusions of lactose removal studies

1. Type of decanter: The Centrico Inc. concluded that the decanter model did not work in the PDU trials because the lactose crystals developed during the process were too small and were beyond the operational range of the model used.

2. Viscosity: The open design of the decanter caused excessive foaming of the concentrate in stage 1. This increased the viscosity of the concentrate to very high levels that interfered with ice production. This caused the percentage of ice crystals to drop quickly, making it difficult to maintain steady-state conditions.

3. Heat exchanger capacities: The heat exchangers reached maximum capacity because of the increased concentrate viscosity and excessive heat loads generated during the decantation. This may have occurred because of the poor insulation on the decanter setup and a greater surface area in the decanter. It was concluded that in order to compensate for the additional heat input from the decanter a third heat exchanger was needed.

Ice Crystallization

Niro developed a special device to visualize the ice crystals. The ice crystals are diverted through a sample block in which they are exposed under a small piece of glass through which they are magnified and photographed. Ice-crystal photographs can be taken at any moment during a run in order to obtain a "representative" view. Ice crystal "size" is measured in terms of length. Surface area and volume are calculated from the crystal diameter. Using a video camera, the photos can be digitized to a computer screen in order to determine ice-crystal size distribution using a specially developed computer program.

Two runs were conducted on skim milk: a five-day run conducted March 3-10, 1992 and a second run conducted April 3-5, 1992. Ice crystallization was studied using the Niro computer program during both start-up and steady-state operating conditions. Average ice crystal size as a function of feed concentration is presented along with photographs in Figures 4-5, 4-6 (stage 1) and 4-7, 4-8 (stage 2). Operating conditions for those two runs are presented in Appendix D. Average crystal size followed a sinusoidal pattern in both freeze concentration stages. Mean crystal size peaked prior to steady-state feed concentration being attained followed by a troughing and recovery. It should be noted, however, that standard deviations for the ice-crystal size distributions were very high. Typical ice-crystal distribution profiles are presented in Appendix E.

Process parameters had a significant impact on ice crystal size. The most important variable was plant performance indicating that most parameters which affect ice crystal size distribution are fixed. Lactose precipitation made it difficult to analyze the crystal photos, particularly in stage 1.

The following conclusions were arrived at on the basis of these two runs and those conducted on the pilot plant unit.

1. Average crystal size for both skim milk and whey protein concentrate is relatively large (750 microns +/- 300 microns) compared to the average crystal sizes of crystals obtained during the freeze concentration of coffee, beer or citrus.

2. Processing start-up is accompanied by a sudden drop in average crystal size. This is happening because of the high growth rates during the long start-up (during these runs) at which time the concentration and viscosities were low. Under these conditions large crystals are formed. An increase in concentration will bring a sudden drop in crystal size.

3. Ice-crystal size profiles followed a sinusoidal course during the freeze concentration processes. According to Niro, this would be indicative that the process had not achieved steady-state conditions.

Figure 4-5
Ice Crystal Photograph of Skim Milk Slurry from Recrystallizer 1

Figure 4-6
Ice Crystal Photograph of Skim Milk Slurry from Recrystallizer 2

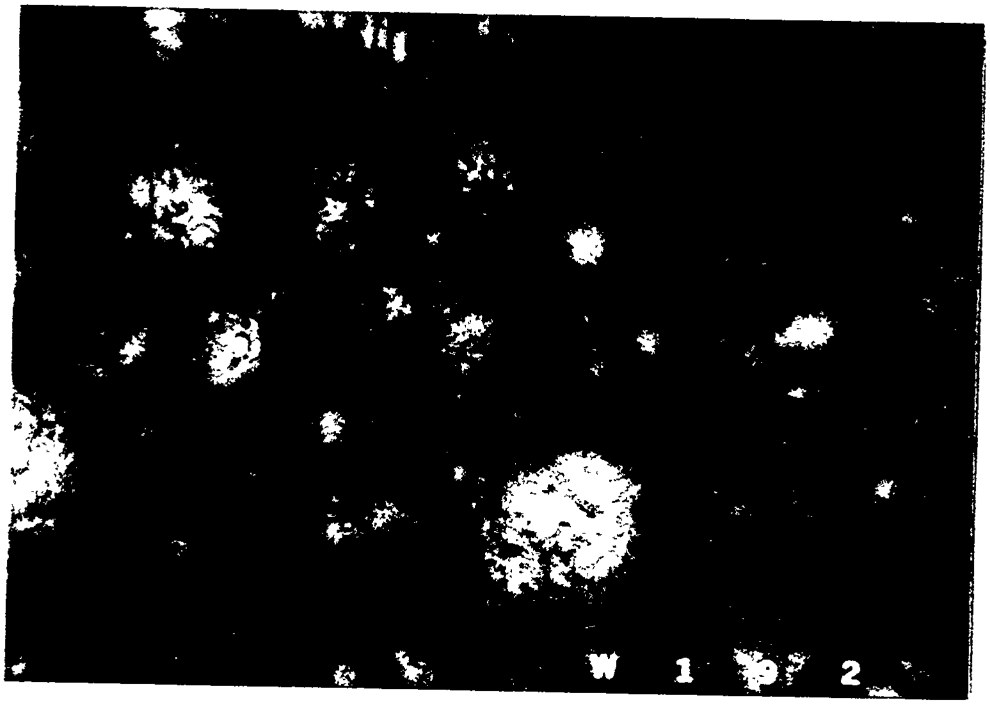


Figure 4-7
Ice Crystal Photograph of WPC Slurry from Recrystallizer 1

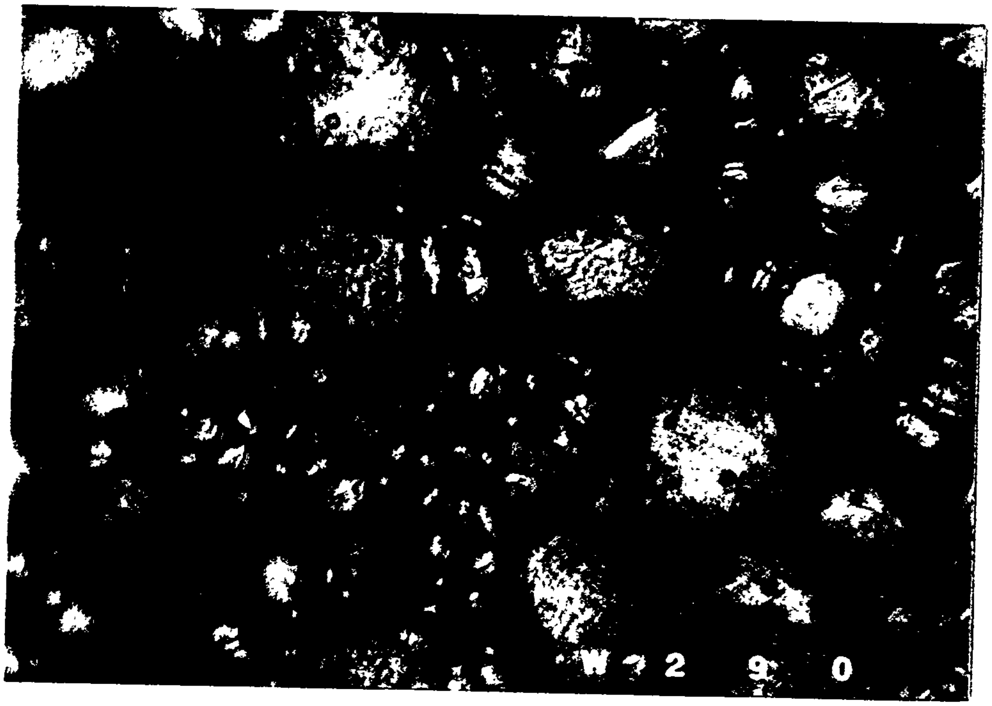


Figure 4-8
Ice Crystal Photograph of WPC Slurry from Recrystallizer 2

5

ECONOMIC ANALYSIS

Economic Assumptions

A preliminary economic analysis of the relative operating efficiencies of freeze concentration, thermal vapor recompression (TVR) and mechanical vapor recompression (MVR) evaporation systems was undertaken with the following assumptions:

- CIP chemical costs and energy costs per CIP cycle were the same for all three systems.
- MVR and TVR require 4-hours of CIP per day against one-day per month for freeze concentration.
- Labor costs were the same for all three systems.
- Electricity costs were fixed at $0.035 per kwh while steam energy costs were fixed at $3.50 per 1,000 lbs. of steam.
- Conversion factors used for Btu calculations were as follows: 1,000 Btu's per lb. of steam and 10,500 Btu's per kWh of electricity. The conversion factor for electricity was supplied by EPRI and reflects inefficiencies in the production of electrical energy.

Comparative economic valuations were done based upon the costs the three systems did not have in common: These were termed 'differential operating costs.'

Energy utilization by the PDU was monitored at the following points:

- The ice scraper for the thickener
- The ice scraper for the washcolumn
- Transporter (thickener)
- Transporter (washcolumn)
- Scraped surface heat exchangers (4 units)

- o Recrystallizers (2 units)
- o Compressor

The MVR and TVR energy operating cost data was based upon industry data collected and supplied by Niro Process Technology through their extensive contacts in the field of MVR and TVR technologies. It was presented as being typical of those processes. The stated production capacity for the TVR and MVR systems was 33,776,203 lbs. of solids per year against a production capacity of 12,379,443 lbs. per year for the PDU. Complete breakouts of the cost assumptions used in the economic analyses for freeze concentration (PDU and commercial scale), MVR and TVR are included in Appendix F.

Freeze concentration results were based upon one run of skim milk concentrated to 31.3% T.S in a 430 lb./hr. run, and one run of whey protein concentrated to 41.5% in a 252 lb./hr. run.

Results

The PDU freeze concentrator's differential operating costs were slightly higher than those for TVR and MVR evaporation (see Table 5-1). Operating costs for freeze concentration on the PDU, which include the cost of steam for pasteurization, amounted to $0.01320 per pound of product produced, compared to $0.01289 per pound for TVR and $0.01225 per pound for MVR. At first glance, freeze concentration would not appear to be as coat efficient as MVR evaporation.

However, scale-up projections of operating costs for freeze concentration on a commercial level, which were based upon the PDU data, suggest that freeze concentration should be more economical than either TVR or MVR evaporation on a commercial-scale operating level (see Table 5-2).

Table 5-1
Annual Operational Costs - Commercial Scale TVR and MVR vs. PDU-FC

	TVR		MVR		FC	
	$	%	$	%	$	%
Electricity	19,110	0.90	92,820	26.31	154,791	94.49
Steam	122,850	56.30	27,300	7.02	0	0.00
Losses	260,000	37.53	260,000	58.46	7,451	4.55
Cleaning	33,539	5.27	33,539	8.21	1,574	0.96
Total	435,499	100.00	413,659	100.00	163,816	100.00
Production (Total lbs. solids processed)						
	33,776,203		33,776,203		12,379,443	
Cost/lb. solids						
	$0.01289		$0.01225		$0.01320	

Table 5-2
Annual Operational Costs - Commercial Scale FC vs. MVR and TVR

	TVR		MVR		FC	
	$	%	$	%	$	%
Electricity	19,110	0.90	92,820	26.31	322,140	88.60
Steam	122,850	56.30	27,300	7.02	27,300	7.50
Losses	260,000	37.53	260,000	58.46	11,528	3.20
Cleaning	33,539	5.27	33,539	8.21	2,694	0.70
Total	435,499	100.00	413,659	100.00	363,662	100.00
Production (Total lbs. solids processed)						
	33,776,203		33,776,203		33,158,095	
Cost/lb. solids						
	$0.01289		$0.01225		$0.01097	

A comparative evaluation of operating costs for commercial freeze concentration vs. MVR as a function of steam (for MVR) and electricity costs illustrates the energy cost-elasticity of operational costs for commercial freeze concentration vs. MVR concentration (See Figure 5-1).

The differential MVR operating costs are little affected by changes in either steam or electricity costs. Freeze concentration's differential operating costs, on the other hand, are highly elastic to the cost of electricity. The graph would suggest that commercial freeze concentration is cost-competitive with MVR if electrical energy costs fall below $0.037 and $0.039 per kWh, given the assumptions upon which the calculations were based.

The reasons for the relatively low energy elasticity of MVR's differential operating costs relate to the process's cost allocations.

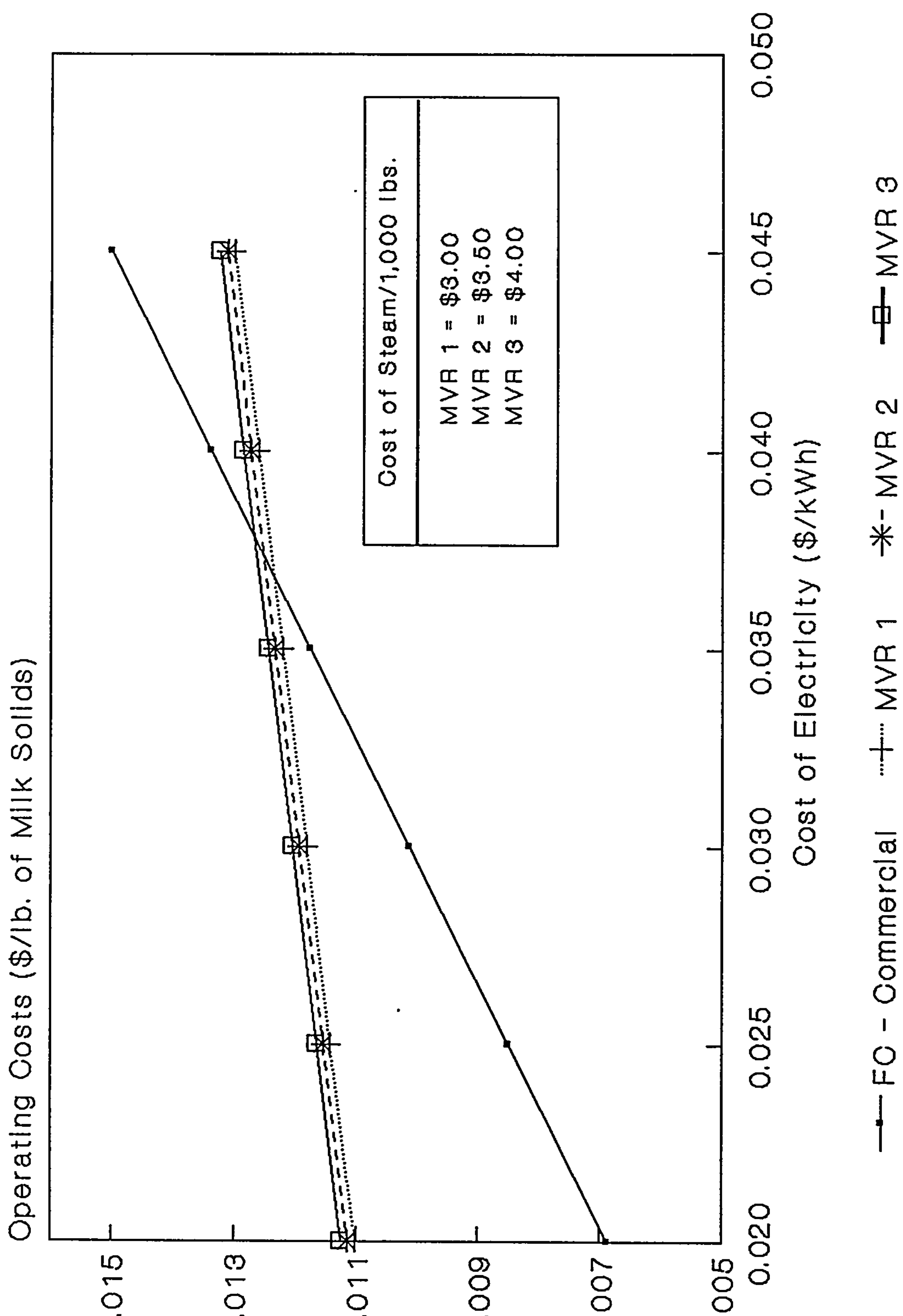


Figure 5-1
Differential Operating Costs

Product losses and electrical energy costs differentiate freeze concentration's operating costs. Electricity utilization represents 94.5% of the PDU's total differential operating costs (Table 5-1, 5-2) and 88.6% for a commercial-scale freeze concentrator, according to the model. The commercial-scale freeze concentration operational cost estimates include the cost of a pasteurization step. This compares to 0.9% for TVR and 26.3% for MVR. The greatest differential cost contributor for MVR is product loss, which represents 58.5% of the costs for MVR. The major differential cost contributor for TVR is the cost of steam, which represents 56.3% of TVR's differential operating costs. Product losses for a commercial-scale freeze concentration unit are only expected to represent 3.2% of the unit's differential operating costs. The operating costs per 1000 lbs. of milk solids processed are presented in Figure 5-2.

All told, energy costs represent 33.3% of the differential operating costs for MVR, 32.6% of the costs for TVR, and a projected 91.7% of the operating costs for commercial freeze concentration. These correlate directly to the energy elasticity of the three technologies' differential operating costs.

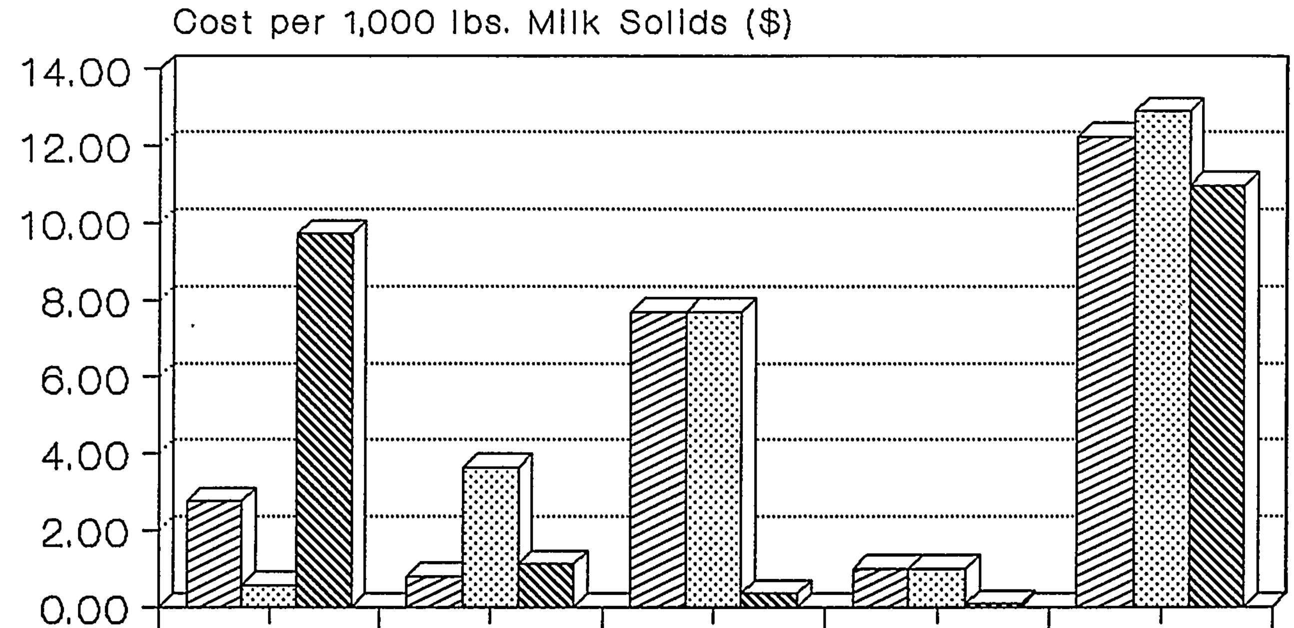
These numbers underscore that relative operating costs for freeze concentration are highly energy cost-elastic while operating costs are relatively energy cost-inelastic for MVR and TVR processing.

Freeze concentration is far less energy efficient than either TVR or MVR evaporation in terms of absolute energy utilization (Figure 5-3). Commercial freeze concentration will require an estimated 3,233 Btu's per 1,000 lbs. of milk solids versus 1,211 Btu's for TVR and 1,053 Btu's for MVR evaporation.

Given that electrical energy represents the greatest operating cost contributor to freeze concentration, it also offers the greatest opportunity for incorporating additional design efficiencies into the PDU and possibly commercial units, consequently shifting the operating cost line for freeze concentration downward in Figure 5-1. In contrast, the elasticity profile for MVR suggests that relatively little is to be gained in operating efficiency by improving the system's energy efficiency.

Refrigeration (i.e., the compressor) accounted for 41% of the energy costs in whey protein freeze concentration and 47% of the energy costs for skim milk freeze concentration on the PDU (See Figures 5-4, 5-5 and Tables 5-3, 5-4). Next in demand for electrical energy were the two recrystallizers, which collectively represented 31% of the total electrical consumption of skim milk concentration and 23% of the electrical consumption of whey protein concentration.

These results suggest that improvements in refrigeration and ice crystallization efficiencies offer two opportunities for improving freeze concentration's operating efficiencies. Consequently, considerable improvements in operating efficiencies could be expected by achieving better control over the process of ice crystallization and improving the refrigeration efficiency of the PDU through insulation.



	Electricity	Steam	Losses	Cleaning	Total
MVR	2.75	0.80	7.70	0.99	12.25
TVR	0.57	3.64	7.70	0.99	12.89
FC - Commercial	9.72	1.12	0.35	0.08	10.97

Operating Costs ($)

MVR TVR FC - Commercial

Figure 5-2
Differential Operating Costs

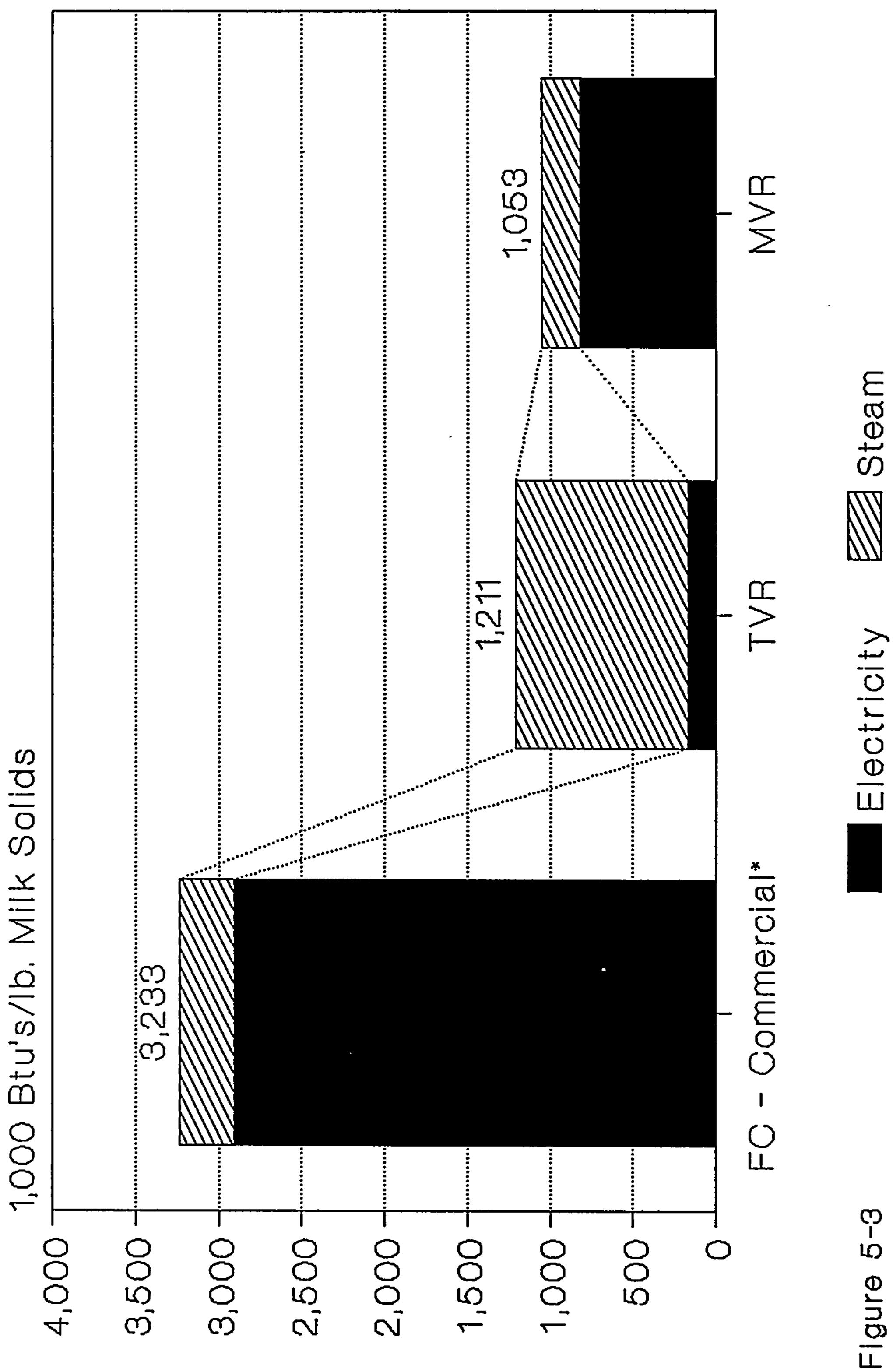


Figure 5-3
Energy Consumption by FC-Commercial, TVR and MVR Plants

* *Includes pasteurization*

Table 5-3
Power Consumption of Skim Milk Run

Power Data

Channel Number	Location	Power Consumption (kW) Average	Max.	Min.	Std.Dev.
1	Ice Scrapper Thickener	0.481	0.532	0.450	0.024
2	Ice Scrapper Washcolumn	1.784	1.903	1.631	0.062
3	Transporter Thickener	1.021	1.073	0.999	0.018
4	Transporter Washcolumn	1.415	2.086	0.880	0.289
5	SSHE #11	2.527	2.593	2.460	0.032
6	SSHE #12	2.537	2.638	2.460	0.049
7	SSHE #21	2.496	2.541	2.282	0.055
8	SSHE #22	2.359	1.517	2.101	0.082
9	Recrystallizer #10	19.118	20.420	18.370	0.663
10	Recrystallizer #20	13.618	13.840	13.220	0.121
11	Compressor	50.238	52.530	44.430	1.731
12	Total	97.567	100.242	90.814	1.759
-	Control Panel & Misc.	9.500			

Operating parameters: Feed concentration 8.38% T.S.
Produt concentration 31.30% T.S.
Production 430.00 lbs./hr. (196.00 kg/hr.).

Power consumption: 97.7 kWh/1000 lbs.(345.7 kWh/MT) water removed.
119.7 kWh/1000 lbs.(215.2 kWh/MT) feed processed.

Equals to W60 components: 70.2 kWh/1000 lbs.(154.5 kWh/MT) water removed.
42.1 kWh/1000 lbs.(92.7 kWh/MT) feed. processed.

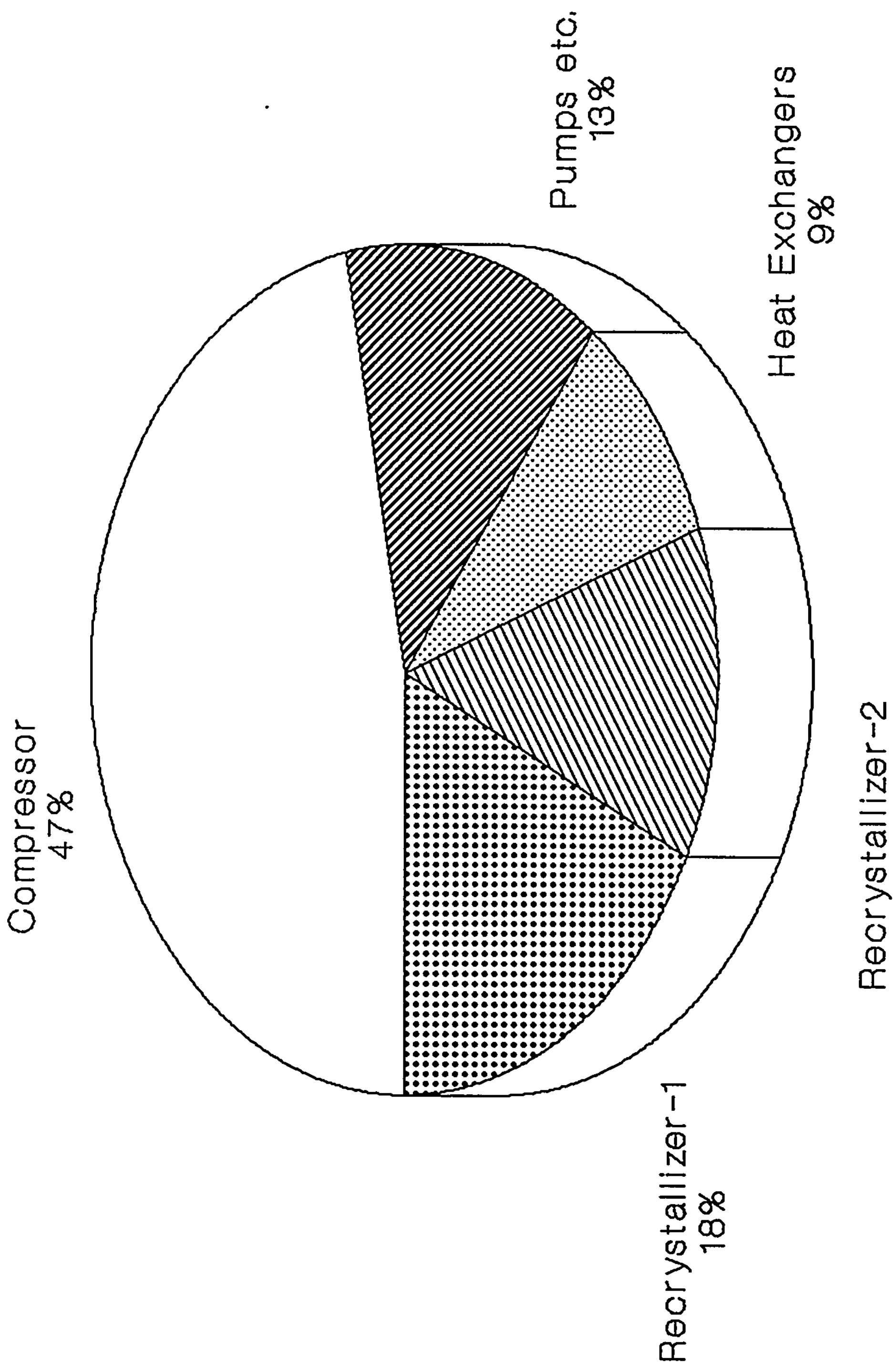


Figure 5-4
Energy Utilization During Skim Milk Run

Table 5-4
Power Consumption of WPC Run

Power Data

Channel Number	Location	Power Consumption (kW) Average	Max.	Min.	Std.Dev.
1	Ice Scrapper Thickener	0.410	0.447	0.087	0.059
2	Ice Scrapper Washcolumn	1.775	1.865	1.469	0.071
3	Transporter Thickener	0.668	0.692	0.651	0.009
4	Transporter Washcolumn	1.574	2.187	1.268	0.172
5	SSHE #11	6.248	6.697	5.897	0.227
6	SSHE #12	6.485	6.688	6.184	0.153
7	SSHE #21	2.750	2.785	2.686	0.021
8	SSHE #22	2.470	2.563	2.403	0.033
9	Recrystallizer #10	28.298	30.120	26.900	0.879
10	Recrystallizer #20	14.335	14.660	13.880	0.263
11	Compressor	52.085	52.340	50.750	0.217
12	Total	117.095	117.913	115.366	0.469
-	Control Panel & Misc.	9.500			

Operating parameters: Feed concentration 9.88% T.S.
Product concentration 41.50% T.S.
Production 252.00 lbs./hr. (115.00 kg/hr.).

Power consumption: 157.2 kWh/1000 lbs.(345.7 kWh/MT) water removed.
119.7 kWh/1000 lbs.(263.3 kWh/MT) feed processed.

Equals to W60 components: 94.3 kWh/1000 lbs.(207.4 kWh/MT) water removed.
71.8 kWh/1000 lbs.(158.0 kWh/MT) feed processed.

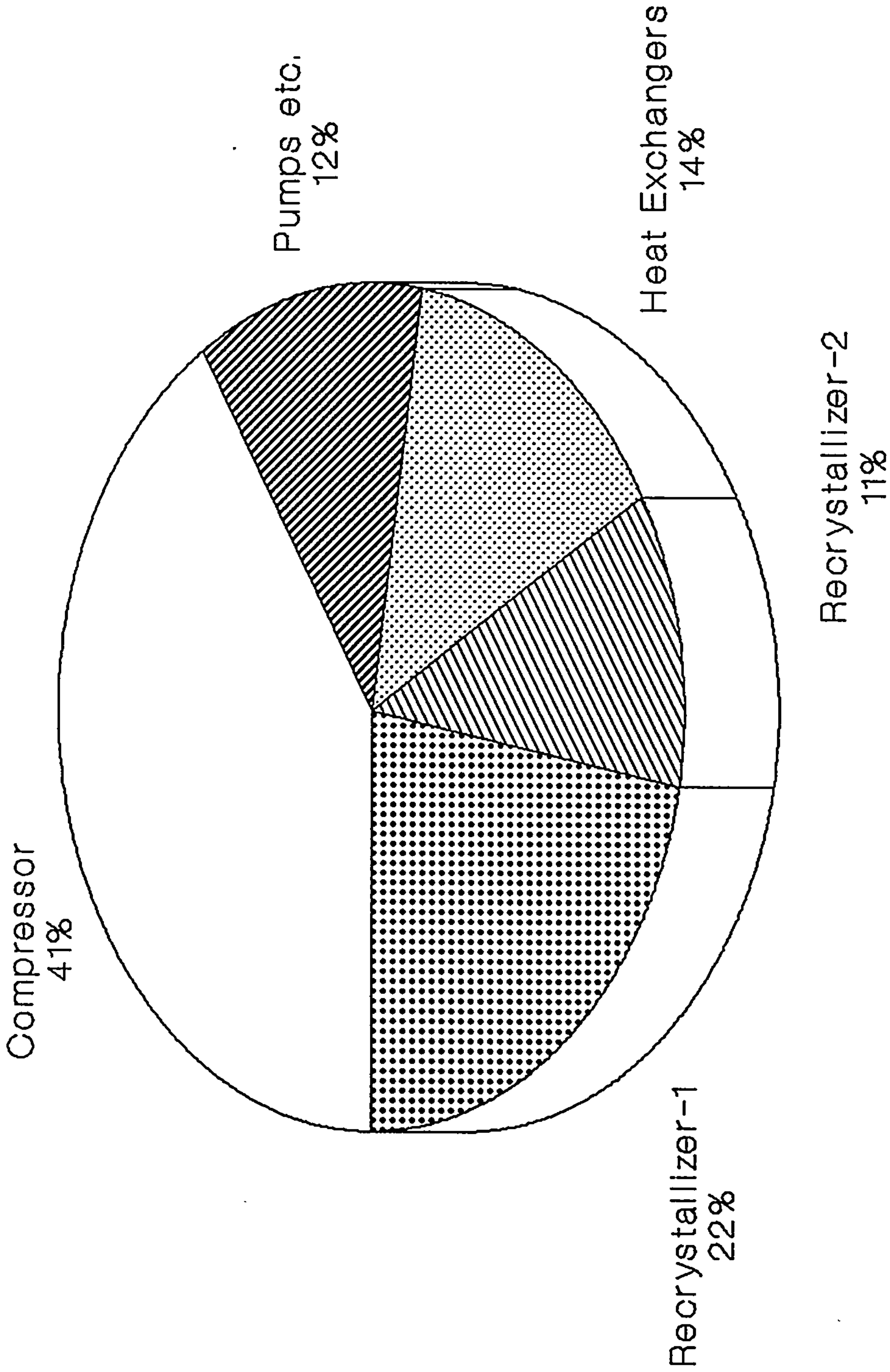


Figure 5-5
Energy Utilization During WPC Run

Additional efficiencies could be captured by regeneration--that is, utilizing the refrigeration capacity of the concentrate to cool the feed stream through a heat exchanger prior to concentration. The concentrate exits the PDU at near-freezing temperatures whereas the product's holding temperature is closer to 5°C. In particular, these gains would accrue to concentrate that is subsequently diverted to a spray dryer and for which holding temperatures could be much higher.

Conclusion

Based upon the data accumulated from the PDU, the scale-up models project that full-scale commercial freeze concentration should be more cost-effective than either TVR or MVR evaporation. Freeze concentration is more energy intensive and energy elastic than either MVR or TVR concentration, suggesting that additional processing economies may be attainable through energy conservation and energy management enhancements to the process.

Recommendations

The following are some recommended next steps for a full comparative analysis of freeze concentration's operating costs:

- Operating costs for commercial-scale freeze concentration should be more closely evaluated against a range of commercially available MVR and TVR units in order to better extrapolate freeze concentration's operating costs under full-scale commercial production.

- A model should be developed that compares the relative operating cost elasticities of freeze concentration, TVR and MVR as a function of the price differentials between steam and electrical energy. This would permit better projections of freeze concentration's financial advantages/disadvantages under different economic scenarios.

- Efforts to improve PDU operating efficiencies should focus upon improving refrigeration and ice crystallization efficiencies, as well as energy recovery and regeneration opportunities.

- Capital depreciation costs and the tax implications thereof should be factored into future cost analyses given the considerable capital cost differences between the systems.

6

PRODUCT EVALUATION

GRAS Evaluation

An expert panel was established to evaluate the Generally Recognized As Safe status of freeze-concentrated milk products.

Summary of Expert Panel Report

The Food and Drug Administration (FDA) is the primary Federal agency responsible for ensuring the safety of commercial food and food additives, except meat and poultry products. FDA works closely within the U.S. Department of Agriculture (USDA) which regulates meat and poultry products, and with the Environmental Protection Agency (EPA), which regulates pesticides and sets tolerances for pesticides in food. FDA's authority is under the Public Health Service Act which gives it broad authority to initiate legal action against a food that is adulterated or misbranded within the meaning of the act. This authority centers on the product that is introduced into interstate commerce, rather than on the method of manufacture.

Milk and cream are regulated as standardized food products under Sections 401, 701 and 52 of the FD&C Act with specific regulatory provisions described in CFR 21 Part 131. On December 4, 1992 FDA revised its definition of "milk products." [Federal Register, Vol. 57, No. 234; CFR 21 Part 1240]:

> "Food products made exclusively or principally from the lacteal secretion obtained from one or more healthy milk-producing animals, e.g. cows, goats, sheep and water buffalo, including but not limited to, the following: lowfat milk, skim milk, cream, half and half, dry milk, nonfat dry milk, dry cream, condensed or concentrated milk products, cultured or acidified milk or milk products, kefir, eggnog, yogurt, butter, cheese (where not specifically exempted by regulation), whey, condensed or dry whey or whey products, ice by modifying the chemical or physical characteristics of milk, cream or whey using enzymes, solvents, heat, pressure, cooling vacuum, genetic engineering, fractionation or other similar processes, and any such product made by the addition or subtraction of milk fat or the addition of safe and suitable optional ingredients for the protein, vitamin or mineral fortification of the product."

At the same time FDA revised its regulations to clarify that the requirement for pasteurization applies to the dairy ingredients of certain dairy products, such as nonfat dry milk, cottage cheese or butter. The revised Public Health Service regulation provides:

> "No person shall cause to be delivered into interstate commerce or shall sell, otherwise distribute or hold for sale or other distribution after shipment in interstate commerce any milk or milk products in final package form for direct human consumption unless the product has been pasteurized or is made from dairy ingredients (milk or milk products) that have all been pasteurized, except where alternative procedures to pasteurization are provided for by regulation, such as ... for curing of certain cheese varieties."

Compared to foods themselves, the FD&C Act is more specific and detailed in spelling out the regulatory requirements for materials permitted to be added to foods, including the categories: food additives, color additives, GRAS and prior sanctioned materials.

Prior sanctioned items are those materials for which there was explicit approval by the FDA or USDA prior to September 6, 1958. The Code of Federal Regulations (CFR) 181.1 states "An ingredient whose use in food or food packaging is subject to a prior sanction or approval within the meaning of section 201(s)(4) of the Act is exempt from classification as a food additive."

While pre-market scientific testing is required prior to approval of food and colored additives, materials that are generally recognized as safe (GRAS) can be accepted for use based only on the views of experts qualified by scientific training and experience to evaluate the safety of substances directly or indirectly added to food. The basis of such views may be either (1) scientific procedures or (2) in the case of a substance used in food prior to January 1, 1959, through experience based on common use in food. General recognition of safety requires common knowledge about the substance throughout the scientific community knowledgeable about the safety of substances directly or indirectly added to food.

Individual states shoulder the primary responsibility, in close collaboration with FDA, for approval of production equipment and process design and plant inspections in the dairy industry.

There are no statutory provisions or regulations that address new technologies but FDA possesses extensive experience in the safety evaluation of products made by traditional methods, and food products can be adequately regulated within the framework of existing law. Also, FDA can remove a food from the market if there is any reasonable possibility that a substance added by human intervention might be unsafe.

The safety of food can be affected by many factors and thus requires continuous attention and vigilance as promulgated under Good Manufacturing Practices (GMP). Therefore, regardless of the particular category (e.g. food; food additive; color additive; GRAS; prior sanction) under which one or another government agency regulates that food material, it is the ultimate responsibility of a food manufacturer to ensure the safety, wholesomeness and quality of the products placed into the marketplace. It is therefore, particularly important for new products and processes to be carefully evaluated, scientifically and technically, by the manufacturers for their safety prior to their being introduced into commerce.

Wisconsin Department of Agriculture officials have approved the Niro freeze concentration product development unit (FC/PDU) for Grade A milk. They have also ruled that the freeze-concentrated products meet the requirements of Grade A Pasteurized Milk Ordinance, published by FDA Public Health Service. Their advisory opinion holds that no further approval is needed for using products concentrated on the PDU (Appendix C). These products will be treated as Grade A milk products requiring no further approval from the FDA or USDA.

Certainly the input dairy streams and products being considered for application of the Niro process are considered to be foods, and are regulated accordingly. However, the myriad of liquid milks, processed milk and dairy by-products are continuously changing as a result of market and technological forces. These forces can bring about shifts in definitions and regulatory categorizations, such as the above clarification and revision.

Fine lines can exist between classification of some materials known as foods that are also important as added ingredients to processed foods. Are such items then to be regulated as foods or food additives? Examples of such items include starch, corn sugar, and pectin for which purity specifications appear in the third edition of Food Chemicals Codex (FCC). The fourth edition of this compendium being prepared by the National Academy of Sciences will also contain specifications of more materials of this sort including the dairy related items of lactose, whey, lactose reduced whey, mineral reduced whey, and whey protein concentrate.

Accordingly, in order to cover the broadest regulatory implications, the charge to this committee by the Dairy Research Foundation was to determine whether or not products of the Niro process can be generally recognized as safe. It is in this light that the committee performed a full scientific review of the safety considerations or products generated by the Niro freeze concentration process.

Discussion

Generally one does not anticipate that food products developed through methods similar to classical methods need to be viewed any differently than in the past.

Since the products under evaluation here are made by the application of a new process to traditional foods (i.e. whole milk; skim milk; sweet whey; whey permeate; acid whey; whey protein concentrate) the prime objective is to evaluate whether the new process results in changes in chemical identity of the ingredient, introduction into the food supply of new or altered levels of impurities, or an increase in dietary exposure for consumers to any component that is not justified by available data.

Since lowering of temperature reduced the rate of chemical reactions, the operating temperature range of -4.5 to -1.5° C for the Niro freeze concentration process is not conducive to increasing chemical reactions and thereby causing any change in the chemical constituents entering the process as starting materials.

Nutrition

The freeze concentrated products compare very well nutritionally with other commercial products.

While not reasonably expected, and having done no specific test for denaturation, secondary data indicates that protein denaturation is not caused by the Niro process thus maintaining the original protein quality.

Proximate analyses, mineral and riboflavin content, as well as amino acid profiles are essentially the same for products whether freeze concentrated, Mechanical Vapor Recompression (MVR) processed or frozen liquids.

Microbiological and Chemical Safety

USDA and Wisconsin Health Department inspected the unit during its construction at Galloway West. The Wisconsin Health Department then provided a letter rating the Niro unit of Grade A quality.

GMPs are the underpinning for controlling the operation of this process. All structural components of the equipment as well as lubricants, gaskets, etc. are already approved for use in dairy processing equipment.

From the microbiological as well as chemical standpoints the quality of products generated by this process is substantially dependent upon the quality of the incoming dairy stream. Crucial then to maintaining production of acceptable final product are tight screening and control of the quality attributes of the incoming dairy stream. When properly maintained and operated, this process will add neither increased levels of microbiological organisms nor new chemical species to the final product. It is important that only dairy streams of high quality be introduced into the process in order to ensure that the final product, at whatever concentration, can meet the required safety criteria.

While little growth of microorganisms will occur during the process, their concentration and that of any chemical burdens (e.g. antibiotics, pesticides) will increase concomitantly with each degree to which the stream is concentrated from its original condition.

Experience with operation of the unit has shown that bacteriological loads do not change over a 3 week period - total plate counts ran from 100-300.

The Niro process will neither increase nor decrease a product's allergenicity potential. The chemical integrity of proteins entering this process is not measurably altered by its operating conditions. Accordingly, the allergenicity potential, which certainly is of concern to a selected sensitive portion of the population, will be neither increased nor decreased as a result of this processing. Thus, there are no special handling requirements for freeze-concentrated milk over those required for condensed milk. Indeed, because of higher temperatures and amount of heat to which condensed milk is exposed, freeze concentrated milk incurs none of the heat induced chemical and flavor changes observed in condensed milk.

Summary and Conclusions

At the request of the Dairy Research Foundation, a committee of scientists expert in food safety sciences was assembled in order to determine whether or not freeze concentrated dairy products produced by the Niro process (Niro Process Technology B.V.), can be Generally Recognized As Safe (GRAS). This report includes a description of the process and all other data and information reviewed by the committee. A letter confirming the panel's conclusion that freeze-concentrated dairy ingredients should be considered GRAS is attached in Appendix G.

Evaluations of Niro freeze-concentrated food grade skim milk and whey protein concentrate led the panel to conclude that if these specific products were to be used and regulated under existing food additive regulations they should be considered to be GRAS.

The overriding factor relative to the wholesomeness of these products is the obligatorily low temperature range of operation which precludes change in chemical constituents and minimizes any potential for microbiological proliferations. Properly constructed, maintained, and cleansed equipment of the specified design when operated under the Good Manufacturing Guidelines cannot be expected to reduce the safety and wholesome quality of the starting dairy stream.

Organoleptic Quality of Skim Milk - UGA Sensory Study

Reconstituted Skim Milk

The physical and sensory properties of freeze-concentrated skim milk were evaluated by the University of Georgia's Center for Food Safety and Quality Enhancement. Full details of the report are attached in Appendix H. The study was conducted in two phases:

Phase I: The objectives for this phase were to evaluate the sensory profiles of freeze-concentrated skim milk in liquid concentrate, spray-dried, and freeze-dried forms when reconstituted as a skim milk beverage; to determine the effects of freeze concentration on skim milk; and to determine the effects of freezing, spray drying, and freeze drying on the sensory quality of freeze-concentrated skim milk liquid concentrate.

The sensory evaluations were based upon the responses of a panel of 11 consumers that spent a total of 12-hours each being trained to the specific sensory requirements of the study. The panelists were asked to compare freeze-concentrated milk samples against reconstituted evaporated condensed milk, reconstituted nonfat dry milk, and fresh (retail) skim milk. All samples were reconstituted to the same solids content as the control skim milk sample. All evaluations were done using unstructured lines (150 mm scale) along which the intensities of individual product attributes were measured.

Phase II: This phase assessed both the consumer acceptance of the freeze-concentrated products in relation to the milk consumption patterns of consumers and determined the market potential for freeze-concentrated skim milk in terms of purchase intentions and expected purchase frequencies of the consumers surveyed. Color and viscosity were also measured in the milk samples.

This phase involved 104 consumers selected on the basis of their milk consumption patterns and demographic characteristics. The minimum requirement was that consumer panelists consumed a minimum of three cups of milk per week. A breakdown of the consumers profiled in the study is presented in tables (Table 6-1) and (Table 6-2). The panelists were asked to rate the organoleptic properties of the same liquid skim milk used as the feedstream to the PDU; reconstituted skim milk from freeze-concentrated concentrate and spray-dried powder; and reconstituted skim milk from commercial nonfat dry milk. The consumers were then asked about their purchase intentions for freeze-concentrated skim milk based upon their organoleptic evaluations of the products.

Results

Phase I: Freeze concentration did not affect any of the sensory qualities of skim milk: The products were not judged to be significantly different than commercial skim milk on individual characteristics. Freeze-concentrated skim milk (from liquid concentrate) was found to be significantly more viscous and darker in color than the fresh skim milk against which it was compared (Table 6-3). The reconstituted freeze-concentrated skim milk from frozen concentrate was judged to be significantly sweeter than commercial fresh skim milk and reconstituted evaporated condensed milk, although it was not found to be significantly different than the liquid freeze-concentrated skim milk sample (Table 6-4).

Also, no significant differences were found between the physical and sensory characteristics of the commercial skim milk control samples and freeze-concentrated skim milk reconstituted from frozen, spray-dried or freeze-dried samples (Table 6-5). However, freeze-concentrated skim milk reconstituted from spray-dried samples was

Table 6-1
Demographics of Participants in the Consumer Acceptance Tests on F/C Skim Milk

		Frequency	Percent
Age	under 25 yrs old	5	4.8
	25 - 34 yrs old	15	14.4
	35 - 44 yrs old	28	26.9
	45 - 54 yrs old	30	28.8
	55 - 64 yrs old	16	15.4
	over 64 yrs old	10	9.6
Sex	Female	91	87.5
	Male	13	12.5
Race	White	75	72.1
	Black	22	21.2
	Others (Hispanic, etc)	7	6.7
Marital Status	Single	8	7.7
	Married	78	75.0
	Others	18	17.3
Educational Attainment	some high school	7	6.7
	completed high school	42	40.4
	some college	25	24.0
	completed college	19	24.0
	graduate school	7	6.7
Household Income	under $9,999	8	8.2
	$10,000 - $19,999	16	16.3
	$20,000 - $29,999	23	23.5
	$30,000 - $39,999	16	16.3
	$40,000 - $49,999	13	13.3
	$50,000 - $59,999	12	12.2
	$60,000 and over	10	10.2

Table 6-2
Milk Consumption Pattern of Participants in Consumer Acceptance Tests on F/C Skim Milk

		Frequency	Percent
Daily milk consumption			
	<1 cup	5	4.8
	1 cup	48	46.2
	2 cups	36	34.6
	3 cups	9	8.7
	4 cups	2	1.9
	>4 cups	4	3.8
Time of day of milk consumption	breakfast	82	44.8
	A.M. snacks	11	6.0
	lunch	14	7.7
	P.M. snacks	14	7.7
	supper	15	8.2
	midnight snack	47	25.7
Weekly milk purchases			
	<1/2 gal	7	6.7
	1/2 gal	10	9.6
	1 gal	54	51.9
	2 gal	25	24.0
	>2 gal	8	7.7
Type of milk bought			
	whole milk	42	20.8
	2% fat milk	41	20.3
	skim milk	31	15.3
	1% fat milk	22	10.9
	evap. whole milk	19	9.4
	non-fat dry milk	16	7.9
	evap. skim milk	14	6.9
	sweet cond. milk	10	5.0
	other (buttermilk)	7	3.5

Table 6-3
Effect of Freeze Concentration on the Viscosity, Lightness, Hue, and Chroma of Skim Milk[x]

Sample	Viscosity (cps)	Color[y]		
		Lightness (L*)	Chroma	Hue
F/C Skim Milk, liquid, reconstituted	2.06 a	66.97 c	4.29 ab	209.36 a
Evaporated Condensed Milk, reconstituted	1.95 b	73.30 a	3.33 b	173.21 b
Commercial Skim Milk	1.89 b	70.14 b	4.42 b	209.63 b

[x] Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by least significant difference tests (LSD).

[y] Lightness values range from 0 = black to 100 = white. Chroma = $[a^2 + b^2]^{1/2}$. Chroma values range from 0 (for gray) to 20.

Table 6-4
Effect of Freezing on the Sensory Attributes of Reconstituted F/C Skim Milk Liquid Concentrate[x]

	Attributes[y]					
Sample[z]	Color	Vslthick	Sweet	Salt	Sour	Bitter
A	32.4 a	19.5 a	25.2 ab	11.1	9.4	7.9
B	30.8 ab	20.4 a	28.0 a	12.6	9.8	6.9
E	28.3 b	23.5 b	22.0 b	12.6	10.2	8.2
F	30.6 ab	19.7 a	24.5 b	13.5	10.6	8.4
Sample[z]	Milky	Creamy	Cooked	Caramel	Gritty	Thick
A	34.6	25.9	20.5	18.3	1.4	17.6
B	36.4	25.3	19.9	17.7	0.6	17.3
E	35.0	26.6	22.1	16.6	0.6	17.6
F	35.0	24.8	21.4	18.7	0.7	16.8

[x] 150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

[y] VSLTHICK represents the appearance attribute 'thickness'. Means within a column followed by the same letter or not followed by letters are not significantly different at 5% level of significance as determined by Least Significance Difference Tests (LSD).

[z] Samples were: A - F/C Skim Milk, liquid; B - F/C Skim Milk, frozen; E - Evaporated Condensed Milk; F - Commercial Fresh Skim Milk. Samples A, B, and E were reconstituted.

Table 6-5
Effect of Freeze Concentration with Freezing, Spray-Drying, or Freeze-Drying on the Sensory Attributes of Skim Milk[x]

	Attributes[y]					
Sample[z]	Color	Vslthick	Sweet	Salt	Sour	Bitter
B	27.9	21.0	26.8	11.8	8.9	7.5
C	27.0	21.3	27.0	9.7	7.7	7.3
D	27.3	20.9	27.3	9.8	8.5	8.7
F	26.9	21.0	25.9	11.7	10.5	8.2
G	26.6	23.9	26.3	11.1	8.3	8.1

Sample[z]	Milky	Creamy	Cooked	Caramel	Gritty	Thick
B	38.6	26.0	19.9	15.0	0.1	16.7
C	35.9	25.8	19.5	13.0	0.2	17.2
D	38.8	24.8	22.2	16.1	0.5	17.5
F	36.1	25.5	19.1	15.0	0.2	18.0
G	39.5	26.3	22.3	15.1	2.1	17.9

[x]150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

[y]VSLTHICK represents the appearance attribute 'thickness'. Means within a column followed by the same letter or not followed by letters are not significantly different at 5% level of significance as determined by Least Significance Difference Tests (LSD).

[z]Samples were: B - F/C Skim Milk, frozen; B - F/C Skim Milk, spray-dried; D - F/C Skim Milk, freeze-dried; F - Commercial Fresh Skim Milk; G - Commercial Non-Fat Dry Milk. Sample B,C,D, and G were reconstituted.

found to be significantly less viscous than the reconstituted nonfat dry milk sample (Table 6-6).

Table 6-6
Effect of Freeze Concentration with Spray-Drying or Freeze-Drying on the Sensory Attributes of Dry Skim Milk[x]

	Attributes[y]					
Sample[z]	**Color**	**Vslthick**	**Sweet**	**Salt**	**Sour**	**Bitter**
C	28.7	20.5	26.6	10.9	8.4	7.0
D	28.2	20.8	25.6	10.1	8.6	7.1
G	25.6	25.2	26.0	10.7	9.6	8.8
Sample[z]	**Milky**	**Creamy**	**Cooked**	**Caramel**	**Gritty**	**Thick**
C	37.5	25.1	22.7	13.6	0.4	15.9
D	34.5	22.0	23.3	13.1	0.1	16.0
G	39.6	26.2	22.8	15.4	0.5	17.9

x 150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

y VSLTHICK represents the appearance attribute 'thickness'. Means within a column followed by the same letter or not followed by letters are not significantly different at 5% level of significance as determined by Least Significance Difference Tests (LSD).

z Samples were: C - F/C Skim Milk, spray-dried; D - F/C Skim Milk, freeze-dried; G - Commercial Non-Fat Dry Milk. All samples were reconstituted.

Freeze-concentrated skim milk reconstituted from liquid samples was found to be significantly sweeter than commercial skim milk whereas the freeze-concentrated skim milk reconstituted from spray-dried samples had significantly more 'cooked' flavor (Table 6-7).

Table 6-7
Effects of Freezing, Spray-Drying, and Freeze-Drying on the Sensory Attributes of Freeze-Concentrated (F/C) Skim Milk[x]

	Attributes[y]					
Sample[z]	Color	Vslthick	Sweet	Salt	Sour	Bitter
A	30.2	19.0	29.9	10.6	8.9	6.3
B	36.3	19.5	26.7	11.8	8.3	6.2
C	27.3	23.5	26.0	10.5	8.1	7.3
E	26.9	24.2	23.3	10.5	9.4	6.5
F	28.9	20.8	25.0	9.7	10.8	8.5
G	27.6	24.5	27.3	9.9	9.8	7.5

Sample[z]	Milky	Creamy	Cooked	Caramel	Gritty	Thick
A	38.6	23.0	19.0	14.4	0.4	17.1
B	35.7	21.8	22.4	12.7	0.4	17.5
C	34.9	23.4	23.9	13.9	0.4	17.9
E	36.3	24.1	22.0	12.4	0.4	18.5
F	35.3	21.3	17.3	12.8	0.0	18.0
G	39.2	24.5	22.4	14.9	0.3	18.5

[x] 150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

[y] VSLTHICK represents the appearance attribute 'thickness'. Means within a column followed by the same letter or not followed by letters are not significantly different at 5% level of significance as determined by Least Significance Difference Tests (LSD).

[z] Samples were: A - F/C Skim Milk, liquid; B - F/C Skim Milk, frozen; C - F/C Skim Milk, spray-dried; E - Evap. Condensed Milk; F - Commercial Fresh Skim Milk; G - Commercial Non-Fat Dry Milk. Samples A, B, C, E, and G were reconstituted.

It was noted that while statistically significant differences were found among specific objective and sensory measurements in the just-cited studies, the differences tended to be very small nonetheless in terms of the scales of measurement (150 mm) used. In many instances, for example, a mean difference of 5 mm on a scale of 150 mm would be judged to be a statistically significant difference within a probability of $p < 0.05$.

Phase II: While Phase I indicated that there were little, if any, perceived differences between freeze-concentrated skim milk samples and fresh skim milk, the results from Phase II were somewhat more equivocal, particularly with respect to skim milk reconstituted from freeze-concentrated powders.

No statistical differences were found between the mean consumer acceptance scores for fresh skim milk; skim milk reconstituted from freeze-concentrated skim milk concentrate and powder; and reconstituted nonfat dried milk based upon the parameters of color, appearance, dairy flavor, taste, mouthfeel, and overall acceptability (Table 6-8).

Those panelists that were regular commercial skim milk users found no difference in the overall acceptability of skim milk reconstituted from liquid concentrate and commercial skim milk. However, the overall acceptabilities of skim milks reconstituted from freeze-concentrated powder and from reconstituted commercial nonfat dry milk powder were judged to be lower than that of commercial skim milk. The appearance of the reconstituted freeze-concentrated skim milk powder was preferred over that of commercial skim milk. The taste of reconstituted skim milk made from freeze-concentrated (spray-dried) powder was also judged to be significantly inferior to that of fresh commercial skim milk, however (Table 6-9).

The skim milk reconstituted from freeze-concentrated skim milk powder received the lowest (i.e., more inferior) rating for the presence of off-flavors when compared to fresh skim milk, skim milk reconstituted from freeze-concentrated concentrate and reconstituted commercial nonfat dry milk. Off-flavors detected in all the skim milk samples were typically described as "cooked," "stale," "cardboardy," " barny," "chalky," "medicinal," "metallic," or "powdered milk-like." (Tables 6-10 and 6-11). Descriptors such as "stale," "carboardy," or "powdered milk-like" are often associated with oxidative deterioration. While 28% of the panelists detected "cooked" off-flavors in the commercial skim milk samples, 33% did so in the samples reconstituted from freeze-concentrated powder; 37% did so from the skim milk reconstituted from the freeze-concentrated concentrate; and 40% did so from the reconstituted nonfat dried milk samples. Consequently, it is unlikely that the lower taste acceptance scores

Table 6-8
Mean Consumer Acceptance Scores for the Different Characteristics of the Skim Milk Samples (n=104)[x].

Treatment	Color	Appearance	Dairy Flavor	Taste	Mouthfeel	Overall Acceptability
Fresh Skim Milk (Comm.)	5.4 ± 1.7	5.5 ± 1.6	5.5 ± 1.9	5.4 ± 1.8	5.4 ± 1.8	5.5 ± 1.8
F/C Skim Milk Conc. (Reconst.)	5.8 ± 1.7	5.8 ± 1.4	5.3 ± 2.0	5.2 ± 1.9	5.5 ± 1.8	5.3 ± 1.9
Non-fat Dried Milk (Reconst. from a Commercial Sample)	5.7 ± 1.6	5.8 ± 1.4	5.9 ± 2.0	4.8 ± 1.9	5.3 ± 1.8	4.9 ± 2.0
Powdered F/C Skim Milk (Reconst.)	5.9 ± 1.5	5.9 ± 1.4	5.1 ± 1.9	5.1 ± 2.0	5.6 ± 1.7	5.1 ± 2.0

[x] 9-point Hedonic scales were used with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely.

Table 6-9
Mean Consumer Acceptance Scores from Fresh Skim Milk Users (n=31) for the Different Characteristics of the Skim Milk Samples[x].

Treatment	Color	Appearance	Dairy Flavor	Taste	Mouthfeel	Overall Acceptability
Fresh Skim Milk (Commercial)	5.8 ± 1.4a	5.5 ± 1.6b	6.3 ± 1.7a	5.9 ± 1.8ab	5.9 ± 1.6a	6.0 ± 1.7a
F/C Skim Milk Conc. (Reconst.)	6.3 ± 1.6a	6.2 ± 1.3a	5.1 ± 2.2b	5.2 ± 2.0ab	5.7 ± 1.9a	5.1 ±2.1ab
Non-fat Dried Milk (Reconst.from a Commercial Sample)	6.1 ± 1.5a	6.3 ± 1.0a	5.0 ± 2.3b	5.0 ± 2.1ab	5.7 ± 1.8a	4.9 ± 2.2b
Powdered F/C Skim Milk Reconst.)	6.1 ± 1.5a	5.8 ± 1.4a	4.7 ± 2.2b	4.7 ± 2.2b	5.4 ± 1.9a	4.6 ± 2.2b

[x] 9-point Hedonic scales were used with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by Least Significant Difference (LSD) test.

Table 6-10
Mean Consumer Rating from Fresh Skim Milk Users for Appearance and Off-Flavor of Skim Milk Samples[w]

Treatment	Appearance[x]	Off-Flavor[w]
Fresh Skim Milk (Commercial)	4.5 a	4.4 a
F/C Skim Milk Conc. (Reconstituted)	4.8 a	3.8 ab
Non-fat Dried Milk (Reconstituted from a Commercial Sample)	4.9 a	3.8 ab
Powdered F/C Skim Milk (Reconstituted)	5.2 a	3.6 b

[W] Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by Least Significant Difference (LSD) analysis.

[X] 9-point scales were used with 1 = extremely thin (transparent), 5 = neither thin nor thick, and 9 = extremely thick (opaque).

[Y] 5-point scales were used with 1 = very strong, 3 = moderate, and 5 = none.

Table 6-11
Off-Flavor Descriptors and the Percent of Consumers that Detected Each One in the Skim Milk Samples Tested

Descriptors	Fresh Skim Milk (Comm.) (%)	F/C Skim Milk Conc. (Reconst.) (%)	Non-fat Dried Milk (Reconst.) (%)	Powdered F/C Skim (Reconst.) (%)
"Barn"	5.7	13.0	8.3	12.5
"Cardboardy"	17.1	17.4	10.4	27.1
"Chalky"	-	2.2	4.2	-
"Cooked"	28.6	37.0	39.6	33.3
"Medicinal"	8.6	10.9	12.5	6.3
"Metallic"	2.9	-	-	-
"Powdered-Milk"	2.9	-	4.2	-
"Stale"	28.6	17.4	20.8	20.8

associated with freeze-concentrated skim milk powders is associated with the presence of "cooked" flavors typically associated with the heat abuse of spray-drying.

The freeze-concentrated skim milk reconstituted from powder received the highest level of detection of "cardboardy" off-flavors of all the samples evaluated, however. Cardboardy flavors were detected in these samples by 27% of the panelists, compared to 17% who detected the same off-flavor in the commercial skim milk sample.

The possibility exists that some of the freeze-concentrated skim milk powder samples used in the University of Georgia study were of less-than optimum quality, particularly in the Part II studies: Subsequent to the completion of the University of Georgia study, EPRI and Galloway West personnel noticed that some of the freeze-concentrated samples exhibited oxidized flavor properties upon storage, reconstitution, and overnight storage of the reconstituted products. Samples used in the University of Georgia study were similarly reconstituted and stored overnight under refrigeration prior to evaluation.

One hypothesis proffered to explain the unanticipated oxidation was the possible occurrence of in-line foaming in the PDU. The possibility that the freeze-concentrated skim milk samples may have oxidized is consistent with some of the sensory descriptors ("cardboardy" and "barn,") that had a higher incidence of detection in the freeze-concentrated samples than in others. Similar problems with in-process oxidation in the orange juice, beer and coffee industries have been addressed successfully by deaerating the feedstream prior to freeze concentration, according to Niro.

Purchase Intentions

Based upon the product evaluations conducted, panelists indicated that they would consume about the same or less of all the milk samples tested than they would normally do. They indicated that they would be willing to pay the same or less-than the present price for the samples presented. The outcome of the study suggests that all the samples tested could compete in quality against the commercial skim milk tested on an equivalent-price basis (Table 6-12).

Table 6-12
Mean Consumer Purchase Intent from Fresh Skim Milk Users for Skim Milk Samples Tested

Treatment	Amount[x]	Price[w]
Fresh Skim Milk (Commercial)	1.6	1.6
F/C Skim Milk Conc. (Reconstituted)	1.3	1.5
Non-fat Dried Milk (Reconstituted from a Commercial Sample)	1.4	1.5
Powdered F/C Skim Milk (Reconstituted)	1.4	1.5

[x] 3-point scales were used with 1 = less than normal consumption, 2 = same as normal consumption , and 3 = more than normal consumption.

[y] 4-point scales were used with 1 = less than present price, 2 = same as present price, 3 = 1-5% more than present price, and 4 = 6-10 % more than present price.

Food Ingredient Applications - ABIC Study

The functional and organoleptic quality of freeze concentrated milk products were evaluated in ten different prototypic food products. Product formulations and evaluations were conducted by ABIC International Consultants. The freeze concentrated milk products used in the product formulation studies were:

- spray-dried, freeze concentrated skim milk
- spray-dried, freeze concentrated whey protein concentrate
- frozen, freeze concentrated skim milk powder
- frozen, freeze concentrated whey protein concentrate

Control samples were formulated with corresponding milk ingredients and concentrated through Mechanical Vapor Recompression (MVR) technology.

The prototype formulations developed for the study were chosen for the characterizing role that dairy ingredients contribute to their formulations. The following prototypes were developed:

1. Buttermilk cookies
2. Hard pack ice milk (2%)
3. Soft-serve ice milk (2%)
4. Sour cream (33% fat reduced)
5. Cream cheese (33% fat reduced)
6. Pound cake (dry mix)
7. Nonfat salad dressing (dry mix)
8. White sauce
9. Milk chocolate
10. Whipped topping

Formulations for the above products are presented in Appendix I (see page I-13 to I-18).

Organoleptic Evaluations

The organoleptic evaluation of products was conducted by an ABIC expert panel. The panel consisted of a number of judges who had been screened and trained to evaluate, articulate, and quantify the flavor and texture attributes of food systems. The evaluations were performed in a light and temperature controlled panel room. Products were presented "blind" to the judges and were coded with random triple digit numbers.

Attributes were quantified in a sequential monadic study design. Attribute evaluations included color, aroma, flavor, and texture, including the presence and/or level of off-flavors, and were specifically chosen to reflect established characteristics of the food. Other evaluations were made as needed. Examples of such measurements include "height" for the pound cake; "emulsion stability" for the salad dressings; the presence ice crystals in ice milk; and "viscosity" for the white sauce.

When attribute differences were ≥ 1.0, the data was subjected to statistical analysis.

Results

The principle observation resulting from the attribute evaluation data was that food model systems whose primary flavor characteristics were "dairy-like" in nature were judged to be superior when freeze concentrated ingredients were employed, as compared to the controls.

Hard-Pack Ice Milks (2%): The products formulated from freeze concentrated ingredients were judged to have significantly better overall flavor ($p<0.02$), dairy notes ($p<0.01$), smoother mouthfeel ($p<0.01$), and mouthclearing properties ($p<0.01$) than the controls. Additionally, the freeze concentrated milk formulations were perceived to be creamier ($p<0.01$), less icy ($p<0.01$), and more spoonable ($p<0.01$) than the control product. (Table 6-13a and 6-13b)

Soft-Serve Ice Milk (2%): The soft-serve ice milk systems formulated from reconstituted freeze concentrated skim milk, freeze concentrated skim milk powder, and whey protein concentrate were judged superior to other formulations developed using MVR-ingredients or freeze concentrated ingredients without the whey protein concentrate. The preferred formulations were judged to possess an increased level of overall flavor ($p<0.02$), and tended toward a better "dairy" flavor characteristic of soft serve ice milk as well ($p<0.06$). The other systems were characterized by either diminished dairy flavor intensity or atypical flavors. (Tables 6-14a and 6-14b)

Sour Cream: After 36-hours the freeze concentrated sour cream formulation was judged to have a significantly better dairy aroma ($p<0.01$) and dairy flavor ($p<0.01$) than the controls. The freeze concentrated sour cream formulation was found to be significantly less sour ($p<0.02$) and have a "more balanced" flavor profile than the controls. It was thicker but was also judged to offer a "better mouthfeel."

However, after seven days the perceived differences between the sour cream products vanished. (Tables 6-15a and 6-15b)

Cream Cheese: Cream cheese prototypes with 3.5% added skim milk powder were evaluated at 36-hours and at seven days. Prototypes containing 5.0% added skim milk powder were only evaluated at seven days.

At 36-hours the freeze concentrated cream cheese was judged to be superior to control products in dairy aroma ($p<0.04$) and dairy flavor ($p<0.01$). The freeze concentrated product was also perceived to have better "flavor balance" partly due to the absence of off-flavors. Textural ratings were not reliable since the experimental systems were not thickened with stabilizers. (Table 6-16a)

After seven days the freeze concentrated cream cheese produced with 3.5% skim milk powder was still judged to be superior in overall flavor ($p<0.03$), creaminess ($p<0.01$), and balance. The 5.0% skim milk powder systems were not perceived to be as good as the 3.5% systems. (Tables 6-16b and 6-16c)

White Sauce: White sauce prepared from freeze concentrated ingredients was judged to be superior to the control formulations, especially in dairy flavor ($p<0.05$). However, unlike other model food systems the control sauce was judged to have a superior dairy aroma ($p<0.02$). (Table 6-27)

Nonfat Salad Dressings: The control and freeze concentrated formulations were judged to be similar although there was a slight trend toward improved dairy flavor in the freeze concentrated model system. (Table 6-18)

Milk Chocolate: Milk chocolate prepared with freeze concentrated ingredients was judged to be significantly better than milk chocolate prepared with standard ingredients. The expert panel judged the freeze concentrated product to be superior in chocolate aroma ($p<0.03$) and dairy flavor ($p<0.04$) when compared to the control. The freeze concentrated milk chocolate was also judged to be creamier ($p<0.01$) than the control with better "melt-in-the-mouth" qualities ($p<0.03$). (Table 6-19)

Whipped Topping: A number of formulations were developed from varying combinations of freeze concentrated ingredients and standard ingredients, with and without emulsifiers. Products made with whey protein concentrate replacing the emulsifiers demonstrated approximately a 150% over-run, but were so thin in texture that they could no longer be considered whipped toppings. Generally, there were no significant differences in attributes between any of the products. However, products formulated with freeze concentrated skim milk powder, no emulsifiers, and whey protein concentrate, tended toward increased dairy flavor ($p<0.53$), but not increased overall flavor, compared to the other systems evaluated.

Ingredient combinations significantly affected physical attributes of the whipped toppings. The systems containing emulsifiers with either caseinate or skim milk powder had over-runs ranging from 64 (caseinate) to approximately 90 (MVR and freeze concentrated skim milk powder). When the emulsifiers were replaced with whey protein concentrate, retaining the caseinate, over-run increased to 140 for MVR and 155 for freeze concentrated whey protein concentrate. Finally, when both the caseinate and emulsifiers were replaced, the over-run again dropped to 71 for MVR and 61 for freeze concentrated ingredients. (Tables 6-20a and 20b)

Buttermilk Cookies and Pound Cake: No significant differences were detected between freeze concentrated and control samples. (Tables 6-21 and 6-22).

Table 6-13a
Results of Sensory Evaluation of Hard Pack Ice Milk (2% Fat) Utilizing Skim Milk Ingredients for Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	4.0	4.0
2.	Aroma[b]	2.2	2.6
3.	Spoonability[c]	3.5	4.6
4.	Overall Flavor[b]	4.7	6.1
5.	Sweet[b]	4.2	4.2
6.	Sour[b]	0.4	0.2
7.	Salty[b]	0.0	0.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	3.6	5.2
10.	Off Flavor[b]	0.4	0.2
11.	Creaminess[b]	3.0	5.4
12.	Mouthfeel[d]	5.0	6.7
13.	Mouthclearing[e]	2.8	4.1
14.	Iciness[b]	2.6	0.6
B. Physical Measurements			
15.	Density of mix (g/cc)	1.12	1.13
16.	Over-run (%)	100.00	100.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = too soft, 4 = about right, 8 = too hard)
[d]:(0 = very gritty, 8 = very smooth)
[e]:(0 = rapid, thin, watery; 4 = about right; 8 = slow, gummy, thick)

Table 6-13b
Results of Sensory Evaluation of Hard Pack Ice Milk (2% Fat) Utilizing Skim Milk and WPC Ingredients for Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	4.0	3.8
2.	Aroma[b]	2.2	2.3
3.	Spoonability[c]	5.0	4.1
4.	Overall Flavor[b]	6.0	6.8
5.	Sweet[b]	4.6	4.1
6.	Sour[b]	0.0	0.0
7.	Salty[b]	0.0	0.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	5.4	6.5
10.	Off Flavor[b]	0.0	0.8
11.	Creaminess[b]	3.8	5.4
12.	Mouthfeel[d]	5.7	6.8
13.	Mouthclearing[e]	3.2	4.6
14.	Iciness[b]	2.1	0.8
B. Physical Measurements			
15.	Density of mix (g/cc)	1.13	1.13
16.	Over-run (%)	100.00	100.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = too soft, 4 = about right, 8 = too hard)
[d]:(0 = very gritty, 8 = very smooth)
[e]:(0 = rapid, thin, watery; 4 = about right; 8 = slow, gummy, thick)

Table 6-14a
Results of Sensory Evaluation of Soft Serve Ice Milk (2% Fat) Utilizing Skim Milk Ingredients for Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	4.0	4.0
2.	Aroma[b]	1.2	1.6
3.	Spoonability[c]	3.1	4.0
4.	Overall Flavor[b]	4.2	5.9
5.	Sweet[b]	3.5	3.4
6.	Sour[b]	0.0	0.0
7.	Salty[b]	0.0	0.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	4.4	5.4
10.	Off Flavor[b]	0.0	0.0
11.	Creaminess[b]	6.2	6.7
12.	Mouthfeel[d]	6.7	7.1
13.	Mouthclearing[e]	4.0	4.1
14.	Iciness[b]	0.0	0.0
B. Physical Measurements			
15.	Density of mix (g/cc)	1.12	1.12
16.	Over-run (%)	100.00	100.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = too soft, 4 = about right, 8 = too hard)
[d]:(0 = very gritty, 8 = very smooth)
[e]:(0 = rapid, thin, watery; 4 = about right; 8 = slow, gummy, thick)

Table 6-14b
Results of Sensory Evaluation of Soft Serve Ice Milk (2% Fat) Utilizing Skim Milk and WPC Ingredients for Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	3.9	3.8
2.	Aroma[b]	2.1	1.4
3.	Spoonability[c]	3.8	3.8
4.	Overall Flavor[b]	5.7	6.5
5.	Sweet[b]	4.1	3.5
6.	Sour[b]	0.0	0.0
7.	Salty[b]	0.0	0.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	5.3[*]	6.3
10.	Off Flavor[b]	1.5	0.5
11.	Creaminess[b]	6.7	7.5
12.	Mouthfeel[d]	6.8	7.5
13.	Mouthclearing[e]	4.6	4.3
14.	Iciness[b]	0.0	0.0
B. Physical Measurements			
15.	Density of mix (g/cc)	1.12	1.12
16.	Over-run (%)	100.00	100.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = too soft, 4 = about right, 8 = too hard)
[d]:(0 = very gritty, 8 = very smooth)
[e]:(0 = rapid, thin, watery; 4 = about right; 8 = slow, gummy, thick)
[*]:(off flavor - atypical for whey)

Table 6-15a
Results of Sensory Evaluation of Sour Cream at 36-Hours

A. Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Color[a]	4.1	4.0
2.	Dairy Aroma[b]	3.2	4.3
3.	Overall Flavor[b]	6.0	5.7
4.	Sweet[b]	1.5	1.5
5.	Sour[b]	3.7	2.7
6.	Salty[b]	1.5	0.8
7.	Bitter[b]	0.2	0.0
8.	Dairy[b]	3.6	4.8
9.	Off Flavor[b]	0.2	0.0
10.	Creaminess[b]	5.7	5.5
11.	Mouthcoating/Mouthfeel[c]	3.6	3.3
12.	Mouthclearing[d]	4.0	3.3
B. Physical Measurements			
13.	pH	4.55	4.55

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table 6-15b
Results of Sensory Evaluation of Sour Cream at 7-Days

A. Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Color[a]	4.3	4.0
2.	Dairy Aroma[b]	3.8	3.8
3.	Overall Flavor[b]	5.9	6.0
4.	Sweet[b]	1.1	1.0
5.	Sour[b]	3.8	4.0
6.	Salty[b]	1.3	1.3
7.	Bitter[b]	0.0	0.3
8.	Dairy[b]	5.0	4.5
9.	Off Flavor[b]	0.3	0.0
10.	Creaminess[b]	4.9	4.9
11.	Mouthcoating/Mouthfeel[c]	4.3	3.6
12.	Mouthclearing[d]	4.6	4.0
B. Physical Measurements			
13.	pH	4.5	4.5

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table 6-16a
Results of Sensory Evaluation of Cream Cheese (3.5% Skim Powder Formula) at 36-Hours

A. Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Color[a]	4.1	3.9
2.	Dairy Aroma[b]	2.3	6.5
3.	Overall Flavor[b]	6.4	6.5
4.	Sweet[b]	0.9	1.2
5.	Sour[b]	3.8	3.8
6.	Salty[b]	4.3	2.8
7.	Bitter[b]	0.0	0.0
8.	Dairy[b]	3.7	5.4
9.	Off Flavor[b]	1.2	0.0
10.	Creaminess[b]	6.2	6.9
11.	Spreadability[c]	2.1	2.9
12.	Mouthfeel[c]	2.8	3.6
13.	Mouthclearing[d]	2.8	4.5
B. Physical Measurements			
14.	pH	4.55	4.55

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table 6-16b
Results of Sensory Evaluation of Cream Cheese (3.5% Skim Powder Formula) at 7-Days

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	4.0	4.0
2.	Dairy Aroma[b]	2.6	4.5
3.	Overall Flavor[b]	5.4	6.4
4.	Sweet[b]	0.4	1.0
5.	Sour[b]	4.0	3.1
6.	Salty[b]	1.4	1.4
7.	Bitter[b]	0.1	0.1
8.	Dairy[b]	4.1	5.0
9.	Off Flavor[b]	1.0	0.3
10.	Creaminess[b]	4.3	6.1
11.	Spreadability[c]	5.5	4.3
12.	Mouthfeel[c]	5.5	3.9
13.	Mouthclearing[d]	4.8	3.9
B. Physical Measurements			
14.	pH	4.5	4.5

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table 6-16c
Results of Sensory Evaluation of Cream Cheese (5.0% Skim Powder Formula) at 7-Days

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	3.6	4.0
2.	Dairy Aroma[b]	2.1	3.8
3.	Overall Flavor[b]	6.6	6.3
4.	Sweet[b]	0.5	0.6
5.	Sour[b]	4.0	4.0
6.	Salty[b]	1.6	1.4
7.	Bitter[b]	0.1	0.1
8.	Dairy[b]	2.4	3.9
9.	Off Flavor[b]	0.3	0.0
10.	Creaminess[b]	3.0	4.8
11.	Spreadability[c]	2.1	3.3
12.	Mouthfeel[c]	2.6	3.1
13.	Mouthclearing[d]	2.5	3.1
B. Physical Measurements			
14.	pH	4.5	4.5

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table 6-17
Results of Sensory Evaluation of White Sauce

Sensory Attributes	Formulated with Conventional Ingredients	Formulated with FC Ingredients
1. Dairy Aroma[a]	2.1	3.8
2. Overall Flavor[a]	6.6	6.3
3. Sweet[a]	0.5	0.6
4. Sour[a]	4.0	4.0
5. Salty[a]	1.6	1.4
6. Bitter[a]	0.1	0.1
7. Dairy[a]	2.4	3.9
8. Creaminess[a]	3.0	4.8
9. Grittiness/Chalkiness[a]	2.1	3.3
10. Mouthclearing[b]	2.6	3.1

[a]:(0 = none, 4 = definite, 8 = extensive)
[b]:(0 = very thin, 4 = about right, 8 = very thick, heavy)

Table 6-18
Results of Sensory Evaluation of Nonfat Salad Dressing - Dry Mix Utilizing Skim Milk Ingredients for Comparison

Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Overall Appearance[a]	4.0	3.9
2.	Aroma[b]	3.0	3.1
3.	Overall Flavor[b]	5.4	5.1
4.	Sweet[b]	1.9	2.2
5.	Sour/Acidity[b]	4.1	3.5
6.	Salty[b]	2.1	2.0
7.	Bitter[b]	0.0	0.0
8.	Dairy[b]	1.7	2.4
9.	Thickness/Viscosity[c]	3.3	3.6
10.	Mouthclearing[d]	1.4	1.7
11.	Lubricity/Creaminess[b]	0.0	0.2

[a]:(0 = very poor, 8 = excellent)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = Too Thin, 4 = about right, 8 = too thick)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table 6-19
Results of Sensory Evaluation of Milk Chocolate

Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Chocolate Aroma[a]	4.0	4.0
2.	Aroma[a]	1.2	1.6
3.	Overall Flavor[a]	4.2	5.9
4.	Sweet[a]	3.5	3.4
5.	Sour[a]	0.0	0.0
6.	Salty[a]	0.0	0.0
7.	Bitter[a]	0.0	0.0
8.	Chocolate[a]	3.6	5.1
9.	Dairy[a]	4.4	5.4
10.	Off Flavor[a]	0.0	0.0
11.	Creaminess[a]	6.2	6.7
12.	Degree of Hardness[b]	6.7	7.1
13.	Melt[c]	4.0	4.1

[a]:(0 = none, 4 = definite, 8 = extensive)
[b]:(0 = too soft, 4 = about right, 8 = too hard)
[c]:(0 = rapid, 4 = typical, 8 = slow)

Table 6-20a
Results of Sensory Evaluation of Whipped Topping Prepared Utilizing Skim Milk and WPC Ingredients for Comparison

		Replace caseinate with skim milk powder control			Replace emulsifiers with WPC	
A. Sensory Attributes		**Caseinate**	**MVR**	**FC**	**MVR**	**FC**
1.	Color[a]	2.8	3.0	3.0	2.9	2.9
2.	Overall Flavor	4.2	5.1	4.8	4.5	4.5
3.	Sweet	3.2	4.0	4.5	4.5	4.3
4.	Sour	0.0	0.0	0.0	0.0	0.0
5.	Salty	0.0	0.2	0.0	0.0	0.0
6.	Bitter	1.5	0.4	0.4	0.2	0.1
7.	Dairy	0.8	2.6	3.1	1.5	1.9
8.	Off Flavor	2.2	1.0	0.9	0.4	0.4
9.	Creaminess	5.6	6.4	6.2	4.0	4.5
10.	Mouthfeel/Mouthcoating[b]	5.6	5.5	6.1	2.6	3.0
11.	Mouthclearing[c]	5.1	4.5	4.8	2.6	3.5
B. Physical Measurements						
12.	Base pH	6.50	6.50	6.80	6.30	6.30
13.	Density of mix (g/cc)	0.99	0.98	0.99	0.95	0.91
14.	Over-run (%)	64.00	90.00	91.00	140.00	155.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = too thin, 4 = about right, 8 = too thick)
[c]:(0 = rapid, 4 = about right; 8 = slow)

Table 6-20b
Results of Sensory Evaluation of Whipped Topping Prepared Utilizing Skim Milk and WPC Ingredients for Comparison

A. Sensory Attributes		Replace caseinate with skim milk powder: replace emulsifiers with WPC MVR	FC
1.	Color[a]	4.3	4.3
2.	Overall Flavor	4.0	4.0
3.	Sweet	3.3	2.5
4.	Sour	0.3	0.1
5.	Salty	0.3	0.3
6.	Bitter	0.9	0.9
7.	Dairy	3.9	3.6
8.	Off Flavor	0.4	0.3
9.	Creaminess	3.5	4.4
10.	Mouthfeel/Mouthcoating[b]	3.0	3.4
11.	Mouthclearing[c]	2.9	3.2
B. Physical Measurements			
12.	Base pH	6.70	6.70
13.	Density of mix (g/cc)	0.97	0.97
14.	Over-run (%)	71.00	61.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = too thin, 4 = about right, 8 = too thick)
[c]:(0 = rapid, 4 = about right; 8 = slow)

Table 6-21
Results of Sensory Evaluation of Buttermilk Cookies Utilizing Skim Milk Ingredients for Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	4.0	4.0
2.	Overall Aroma[b]	2.9	2.1
3.	Overall Flavor[b]	5.9	6.0
4.	Sweet[b]	4.9	4.5
5.	Sour[b]	0.0	0.0
6.	Salty[b]	0.9	0.8
7.	Bitter[b]	0.0	0.0
8.	Dairy[b]	2.2	2.9
9.	Off Flavor[b]	0.0	0.0
10.	Chew Qualities[c]	3.9	4.1
B. Physical Measurements			
11.	Batter pH	7.00	7.00
12.	Batter density (g/cc)	1.07	1.08
13.	Weight loss on baking (%)	11.50	11.50
14.	Spread (cm)	6.80	5.90
15.	Height (cm)	0.70	0.90
20.	Moisture (%)	4.22	4.83

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)

Table 6-22
Results of Sensory Evaluation of Pound Cake - Dry Mix Utilizing Skim Milk Ingredients for Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Crust Color[a]	6.0	6.0
2.	Crumb Color[a]	2.0	2.0
3.	Aroma[b]	4.0	3.9
4.	Overall Flavor[b]	6.5	6.9
5.	Sweet[b]	6.1	6.9
6.	Sour[b]	0.0	0.5
7.	Salty[b]	1.0	1.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	2.9	3.1
10.	Off Flavor[b]	0.0	0.0
11.	Moistness[c]	6.5	6.4
12.	Grain[d]	2.9	2.9
13.	Toothpacking	2.9	2.8
B. Physical Measurements			
14.	Batter pH	6.55	6.70
15.	Batter density (g/cc)	0.65	0.64
16.	Flow (Bostwick cm/2 minutes)	2.50	1.50
17.	Weight loss on baking (%)	6.03	6.00
18.	Height (cm)	4.50	4.60
19.	Volume (cc)	1000.00	994.00
20.	Moisture (%)	26.31	25.64

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = too dry, 4 = about right, 8 = too moist, cohesive)
[d]:(0 = too dense, 4 = about right, 8 = open grain, voids, coarse)

Functional Properties and Other On-going Studies

Two additional studies have been initiated to evaluate the functional properties of freeze-concentrated milk. Both studies were ultimately funded by the National Dairy Promotion and Research Board. National Dairy Promotion and Research Board policies preclude the release of interim results of the studies. Upon completion the studies will be made available to EPRI. The studies are as follows:

1. "The Effects of Freeze Concentration on the Hydration and Functional Properties of Milk Proteins in Food Systems." Principal Investigator: Michael E. Mangino, Ph.D., Ohio State University; Columbus, Ohio.

   The study will investigate the basis for the perceived viscosity enhancements associated with freeze-concentrated milk samples upon reconstitution and relate these changes to the molecular and physical properties of the freeze-concentrated milk proteins.

2. "Lowfat Ice Cream from Freeze-Concentrated Milk Products." Principal Investigator: Robert T. Marshall, Ph.D., University of Missouri; Columbia, Missouri.

   The study will compare the flavor and texture quality of lowfat ice cream (ice milk) produced from freeze-concentrated skim milk against that produced with heat-concentrated nonfat dried milk solids. The premise is based upon the possibility that the documented textural and mouthfeel enhancements associated with reconstituted freeze-concentrated skim milk could impart fat mimetic qualities to products it is used in.

Conclusions

1. Freeze-concentrated milk products should be considered to be Generally Recognized as Safe (GRAS).

2. Freeze-concentrated skim milk was not demonstrably better or worse in organoleptic quality than the commercial skim milks it was compared to and/or to nonfat dry milk powder when the freeze-concentrated skim milk powder was reconstituted from its frozen concentrate, freeze-dried and spray-dried forms. These results are inconsistent with those derived in the ABIC studies which documented significantly enhanced product qualities when freeze-concentrated skim milk was used as a food ingredient. It is possible that some of the freeze-concentrated samples evaluated in the University of Georgia study had undergone oxidative deterioration prior to being evaluated.

3. Consumers indicated a willingness to pay at parity with but not at a premium to commercial skim milk (used as a beverage) for skim milk that was reconstituted from freeze-concentrated milk.

4. Freeze-concentrated ingredients either improved significantly or demonstrated equivalency in all food ingredient model systems studied. Together with the potential cost savings associated with commercial freeze concentration, these ingredients represent novel opportunities for value addition in the food and dairy industries.

5. Freeze-concentrated ingredients generally improved the dairy flavor, overall flavor and texture in food systems where dairy flavors normally predominate, such as:

   Hard-pack ice milk (2%)
   Sour cream
   Cream cheese
   White sauce

   In the case of freeze-concentrated soft serve-ice milk (2%) there was an improvement in the dairy flavor but no difference in textural attributes.

6. Freeze-concentrated skim milk powder improved the chocolate and dairy aromas, overall flavor, flavor balance, and texture of milk chocolate.

7. When standard formulations were employed, freeze-concentrated ingredients did not appreciably improve the following:

   Pound cake
   Buttermilk cookies
   Nonfat salad dressing
   Whipped toppings

It is not known if formula modification or optimization would result in improved finished product qualities for the products evaluated.

7

PROMOTIONAL ACTIVITIES

The Dairy Research Foundation, together with Niro, EPRI, and the U.S. Department of Energy, initiated a number of activities designed to promote the realized and potential benefits of freeze concentration for the dairy industry. The campaign involved:

* A public relations campaign initiated in 1991 to inform the public and business media on the progress of the freeze concentration program.

* The commissioning of a promotional video to explain the principles of freeze concentration and its benefits to the dairy industry.

* An open house reception along with a press conference was hosted by the four principal parties during the October, 1992 International Dairy Show in New Orleans. The objective was to introduce freeze concentrated products to attendees and members of the press.

Results

Information on the freeze concentration of dairy products was widely disseminated and reported on by the public and trade press. During 1991, more than 29 newspapers and magazines published stories addressing the positive benefits that freeze concentration could provide. Examples include the New York Times, Business Week, Minneapolis Star Tribune, Seattle Post-Intelligence and the San Francisco Chronicle. Examples are included in Appendix J.

A 20-minute promotional video was developed that explains the process of freeze concentration and puts it into the context of consumer and dairy industry needs. Numerous copies were made available for use in promotional campaigns. This video has been modified by EPRI for dissemination to electrical utility companies.

More than 350 dairy industry executives were invited to the reception in New Orleans. Several products that were formulated using freeze concentrated milk products were offered to reception attendees for taste evaluation.

8

CONCLUSIONS AND RECOMMENDATIONS

Phase II of the study of freeze concentration of dairy products demonstrated the feasibility of freeze-concentrating dairy streams under semi-commercial conditions. Furthermore, the study suggests that freeze concentration should prove cost-competitive with TVR and MVR concentration technologies on a commercial scale. The results suggest that freeze concentration has significant potential for benefiting the dairy industry in three well-defined ways:

1. A lower-cost processing technique for concentrating dairy streams to 40% T.S. or more in comparison to the current evaporative technologies.

2. Reduction of milk transportation costs of milk between the producer and the processor.

3. Development of higher quality dairy products with a high consumer appeal for domestic and export markets.

The results of Phase II are summarized as follows:

Pilot Plant

Pilot plant tests demonstrated that viscosity build-up can be a process-limiting factor in the concentration of high-casein milk fractions such as whole milk and skim milk. Homogenization was successfully used to reduce the viscosity of the concentrate but it remains questionable whether it provides a practical option. Instead, additional studies should evaluate alternate and more cost-competitive options for reducing concentrate viscosities during processing.

Process Development Unit

The Niro PDU was successfully installed and brought into operation within 3A Standards. Several problems need to be addressed, however:

1. The SSHE scraper blades persist as a problem. The plastic blades installed did not perform optimally and wear continues to be a problem. Wear is believed to be attributable to both the relatively high viscosity of milk concentrates as well as the crystallization of highly abrasive lactose crystals. This issue should be addressed in further studies as downtime associated with scraper blade replacement could prove to be an encumbrance to production efficiency.

2. The removal of lactose crystals from the concentrate using a commercial decanter was evaluated with no success.

3. The cylindrical recrystallizer filter design chosen over the original flat-filter design appears to be more efficient but still needs to be brought into full conformance with a 3A Standards. This point is particularly important as ice-crystallization behavior in the recrystallizer is intimately related to production efficiencies.

It is recommended that additional research improve scraper blade designs, redesign the recrystallizer to bring it into full conformance with 3A Standards, and evaluate alternate technologies for removing lactose crystals from the concentrate.

Both skim milk and whey protein streams were successfully concentrated to about 40% solids, although not on a consistent basis. It typically requires between 20 and 30-hours to bring the PDU to steady state conditions. Future studies should focus on the following objectives:

1. Confirm that freeze concentration of other product streams such as sweet whey and acid whey is also commercially feasible.

2. Establish maximum concentration levels for different product streams and confirm that they can be consistently attained.

3. Reduction of the time needed to bring the freeze concentration system to steady state operation. Given that freeze concentration is expected to require one-day of downtime for cleaning every 30-day run period, a 20 to 30-hour warm-up period to attain steady-state operating conditions represents a significant loss in operating efficiency.

4. Continue the effort to extend the practical time limitations of processing runs for each product stream. The longest run undertaken was a 510-hour run of skim milk that produced an average 32.3% T.S. concentrate. Subsequent runs undertaken, with the recrystallizer containing a standard filter design produced products at a concentration of 38.5% T.S. Consequently, concentration limits are thought to be a function of equipment design rather than process parameters.

Freeze concentration operates under good conditions of sanitation but the microbiological quality of the final product nonetheless remains a function of the initial microbial quality of the feed stream. No outgrowth of bacteria was observed during the actual concentration process although bacterial populations initially present in the feed were concentrated in proportion to the concentration of the feed stream. Nevertheless, bacterial population counts dropped rapidly as samples were stored under frozen conditions. Additional studies could confirm these findings using inoculation studies under controlled conditions. For now, based upon the limited data available, freeze concentration appears to be a microbiologically neutral process.

Key sanitation considerations in the operation of the PDU include minimizing water hardness and paying particularly close attention to seal integrity.

Ice crystallization is critical to the processing efficiency of freeze concentration. It affects product loss rates, product quality and energy efficiency. The recrystallizers represent the second greatest user of electrical energy after the compressor. A major finding of the Phase II study is that ice crystallization does not follow straight-line dynamics of other freeze concentration processes modeled by Niro. Ice crystallization follows a sinusoidal pattern, suggesting that appropriate design changes should be incorporated and longer steady state runs should be conducted prior to concluding that a new model needs to be developed to explain the ice crystallization behavior of milk products and its consequences for production efficiencies.

Production economics suggest that the PDU, as configured, is less efficient than either full scale MVR or TVR evaporation when the energy costs are calculated in dollars. It is to be expected that a semi-commercial-scale PDU would operate at a lower production efficiency than a full-scale commercial unit. A scale-up model for commercial-scale freeze concentration indicates that commercial freeze concentration will be less energy-efficient but more economical to operate than either MVR or TVR evaporation. Critical cost-variables to consider in comparing the economics of freeze concentration, MVR and TVR include electricity, product loss, and depreciation costs.

Operating costs for freeze concentration are considerably more elastic to energy costs than they are for MVR, suggesting that achieving better control of energy requirements would significantly enhance operating efficiencies. Specifically, the two common variables that determine the relative cost advantage between freeze concentration and MVR are the cost of electricity per lb. of concentrate produced and the economic value of the product losses associated with each system. Future studies should focus on the following areas as offering the best potential for improving the energy efficiencies of freeze concentration.

1. Improving the reliability ergo performance of the scraper blades (knives) in the washcolumn and recrystallizers.

2. Improving the recrystallizer filter design to optimize product throughput.

3. Reducing electricity requirements of the equipment through improved controls.

4. Reducing feed viscosity, especially for skim and whole milk product streams.

5. Removing lactose crystals to reduce wear on the system.

6. Improving the refrigeration efficiency of the system through insulation in order to reduce the electrical energy consumption.

7. Reconfiguring the system for energy regeneration by, for example, installing a heat exchanger between product outputs and product feed inlets.

8. Improving compressor efficiency by optimizing its design.

A major unexplored opportunity for freeze concentration is its potential impact on reducing milk transportation costs. This opportunity should be subjected to a full economic analysis.

Product Evaluations

The Generally Recognized as Safe (GRAS) status of freeze-concentrated milk was self-affirmed by an appointed expert panel.

Freeze-concentrated skim milk was demonstrated to either meet or exceed the organoleptic and functional quality of traditionally concentrated milk in numerous product applications, including low-fat ice milks, sour cream, cream cheese, and milk chocolate. The higher viscosity of freeze-concentrated skim milk confers upon it fat-simulating qualities that may also find a strong commercial application.

It is recommended that Phase III of the study attempt to affix a market value for freeze-concentrated ingredients to determine if their superior organoleptic and functional qualities translates into higher market cost and/or higher market value for similar ingredients.

Promotional Activities

Initial promotional activities focused on introducing the concept of freeze concentration to the industry. It is recommended that Phase III-related promotional activities focus on quantifying and documenting the quality and economic benefits offered by the freeze concentration of milk.

APPENDIX A: PHASE 1 CONCENTRATIONS CHARTS

Product concentration charts of dairy stream runs conducted on the "Freeze Concentration of Dairy Streams" during Phase 1.

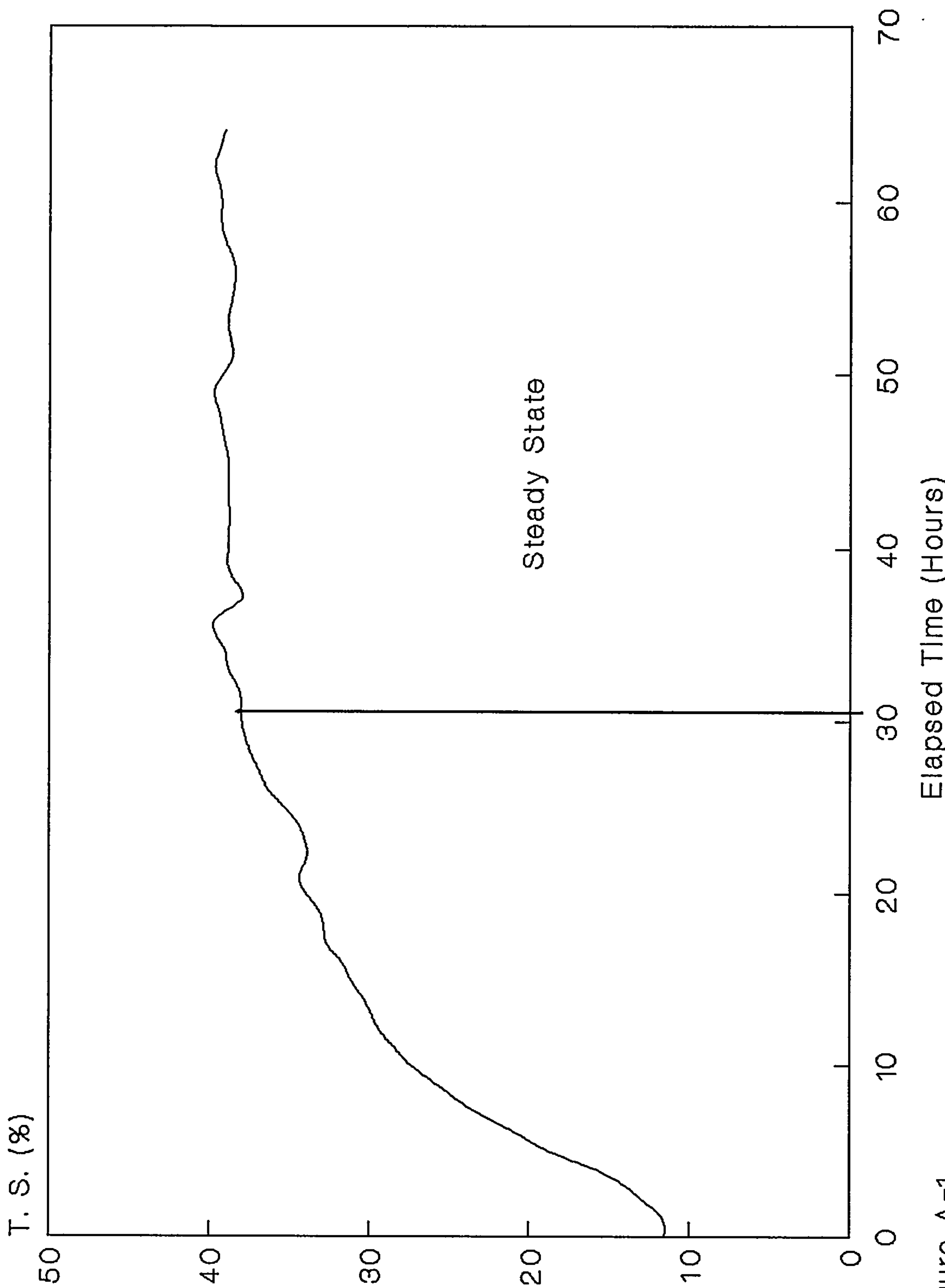


Figure A-1
T.S. Concentrations of Whole Milk During Single-Stage Pilot Plant Run

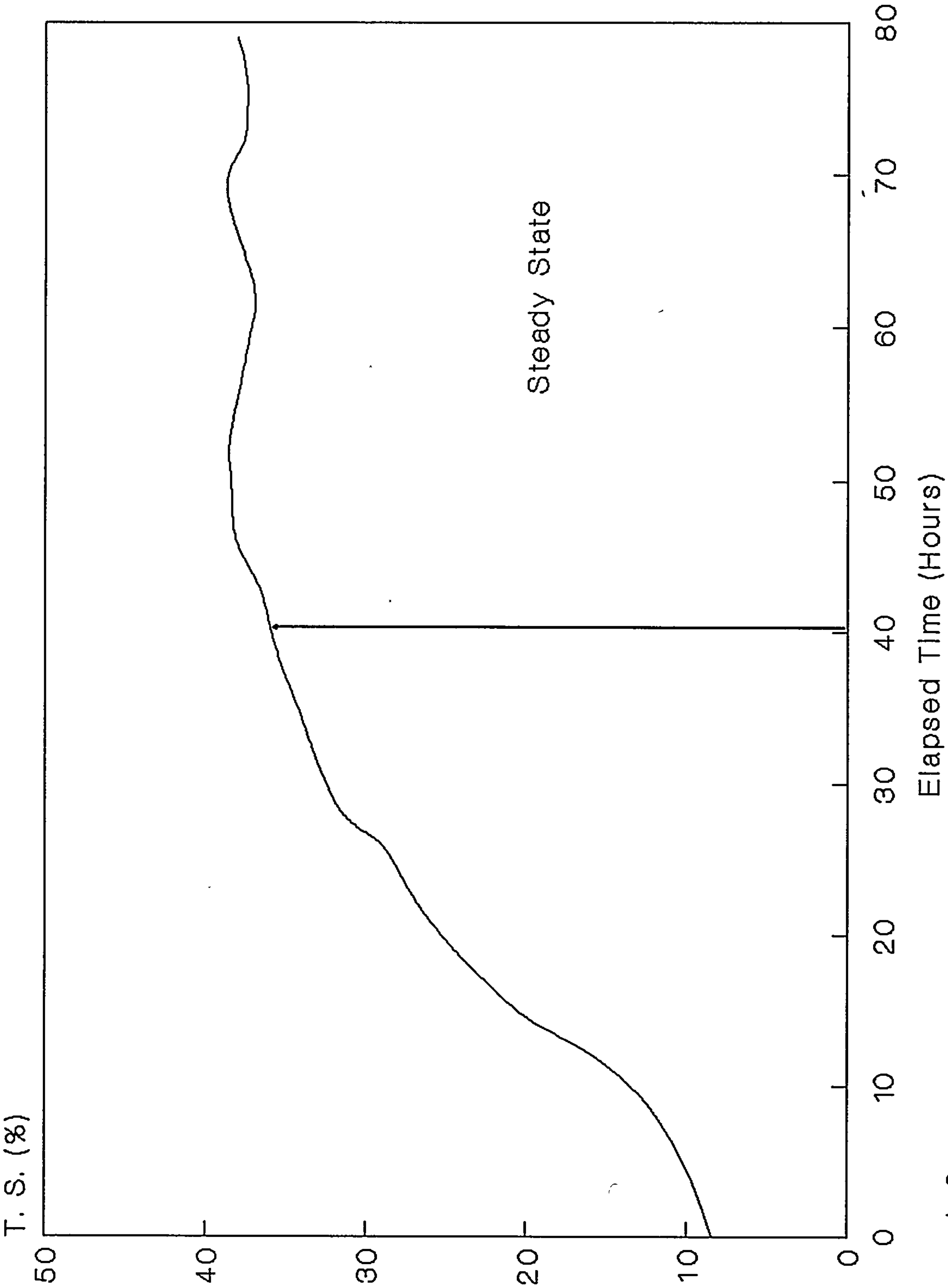


Figure A-2
T.S. Concentrations of Skim Milk During Single-Stage Pilot Plant Run

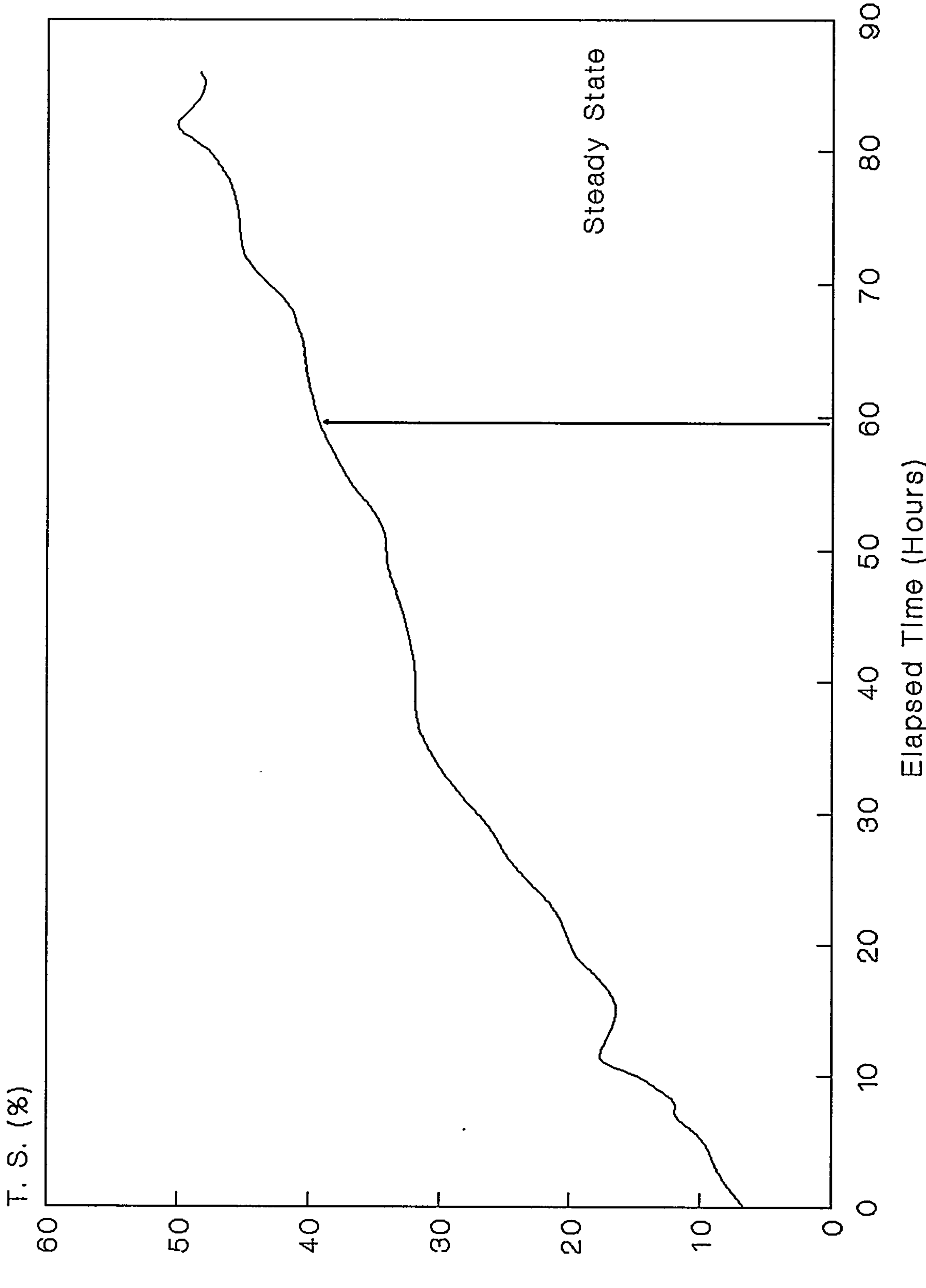


Figure A-3
T.S. Concentrations of Sweet Whey During Single-Stage Pilot Plant Run

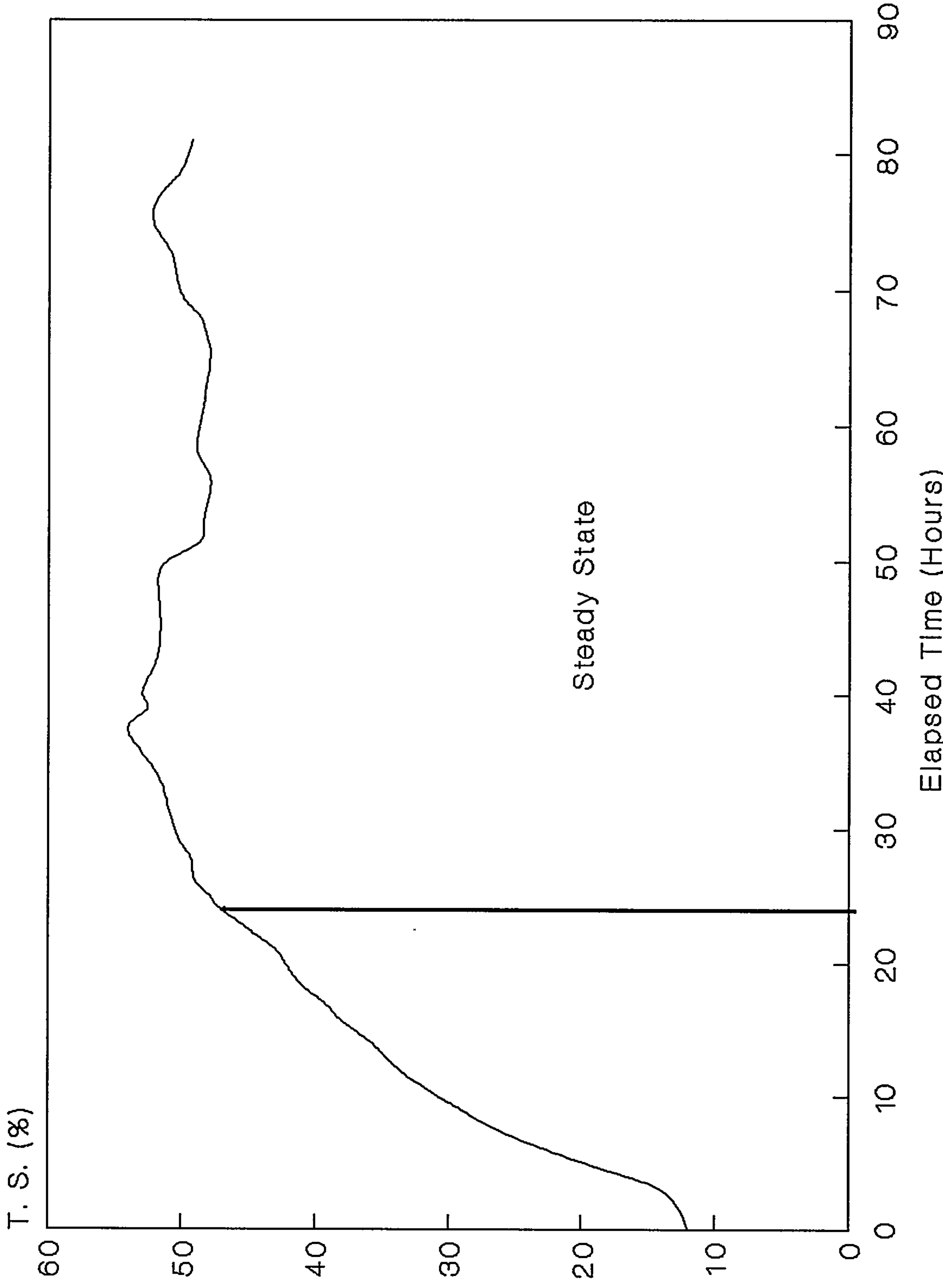


Figure A-4
T. S. Concentrations of WPC During Single-Stage Pilot Plant Run

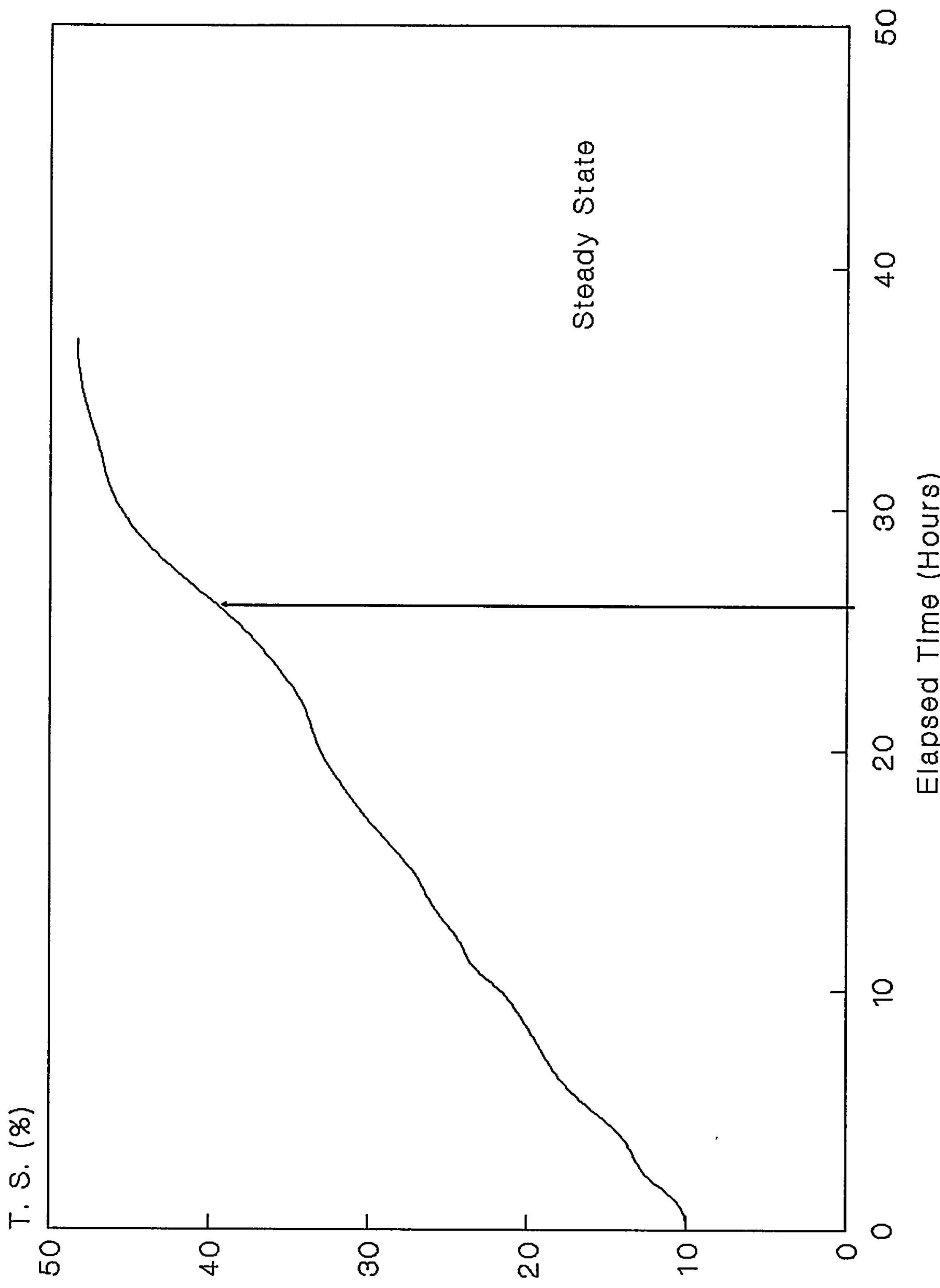


Figure A-5
T. S. Concentrations of Permeate During Single-Stage Pilot Plant Run

APPENDIX B: PDU FLOW DIAGRAM

Product flow diagram, flow rates and temperatures of dairy streams in the two stage PDU system.

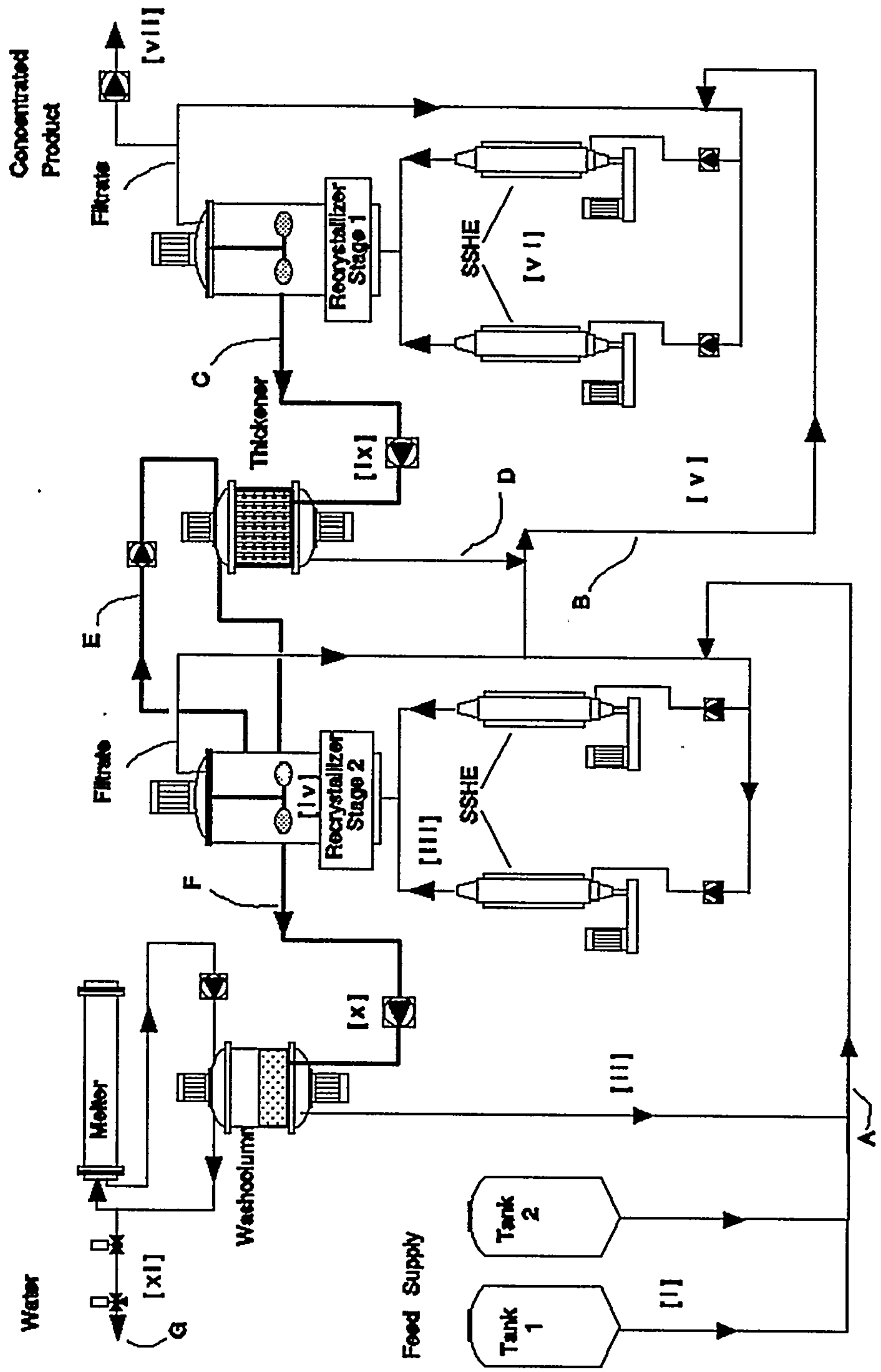


Figure B-1. Flow diagram of PDU*

* See attached Table B-1 for location explanation

Table B-1
Typical Product Temperatures and Flow Rates in the PDU During the Freeze Concentration Process

Location	Details	Temperature (oC.)	Flow Rates (kg/hr.)
i	Feed to the PDU	+3.0	450
ii	Conc. from washcolumn	-1.5	710
iii	Stage 2 recirculation	-1.5	3,000
iv	Circulation in recryst. 2	-1.5	10,000
v	Conc. to stage 1	-2.5	400
vi	Stage 1 recirculation	-4.0	3,000
vii	Circulation in recryst. 1	-4.0	10,000
viii	Concentrate output	-4.0	100
ix	Slurry to thickener	-4.0	300
x	Slurry to washcolumn	-1.5	1,060
xi	Wash water output	+5.0	350

APPENDIX C: GRADE A CONFIRMATION

Letter from the Wisconsin Department of Agriculture, Trade and Consumer Protection granting Grade A status to the Niro Freeze Concentration Product Development Unit.

State of Wisconsin
Department of Agriculture, Trade and Consumer Protection

Alan T. Tracy, Secretary

801 West Badger Road • PO Box 8911
Madison, WI 53708-8911

April 2, 1992

Kam Vasavada
Dairy Research Foundation
95 King St.
Elm Grove Village, IL 60007

Dear Kam:

This letter is in regards to our inspection of the Grenco equipment installed at Galloway West, Fond du Lac, WI, on March 31, 1992.

It is the opinion of the Wisconsin Department of Agriculture, Trade and Consumer Protection that the Grenco Freeze Concentration equipment complies with the construction requirements in Wisconsin dairy and food regulations and requirements in the Grade A Pasteurized Milk Ordinance, published by FDA Public Health Service.

If I can be of further assistance, please contact me.

Sincerely,

Everett E. Johnson
Technical Specialist
FOOD DIVISION

eej 92 45

cc: Don Lange-Galloway West
Dr. Woolf
Arnold Leestma
Bob Ellingen
Don Haase

APPENDIX D: PDU PROCESS DATA

Table D-1
Skim Milk and WPC Process Summary - Product Data

Parameters	**Skim Milk**	**WPC**
Length of run (hrs.)	510.00	138.00
Concentrate		
Average Total Solids (%)	32.30	38.40
Maximum Total Solids (%)	37.30	43.70
pH	6.30	6.60
Maximum Precipitation (%)	12.20	2.50
Maximum Viscosity (cst)	352.00	130.00
Wash Water		
Average Conductivity (milliseimens)	0.42	1.68
Dewatering Rate (liters/hr.)	316.00	431.00

APPENDIX E: CRYSTAL STUDIES DATA AND CHARTS

Crystal Study Data and Charts.

TABLE E-1
Conditions for Crystal Size Distribution

CODE	DATE	TIME	PRODUCT	STAGE	CONC. %(w/w)	VISCO-SITY (cst)	RESIDENCE TIME (hour)
A1535	03/06/92	20.00	Skim Milk	1.0	19.0	10.0	7.0
A1536	03/07/92	9.00	Skim Milk	1.0	29.3	30.0	4.6
A1537	03/07/92	9.00	Skim Milk	2.0	23.0	17.0	2.3
A1538	03/08/92	7.00	Skim Milk	1.0	36.7	90.0	7.0
A1539	03/08/92	7.00	Skim Milk	2.0	27.0	22.0	2.3
A1541	03/08/92	12.00	Skim Milk	2.0	25.6	20.0	2.3
A1543	03/08/92	19.00	Skim Milk	2.0	25.3	20.0	2.3
A1545	03/08/92	23.00	Skim Milk	2.0	25.5	20.0	2.3
A1546	03/09/92	9.00	Skim Milk	1.0	36.0	80.0	7.0
A1547	03/09/92	9.00	Skim Milk	2.0	25.2	20.0	2.3
A1548	03/09/92	15.00	Skim Milk	1.0	34.7	70.0	7.0
A1549	03/09/92	15.00	Skim Milk	2.0	24.5	19.0	2.3
A1550	03/09/92	22.00	Skim Milk	1.0	33.7	62.0	6.3
A1551	03/09/92	22.00	Skim Milk	2.0	25.0	20.0	2.3
A1553	03/10/92	9.00	Skim Milk	2.0	28.8	33.0	2.3

TABLE E-1
Conditions For Crystal Size Distribution (Continued)

CODE	DATE	TIME	PRODUCT	STAGE	CONC. %(w/w)	VISCO-SITY (cst)	RESIDENCE TIME (hour)
A1575	04/03/92	9.00	Skim Milk	1.0	19.0	10.0	7.0
A1576	04/03/92	9.00	Skim Milk	2.0	14.7	8.0	3.0
A1578	04/03/92	11.00	Skim Milk	1.0	20.0	11.0	5.4
A1579	04/03/92	11.00	Skim Milk	2.0	15.0	8.0	2.8
A1580	04/03/92	13.00	Skim Milk	1.0	20.3	11.0	4.5
A1581	04/03/92	13.00	Skim Milk	2.0	16.0	8.0	2.5
A1582	04/03/92	15.00	Skim Milk	1.0	21.0	13.0	4.5
A1583	04/03/92	15.00	Skim Milk	2.0	16.6	9.0	2.5
A1584	04/03/92	18.00	Skim Milk	1.0	23.0	15.0	4.6
A1585	04/03/92	18.00	Skim Milk	2.0	18.0	10.0	2.5
A1586	04/04/92	0.00	Skim Milk	1.0	27.5	24.0	4.6
A1587	04/04/92	0.00	Skim Milk	2.0	21.0	13.0	2.3
A1588	04/04/92	7.00	Skim Milk	1.0	21.8	48.0	5.4
A1589	04/04/92	7.00	Skim Milk	2.0	24.4	19.0	2.5
A1590	04/04/92	9.00	Skim Milk	1.0	32.3	53.0	5.4
A1591	04/04/92	9.00	Skim Milk	2.0	25.4	20.0	2.5
A1592	04/04/92	11.00	Skim Milk	1.0	33.6	62.0	6.9
A1593	04/04/92	11.00	Skim Milk	2.0	26.5	21.0	2.5
A1594	04/04/92	13.00	Skim Milk	1.0	34.5	68.0	7.0
A1595	04/04/92	13.00	Skim Milk	2.0	26.9	22.0	2.5
A1596	04/04/92	15.00	Skim Milk	1.0	34.8	71.0	4.6
A1597	04/04/92	15.00	Skim Milk	2.0	27.2	22.0	2.5
A1598	04/04/92	20.00	Skim Milk	1.0	35.0	75.0	9.1
A1599	04/04/92	20.00	Skim Milk	2.0	27.9	25.0	2.5
A1601	04/05/92	10.00	Skim Milk	1.0	36.3	83.0	12.5
A1602	04/05/92	10.00	Skim Milk	2.0	27.9	25.0	2.5
A1603	04/05/92	12.00	Skim Milk	1.0	35.1	76.0	12.5
A1604	04/05/92	12.00	Skim Milk	2.0	28.0	25.0	2.5

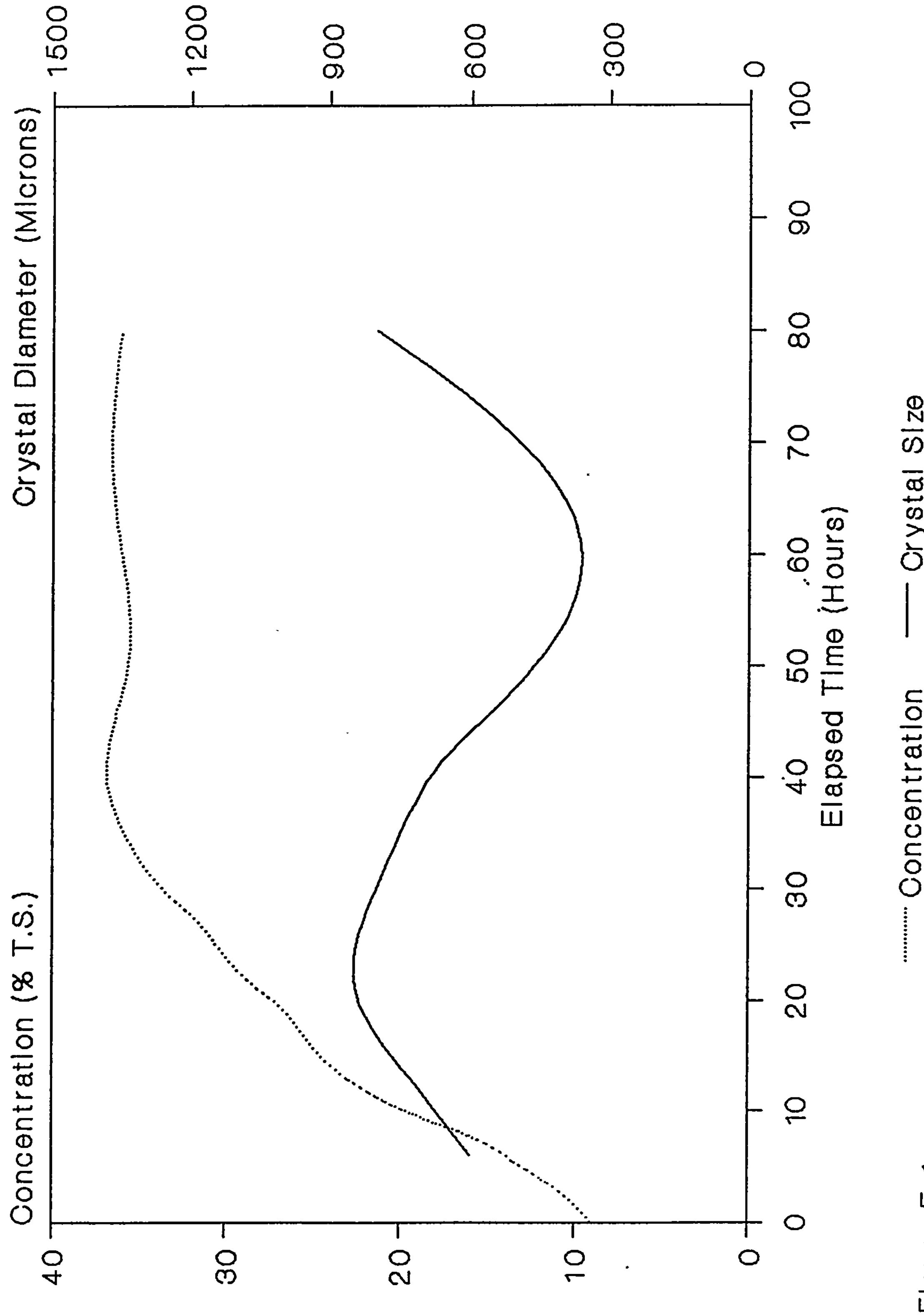


Figure E-1
Crystal Size Course Stage 1, Skim Milk Run - March 1992
(SOURCE: Niro Process Technology)

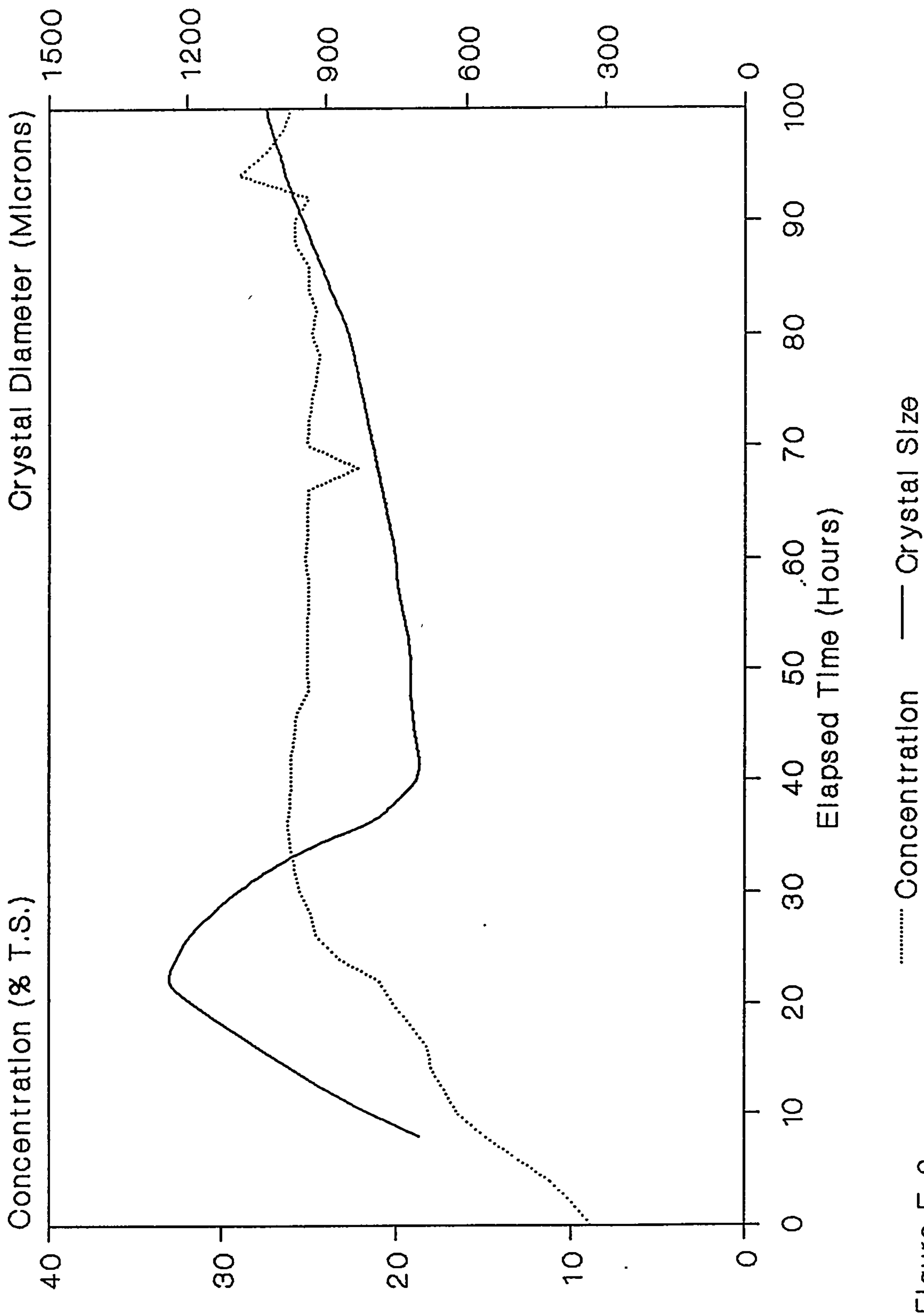


Figure E-2
Crystal Size Course Stage 2, Skim Milk Run - March 1992
(SOURCE: Niro Process Technology)

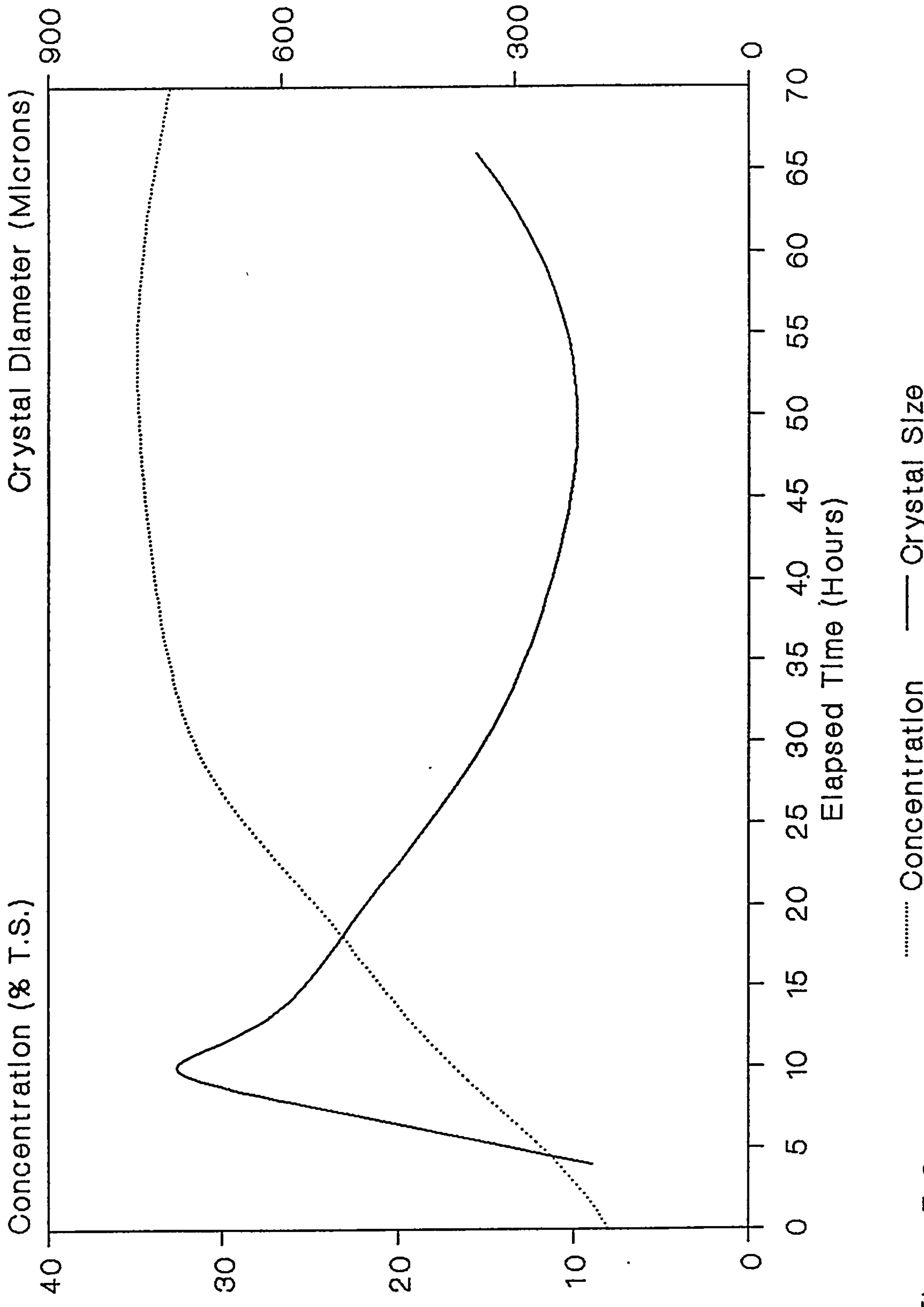


Figure E-3
Crystal Size Course Stage 1, Skim Milk Run - April 1992
(SOURCE: Niro Process Technology)

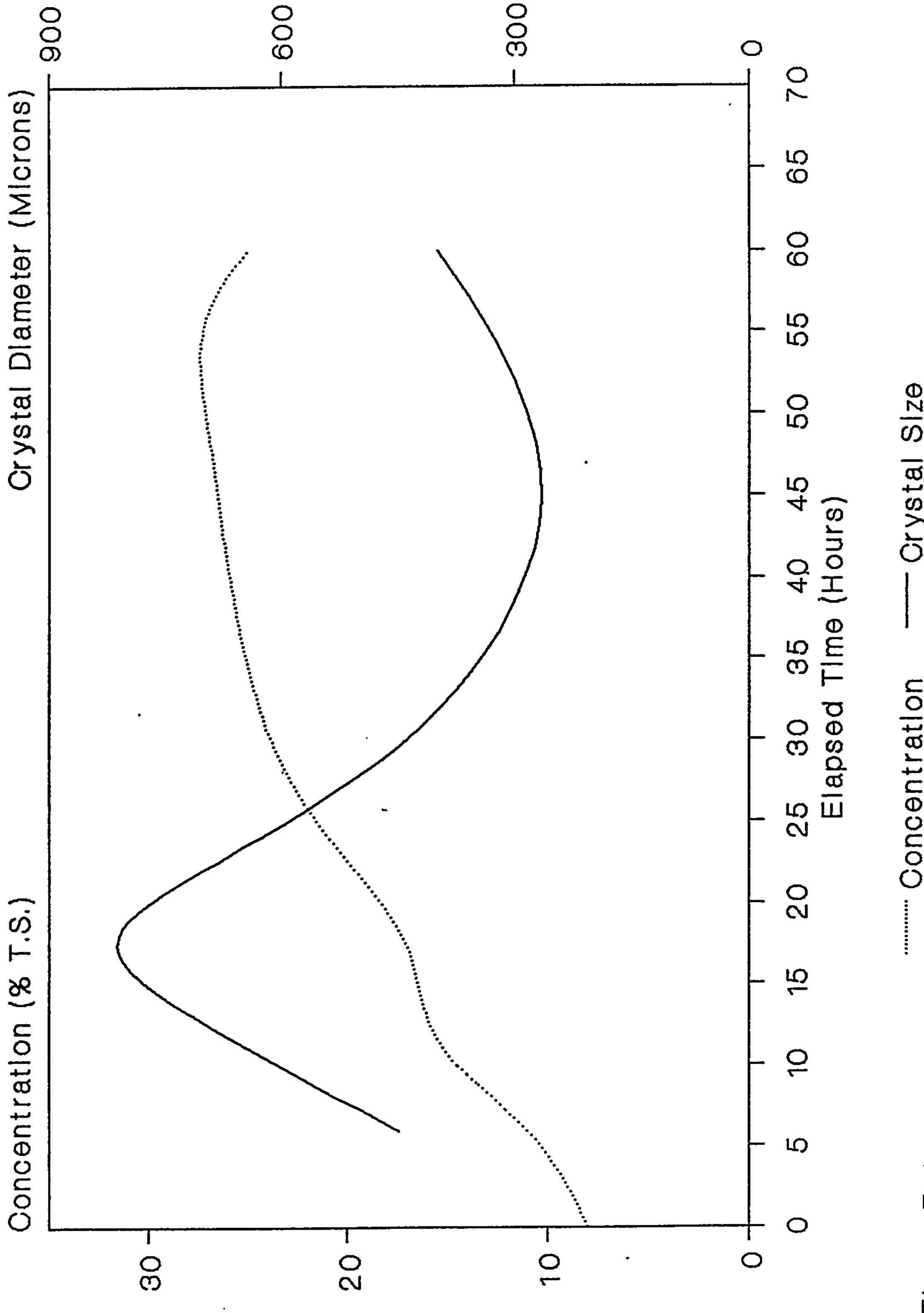


Figure E-4
Crystal Size Course Stage 2, Skim Milk Run - March 1992
(SOURCE: Niro Process Technology)

APPENDIX F: OPERATION COSTS ASSUMPTIONS

Operational costs comparisons and assumptions for TVR, MVR and FC plants.

Table F-1
Operating Costs Assumptions

Type Evaporator	Commercial TVR	Commercial MVR	Commercial FC	PDU
Feed	8.5%	8.5%	8.5%	8.9%
Product	48.0%	48.0%	40.0%	42.0%
Water Removal(lbs./hr.)	50,000	50,0000	40,000	15,000
Operating days	325	325	325	315
CIP (hours per cycle)	4	4	12	24
Cycles/year	325	325	10	10.5
CIP hours/year	1260	1260	120	262
CIP Chemicals ($/year)				
Caustic	$19,675	$19,675	$2,243	$1,295
Acid	$8,782	$8,782	$0	$0
Sanitizer	$5,082	$5,082	$451	$278
Total	$33,539	$33,539	$2,694	$1,574
Product losses				
Solids (lbs./CIP cycle)	800	800	1,153	711
% of holdup	10.0%	10.0%	2.0%	2.0%
Product loss/year	260,000	260,000	11,528	7,471
Energy consumption				
Electricity (kWh/hr.)	70	340	1,180	585
Steam (lbs./hr.)	4,500	1,000	0	0

* Labor is equal for both systems.
* Energy consumption cost during CIP equals to operating costs.
* Waste disposal is equals to 25% premium.
* Evaporator caustic recovery is equals to 3 times.

Table F-2
Component Costs and Clean-up Costs

Electricity ($/kWh)	$0.035
Steam ($/1000 lbs.)	$3.50
Milk Solids ($/lb.)	$1.00
Caustic	0.25
Acid	0.65
Sanitizer	5.00

CIP capacities

	MVR	TVR	FC-Com.	FC-PDU
Holdup (lbs.)	16,667	16,667	144,100	84,700
Caustic (%)	3.500	3.500	0.500	0.500
Acid (%)	0.200	0.200	0.000	0.000
Sanitizer (%)	0.015	0.015	0.005	0.015
Chemical Usage (lbs./CIP cycle)				
Caustic	583	583	721	424
Acid	33	33	0	0
Sanitizer	3	3	7	4

Table F-3
Comparison of Operating Costs

Type Evaporator	Commercial TVR	Commercial MVR	Commercial FC	PDU
Production (lb. solids/yr.)	33,776,203	3,776,203	33,158,095	12,379,443
(Production + CIP)	7,800	7,800	7,800	7,560
Electricity	$19,110	$92,820	$322,140	$154,791
Steam	$122,850	$27,3000	$0	$0
Losses	$260,000	$260,000	$11,528	$7,471
CIP Chemicals	$33,539	$33,539	$2,694	$1,574
Total	$435,499	$413,659	$336,362	$163,835
Operating costs($/lb.)	$0.0129	$0.01232	$0.01014	$0.01323

APPENDIX G: FC PRODUCT GRASS STATUS REPORT

KIRSCHMAN ASSOCIATES
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Mr. Daniel Best
Dairy Research Foundation
95 King Street
Elk Grove Village, IL 60007

September 2, 1993

Dear Mr. Best,

On October 2, 1992, after reviewing documentation supplied by the Dairy Research Foundation, five scientists (i.e. M. Doyle; J. Kinsella; M. Mangino; S. Taylor; J. Kirschman) experienced and renowned in food safety, met as an independent Expert Panel, and evaluated the safety of freeze concentrated milk (FCM) products produced by the Niro Process (Niro Process Technology, B.V.).

Following review and discussion of this documentation, the panel concluded that the Niro Process, when operated in the manner described and under good manufacturing practices (GMP), will not reduce the safety and wholesome quality of the starting dairy stream. If the incoming dairy stream is food quality the concentrated frozen product will continue to be of food grade quality.

Evaluations of Niro freeze concentrated food grade skim milk and whey protein products led the panel to conclude that if these specific products were to be used and regulated under existing food additive regulations they should be considered to be GRAS.

The overriding factor relative to the wholesomeness of these products is the obligatorily low temperature range of operation which precludes change in chemical constituents and minimizes any potential for microbiological proliferations. Properly constructed, maintained, and cleansed equipment of the specified design when operated under the good manufacturing guidelines cannot be expected to reduce the safety and wholesome quality of the starting dairy stream.

A full report of Expert Panel's deliberations, including the data upon which the above conclusions were reached, is in the final stages of completion. The completed draft should be ready for initial review and approval of the Panel members by the end of this month (9/93).

Sincerely,

John C. Kirschman

John C. Kirschman, Ph.D.
Chairman, FCM Expert Panel

APPENDIX H: UGA Sensory Study Final Report

DESCRIPTIVE SENSORY ANALYSIS AND CONSUMER ACCEPTANCE TEST OF FREEZE-CONCENTRATED (F/C) SKIM MILK:

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Final Report
Prepared for the Dairy Research Foundation

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INTRODUCTION

The technology of freeze-concentration (F/C) was used in the production of a skim milk concentrate by researchers at the Dairy Research Foundation. The concentrate may be stored in the frozen state and reconstituted as needed. The reconstituted product has potentials for use as a substitute for fresh skim milk. The frozen concentrate is stable under frozen storage conditions and will keep for up to a month under refrigeration. The concentrate can be stored and reconstituted into skim milk as needed. The potential for this product as a substitute for commercial skim milk can be evaluated by identifying and quantifying the sensory properties of the product and determine its acceptability to consumers.

This study was conducted in two phases. Phase I involved descriptive sensory profiling of the product with the following objectives: 1) to identify and quantify the sensory properties F/C skim milk liquid concentrate, 2) to determine the effect of freeze concentration on the sensory quality of skim milk, and 3) to determine the effects of freezing, spray-drying, and freeze-drying on the sensory quality of F/C skim milk liquid concentrate.

Phase II involved consumer acceptance tests of the products. The objectives were: 1) to determine consumer acceptance of F/C skim milk (liquid concentrate and powdered), 2) to determine milk consumption patterns of consumers, and 3) to determine market potential (purchase intention and purchase frequency) of F/C skim milk.

MATERIALS AND METHODS

PHASE I : DESCRIPTIVE SENSORY PROFILING
Preparation of Samples

The following products were received from the Dairy Research Foundation and used as test samples.

F/C skim milk liquid concentrate
F/C skim milk liquid concentrate, frozen
F/C skim milk liquid concentrate, spray-dried
F/C skim milk liquid concentrate, freeze-dried
Evaporated condensed milk
Non-fat dry milk

Commercial liquid skim milk was bought from a local grocer. Frozen samples were stored in an ordinary home-type freezer (≈ 0°C); dried samples were stored at room temperature (25°C); all other samples were stored at refrigerated temperature (≈ 5°C) until used (≈ one week).

Samples for the tests were prepared as follows. The solids content of all samples were determined using a CEM Automatic Volatility Computer Model AVC-80 (CEM Corporation, Indian Trail, NC). These were reconstituted to a final solids content identical to that in fresh liquid skim milk sample.

Samples were reconstituted as follows. Cold distilled water (Crystal Springs Water Co., Mabelton, GA) was poured into the Waring blender, the weighed sample was added to it, and the mixture was blended for 30 sec. at medium speed. The remaining water was added to the mixture, blended for another 30 sec., then stored in the refrigerator overnight.

The samples evaluated in the descriptive analysis tests were:

F/C skim milk liquid concentrate
F/C skim milk liquid concentrate,reconstituted
F/C skim milk liquid concentrate, frozen then reconstituted
F/C skim milk liquid concentrate, spray-dried, reconstituted
F/C skim milk liquid concentrate, freeze-dried, reconstituted
Evaporated condensed milk, reconstituted
Fresh liquid skim milk

Non-fat dry milk, reconstituted

Recruitment of Panelists

Eleven panelists were recruited by phone from participants in an existing consumer database maintained in the laboratory. Participants were screened for their availability during all the training and test periods and their suitability for the tests by ensuring that they did not detest milk.

Training of Panelists

The panelists were trained for a period of six days for at least two hours each day. A brief backgrounder about sensory evaluation was discussed with the panelists. This included discussions on the definition, importance, and application of sensory evaluation, the basic tastes, and olfaction among others.

The capability of the trainees to recognize and distinguish the four basic tastes from each other was assessed by conducting taste exercises that included samples labeled sweet (5% sugar), sour (0.08% citric acid), salty (0.5% iodized salt), and bitter (0.08% caffeine) and samples of lower concentrations that panelists identified. The tests were conducted such that some of the solutions were in duplicate to minimize the opportunity for the trainees to guess the identity of a given solution. This was done until all trainees were 100% successful in identifying the basic tastes.

Olfaction exercises were likewise conducted to test the ability of the panelists to recognize and identify common aromatic compounds such as anise, orange, vanilla, lemon, peppermint, pineapple, and banana. This was done to determine if they can identify the odor of familiar substances and describe the odor of materials new to them in terms of some other substances whose odor is known to them.

Panelists were then presented with several milk samples believed to possess attributes representative of the sensory characteristics of the product. Descriptive terms that characterized the sensory properties of the samples were suggested by the panel after evaluating these. These terms were listed then similar terms were grouped to avoid redundancy. The final set of descriptors were defined by the panelists (Table 1).

Calibration of Panelists

The panelists were trained to scale the intensity of stimuli so that ultimately each panelist brings his or her scaling system into line with the other members of the panel. This was accomplished by presenting panelists and making them familiar, through several test exercises, with standard references for the basic tastes and for flavor and their intensities (Meilgaard et al., 1987). The panelists were then given milk samples and selected reference standards for each attribute defined previously (Table 2). Test exercises using different milk samples were conducted to make sure that each panelist's scaling system was in line with the others.

Table 1
Definitions of Terms Used by Trained Sensory Panel to Evaluate F/C Skim Milk

Appearance	
Color	The actual color name or hue.
Thickness	The consistency of the milk sample.
Taste	
Sweet	The taste on the tongue associated with sugar.
Salty	The taste on the tongue associated with salt.
Sour	The taste on the tongue associated with citric acid.
Bitter	The taste on the tongue associated with caffeine.
Aromatic	
Milky	The aromatic associated with full milk.
Creamy	The aromatic associated with cream.
Cooked	The aromatic associated with milk that was heated to 90°C then cooled.
Caramel	The aromatic associated with caramel
Mouthfeel	
Grittiness	The mouthfeel associated with the presence of grits.

Table 2
Reference Standards and Their Intensities for the Terms Used by Trained Sensory Panel to Evaluate Skim Milk

Terms	Reference Standards	Intensities
Appearance		
Color	white color reference plaque (Gardner Tristimulus Colorimeter, Gardner Laboratory Div., Pacific Scientific Co., Bethesda, MD)	0
	yellow color ref. plaque (Gardner Tristimulus Colorimeter)	150
Thickness	distilled water (Crystal Springs Water Co. Mabelton, GA)	0
	sweetened condensed milk (Eagle Brand, Borden, Inc.-T Columbus, Ohio)	150
Taste		
Sweet	2.0% sugar	20
	5.0% sugar	50
Salty	0.2% iodized salt	20
	0.5% iodized salt	50
Sour	0.05% citric acid	20
	0.08% citric acid	50
Bitter	0.05% caffeine	20
	0.08% caffeine	50

Table 2
Continued

Terms	Reference Standards	Intensities
Aromatics		
Milky	full milk (Kroger brand, Kroger Griffin, GA)	75
Creamy	pure cream (Olde Tyme Coffee Cream, Pace Dairy Foods Co., Cincinnati, OH)	80
Cooked	cooked standard (Kroger fresh skim milk cooked in a double boiler for 14 min)	42
Caramel	caramel standard (1 pc, 9 g, Kraft caramel candy dissolved in 30 ml d. water and mixed with 500 ml Kroger skim milk)	50
For All aromatics	baking soda in saltines (Nabisco Brands Inc. East Hanover, NJ)	20
	cooked apple in apple sauce (Mott's U.S.A. a division of Cadbury Schweppes Inc. Stamford, CT)	50
	orange in reconstituted frozen orange juice concentrate (Minute Maid, Coca-Cola Foods, Houston, TX)	70
	cooked Concord grape in grape juice (Welch's, Concord, MA)	100
	cinnamon in Big Red cinnamon gum (W.M. Wrigley Jr. Co., Chicago, IL)	125

Table 2
Continued

Terms	Reference Standards	Intensities
Mouthfeel		
Grittiness	cooked Aunt Jemima quick grits (The Quaker Oats Co., P.O. Box 9003, Chicago, IL)	150
Thickness	spring water (Crystal Springs Water Co., Mabelton, GA)	10
	evaporated milk (Carnation Co., Los Angeles, CA)	39
	chocolate syrup (Hershey Chocolate, Hershey, PA)	92

[a] 150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

Sensory Evaluation of Products

Panelists evaluated each milk sample under white incandescent lights in partitioned booths equipped with computer terminals in a sensory evaluation laboratory. Approximately 4 oz of samples , prepared as described earlier, were served in 7 oz clear plastic cups. Samples were coded with three-digit random numbers obtained using the table of random numbers (Meilgaard et al. 1987) and presented to the panelists monadically. Sample order of presentation to panelists was randomized at every session to minimize bias. Each judge was provided with all reference standards, and water and crackers to clear the palate.

Unstructured line scales were used to rate samples for intensities of each attribute. The sensory ballots employed utilized a computer interactive program designed to ask judges for their ratings of one attribute per sample at a time. The line scales consisted of 150-mm lines with a marker that can be moved from end to end with the cursor keys. The line scales were anchored with words at 12.5 mm from both ends. Judges marked each scale to indicate their rating of intensities of the attributes. A sample score sheet is shown in Appendix A. Each sample was evaluated four times, once in the morning and in the afternoon in two days.

Physical Measurements

Objective measurements of color was done with a spectrocolorimeter (ACS CS-5 Chroma Sensor, Applied Color Systems, Inc., 5 Princess Rd., Lawrenceville, NJ). Lightness (L^*), a^*, b^*, chroma, and hue values were measured. Values reported are means of three determinations.

Viscosity measurements were taken on 15 ml of reconstituted milk samples using the UL Adapter and spindle of the Brookfield digital viscometer (Model LVTDV-II, Brookfield Engineering Labs., Inc., Stoughton, MA) which gave direct readings of viscosity in cps. The spindle speed used was 60 rpm. The readings were recorded using the Brookfield DV Gather Software (Brookfield Engineering Labs., Inc., Stoughton, MA). Values reported are means of three determinations.

Statistical Analysis

All analyses were performed using the Statistical Analysis System (SAS, 1985). The analysis of variance (ANOVA) procedure was conducted to determine significant differences between treatments. Least significance difference (LSD) tests were used to determine which treatments are significantly different from each other.

PHASE II - CONSUMER ACCEPTANCE TESTS

A total of 104 consumers participated in this study. The consumer tests consisted of four parts. First, consumer panelists were asked to complete a questionnaire on their demographic characteristics. Second, panelists completed a questionnaire regarding their milk consumption patterns. Third, the panelists rated their feelings for each of the milk samples presented to them. Fourth, participants answered questions on purchase intent for each of the products tested.

Panelists

Panelists used in this study are participants of an existing consumer panel and database maintained since 1984. Panel members were recruited during various occasions from 1984 to 1993. Upon recruitment, panelists completed a questionnaire that included items asking about their demographic characteristics, purchase and eating patterns of different food items, and their attitudes toward food and nutrition related statements. The information is stored in a consumer database maintained at the Food Safety and Quality Enhancement Laboratory.

One hundred twenty consumer panelists from the consumer database were recruited by telephone to participate in this study. An average of 20% of the number of consumer panelists needed for the tests were recruited to allow for absenteeism during the tests. Participants were screened for their suitability for the test by ensuring that each panelist drinks at least three cups of milk every week. Panelists that participated in this study were asked to complete a questionnaire (Appendix B) to update their demographic information in the database.

Milk Consumption Pattern

Participants were asked to answer questions to determine the milk consumption patterns of consumers. The questionnaire is shown in Appendix C.

Consumer Acceptance Tests

Samples Used. Samples prepared at the Dairy Research Foundation, Elk Grove, Ill. were shipped by air to the laboratory in styrofoam coolers with ice packs. These were stored at refrigeration temperature until used. The ready-to-serve samples used in the test were as follows:

Regular feed skim milk to PDU prior to F/C process

Reconstituted skim milk from F/C Skim Milk Concentrate
Reconstituted skim milk from commercial NFDM powder
Reconstituted skim milk from F/C Skim Milk Powder

Scales. Samples were evaluated by consumers for acceptability of color, appearance, dairy flavor, taste, mouthfeel, and overall acceptability using 9-point Hedonic scales (Peryam and Pilgrim, 1957) wherein 1=dislike extremely, 5=neither like nor dislike, and 9=like extremely. Participants were asked to check the box corresponding to their acceptability rating of a particular attribute. Participants were likewise asked to rate the appearance of the samples using a 9-point scale and to indicate the presence of any off-flavor using a 5-point scale. The score sheet used is shown in Appendix D.

Environmental Conditions. Panelists evaluated milk samples under two white incandescent lights (50 W/130 V, AM 8, Reflector, U.S.A.) under environmentally controlled conditions in individual partitioned booths in a sensory evaluation laboratory.

Test Material. Approximately 4 oz of sample in 7 oz clear plastic cups coded with three-digit random numbers obtained using the table of random numbers (Meilgaard et al. 1987) were presented to the panelists using a randomly sequential monadic order of presentation for each panelist.

Test Procedure. A total of six test sessions were conducted each day from 9:00-6:00 P.M. over a period of two days. All four samples were evaluated by each participant. Participants were asked to take at least half of the sample into their mouths when evaluating for flavor, taste, mouthfeel, and overall acceptability. They were likewise instructed to rinse their mouths with water between samples.

Instructions were given to panelists to evaluate the samples for the attributes in the order of appearance in the scoresheets. They were further told that swallowing the samples was optional but should be consistent throughout the testing period. Panelists were provided with cups for expectoration.

Consumer Purchase Intent

Additional questions were included in the consumer acceptance test score sheets to determine the market potential of F/C skim milk.

Statistical Analysis

All analyses were performed using the Statistical Analysis System software (SAS, 1985). Analysis of variance (ANOVA) procedure was conducted to determine significant differences between treatments. Correlation (PROC CORR) and regression analyses (PROC REG) were used to determine relationships between overall acceptability and the other attributes tested.

RESULTS AND DISCUSSION

PHASE I - DESCRIPTIVE SENSORY PROFILING

Characteristics of F/C Skim Milk Liquid Concentrate

Results of descriptive analysis tests of the freeze-concentrated skim milk are shown in Table 3. This product was found to have slightly yellow color and a thickness that was almost like that of Hershey chocolate syrup. It was sweeter than a 2.0% sugar solution but less than a 5.0% solution, slightly more salty than a 0.2% iodized salt solution, slightly less sour than a 0.05% citric acid solution, and less bitter than a 0.05% caffeine solution. The product was less milky than full milk and less creamy than Olde Tyme coffee cream. Slight cooked and caramel notes were likewise detected in the product.

Results of objective measurements of color are likewise shown in Table 3. Lightness is the luminous attribute of the color of objects. It is the perception by which white objects are distinguished from gray

Table 3
Sensory Properties and Physical Characteristics of Reconstituted Freeze-Concentrated (F/C) Skim Milk

Properties	Rating
Sensory[X]	
Appearance	
Color	50.6
Visual Thickness	85.4
Taste	
Sweetness	35.6
Saltiness	29.7
Sourness	18.9
Bitterness	15.1
Aromatics	
Milky	48.2
Creamy	40.6
Cooked	25.0
Caramel	24.0
Mouthfeel	
Grittiness	5.3
Thickness	63.4
Physical[Y]	
Lightness (L*)	77.92
Chroma	10.96

[X]150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

[Y]Lightness values range from 0 = black to 100 = white. Chroma = $[a^2 + b^2]^{½}$. Chroma values range from 0 (for gray) to 20.

objects and light from dark colored objects (Hunter and Harold, 1987). It can have values of 0-100 corresponding to black-white. The higher the lightness values, therefore, the lighter the color of the object. Hue and chroma (saturation) are the chromatic attributes of color. Hue is the actual color. It is the attribute of color perception by means of which an object is judged to be red, yellow, green, blue and so forth. Chroma or saturation can be thought of as a measure of how different the color is from gray. It is expressed on a scale extending from zero for gray to a maximum of about 20 in steps of approximately equal visual importance. Results indicated that the F/C skim milk liquid concentrate was very light yellow in color.

Effect of Freeze-Concentration on the Quality of Skim Milk

Freeze-concentration did not affect any of the sensory characteristics of skim milk. Reconstituted F/C skim milk were not significantly ($p \leq 0.05$) different from the commercial skim milk that was used in this study (Table 4). Both products were almost white in color and have viscosities that are slightly thicker than water. They were sweet and very slightly salty, sour, and bitter. The products were likewise milky and creamy but with slight cooked and caramel notes which are considered off-flavors in milk (Jellinek, 1985).

Compared to evaporated condensed milk, reconstituted F/C skim milk was significantly ($p \leq 0.05$) different from this product only in color and visual thickness when both were reconstituted. Evaporated condensed milk was slightly whiter and looked slightly thicker than reconstituted F/C skim milk.

When objective measurements were obtained, reconstituted F/C skim milk was found to be significantly ($p \leq 0.05$) more viscous and darker

Table 4
Effect of Freezing on the Sensory Attributes of Skim Milk[x]

	Attributes[y]					
Sample[z]	**Color**	**Vslthick**	**Sweet**	**Salt**	**Sour**	**Bitter**
A	32.5 a	18.5 a	24.6	12.3	10.4	8.2
E	28.0 b	22.9 b	22.6	12.6	9.8	8.4
F	30.4 ab	20.0 a	23.8	13.0	9.8	7.2
	Milky	**Creamy**	**Cooked**	**Caramel**	**Gritty**	**Thick**
A	34.5	25.2	19.6	16.4	0.8	16.6
E	36.4	27.0	21.6	17.6	0.8	19.1
F	36.2	24.4	19.9	17.8	0.4	16.8

[x]150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

[y]VSLTHICK represents the appearance attribute 'thickness'. Means within a column followed by the same letter or not followed by letters are not significantly different at 5% level of significance as determined by Least Significance Difference Tests (LSD).

[z]Samples were: A - F/C Skim Milk, liquid; E - Evaporated Condensed Milk; F - Commercial Fresh Skim Milk. All samples were reconstituted.

(lower lightness value) than fresh skim milk (Table 5). The two products, however, appeared to have similar hue and chroma or color saturation.

Effect of Freezing on the Quality of F/C Skim Milk

Freezing has long been recognized as a method of food preservation and is known to conserve desirable quality attributes in foods. Table 6 shows the effect of freezing on the sensory characteristics of F/C skim milk. The reconstituted frozen F/C skim milk was not significantly different from the reconstituted F/C skim milk liquid sample but was found to be significantly sweeter than the commercial fresh skim milk. It was likewise found to be significantly thinner in appearance and sweeter than reconstituted evaporated condensed milk.

Freezing did not affect any of the objective measurements except color lightness (Table 7). The reconstituted frozen sample was found to be significantly ($p \leq 0.05$) lighter in color than the reconstituted F/C liquid skim milk and the commercial fresh skim milk samples.

Effect of Freeze-Concentration With Freezing or Drying on the Quality of Skim Milk

Drying is one of the oldest methods of food preservation and is the most widely used. It works on the principle of reducing water activity in foods. Spray-drying and freeze-drying are two of the methods of drying available. Spray-drying involves the use of adiabatic driers where the food product is dispersed as small droplets which are suspended in the drying air (Desrosier and Desrosier, 1987). It has the advantage of very short drying times and, if properly operated, a large portion of the flavor, color, and nutritive value of the food is retained. Freeze-drying, on the other hand, uses high-vacuum conditions

Table 5
Effect of Freeze-Concentration on the Viscosity, Lightness, Hue, and Chroma of Skim Milk[x]

Sample	Viscosity (cps)	Color[y]		
		Lightness	Chroma	Hue
F/C Skim Milk, liquid, reconstituted	2.06 a	66.97 c	4.29 ab	209.36 a
Evaporated Condensed Milk, reconstituted	1.95 b	73.30 a	3.33 b	173.21 b
Commercial Skim Milk	1.89 b	70.14 b	4.42 b	209.63 b

[X]Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by least significant difference tests (LSD).

[Y]Lightness values range from 0 = black to 100 = white. Chroma = $[a^2 + b^2]^{1/2}$. Chroma values range from 0 (for gray) to 20.

Table 6
Effect of Freezing on the Sensory Attributes Of Reconstituted F/C Skim Milk Liquid Concentrate[x]

	Attributes[y]					
Sample[z]	**Color**	**Vslthick**	**Sweet**	**Salt**	**Sour**	**Bitter**
A	32.4 a	19.5 a	25.2 ab	11.1	9.4	7.9
B	30.8 ab	20.4 a	28.0 a	12.6	9.8	6.9
E	28.3 b	23.5 b	22.0 b	12.6	10.2	8.23
F	30.6 ab	19.7 a	24.5 b	13.5	10.6	8.4
	Milky	**Creamy**	**Cooked**	**Caramel**	**Gritty**	**Thick**
A	34.6	25.9	20.5	18.3	1.4	17.6
B	36.4	25.3	19.9	17.7	0.6	17.3
E	35.0	26.6	22.1	16.6	0.6	17.6
F	35.0	24.8	21.4	18.7	0.7	16.8

[x]150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

[y]VSLTHICK represents the appearance attribute 'thickness'. Means within a column followed by the same letter or not followed by letters are not significantly different at 5% level of significance as determined by Least Significance Difference Tests (LSD).

[z]Samples were: A - F/C Skim Milk, liquid; B - F/C Skim Milk, frozen; E - Evaporated Condensed Milk;F - Commercial Fresh Skim Milk. Samples A, B, and E were reconstituted.

Table 7
Effect of Freezing on the Viscosity, Lightness, Hue, and Chroma of Freeze-Concentrated (F/C) Skim Milk[X]

Sample	Viscosity (cps)	Color[Y]		
		Lightness	Chroma	Hue
F/C Skim Milk, Liquid, Reconstituted	2.12 a	66.20 d	4.43 a	210.71a
F/C Skim Milk, Frozen, Reconstituted	2.13 a	70.81 b	4.51 a	210.23 a
Evaporated Condensed Milk, Reconstituted	2.00 a	74.15 a	3.31 b	169.43 b
Commercial Fresh Milk	1.89 a	70.14 c	4.42 a	209.63 a

[X] Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by least significant difference tests (LSD).

[Y] Lightness values range from 0 = black to 100 = white. Chroma = $[a^2 + b^2]^{1/2}$. Chroma values range from 0 (for gray) to 20.

to establish specific conditions of temperature and pressure whereby the physical state of a food substrate can be maintained at a critical point for successful dehydration.

Tables 8 and 9 show the effects of freeze concentration together with freezing, spray-drying, or freeze-drying on the sensory characteristics and physical properties of skim milk, respectively. No significant ($p \leq 0.05$) differences were found between the commercial fresh skim milk and any of the reconstituted frozen, spray-dried, or freeze-dried F/C skim milk samples. When compared with the commercial non-fat dry milk, both spray-dried and freeze-dried samples were found to be significantly ($p \leq 0.05$) thinner in appearance (Table 10). Using objective measurements, both reconstituted spray-dried and freeze-dried F/C skim milk samples were significantly ($p \leq 0.05$) darker in color and higher in chroma and hue (Tables 9 and 11). The reconstituted spray-dried F/C skim milk sample was likewise found to be significantly ($p \leq 0.05$) less viscous while the reconstituted freeze-dried F/C skim milk sample was similar in viscosity to the commercial non-fat dry milk (Table 11).

Effect of Freezing and Spray-Drying on the Quality of F/C Skim Milk

Freezing and spray-drying did not affect the sensory properties of F/C skim milk except for color whereby the reconstituted frozen F/C skim milk sample was found to be significantly ($p \leq 0.05$) more yellowish (Table 12). When compared with the commercial fresh skim milk, the reconstituted liquid F/C skim milk was found to be significantly ($p \leq 0.05$) sweeter whereas the reconstituted spray-dried F/C skim milk had significantly ($p \leq 0.05$) more cooked flavor. When compared with the commercial non-fat dry milk, only the reconstituted spray-dried F/C skim

Table 8
Effect of Freeze Concentration With Freezing, Spray-Drying, or Freeze-Drying on The Sensory Attributes of Skim Milk[x]

	Attributes[y]					
Sample[z]	Color	Vslthick	Sweet	Salt	Sour	Bitter
B	27.9	21.0	26.8	11.8	8.9	7.5
C	27.0	21.3	27.0	9.7	7.7	7.3
D	27.3	20.9	27.3	9.8	8.5	8.7
F	26.9	21.0	25.9	11.7	10.5	8.2
G	26.6	23.9	26.3	11.1	8.3	8.1

Sample[z]	Milky	Creamy	Cooked	Caramel	Gritty	Thick
B	38.6	26.0	19.9	15.0	0.1	16.7
C	35.9	25.8	19.5	13.0	0.2	17.2
D	38.8	24.8	22.2	16.1	0.5	17.5
F	36.1	25.5	19.1	15.0	0.2	18.0
G	39.5	26.3	22.3	15.1	2.1	17.9

[x]150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

[y]VSLTHICK represents the appearance attribute 'thickness'. Means within a column followed by the same letter or not followed by letters are not significantly different at 5% level of significance as determined by Least Significance Difference Tests (LSD).

[z]Samples were: B - F/C Skim Milk, frozen; B - F/C Skim Milk, spray-dried; D - F/C Skim Milk, freeze-dried; F - Commercial Fresh Skim Milk; G - Commercial Non-Fat Dry Milk. Sample B,C,D, and G were reconstituted.

Table 9
Effect of Freeze Concentration with Freezing or drying on the Viscosity, Lightness, Hue, and Chroma of Skim Milk[X]

Sample	Viscosity (cps)	Color[Y]		
		Lightness	Chroma	Hue
F/C Skim Milk, Frozen, Reconstituted	2.15 a	70.61 b	4.43 a	210.71 a
F/C Skim Milk, Spray-Dried, Reconstituted	1.94 a	69.71 d	4.41 a	208.04 a
F/C Skim Milk, Freeze-Dried, Reconstituted	2.07a	69.19 e	4.44 a	209.22 a
Commercial Fresh Milk	1.89 a	70.14 c	4.42 a	209.63 a
Commercial Non-Fat Dry Milk Reconstituted	2.03 a	73.19 a	3.29 b	180.76 b

[X] Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by least significant difference tests (LSD).

[Y] Lightness values range from 0 = black to 100 = white. Chroma = $[a^2 + b^2]^{1/2}$. Chroma values range from 0 (for gray) to 20.

Table 10
Effect of Freeze Concentration With Spray-Drying Or Freeze-Drying On The Sensory Attributes Of Dry Skim Milk[x]

	Attributes[y]					
Sample[z]	Color	Vslthick	Sweet	Salt	Sour	Bitter
C	28.7	20.5	26.6	10.9	8.4	7.0
D	28.2	20.8	25.6	10.1	8.6	7.1
G	25.6	25.2	26.0	10.7	9.6	8.8

Sample[z]	Milky	Creamy	Cooked	Caramel	Gritty	Thick
C	37.5	25.1	22.7	13.6	0.4	15.9
D	34.5	22.0	23.3	13.1	0.1	16.0
G	39.6	26.2	22.8	15.4	0.5	17.9

[x]150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

[y]VSLTHICK represents the appearance attribute 'thickness'. Means within a column followed by the same letter or not followed by letters are not significantly different at 5% level of significance as determined by Least Significance Difference Tests (LSD).

[z]Samples were: C - F/C Skim Milk, spray-dried; D - F/C Skim Milk, freeze-dried; G - Commercial Non-Fat Dry Milk. All samples were reconstituted.

Table 11
Effect of Freeze Concentration with Spray-Drying or Freeze-Drying on the Viscosity, Lightness, Hue, and Chroma of Dry Skim Milk[X]

Sample	Viscosity (cps)	Color[y]		
		Lightness (L*)	Chroma	Hue
F/C Skim Milk, Spray-Dried, Reconstituted	1.96 b	70.03 b	4.42 a	207.94 a
F/C Skim Milk, Freeze-Dried, Reconstituted	2.13 ab	69.38 c	4.40 a	208.70 a
Commercial Non-Fat Dry Milk,	2.00 a	73.21 a	3.31 b	180.47 b

[X] Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by least significant difference tests (LSD).

[Y] Lightness values range from 0 = black to 100 = white. Chroma = $[a^2 + b^2]^{½}$. Chroma values range from 0 (for gray) to 20.

Table 12
Effects of Freezing, Spray-Drying, And Freeze-Drying On The Sensory Attributes Of Freeze-Concentrated (F/C) Skim Milk[x]

			Attribute[s]			
Sample[z]	**Color**	**Vslthick**	**Sweet**	**Salt**	**Sour**	**Bitter**
A	30.2	19.0	29.9	10.6	8.9	6.3
B	36.3	19.5	26.7	11.8	8.3	6.2
C	27.3	23.5	26.0	10.5	8.1	7.3
E	26.9	24.2	23.3	10.5	9.4	6.5
F	28.9	20.8	25.0	9.7	10.8	8.5
G	27.6	24.5	27.3	9.9	9.8	7.5

Sample[z]	**Milky**	**Creamy**	**Cooked**	**Caramel**	**Gritty**	**Thick**
A	38.6	23.0	19.0	14.4	0.4	17.1
B	35.7	21.8	22.4	12.7	0.4	17.5
C	34.9	23.4	23.9	13.9	0.4	17.9
E	36.3	24.1	22.0	12.4	0.4	18.5
F	35.3	21.3	17.3	12.8	0.0	18.0
G	39.2	24.5	22.4	14.9	0.3	18.5

[x]150-mm scales were used anchored at 12.5 mm with 'slight' and at 137.5 mm with 'extreme' for all the attributes except the appearance attributes which were anchored as follows: color - 'white' at 0 mm and 'yellow' at 150 mm, thickness - 'very thin' at 12.5 mm and 'very thick' at 137.5 mm.

[y]VSLTHICK represents the appearance attribute 'thickness'. Means within a column followed by the same letter or not followed by letters are not significantly different at 5% level of significance as determined by Least Significance Difference Tests (LSD).

[z]Samples were: A - F/C Skim Milk, liquid; B - F/C Skim Milk, frozen; C - F/C Skim Milk, spray-dried; E - Evap. Condensed Milk; F - Commercial Fresh Skim Milk; G - Commercial Non-Fat Dry Milk. Samples A, B, C, E, and G were reconstituted.

milk sample was found to be not significantly ($p \leq 0.05$) different from it in all the sensory attributes tested.

The commercial non-fat dry milk was significantly ($p \leq 0.05$) different from all the reconstituted F/C skim milk samples in all the objective properties measured except viscosity (Table 13). The reconstituted liquid and spray-dried F/C skim milk samples were likewise not significantly ($p \leq 0.05$) different from the commercial fresh skim milk sample while the reconstituted frozen F/C skim milk was found to be significantly ($p \leq 0.05$) more viscous.

Phase II - Consumer Acceptance Tests

Demographic Characteristics

One-hundred-four consumers participated in the tests. Their demographic characteristics are shown in Table 14. The panel was composed of 75% caucasian participants and represented a wide range of age categories from 18-70 yrs. of age with 90% under 64 years old. About 90% of the panelists were female because the consumer panel targeted major shopper of food in a household during recruitment. Married panelists made up 75% of the sample.

The panel consisted of 90% who received a high school diploma and 51% who either attended college courses, completed a college degree, or attended graduate courses. The median household income of the panel was between $30,000 to $39,000.

Consumer Milk Consumption Pattern

The milk consumption pattern of the participants is shown in Table 15. Ninety-five percent of the participants drink at least one cup of milk daily. It is a very popular item for breakfast (45%) or as part of

Table 13
Effects of Freezing, Spray-Drying, and Freeze-Drying on the Viscosity, Lightness, Hue, and Chroma of Freeze Concentrated Skim Milk[X]

Sample	Viscosity (cps)	Color[Y]		
		Lightness (L*)	Chroma	Hue
F/C Skim Milk, Liquid,	2.06 a	66.97 c	4.29 ab	209.36 a
F/C Skim Milk, Liquid, Reconstituted	2.31 b	69.41 b	4.55 a	208.95 a
F/C Skim Milk, Frozen, Reconstituted	3.12 a	67.16 c	4.77 a	214.46 a
F/C Skim Milk, Spray-Dried, Reconstituted	1.92 b	69.93 b	4.44 a	207.92 a
Evaporated Condensed Milk, Reconstituted	2.15 b	73.68 a	3.36 b	170.71 c
Commercial Fresh Skim Milk	1.89 b	70.14 b	4.42 a	209.63 a
Commercial Non-Fat Dry Milk	2.04 b	72.46 a	3.34 b	178.54 b

[X]Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by least significant difference tests (LSD).

[Y]Lightness values range from 0 = black to 100 = white. Chroma = $[a^2 + b^2]^{1/2}$. Chroma values range from 0 (for gray) to 20.

Table 14
Demographics of Participants in the Consumer Acceptance Tests on F/C Skim Milk

		Frequency	Percent
Age	under 25 yrs old	5	4.8
	25 - 34 yrs old	15	14.4
	35 - 44 yrs old	28	26.9
	45 - 54 yrs old	30	28.8
	55 - 64 yrs old	16	15.4
	over 64 yrs old	10	9.6
Sex	Female	91	87.5
	Male	13	12.5
Race	White	75	72.1
	Black	22	21.2
	Others (Hispanic, etc)	7	6.7
Marital Status	Single	8	7.7
	Married	78	75.0
	Others	18	17.3
Educational Attainment	some high school	7	6.7
	completed high school	42	40.4
	some college	25	24.0
	completed college	19	24.0
	graduate school	7	6.7
Household Income	under $9,999	8	8.2
	$10,000 - $19,999	16	16.3
	$20,000 - $29,999	23	23.5
	$30,000 - $39,999	16	16.3
	$40,000 - $49,999	13	13.3
	$50,000 - $59,999	12	12.2
	$60,000 and over	10	10.2

Table 15
Milk Consumption Pattern of Participants in Consumer Acceptance Tests on F/C Skim Milk

		Frequency	Percent
Daily milk consumption			
	<1 cup	5	4.8
	1 cup	48	46.2
	2 cups	36	34.6
	3 cups	9	8.7
	4 cups	2	1.9
	>4 cups	4	3.8
Time of day of milk consumption	breakfast	82	44.8
	A.M. snacks	11	6.0
	lunch	14	7.7
	P.M. snacks	14	7.7
	supper	15	8.2
	midnight snack	47	25.7
Weekly milk purchases			
	<1/2 gal	7	6.7
	1/2 gal	10	9.6
	1 gal	54	51.9
	2 gal	25	24.0
	>2 gal	8	7.7
Type of milk bought			
	whole milk	42	20.8
	2% fat milk	41	20.3
	skim milk	31	15.3
	1% fat milk	22	10.9
	evap. whole milk	19	9.4
	non-fat dry milk	16	7.9
	evap. skim milk	14	6.9
	sweet cond. milk	10	5.0
	other (buttermilk)	7	3.5

midnight snack (26%). Some of the participants likewise drink milk during morning and afternoon snacks, lunch, or supper. Most consumers (87%) buy 1 or more gallons of milk every week. Whole (full fat) milk is the most popular among them followed by 2%-fat milk. Skim milk is the third most frequently purchased Form.

Consumer Acceptance of F/C Skim Milk

The mean consumer acceptance scores and standard deviations for the different characteristics, color, appearance, dairy flavor, taste, mouthfeel, and overall acceptability, of the skim milk samples tested by the entire consumer panel (n=104) are shown in Table 16. No significant ($p \leq 0.05$) differences were found between samples on all the characteristics tested. All samples received mean scores of 5.0-5.5 with standard deviations of 2.0.

Commercial skim milk users (n=31), a subsample from the entire consumer panel used, rated the reconstituted F/C skim milk liquid concentrate not significantly ($p \leq 0.05$) different from the commercial skim milk in terms of overall acceptability (Table 17). Ratings for the reconstituted F/C skim milk liquid concentrate were likewise not significantly ($p \leq 0.05$) different from the reconstituted powdered F/C skim milk nor the commercial non-fat dried milk (NFDM). The reconstituted dried milk samples, including the commercial non-fat dry milk, however, were scored significantly ($p \leq 0.05$) different in appearance and dairy flavor from commercial fresh skim milk. These consumers indicated that they preferred the appearance of reconstituted F/C skim milk liquid concentrate and the reconstituted dried milk samples to that of the commercial fresh skim milk sample. However, these participants preferred the dairy flavor of the commercial skim

Table 16
Mean Consumer Acceptance Scores For The Different Characteristics of The Skim Milk Samples (n=104)[x]

Treatment	Color	Appearance	Dairy Flavor	Taste	Mouthfeel	Overall Acceptability
Fresh in Milk (Commer.)	5.4 ± 1.7	5.5 ± 1.6	5.5 ± 1.9	5.4 ± 1.8	5.4 ± 1.8	5.5 ± 1.8
F/C Skim Milk Conc. (Reconst.)	5.8 ± 1.7	5.8 ± 1.4	5.3 ± 2.0	5.2 ± 1.9	5.5 ± 1.8	5.3 ± 1.9
Non-fat Dried Milk (Reconst. from Comm. Sample)	5.7 ± 1.6	5.8 ± 1.4	5.9 ± 2.0	4.8 ± 1.9	5.3 ± 1.8	4.9 ± 2.0
Powdered F/C Skim Milk (Reconstituted)	5.9 ± 1.5	5.9 ± 1.4	5.1 ± 1.9	5.1 ± 2.0	5.6 ± 1.7	5.1 ± 2.0

[x] 9-point Hedonic scales were used with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely.

Table 17
Mean Consumer Acceptance Scores From Fresh Skim Milk Users (n=31) For The Different Characteristics of the Skim Milk Samples[x]

Treatment	Color	Appearance	Dairy Flavor	Taste	Mouthfeel	Overall Acceptability
Fresh Skim Milk (Commercial)	5.8 ± 1.4a	5.5 ± 1.6b	6.3 ± 1.7a	5.9 ± 1.8ab	5.9 ± 1.6a	6.0 ± 1.7a
F/C Skim Milk Conc. (Reconst.)	6.3 ± 1.6a	6.2 ± 1.3a	5.1 ± 2.2b	5.2 ± 2.0ab	5.7 ± 1.9a	5.1 ±2.1ab
Non-fat Dried Milk (Reconst.from a Comme. Sample)	6.1 ± 1.5a	6.3 ± 1.0a	5.0 ± 2.3b	5.0 ± 2.1ab	5.7 ± 1.8a	4.9 ± 2.2b
Powdered F/C Skim Milk Reconst.)	6.1 ± 1.5a	5.8 ± 1.4a	4.7 ± 2.2b	4.7 ± 2.2b	5.4 ± 1.9a	4.6 ± 2.2b

[x] 9-point Hedonic scales were used with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by Least Significant Difference (LSD) test.

milk to that of any of the other samples. Results also showed that the taste of reconstituted F/C skim milk liquid concentrate was not significantly ($p \leq 0.05$) different from that of any of the other samples. The taste of reconstituted powdered F/C skim milk, however, was significantly ($p \leq 0.05$) different from that of the commercial fresh skim milk. When asked to rate the appearance (whether thin-transparent or thick-opaque) and the intensity of off-flavor in the milk samples, these panelists indicated that all samples were neither thin nor thick and had slight off-flavor (Table 18). Off-flavors detected in the milk samples by the participants were described more often (20-40%) as "cooked", "stale", or "cardboardy" (Table 19). Other descriptors used by consumers (3-10%) included "barn", "chalky", "medicinal", "metallic", and "powdered-milk-like".

High ($R > 0.75$), positive, and significant correlations were found between overall acceptability and each of the attributes dairy flavor, taste, and mouthfeel and the absence of off-flavor (Tables 20 and 20a). These same attributes together with intensity ratings for appearance were found to be the significant contributing parameters for overall acceptability as determined by regression analysis. The parameter estimates are shown in Table 21. The regression model obtained represented by the sum of all the attributes tested had an r^2=0.91. It was apparent from the results that taste had considerably more significant contribution to the overall acceptance rating of the samples as shown by its highest correlation coefficient and highest parameter estimate in the regression model. This indicates that consumers' (skim milk users) overall ratings are influenced primarily by taste followed by mouthfeel and the absence of off-flavor. The dairy flavor is not the

Table 18
Mean Consumer Rating from Fresh Skim Milk Users for Appearance and Off-Flavor of Skim Milk Samples[w]

Treatment	Appearance[x]	Off-Flavor[w]
Fresh Skim Milk (Commercial)	4.5 a	4.4 a
F/C Skim Milk Conc. (Reconstituted)	4.8 a	3.8 ab
Non-fat Dried Milk (Reconstituted from a Commercial Sample)	4.9 a	3.8 ab
Powdered F/C Skim Milk (Reconstituted)	5.2 a	3.6 b

[W] Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by Least Significant Difference (LSD) analysis.

[X] 9-point scales were used with 1 = extremely thin (transparent), 5 = neither thin nor thick, and 9 = extremely thick (opaque).

[Y] 5-point scales were used with 1 = very strong, 3 = moderate, and 5 = none.

Table 19
Off-Flavor Descriptors and the Percent of Consumers that Detected Each One in the Skim Milk Samples Tested

Descriptors	Fresh Skim Milk (Comme.) (%)	F/C Skim Milk Conc. (Reconst.) (%)	Non-fat Dried Milk (Reconst.) (%)	Powdered F/C Skim (Reconst.) (%)
"Barn"	5.7	13.0	8.3	12.5
"Cardboardy"	17.1	17.4	10.4	27.1
"Chalky"	-	2.2	4.2	-
"Cooked"	28.6	37.0	39.6	33.3
"Medicinal"	8.6	10.9	12.5	6.3
"Metallic"	2.9	-	-	-
"Powdered-Milk"	2.9	-	4.2	-
"Stale"	28.6	17.4	20.8	20.8

Table 20
Pearson Correlation Coefficients of Consumer Ratings for the Attributes of Skim Milk Samples

	Parameters[x]							
	A	B	C	D	E	F	G	H
Color	-	0.25	0.67	0.27	0.21	0.27	0.38	0.31
Appearance (Intensity)	0.25	-	0.33	0.19	0.08	0.11	0.21	0.07
Appearance (Hedonic)	0.67	0.32	-	0.34	0.28	0.40	0.42	0.40
Dairy Flavor	0.27	0.19	0.34	-	0.72	0.85	0.70	0.85
Off-Flavor	0.21	0.08	0.28	0.72	0.85	0.70	0.58	0.75
Taste	0.27	0.11	0.40	0.85	0.70	-	0.79	0.94
Mouthfeel	0.38	0.21	0.42	0.70	0.58	0.79	-	0.81
Overall Acceptability	0.31	0.07	0.40	0.85	0.75	0.94	0.81	-

A = Color; B = Appearance (Intensity); C = Appearance (Hedonic); D = Dairy Flavor; E = Off-Flavor; F = Taste; G = Mouthfeel; H = Overall Acceptability

Table 20a
Probability Levels of Pearson Correlation Coefficients Of Consumer Ratings For The Attributes Of Skim Milk Samples

	Parameters[x]							
	A	B	C	D	E	F	G	H
Color	-	0.004	0.000	0.002	0.017	0.002	0.000	0.001
Appearance (Intensity)	0.004	-	0.000	0.039	0.393	0.223	0.020	0.445
Appearance (Hedonic)	0.000	0.000	-0.000	0.002	0.000	0.000	0.000	0.000
Dairy Flavor	0.002	0.039	0.000	-	0.000	0.000	0.000	0.000
Off-Flavor	0.017	0.393	0.002	0.000	-	0.000	0.000	0.000
Taste	0.002	0.223	0.000	0.000	0.000	-	0.000	0.000
Mouthfeel	0.000	0.020	0.000	0.000	0.000	0.000	-	0.000
Overall Acceptability	0.001	0.445	0.000	0.000	0.000	0.000	0.000	-

A = Color; B = Appearance (Intensity); C = Appearance (Hedonic); D = Dairy Flavor; E = Off-Flavor; F = Taste; G = Mouthfeel; H = Overall Acceptability

Table 21
Regression Coefficients of the Variables in the Model Obtained for Overall Acceptability

Variables	Regression Coefficients	Probability Levels
Intercept	-0.442	0.180
Color	0.016	0.757
Appearance (Intensity)	-0.130	0.006
Appearance (Hedonic)	0.053	0.388
Dairy flavor	0.134	0.015
Absence of off-flavor	0.230	0.001
Taste	0.570	0.000
Mouthfeel	0.218	0.000

Table 22
Mean Consumer Acceptance Scores From Fresh Whole Milk Users (n=42) For The Different Characteristics Of The Skim Milk Samples[x].

Treatment	Color	Appearance	Dairy Flavor	Taste	Mouthfeel	Overall Acceptability
Fresh Skim Milk (Comme.)	5.5 ± 1.7	5.6 ± 1.6	5.6 ± 1.9	5.3 ± 2.0	5.3 ± 2.0	5.5 ± 1.9
F/C Skim Milk Conc. (Reconst.)	5.8 ± 2.0	5.7 ± 1.6	5.2 ± 2.0	5.0 ± 2.0	5.4 ± 2.0	5.0 ± 1.9
Non-fat Dried Milk (Recon. from a Comme. sample)	5.7 ± 1.7	5.8 ± 1.6	5.3 ± 1.8	4.9 ± 1.8	5.3 ± 1.8	5.3 ± 1.8
Powdered F/C Skim Milk (Reconst.)	5.9 ± 1.8	5.9 ± 1.4	5.3 ± 1.9	5.4 ± 1.9	5.6 ± 1.8	5.6 ± 1.8

[x] 9-point Hedonic scales were used with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ as determined by Least Significant Difference (LSD) analysis.

Table 23
Mean Consumer Purchase Intent from Fresh Skim Milk Users for Skim Milk Samples Tested

Treatment	Amount[x]	Price[w]
Fresh Skim Milk (Commercial)	1.6	1.6
F/C Skim Milk Conc. (Reconstituted)	1.3	1.5
Non-fat Dried Milk (Reconstituted from a Commercial sample)	1.4	1.5
Powdered F/C Skim Milk (Reconstituted)	1.4	1.5

[x] 3-point scales were used with 1 = less than normal consumption, 2 = same as normal consumption , and 3 = more than normal consumption.

[y] 4-point scales were used with 1 = less than present price, 2 = same as present price, 3 = 1-5% more than present price, and 4 = 6-10 % more than present price.

major determinant of overall ratings, but falls behind taste, mouthfeel, and absence of off-flavor.

Results from whole milk (full-fat) users are similar to those of the entire consumer sample. No significant differences were found between the reconstituted F/C skim milk and the commercial samples either liquid or powdered skim milk (Table 22).

Consumer Purchase Intent

The means for the amount and price the consumers are willing to buy and pay for are shown in Table 23. Participants indicated that their household will consume the same amount or less of all the milk samples tested than what they normally do. Furthermore, in general, the panelists were willing to pay the same or less than the present price they currently pay for milk.

Summary And Conclusion

Freeze-concentrated (F/C) skim milk liquid concentrate was found to be very light yellow in color and as thick in viscosity as Hershey chocolate syrup. It was sweet and slightly salty, sour, and bitter. The product was less milky than full milk and less creamy than Olde Tyme coffee cream with slight cooked and caramel notes. Reconstituted F/C skim milk liquid concentrate was not significantly ($p \leq 0.05$) different from commercial fresh skim milk except in sweetness where the former was found to be sweeter. Both products were almost white in color, slightly thicker than water in viscosity, very slightly salty, sour and bitter, milky, creamy, and with slight cooked and caramel notes.

Freezing did not significantly ($p \leq 0.05$) affect the sensory nor the physical properties of F/C skim milk, when reconstituted, except color lightness where the reconstituted frozen sample was found to be lighter. Spray-drying the F/C skim milk liquid concentrate resulted in significantly more cooked flavor in the reconstituted product. The reconstituted spray-dried F/C skim milk was, however, not significantly ($p \leq 0.05$) different from reconstituted commercial non-fat dry milk.

Consumer acceptance tests using participants who were skim milk users indicated that consumers liked reconstituted F/C skim milk liquid concentrate as much as they did commercial fresh skim milk. They, however, preferred the appearance of reconstituted F/C skim milk liquid concentrate and the reconstituted dried milk samples to that of the commercial fresh skim milk but preferred the latter's dairy flavor. Results likewise indicated that consumers' overall rating are influenced primarily by taste followed by mouthfeel and the absence of off-flavor. The dairy flavor is not the major determinant of overall ratings but falls behind taste, mouthfeel, and absence of off-flavor.

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APPENDIX A

SAMPLE SCORE SHEET USED DURING DESCRIPTIVE SENSORY TESTS

SCORE SHEET

APPEARANCE

Color

white ———————————————————————— yellow

Thickness

very thin ———————————————————————— very thick

TASTE

Sweet

slight ———————————————————————— extreme

Salty

slight ———————————————————————— extreme

Sour

slight ———————————————————————— extreme

Bitter

slight ———————————————————————— extreme

AROMATICS

Milky

slight extreme

Creamy

slight extreme

Cooked

slight extreme

Caramel

slight extreme

MOUTHFEEL

Grittiness

slight extreme

Thickness

slight extreme

APPENDIX B

DEMOGRAPHICS QUESTIONNAIRE

Code No.

Please answer all questions. Your name is not on this questionnaire and will not be identified with your answers.

If you would like a copy of the results of this study, place a check here _____ .

We want to ask you a few questions about yourself to update our files. JThis information will help us compare opinions of people with different backgrounds. As before, all information is confidental and will not be identified with your name.

What is your age group? (Please check your answer.)

Under 25 yrs old _____
25-34 years old _____
35-44 years old _____
45-54 years old _____
55-64 years old _____
over 64 years old _____

What is your marital status? (Please check your answer.)

Never married _____
Married _____
Separated _____
Divorced _____
Widowed _____

On each of the lines below, please put the number of people in each group who live in your household. Include yourself in the count.

Under 6 years old _____
7-12 years old _____
13-18 years old _____
19-24 years old _____
25-64 years old _____
over 64 years old _____

Total No. _____

What is the approximate level income of your household before taxes last year? (Please check one.)

Under $9,999 _____
$10,000 to $19,999 _____
$20,000 to $29,999 _____
$30,000 to $39,999 _____
$40,000 to $49,999 _____
$50,000 to $59,999 _____
$60,000 to $69,999 _____
$70,000 and over _____

APPENDIX C

MILK CONSUMPTION PATTERN QUESTIONNAIRE

CODE NO. ______

MILK CONSUMPTION PATTERN QUESTIONNAIRE

PLEASE ANSWER THE FOLLOWING QUESTIONS:

1. How much milk do you drink per day?

___ rarely/never
___ 1 cup/day
___ 2 cups/day
___ 3 cups/day
___ 4 cups/day
___ more than 4 cups/day

2. Which time(s) of the day do you drink milk? (Please check all that apply.)

___ breakfast
___ morning snacks
___ lunch
___ afternoon snacks
___ supper
___ evening/midnight snacks

3. If you don't drink milk everyday, how often do you drink milk?

___ rarely/never
___ only in coffee or tea
___ cups per week (Please indicate how many.)

4. How much milk do you buy in one week?

___ less than 1/2 gallon per week
___ 1/2 gallon per week
___ 1 gallon per week
___ 2 gallons per week
___ more than 2 gallons per week (Please specify amount _____ gallons)

5. How much of these types of milk do you buy? (Please circle the dot for each type that you buy.)

Type of Milk	less than 1/2 gal./wk.	1/2 gal per wk.	1 gallon per week	2 gallons per week	more than 2 gal per wk.
fresh whole milk (full fat)	.	.	.	.	.
fresh skim milk	.	.	.	.	.
2% fat fresh milk	.	.	.	.	.
1% fat fresh milk	.	.	.	.	.
evaporated whole milk	.	.	.	.	.
evaporated skim milk	.	.	.	.	.
sweetened condensed milk	.	.	.	.	.
powdered non-fat dry milk	.	.	.	.	.
others (please apecify)	.	.	.	.	.

APPENDIX D

SAMPLE SCORE SHEET USED FOR CONSUMER TESTS

CODE NO. __________

DATE ______________

SCORE SHEET

Please evaluate SAMPLE ____________ and answer the following questions. Put a check on the square that best reflects your feeling about this sample.

1. How do you like the "COLOR" of this sample?

dislike extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

2. How will you rate the "APPEARANCE" of this sample?

extremely thin (transparent)	very thin	moderately thin	slightly thin	neither thin nor thick	slightly thick	moderately thick	very thick	extremely thick (opaque)
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

3. How do you like the "APPEARANCE" of this sample?

dislike extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

4. How do you like the "DAIRY FLAVOR (milky & creamy flavors)" of this sample?

dislike extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like extremely
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
1	2	3	4	5	6	7	8	9

5. Please indicate if this sample has any "cardboardy, cooked, barn, medicinal, or stale (old) OFF-FLAVOR".

none	slight	moderate	strong	very strong
[ ]	[ ]	[ ]	[ ]	[ ]

Please specify. ______________________________

6. How do you like the "TASTE - blend of sweet, sour, salty, and bitter tastes" of this sample?

dislike extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like extremely
[ ] 1	[ ] 2	[ ] 3	[ ] 4	[ ] 5	[ ] 6	[ ] 7	[ ] 8	[ ] 9

7. How do you like the "MOUTHFEEL (thinness/thickness, smoothness, creamy texture)" of this sample?

dislike extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like extremely
[ ] 1	[ ] 2	[ ] 3	[ ] 4	[ ] 5	[ ] 6	[ ] 7	[ ] 8	[ ] 9

8. OVERALL, how do you like this sample?

dislike extremely	dislike very much	dislike moderately	dislike slightly	neither like nor dislike	like slightly	like moderately	like very much	like extremely
[ ] 1	[ ] 2	[ ] 3	[ ] 4	[ ] 5	[ ] 6	[ ] 7	[ ] 8	[ ] 9

9. How much of this milk product would your household consume compared to what you normally consume? (Please check one.)

[] less than what we normally consume
[] same as what we normally consume
[] more than what we normally consume

10. How much would you be willing to pay for this milk product compared to the price you are paying now?

[] less than what I pay now
[] same price
[] 1-5% more than what I pay now
[] 6-10% more than what I pay now

APPENDIX I: ABIC REPORT

AN EVALUATION OF TEN MODEL FOOD SYSTEMS FORMULATED WITH FREEZE CONCENTRATED DAIRY INGREDIENTS - A final report prepared exclusively for Dairy Research Foundation by ABIC International Consultants, Inc., Orange, California - October 1992.

CONTENTS

1

INTRODUCTION

The Dairy Research Foundation (DRF) has successfully demonstrated that freeze concentration of dairy products provide an opportunity for the development of improved dairy ingredients at lower energy expenditures. This research, sponsored by the Electric Power Research Institute (EPRI), indicates that the implementation of freeze concentration in the dairy industry will result in potential energy savings of 14,500 billion Btu's annually. This freeze concentration process and its benefits have recently been described in U.S. patent No. 4,959,349 assigned to EPRI.

However, before DRF can successfully market the freeze-concentrated dairy ingredients, it must demonstrate their applicability to the food industry. Toward that end it was necessary for DRF to develop many different food prototypes in order to demonstrate ingredient utility. Additionally, the utilization of these ingredients were evaluated for potential novel product opportunities and/or improved product characteristics. Additionally, advantages proven to be of a proprietary nature would be identified for possible patent applications.

Since DRF and EPRI wish to move ahead expeditiously with this program, it was necessary to develop a large number of food prototypes containing the freeze concentrate material, in a relatively short period of time. Toward that end, DRF has concluded that the most cost effective way of pursuing this program was to utilize the services of an extramural organization. Since ABIC has demonstrated expertise in new ingredient utilization, it was commissioned under Proposal 1927-01 to perform the necessary product development studies. The list of ten products to be evaluated in this study was compiled by DRF. These products are listed in TABLE A-I.

Table A-I

List of the products developed.

I. Buttermilk Cookies

II. Hard Pack Ice Milk (2% Fat)

III. Soft Serve Ice milk (2% Fat)

IV. Sour Cream, 33% Fat-Reduced

V. Cream Cheese, 33% Fat-Reduced

VI. Pound Cake - Dry Mix

VII. Salad Dressing

VIII. White Sauce

IX. Milk Chocolate

X. Whipped Topping

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EXPERIMENTAL METHOD

To meet the objectives of the program, the following tasks were performed.

1. Defined Freeze Concentrate Product Needs

   Upon approval of this project ABIC determined the amount of each freeze concentrated ingredient (powder or frozen whey protein concentrate or skim milk) required for the study. This information was given to DRF and appropriate quantities of materials were received.

2. Developed Product Prototypes

   Utilizing standard food formulations as a base, prototypes of the ten identified foods were developed incorporating the appropriate feed/MVR or freeze concentrate ingredients. These formulations are presented in (Appendix A - Formulations).

3. Evaluate Product Prototypes

   The prototype products were appropriately evaluated, consistent with the particular system, by the ABIC Expert Panel. The Panel consisted of a number of judges who were screened and trained to evaluate, articulate, and quantify flavor and texture attributes of food systems. For this study, five judges rated the products. The evaluations were performed in a light and temperature controlled Panel Room. The products were presented "blind" to the judges, and were coded with random triple digit numbers. Between attribute evaluations the judges cleansed their palates with unsalted crackers and water. Attributes were quantified in a sequential monadic study design. Attribute evaluations included color, aroma, flavor, and texture, including presence/level of off-flavors, and were specifically chosen to reflect established characteristics of the food. Other appropriate evaluations were also made for each product. For instance, measurements or observations included the height (rise) of a cake, the stability of the salad dressing emulsions, the presence/size of ice crystals in ice milk, and viscosity/texture of the sauce.

When attribute differences were ≥1.0, the data were subjected to statistical analysis. Attribute differences ≥1.0, with a $p \leq 0.5$, obtained as a result of a Student *t*-Test, were required before an attribute of one product was considered significantly different (e.g. superior) from that of another product. Statistical tables of the identified attributes are presented in Appendix C - Statistical Analysis.

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OBSERVATION AND RESULTS

The ten identified food model systems were prepared using standard formulations obtained from text books, ingredient suppliers, or the ABIC non-proprietary files. In each case the particular relevant ingredient, such as skim milk, was replaced in the formulation with the freeze concentrate version. Food systems containing the standard dairy ingredient(s) and the freeze concentrate ingredient(s) were then prepared and evaluated. The standard formulas were either completely unmodified or modified only slightly. No attempt was made to optimize the formulas to favorably reflect the advantages of freeze concentrate ingredients. The evaluations of the ten model food systems made by the ABIC Expert Panel are presented in tabular form in Appendix B - Product Evaluations.

It was concluded that the principle observation resulting from the attribute evaluation data was that food model systems whose primary flavor characteristic was dairy-like in nature were judged superior when freeze concentrate ingredients were employed, as compared to controls (standard ingredients; feed/MVR).

Hard pack ice milks (2% fat) prepared from freeze concentrate ingredients were judged to have significantly better overall flavor ($p=0.02$), dairy notes ($p<0.01$), mouthfeel ("smoother") ($p<0.01$), and mouthclearing ($p<0.01$) than controls. Additionally, the freeze concentrate systems were perceived to be creamier ($p<0.01$), less icy ($p<0.01$), and more spoonable ($p=0.01$) than controls. Of the four systems produced, the one that contained reconstituted freeze concentrate skim milk and freeze concentrate skim milk powder (system #3-2), and one that contained feed skim milk and MVR skim milk powder (system #3-1), were sent to New Orleans for presentation.

Soft serve ice milk was formulated with either 4-1) feed skim milk, MVR skim milk powder, 4-2) reconstituted freeze concentrate skim milk, freeze concentrate skim milk powder, 4-3) feed skim milk, MVR skim milk powder and whey protein concentrate, and 4-4) reconstituted freeze concentrate skim milk, freeze concentrate skim milk powder and whey protein concentrate. System 4-2 was judged to have superior overall flavor ($p<0.01$) and dairy flavor ($p=0.04$) when compared to 4-1.

The system prepared from reconstituted freeze concentrate skim milk, freeze concentrate skim milk powder and whey protein concentrate (4-4) was judged to possess an increased level of overall flavor ($p<0.02$) and showed a trend toward improved dairy flavor ($p<0.06$) characteristic of a soft serve ice milk when compared to system 4-3. The other systems had either diminished dairy flavor intensity or atypical flavors. Other attributes of the four systems were generally judged to be similar.

Sour cream prepared with freeze concentrate ingredients was judged after 36-hours to have a significantly better dairy aroma ($p<0.01$) and dairy flavor ($p<0.01$) than control. Additionally, the freeze concentrate product was found to be significantly less sour ($p<0.02$) and exhibited a "more balanced" flavor profile than controls. Since the control was thicker, however, it was judged to have a slightly better mouthfeel. These samples were also sent to New Orleans for presentation.

After seven days the differences between the sour cream products, both positive and negative, were diminished to the extent that there no longer appeared to be any significant attribute differences.

Cream cheese prepared from standard and freeze concentrate ingredients (skim milk plus 3.5% skim milk powder) were also evaluated at 36 hours and seven days. Cheese made from standard and freeze concentrate ingredients (skim milk plus 5% skim milk powder) were only evaluated at seven days. At 36 hours, the cheese produced with freeze concentrate ingredients were judged superior to the control in dairy aroma ($p<0.04$) and dairy flavor ($p<0.01$). Additionally, this product was also perceived as having better flavor balance, partly because of the absence of off-flavors, as compared to the control. Texture ratings were not reliable comparison indicators since the experimental systems were not thick enough because of the lack of stabilizers.

After seven days the cream cheese produced with freeze concentrate ingredients (3.5% skim milk powder) was still judged to be superior in overall flavor ($p<0.03$), creaminess (($p<0.01$) and "balance." The 5.0% skim milk powder systems were not perceived to be as good as the 3.5% systems. However, the 5.0% freeze concentrate system was judged superior to the control in terms of dairy aroma ($p<0.01$) and creaminess ($p<0.01$).

The white sauce prepared with freeze concentrate ingredients was judged superior to the control, especially in dairy flavor ($p<0.05$). However, unlike the other model food systems, the control sauce was judged to have a superior dairy aroma ($p=0.02$).

Nonfat salad dressings, made from a dry mix containing standard or freeze concentrate ingredients, generally were perceived to be similar by the judges. There was a trend toward improved dairy flavor in the freeze concentrate model system.

The milk chocolate prepared with freeze concentrate ingredients was judged to be significantly better than milk chocolate prepared with standard ingredients. The Expert Panel judged the experimental product to be superior in chocolate aroma ($p<0.01$), overall flavor ($p<0.01$), chocolate flavor ($p<0.03$), and dairy flavor ($p<0.04$), when compared to the control. Additionally, the experimental milk chocolate was perceived to be creamier ($p<0.01$) than the control, and exhibited better melt-in-the-mouth ($p=0.03$) characteristics. These samples were sent to New Orleans for presentation.

Whipped topping was prepared with several combinations of freeze concentrate and standard ingredients, with and without emulsifiers. Products made with whey protein concentrate replacing the emulsifiers demonstrated an approximate 150% over-run, but was so thin in texture that they could no longer be considered whipped toppings. Generally, there were no significant differences in attributes between any of the products. However, products formulated with freeze concentrate skim milk powder, no emulsifiers, and whey protein concentrate, tended toward increased dairy flavor ($p=0.53$) (but not increased overall flavor), compared to the other systems evaluated.

Ingredient combinations significantly affected physical attributes of the whipped toppings. The systems containing emulsifiers with either caseinate or skim milk powder had over-runs ranging from 64 (caseinate) to approximately 90 (MVR and freeze concentrate skim milk powder). When the emulsifiers were replaced with whey protein concentrate, but the caseinate remained, the over-run increased to 140 for MVR and 155 for freeze concentrate whey protein concentrate. Finally, when both the caseinate and emulsifiers were replaced, the over-run again dropped to 71 for MVR and 61 for freeze concentrate ingredients.

Buttermilk cookies and pound cake made from dry mix were judged to have comparable attributes, regardless of ingredient source. No immediate advantages (or disadvantages) were observed when freeze concentrate ingredients replaced standard ingredients.

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CONCLUSIONS

1. Freeze concentrate ingredients improved or demonstrated comparably in all food model systems studied. Because of the potential cost and energy savings associated with this process, these ingredients represent novel opportunities in the food and diary industries.

2. Freeze concentrate ingredients generally improve dairy flavor, overall flavor, and texture in the food model systems where dairy flavors normally predominate. Examples:

   Hard Pack Ice Milk (2% Fat)
   Sour Cream
   Cream Cheese
   White Sauce

   In the case of Soft Serve Ice Milk (2% Fat) while there was an improvement in dairy flavor, there weren't any perceived differences in texture attributes.

3. Freeze concentrate skim milk powder improved the chocolate and dairy aromas, overall flavor, flavor balance, and texture of:

   Milk Chocolate

4. When standard formulations were employed, freeze concentrate ingredients did not appreciably improve

   Buttermilk Cookies
   Pound Cake - Dry Mix
   Salad Dressing - Dry Mix
   Whipped Topping

   It is not known if formula modification/optimization will result in improvement in product quality.

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RECOMMENDATIONS

1. Continue to evaluate the use of freeze concentrate ingredients in products with predominant dairy flavor characteristics, such as yogurt, cheese spreads, and both powdered and liquid dairy-based salad dressings.

2. Identify food items that represent potential commercial importance but did not improve when freeze concentrate ingredients were employed in standard formulas, such as baked goods. Attempts should be made to develop formulas that optimize the effects of freeze concentrate ingredients before concluding that these ingredients do not offer any advantage in these systems.

3. Continue to evaluate the contribution of freeze concentrate ingredients in other dairy or related food model systems not assessed in this study.

APPENDIX A - FORMULATIONS

Table A-1
Buttermilk Cookies

Ingredients	Percent
Flour	36.45
Sugar	32.60
Water	11.25
Shortening	10.94
Buttermilk Powder	3.65*
Whole Eggs	3.65
Salt	0.73
Baking Soda	0.73

* Evaluated powdered feed (MVR) and freeze concentrate skim milk as a one-for-one replacement for buttermilk powder.

Table A-2
Hard Pack Ice Milk (2% Fat)

	Percent	
Ingredients	Skim Milk	Skim Milk + WPC
Skim Milk Liquid	69.45*	69.45*
Heavy Cream (37% fat)	5.40	5.40
Skim Milk Powder	6.40*	3.15*
Sugar	12.00	12.00
Corn Syrup Solids, 36DE	6.00	6.00
Stabilizer	0.45	0.45
Vanilla	0.30	0.30
Whey Protein Concentrate	0.00	3.25*

* Evaluated use of feed and freeze concentrate material for * ingredients. Reconstituted frozen feed, powdered feed and powdered freeze concentrate material powders for liquid skim milk replacement.

Table A-3
Soft Serve Ice Milk (2% Fat)

Ingredients	Percent Skim Milk	Skim Milk + WPC
Skim Milk Liquid	72.85*	72.85*
Heavy Cream (37% fat)	5.40	5.40
Skim Milk Powder	5.00*	2.00*
Sugar	12.00	12.00
Corn Syrup Solids, 36DE	4.00	4.00
Stabilizer	0.45	0.45
Vanilla	0.30	0.30
Whey Protein Concentrate	0.00	3.00*

* Evaluated use of feed and freeze concentrate material for * ingredients. Reconstituted frozen feed, powdered feed and powdered freeze concentrate material powders for use as a liquid skim milk replacement.

Table A-4
Sour Cream

Ingredients	Percent
Skim Milk Liquid	57.47*
Heavy Cream (37% fat)	32.50
Skim Milk Powder	10.00*
Culture	0.02
Enzyme Rennilase	0.01

* Evaluated feed/MVR and freeze concentrate material for * ingredients. Reconstitute frozen freeze concentrate skim milk for use as skim milk liquid replacement.

Table A-5
Cream Cheese

Ingredients	Percent Experimental Formulation 1	2	3
Skim Milk Liquid	83.50*	78.50*	80.00*
Heavy Cream (37% fat)	16.00	16.00	16.00
Skim Milk Powder	0.00	5.00*	3.50*
Culture	0.50	0.50	0.50

* Evaluated feed/MVR and freeze concentrate material for * ingredients. Reconstituted frozen freeze concentrate skim milk for use as liquid skim milk replacement.

Table A-6
Pound Cake - Dry Mix

Ingredients	Percent
Sugar	39.35
Cake Four	32.79
Shortening	17.70
Skim Milk Powder	4.59*
Whey Protein Concentrate	2.62*
Baking Powder	1.64
Salt	1.31

* Evaluated powdered feed and freeze concentrate skim milk powder and whey protein powder in the above formulation. Added ½-cup water to 306 grams dry mix to make the cake batter.

Table A-7
Salad Dressing - Dry Mix

Ingredients	Percent
Sugar	38.37
Skim Milk Powder	25.58*
Salt	17.91
Instant Clearjel	12.79
Garlic, Dry Minced	1.79
Red Pepper Pieces	1.15
Xanthan Gum	0.64
Garlic Powder	0.51
Onion Powder	0.51
Potassium Citrate	0.26
White Pepper	0.26
Oregano	0.13
Caramel Color	0.10

* Evaluated powdered MVR and freeze concentrate skim milk powder.

Reconstitution formula:

Powdered mix	28	grams
Vinegar	60	grams (¼ cup)
Water	120	grams (½ cup)

Add together and mix the contents.

Table A-8
White Sauce

Ingredients	Percent
Skim Milk	90.45*
Butter	5.22
All-Purpose Flour	3.66
Salt	0.67

* Evaluated feed and reconstituted freeze concentrate skim milk, on a one-for-one replacement for skim milk in the formula.

Table A-9
Milk Chocolate

Ingredients	Percent
Sugar	31.90
Cocoa Butter	31.20
Chocolate Liquor	14.20
Whole Milk Powder	13.30
Skim Milk Powder	8.80*
Lecithin	0.50
Vanillin	0.30

* Evaluated MVR and freeze concentrate skim milk powder as a skim milk powder replacement in the formula.

Table A-10
Whipped Topping

Ingredients	Percent			
		Experimental Formula*		
	Control	1	2	3
Water	58.05	58.05	58.05	58.05
Paramount C (a)	20.00	20.00	20.00	20.00
Hydrol 92 (b)	10.00	10.00	10.00	10.00
Sugar	6.00	6.00	6.00	6.00
Sodium Caseinate	3.00	0.00	3.00	0.00
Corn Syrup Solids, 36DE	2.00	2.00	2.00	2.00
CMC, 7HF	0.50	0.50	0.50	0.50
Sorbitan Monostearate	0.24	0.24	0.00	0.00
Polysorbate	0.16	0.16	0.00	0.00
Disodium Phosphate	0.05	0.05	0.00	0.00
Skim Milk Powder	0.00	3.00	0.00	3.00
WPC Powder	0.00	0.00	0.45	0.45

* 1: Evaluated MVR and freeze concentrate skim milk powder in place of caseinate.
2: Replaced caseinate with freeze concentrate whey protein concentrate powder.
3: Replaced emulsifiers and caseinate with freeze concentrate skim milk and WPC powders.
a: Partially hydrogenated vegetable oil.
b: Partially hydrogenated coconut.

APPENDIX B - PRODUCT EVALUATION

Table B-1
Results Of Sensory Evaluation Of Buttermilk Cookies Utilizing Skim Milk Ingredients For Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	4.0	4.0
2.	Overall Aroma[b]	2.9	2.1
3.	Overall Flavor[b]	5.9	6.0
4.	Sweet[b]	4.9	4.5
5.	Sour[b]	0.0	0.0
6.	Salty[b]	0.9	0.8
7.	Bitter[b]	0.0	0.0
8.	Dairy[b]	2.2	2.9
9.	Off Flavor[b]	0.0	0.0
10.	Chew Qualities[c]	3.9	4.1
B. Physical Measurements			
11.	Batter pH	7.00	7.00
12.	Batter density (g/cc)	1.07	1.08
13.	Weight loss on baking (%)	11.50	11.50
14.	Spread (cm)	6.80	5.90
15.	Height (cm)	0.70	0.90
20.	Moisture (%)	4.22	4.83

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)

Table B-2a
Results Of Sensory Evaluation Of Hard Pack Ice Milk (2% Fat) Utilizing Skim Milk Ingredients For Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	4.0	4.0
2.	Aroma[b]	2.2	2.6
3.	Spoonability[c]	3.5	4.6
4.	Overall Flavor[b]	4.7	6.1
5.	Sweet[b]	4.2	4.2
6.	Sour[b]	0.4	0.2
7.	Salty[b]	0.0	0.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	3.6	5.2
10.	Off Flavor[b]	0.4	0.2
11.	Creaminess[b]	3.0	5.4
12.	Mouthfeel[d]	5.0	6.7
13.	Mouthclearing[e]	2.8	4.1
14.	Iciness[b]	2.6	0.6
B. Physical Measurements			
15.	Density of mix (g/cc)	1.12	1.13
16.	Over-run (%)	100.00	100.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = too soft, 4 = about right, 8 = too hard)
[d]:(0 = very gritty, 8 = very smooth)
[e]:(0 = rapid, thin, watery; 4 = about right; 8 = slow, gummy, thick)

Table B-2b
Results Of Sensory Evaluation Of Hard Pack Ice Milk (2% Fat) Utilizing Skim Milk And WPC Ingredients For Comparison

A. Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Color[a]	4.0	3.8
2.	Aroma[b]	2.2	2.3
3.	Spoonability[c]	5.0	4.1
4.	Overall Flavor[b]	6.0	6.8
5.	Sweet[b]	4.6	4.1
6.	Sour[b]	0.0	0.0
7.	Salty[b]	0.0	0.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	5.4	6.5
10.	Off Flavor[b]	0.0	0.8
11.	Creaminess[b]	3.8	5.4
12.	Mouthfeel[d]	5.7	6.8
13.	Mouthclearing[e]	3.2	4.6
14.	Iciness[b]	2.1	0.8
B. Physical Measurements			
15.	Density of mix (g/cc)	1.13	1.13
16.	Over-run (%)	100.00	100.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = too soft, 4 = about right, 8 = too hard)
[d]:(0 = very gritty, 8 = very smooth)
[e]:(0 = rapid, thin, watery; 4 = about right; 8 = slow, gummy, thick)

Table B-3a
Results Of Sensory Evaluation Of soft Serve Ice Milk (2% Fat) Utilizing Skim Milk Ingredients For Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	4.0	4.0
2.	Aroma[b]	1.2	1.6
3.	Spoonability[c]	3.1	4.0
4.	Overall Flavor[b]	4.2	5.9
5.	Sweet[b]	3.5	3.4
6.	Sour[b]	0.0	0.0
7.	Salty[b]	0.0	0.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	4.4	5.4
10.	Off Flavor[b]	0.0	0.0
11.	Creaminess[b]	6.2	6.7
12.	Mouthfeel[d]	6.7	7.1
13.	Mouthclearing[e]	4.0	4.1
14.	Iciness[b]	0.0	0.0
B. Physical Measurements			
15.	Density of mix (g/cc)	1.12	1.12
16.	Over-run (%)	100.00	100.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = too soft, 4 = about right, 8 = too hard)
[d]:(0 = very gritty, 8 = very smooth)
[e]:(0 = rapid, thin, watery; 4 = about right; 8 = slow, gummy, thick)

Table B-3b
Results Of Sensory Evaluation Of Soft Serve Ice Milk (2% Fat) Utilizing Skim Milk And WPC Ingredients For Comparison

		Formulated with	
A. Sensory Attributes		**Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	3.9	3.8
2.	Aroma[b]	2.1	1.4
3.	Spoonability[c]	3.8	3.8
4.	Overall Flavor[b]	5.7	6.5
5.	Sweet[b]	4.1	3.5
6.	Sour[b]	0.0	0.0
7.	Salty[b]	0.0	0.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	5.3[*]	6.3
10.	Off Flavor[b]	1.5	0.5
11.	Creaminess[b]	6.7	7.5
12.	Mouthfeel[d]	6.8	7.5
13.	Mouthclearing[e]	4.6	4.3
14.	Iciness[b]	0.0	0.0
B. Physical Measurements			
15.	Density of mix (g/cc)	1.12	1.12
16.	Over-run (%)	100.00	100.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = too soft, 4 = about right, 8 = too hard)
[d]:(0 = very gritty, 8 = very smooth)
[e]:(0 = rapid, thin, watery; 4 = about right; 8 = slow, gummy, thick)
[*]:(off flavor - atypical for whey)

Table B-4a
Results Of Sensory Evaluation Of Sour Cream At 36-Hours

A. Sensory Attributes		**Formulated with Conventional Ingredients**	**FC Ingredients**
1.	Color[a]	4.1	4.0
2.	Dairy Aroma[b]	3.2	4.3
3.	Overall Flavor[b]	6.0	5.7
4.	Sweet[b]	1.5	1.5
5.	Sour[b]	3.7	2.7
6.	Salty[b]	1.5	0.8
7.	Bitter[b]	0.2	0.0
8.	Dairy[b]	3.6	4.8
9.	Off Flavor[b]	0.2	0.0
10.	Creaminess[b]	5.7	5.5
11.	Mouthcoating/Mouthfeel[c]	3.6	3.3
12.	Mouthclearing[d]	4.0	3.3
B. Physical Measurements			
13.	pH	4.55	4.55

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table B-4b
Results Of Sensory Evaluation Of Sour Cream At 7-Days

A. Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Color[a]	4.3	4.0
2.	Dairy Aroma[b]	3.8	3.8
3.	Overall Flavor[b]	5.9	6.0
4.	Sweet[b]	1.1	1.0
5.	Sour[b]	3.8	4.0
6.	Salty[b]	1.3	1.3
7.	Bitter[b]	0.0	0.3
8.	Dairy[b]	5.0	4.5
9.	Off Flavor[b]	0.3	0.0
10.	Creaminess[b]	4.9	4.9
11.	Mouthcoating/Mouthfeel[c]	4.3	3.6
12.	Mouthclearing[d]	4.6	4.0
B. Physical Measurements			
13.	pH	4.5	4.5

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table B-5a
Results Of Sensory Evaluation Of Cream Cheese (3.5% Skim Powder Formula) At 36-Hours

A. Sensory Attributes		**Formulated with Conventional Ingredients**	**Formulated with FC Ingredients**
1.	Color[a]	4.1	3.9
2.	Dairy Aroma[b]	2.3	6.5
3.	Overall Flavor[b]	6.4	6.5
4.	Sweet[b]	0.9	1.2
5.	Sour[b]	3.8	3.8
6.	Salty[b]	4.3	2.8
7.	Bitter[b]	0.0	0.0
8.	Dairy[b]	3.7	5.4
9.	Off Flavor[b]	1.2	0.0
10.	Creaminess[b]	6.2	6.9
11.	Spreadability[c]	2.1	2.9
12.	Mouthfeel[c]	2.8	3.6
13.	Mouthclearing[d]	2.8	4.5
B. Physical Measurements			
14.	pH	4.55	4.55

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table B-5b
Results Of Sensory Evaluation Of Cream Cheese (3.5% Skim Powder Formula) At 7-Days

A. Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Color[a]	4.0	4.0
2.	Dairy Aroma[b]	2.6	4.5
3.	Overall Flavor[b]	5.4	6.4
4.	Sweet[b]	0.4	1.0
5.	Sour[b]	4.0	3.1
6.	Salty[b]	1.4	1.4
7.	Bitter[b]	0.1	0.1
8.	Dairy[b]	4.1	5.0
9.	Off Flavor[b]	1.0	0.3
10.	Creaminess[b]	4.3	6.1
11.	Spreadability[c]	5.5	4.3
12.	Mouthfeel[c]	5.5	3.9
13.	Mouthclearing[d]	4.8	3.9
B. Physical Measurements			
14.	pH	4.5	4.5

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table B-5c
Results Of Sensory Evaluation Of Cream Cheese (5.0% Skim Powder Formula) At 7-Days

A. Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Color[a]	3.6	4.0
2.	Dairy Aroma[b]	2.1	3.8
3.	Overall Flavor[b]	6.6	6.3
4.	Sweet[b]	0.5	0.6
5.	Sour[b]	4.0	4.0
6.	Salty[b]	1.6	1.4
7.	Bitter[b]	0.1	0.1
8.	Dairy[b]	2.4	3.9
9.	Off Flavor[b]	0.3	0.0
10.	Creaminess[b]	3.0	4.8
11.	Spreadability[c]	2.1	3.3
12.	Mouthfeel[c]	2.6	3.1
13.	Mouthclearing[d]	2.5	3.1
B. Physical Measurements			
14.	pH	4.5	4.5

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = very thin, 4 = about right, 8 = very thick, heavy)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table B-6
Results Of Sensory Evaluation Of Pound Cake - Dry Mix Utilizing Skim Milk Ingredients For Comparison

A. Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Crust Color[a]	6.0	6.0
2.	Crumb Color[a]	2.0	2.0
3.	Aroma[b]	4.0	3.9
4.	Overall Flavor[b]	6.5	6.9
5.	Sweet[b]	6.1	6.9
6.	Sour[b]	0.0	0.5
7.	Salty[b]	1.0	1.0
8.	Bitter[b]	0.0	0.0
9.	Dairy[b]	2.9	3.1
10.	Off Flavor[b]	0.0	0.0
11.	Moistness[c]	6.5	6.4
12.	Grain[d]	2.9	2.9
13.	Toothpacking	2.9	2.8
B. Physical Measurements			
14.	Batter pH	6.55	6.70
15.	Batter density (g/cc)	0.65	0.64
16.	Flow (Bostwick cm/2 minutes)	2.50	1.50
17.	Weight loss on baking (%)	6.03	6.00
18.	Height (cm)	4.50	4.60
19.	Volume (cc)	1000.00	994.00
20.	Moisture (%)	26.31	25.64

a:(0 = too light, 4=about right, 8 = too dark)
b:(0 = none, 4 = definite, 8 = extensive)
c:(0 = too dry, 4 = about right, 8 = too moist, cohesive)
d:(0 = too dense, 4 = about right, 8 = open grain, voids, coarse)

Table B-7
Results Of Sensory Evaluation Of Nonfat Salad Dressing - Dry Mix Utilizing Skim Milk Ingredients For Comparison

Sensory Attributes	Formulated with Conventional Ingredients	FC Ingredients
1. Overall Appearance[a]	4.0	3.9
2. Aroma[b]	3.0	3.1
3. Overall Flavor[b]	5.4	5.1
4. Sweet[b]	1.9	2.2
5. Sour/Acidity[b]	4.1	3.5
6. Salty[b]	2.1	2.0
7. Bitter[b]	0.0	0.0
8. Dairy[b]	1.7	2.4
9. Thickness/Viscosity[c]	3.3	3.6
10. Mouthclearing[d]	1.4	1.7
11. Lubricity/Creaminess[b]	0.0	0.2

[a]:(0 = very poor, 8 = excellent)
[b]:(0 = none, 4 = definite, 8 = extensive)
[c]:(0 = Too Thin, 4 = about right, 8 = too thick)
[d]:(0 = rapid, 4 = about right, 8 = slow)

Table B-8
Results Of Sensory Evaluation Of White Sauce

Sensory Attributes	Formulated with Conventional Ingredients	Formulated with FC Ingredients
1. Dairy Aroma[a]	2.1	3.8
2. Overall Flavor[a]	6.6	6.3
3. Sweet[a]	0.5	0.6
4. Sour[a]	4.0	4.0
5. Salty[a]	1.6	1.4
6. Bitter[a]	0.1	0.1
7. Dairy[a]	2.4	3.9
8. Creaminess[a]	3.0	4.8
9. Grittiness/Chalkiness[a]	2.1	3.3
10. Mouthclearing[b]	2.6	3.1

[a]:(0 = none, 4 = definite, 8 = extensive)
[b]:(0 = very thin, 4 = about right, 8 = very thick, heavy)

Table B-9
Results Of Sensory Evaluation Of Milk Chocolate

Sensory Attributes		Formulated with Conventional Ingredients	Formulated with FC Ingredients
1.	Chocolate Aroma[a]	4.0	4.0
2.	Aroma[a]	1.2	1.6
3.	Overall Flavor[a]	4.2	5.9
4.	Sweet[a]	3.5	3.4
5.	Sour[a]	0.0	0.0
6.	Salty[a]	0.0	0.0
7.	Bitter[a]	0.0	0.0
8.	Chocolate[a]	3.6	5.1
9.	Dairy[a]	4.4	5.4
10.	Off Flavor[a]	0.0	0.0
11.	Creaminess[a]	6.2	6.7
12.	Degree of Hardness[b]	6.7	7.1
13.	Melt[c]	4.0	4.1

[a]:(0 = none, 4 = definite, 8 = extensive)
[b]:(0 = too soft, 4 = about right, 8 = too hard)
[c]:(0 = rapid, 4 = typical, 8 = slow)

Table B-10a
Results Of Sensory Evaluation Of Whipped Topping Prepared Utilizing Skim Milk And WPC Ingredients For Comparison

		Replace caseinate with skim milk powder		Replace emulsifiers with WPC	
	<u>control</u>				
A. Sensory Attributes	**Caseinate**	**MVR**	**FC**	**MVR**	**FC**
1. Color[a]	2.8	3.0	3.0	2.9	2.9
2. Overall Flavor	4.2	5.1	4.8	4.5	4.5
3. Sweet	3.2	4.0	4.5	4.5	4.3
4. Sour	0.0	0.0	0.0	0.0	0.0
5. Salty	0.0	0.2	0.0	0.0	0.0
6. Bitter	1.5	0.4	0.4	0.2	0.1
7. Dairy	0.8	2.6	3.1	1.5	1.9
8. Off Flavor	2.2	1.0	0.9	0.4	0.4
9. Creaminess	5.6	6.4	6.2	4.0	4.5
10. Mouthfeel/Mouthcoating[b]	5.6	5.5	6.1	2.6	3.0
11. Mouthclearing[c]	5.1	4.5	4.8	2.6	3.5
B. Physical Measurements					
12. Base pH	6.50	6.50	6.80	6.30	6.30
13. Density of mix (g/cc)	0.99	0.98	0.99	0.95	0.91
14. Over-run (%)	64.00	90.00	91.00	140.00	155.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = too thin, 4 = about right, 8 = too thick)
[c]:(0 = rapid, 4 = about right; 8 = slow)

Table B-10b
Results Of Sensory Evaluation Of Whipped Topping Prepared Utilizing Skim Milk And WPC Ingredients For Comparison

		Replace caseinate with skim milk powder: Replace emulsifiers with WPC	
A. Sensory Attributes		**MVR**	**FC**
1.	Color[a]	4.3	4.3
2.	Overall Flavor	4.0	4.0
3.	Sweet	3.3	2.5
4.	Sour	0.3	0.1
5.	Salty	0.3	0.3
6.	Bitter	0.9	0.9
7.	Dairy	3.9	3.6
8.	Off Flavor	0.4	0.3
9.	Creaminess	3.5	4.4
10.	Mouthfeel/Mouthcoating[b]	3.0	3.4
11.	Mouthclearing[c]	2.9	3.2
B. Physical Measurements			
12.	Base pH	6.70	6.70
13.	Density of mix (g/cc)	0.97	0.97
14.	Over-run (%)	71.00	61.00

[a]:(0 = too light, 4=about right, 8 = too dark)
[b]:(0 = too thin, 4 = about right, 8 = too thick)
[c]:(0 = rapid, 4 = about right; 8 = slow)

APPENDIX C - STATISTICAL ANALYSIS

Module: TTEST, Independent Groups t-test 10-13-1992
File: RON, Hard Pack IC Attributes Comparisons

FILTER: None

Group 1: PROD = 1, 3-3
Group 2: PROD = 2, 3-4

DAIRY, Dairy

	N	Mean	S.D.			Separate Variances	Separate Variances
Group 1:	5	5.400	0.548		L95%:	-1.884	-1.865
Group 2:	5	6.500	0.500		U95%:	-0.316	-0.335
Difference:		-1.100	0.332				
					T:	-3.317	-3.317
Test of Group 1σ^2 = Group 2σ^2				DF:	7.9	8	
$F(4,4) = 1.200$ $P < 0.8640$					P:	0.0128	0.0106

CREAM, Creaminess

	N	Mean	S.D.			Separate Variances	Separate Variances
Group 1:	5	3.800	0.447		L95%:	-3.008	-2.863
Group 2:	5	5.400	1.140		U95%:	-0.192	-0.337
Difference:		-1.600	0.548				
					T:	-2.921	-2.921
Test of Group 1σ^2 = Group 2σ^2				DF:	5.2	8	
$F(4,4) = 6.500$ $P < 0.0972$					P:	0.0330	0.0193

MTH, Mouth Feel

	N	Mean	S.D.			Separate Variances	Separate Variances
Group 1:	5	5.700	0.447		L95%:	-1.752	-1.752
Group 2:	5	6.800	0.447		U95%:	-0.448	-0.448
Difference:		-1.100	0.283				
					T:	-3.889	-3.889
Test of Group 1σ^2 = Group 2σ^2				DF:	8.0	8	
$F(4,4) = 1.000$ $P < 1.0000$					P:	0.0046	0.0046

MOUTH, Mouth Clearing

	N	Mean	S.D.			Separate Variances	Separate Variances
Group 1:	5	3.200	0.447		L95%:	-2.148	-2.129
Group 2:	5	4.600	0.548		U95%:	-0.652	-0.671
Difference:		-1.400	0.316				
					T:	-4.427	-4.427
Test of Group 1σ^2 = Group 2σ^2				DF:	7.7	8	
$F(4,4) = 1.500$ $P<0.7040$					P:	0.0031	0.0022

ICE, Iciness

	N	Mean	S.D.			Separate Variances	Separate Variances
Group 1:	5	2.100	0.742		L95%:	0.311	0.335
GROUP 2:	5	0.800	0.570		U95%:	2.289	2.265
Difference:		1.300	0.418				
					T:	3.108	3.108
Test of Group 1σ^2 = Group 2σ^2				DF:	7.5	8	
$F(4,4) = 1.692$ $P<0.6228$					P:	0.0171	0.0145

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Soft Serve IC Attribute Comparisons

FILTER: None

Group 1: PROD = 1, 4-1
Group 2: PROD = 2, 4-2

	N	Mean	S.D.		Separate Variances	Pooled Variances
OVERALL, Overall Flavor						
Group 1:	5	4.200	0.447	L95%:	-2.448	-2.429
Group 2:	5	5.900	0.548	U95%:	-0.952	-0.971
Difference:		-1.700	0.316			
				T:	-5.376	-5.376
Test of Group 1σ² = Group 2σ²				DF:	7.7	8
F (4,4) = 1.500 P<0.7040				P:	-0.0010	-0.0007
DAIRY, Dairy						
Group 1:	5	4.400	0.548	L95%:	-1.975	-1.951
Group 2:	5	5.400	0.742	U95%:	-0.025	-0.049
Difference:		-1.000	0.412			
				T:	-2.425	-2.425
Test of Group 1σ² = Group 2σ²				DF:	7.4	8
F (4,4) = 1.833 P<0.5715				P:	0.0457	0.0415

Module: TTEST, Independent Groups t-tests 10-13-1992
file: RON, Soft Serve IC Attribute Comparisons

FILTER: None

Group 1: PROD = 1,4-3
Group 2: PROD = 2, 4-4

	N	Mean	S.D.		Separate Variances	Pooled Variances
OVERALL, Overall Flavor						
Group 1:	5	5.300	0.837	L95%:	-2.376	-2.265
Group 2:	5	6.600	0.418	U95%:	-0.224	-0.335
Difference:		-1.300	0.418			
				T:	-3.108	-3.108
Test of Group 1σ² = Group 2σ²				DF:	2.094	2.031
F (4,4) = 4.000 P< 0.2080				P:	0.0266	0.0145
DAIRY, Dairy						
Group 1:	5	1.500	0.500	L95%:	-0.094	-0.031
Group 2:	5	0.500	0.866	U95%:	2.094	2.031
Difference:		1.000	0.447			
				T:	2.236	2.236
Test of Group 1σ² = Group 2σ²				DF:	6.4	8
F (4,4) = 3.000 P< 0.3125				P:	0.0667	0.0558

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Cream Cheese Attribute Comparisons

FILTER: None

Group 1: PROD = 1, Feed + 3.5% MVR
Group 2: PROD = FC + 3.5% FC

OV, Overall Flavor

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	5.375	0.479	L95%:	-1.828	-1.828
Group 2:	4	6.375	0.479	U95%:	-0.172	-0.172
Difference:		-1.000	0.339			
				T:	-2.954	-2.954
Test of Group 1σ² = Group 2σ²				DF:	6.0	6
F (3,3) = 1.000 P< 1.0000				P:	0.0255	0.0255

CREAM, Creaminess

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	4.250	0.500	L95%:	-2.651	-2.559
Group 2:	4	6.125	0.250	U95%:	-1.099	-1.191
Difference:		-1.875	0.280			
				T:	-6.708	-6.708
Test of Group 1σ² = Group 2σ²				DF:	4.4	6
F (3,3) = 4.000 P< 0.2848				P:	0.0026	0.0005

SPREAD. Spreadability

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	5.500	0.707	L95%:	0.137	0.190
Group 2:	4	4.250	0.500	U95%:	2.363	2.310
Difference:		1.250	0.433			
				T:	2.887	2.887
Test of Group 1σ² = Group 2σ²				DF:	5.4	6
F (3,3) = 2.000 P<0.5836				P:	0.0343	0.0278

COA, Mouth Coating

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	5.500	0.408	L95%:	0.961	1.039
Group 2:	4	3.875	0.250	U95%:	2.289	2.211
Difference:		1.625	0.239			
				T:	6.789	6.789
Test of Group 1σ² = Group 2σ²				DF:	5.0	6
F (3,3) = 2.667 P<0.4419				P:	0.0025	0.0005

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, White Sauce Attribute Comparisons

FILTER: None

Group 1: PROD = 1, 021 FEED
Group 2: PROD = 2, 498 FC

	N	Mean	S.D.		Separate Variances	Separate Variances
DA, Dairy Aroma						
Group 1:	5	4.400	0.548	L95%:	0.201	0.201
Group 2:	5	3.400	0.548	U95%:	1.799	1.799
Difference:		1.000	0.346			
				T:	2.887	2.887
Test of Group 1σ² = Group 2σ²				DF:	8.0	8
F (4,4) = 1.000 P<1.0000				P:	0.0203	0.0203
DAIRY, Dairy						
Group 1:	5	4.000	0.707	L95%:	-1.989	-1.965
Group 2:	5	5.000	0.612	U95%:	-0.011	-0.035
Difference:		-1.000	0.418			
				T:	-2.390	-2.390
Test of Group 1σ² = Group 2σ²				DF:	7.8	8
F (4,4) = 1.333 P< 0.7872				P:	0.0481	0.0438

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Milk chocolate Attribute Comparisons

FILTER: None

Group 1: PROD = 1, 098 FC
Group 2: PROD = 2, 722 MVR

ACHOC, Chocolate (AROMA)

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	5.875	0.250	L95%:	0.567	0.567
Group 2:	4	4.875	0.250	U95%:	1.433	1.433
Difference:		1.000	0.177			
				T:	5.657	5.657
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	6.0	6
F (3,3) = 1.000 P<1.0000				P:	0.0013	0.0013

OV, Overall

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	6.000	0.000	L95%:	0.723	0.960
Group 2:	4	4.250	0.645	U95%:	2.777	2.540
Difference:		1.750	0.323			
				T:	5.422	5.422
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	3.0	6
F = . P< .				P:	0.0123	0.0016

BUTTER, Butter

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	0.750	0.957	L95%:	-2.774	-2.695
Group 2:	4	1.875	0.854	U95%:	0.524	0.445
Difference:		-1.125	0.641			
				T:	-1.754	-1.754
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	5.9	6
F (3,3) = 1.257 P< 0.8553				P:	0.1398	0.1300

DAIRY, Dairy

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	2.750	0.957	L95%:	-2.999	-2.822
Group 2:	4	4.250	0.500	U95%:	-0.001	-0.178
Difference:		-1.500	0.540			
				T:	-2.777	-2.777
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	4.5	6
F (3,3) = 3.667 P < 0.3142				P:	0.0499	0.0321

CHOC, Chocolate (FLAVOR)

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	5.125	0.854	L95%:	0.141	0.302
Group 2:	4	3.625	0.479	U95%:	2.859	2.698
Difference:		1.500	0.489			
				T:	3.065	3.065
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	4.76	
F (3,3) = 3.182 P< 0.3672				P:	0.0375	0.0221

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Cream Cheese Attribute Comparisons 36 hrs.

FILTER: None

Group 1: PROD = 1, FC
Group 2: PROD = 2, MVR

	N	Mean	S.D.		Separate Variances	Pooled Variances
SOUR, Sour						
Group 1:	5	3.800	0.837	L95%:	-0.194	-0.164
Group 2:	5	2.800	0.758	U95%:	2.194	2.164
Difference:		1.000	0.505			
				T:	1.980	1.980
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	7.9	8
F (4,4) = 1.217 P<0.8534				P:	0.0881	0.0830
DAIRY, Dairy						
Group 1:	5	4.800	0.447	L95%:	0.452	0.471
Group 2:	5	1.200	0.316	U95%:	1.948	1.929
Difference:		1.200	0.316			
				T:	3.795	3.795
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	7.7	8
F (4,4) = 1.500 P< 0.7040				P:	0.0068	0.0053
OFF, Off						
Group 1:	5	0.000	0.000	L95%:	-2.510	-2.322
Group 2:	5	1.400	0.894	U95%:	-0.290	-0.478
Difference:		-1.400	0.400			
				T:	-3.500	-3.500
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	4.0	8
F = . P< .				P:	0.0249	0.0081
SPRD, Spreadability						
Group 1:	5	0.400	0.548	L95%:	-2.394	-2.331
Group 2:	5	1.700	0.837	U95%:	-0.206	-0.269
Difference:		-1.300	0.447			
				T:	-2.907	-2.907
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	6.9	8
F (4,4) = 2.333 P< 0.4320				P:	0.0271	0.0197
MOUTH , MouthClearing						
Group 1:	5	1.800	1.095	L95%:	-2.208	-2.063
Group 2:	5	2.600	0.548	U95%:	0.608	0.463
Difference:		-0.800	0.548			
				T:	-1.461	-1.461
Test of Group $1\sigma^2$ = Group $2\sigma^2$				DF:	5.9	8
F (4,4) = 4.000 P< 0.2080				P:	0.2040	0.1823

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Cream Cheese Attribute Comparisons

FILTER: None

Group 1: PROD = 1, Feed + 5% MVR
Group 2: PROD = 2, FC + 5% FC

DA, Dairy Aroma

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	2.125	0.250	L95%:	-2.401	-2.309
Group 2:	4	3.750	0.500	U95%	-0.849	-0.941
Difference:		-1.625	0.280			
				T:	-5.814	-5.814
				DF:	4.4	6
				P:	0.0044	0.0011

Test of Group $1\sigma^2$ = Group $2\sigma^2$
F (3,3) = 4.000 P< 0.2848

	N	Mean	S.D.		Separate Variances	Pooled Variances
DAIRY, Dairy	4	2.375	0.479	L95%:	-2.250	-2.161
Group 2:	4	3.875	0.250	U95%:	-0.750	-0.839
Difference:		-1.500				
				T:	-5.555	-5.555
				DF:	4.5	6
				P:	0.0051	0.0014

Test of Group $1\sigma^2$ = group $2\sigma^2$
F (3,3) = 3.667 P< 0.3142

CREAM, Creaminess

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	3.000	0.577	L95%:	-2.732	-2.684
Group 2:	4	4.750	0.500	U95%:	-0.768	-0.816
Difference:		-1.750	0.382			
				T:	-4.583	-4.583
				DF:	5.9	6
				P:	0.0059	0.0038

Test of Group $1\sigma^2$ = Group $2\sigma^2$
F (3,3) = 1.333 P< 0.8187

SPRD, Spreadability

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	4	2.125	1.031	L95%:	-2.828	-2.435
Group 2:	4	3.250	0.289	U95%:	0.578	0.185
Difference:		-1.125	0.535			
				T:	-2.102	-2.102
				DF:	3.5	6
				P:	0.1263	0.0803

Test of Group $1\sigma^2$ = Group $2\sigma^2$
F (3,3) = 12.750 P< 0.0651

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Cream Cheese Attribute Comparisons 36 hrs.

FILTER: None

Group 1: PROD = 1, FC + 3.5%
Group 2: PROD = 2, MVR + 3.5%

DA, Dairy Aroma

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	3.300	0.671	L95%:	0.069	0.092
Group 2:	5	2.300	0.570	U95%:	1.931	1.908
Difference:		1.000	0.394			
				T:	2.540	2.540
				DF:	7.8	8
				P:	0.0387	0.0347

Test of Group $1\sigma^2$ = Group $2\sigma^2$
F (4,4) = 1.385 P< 0.7602

SALT, Salty

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	2.400	0.418	L95%:	-2.765	-2.715
Group 2:	5	4.300	0.671	U95%:	-1.035	-1.085
Difference:		-1.900	0.354			
				T:	-5.374	-5.374
				DF:	6.7	8
				P:	0.0017	0.0007

Test of Group $1\sigma^2$ = Group $2\sigma^2$
F (4,4) = 2.571 P< 0.3826

DAIRY, Dairy

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	5.400	0.548	L95%:	0.784	0.807
Group 2:	5	3.700	0.671	U95%:	2.616	2.593
Difference:		1.700	0.387			
				T:	4.389	4.389
				DF:	7.7	8
				P:	0.0032	0.0023

Test of Group $1\sigma^2$ = Group $2\sigma^2$
F (4,4) = 1.500 P< 0.7040

OFF, Off

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	0.000	0.000	L95%:	-2.819	-2.545
Group 2:	5	1.200	1.304	U95%:	0.419	0.145
Difference:		-1.200	0.583			
				T:	-2.058	-2.058
				DF:	4.0	8
				P:	0.1087	0.0736

Test of Group $1\sigma^2$ = Group $2\sigma^2$
F = . P< .

MOUTH, MouthCoating

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	3.700	0.447	L95%:	0.248	0.248
Group 2:	5	2.800	0.447	U95%:	1.552	1.552
Difference:		0.900	0.283			
				T:	3.182	3.182
				DF:	8.0	8
				P:	0.0130	0.0130

Test of Group $1\sigma^2$ = Group $2\sigma^2$
F (4,4) = 1.000 P< 1.0000

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Sour Cream Attribute Comparisons 36 hrs.

FILTER: None

Group 1: PROD = 1, 20-2 FEED 909
Group 2: PROD = 2, 20-1 FC 321

	N	Mean	S.D.		Separate Variances	Pooled Variances
DA, Dairy Aroma						
Group 1:	5	3.200	0.274	L95%:	-1.674	-1.641
Group 2:	5	4.300	0.447	U95%:	-0.526	-0.559
Difference:		-1.100	0.235			
				T:	-4.690	-4.690
Test of Group 1o^2 = Group 2o^2				DF:	6.6	8
F (4,4) = 2.667 P< 0.3651				P:	0.0034	0.0016
SOUR, Sour						
Group 1:	5	3.700	0.447	L95%:	0.234	0.253
Group 2:	5	2.700	0.570	U95%:	1.766	1.747
Difference:		1.000	0.324			
				T:	3.086	3.086
Test of Group 1o^2 = Group 2o^2				DF:	7.6	8
F (4,4) = 1.625 P< 0.6496				P:	0.0177	0.0150
DAIRY, Dairy						
Group 1:	5	3.600	0.548	L95%:	-1.904	-1.832
Group 2:	5	4.800	0.274	U95%:	-0.496	-0.568
Difference:		-1.200	0.274			
				T:	-4.382	-4.382
Test of Group 1o^2 = Group 2o^2				DF:	5.9	8
F (4,4) = 4.000 P<0.2080						

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Milk Chocolate Attribute Comparisons

FILTER: None

Group 1: PROD = 1, 098 FC
Group 2: PROD = 2, 722 MVR

	N	Mean	S.D.		Separate Variances	Pooled Variances
CREAM, Creaminess						
Group 1:	4	2.875	0.250	L95%:	0.750	0.839
Group 2:	4	1.375	0.479	U95%:	2.250	2.161
Difference:		1.500	0.270			
				T:	5.555	5.555
Test of Group 1σ² = Group 2σ²				DF:	4.5	6
F (3,3) = 3.667 P< 0.3142				P:	0.0300	0.0300
MELT, Melt						
Group 1:	4	5.250	0.500	L95%:	-1.865	-1.865
Group 2:	4	6.250	0.500	U95%:	-0.135	-0.135
Difference:		-1.000	0.354			
				T:	-2.828	-2.828
F (3,3) == 1.000 P< 1.0000				P:	0.0300	0.0300

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Hard Pack IC Attribute Comparisons

FILTER: None

Group 1: PROD = 1, 3-1
Group 2: PROD = 2, 3-2

	N	Mean	S.D.		Separate Variances	Pooled Variances
MOUTH, Mouth Clearing						
Group 1:	5	2.800	0.447	L95%:	-1.875	-1.816
Group 2:	5	4.100	0.224	U95%:	-0.725	-0.784
Difference:		-1.300	0.224			
				T:	-5.814	-5.814
Test of Group 1o² = Group 2o²				DF:	5.7	8
F (4,4) = 4.000 P< 0.2080				P:	0.0021	0.0004
ICE, Iciness						
Group 1:	5	2.600	0.894	L95%:	4.529	4.529
Group 2:	5	0.600	0.418	U95%:	3.135	3.018
Difference:		2.000	0.442			
				T:	4.529	4.529
Test of Group 1o² = Group 2o²				DF:	5.7	8
F (4,4) 4.571 P< o.1702				P:	0.0062	0.0019

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Whipped Topping Attribute Comparisons

FILTER: None

Module: TTEST, Independent Groups t-tests 10-13-1992
File: RON, Hard Pack IC Attribute Comparisons

FILTER: None

Group 1: PROD = 1, 3-1
Group 2: PROD = 2, 3-2

SPOON, Spoonability

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	3.500	0.500	L95%:	-1.884	-1.865
Group 2:	5	4.600	0.548	U95:	-0.316	-0.335
Difference:		-1.100	0.332			
				T:	-3.317	-3.317
				DF:	7.9	8
				P:	0.0128	0.0106

Test of Group 1σ^2 = Group 2σ^2
F (4,4) = 1.200 P< 0.8640

OV, Overall Flavor

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	4.700	0.671	L95%:	-2.583	-2.553
Group 2:	5	6.100	0.894	U95%:	-0.217	-0.247
Difference:		-1.400	0.500			
				T:	-2.800	-2.800
				DF:	7.4	8
				P:	0.0265	0.0232

Test of Group 1σ^2 = Group 2σ^2
F (4,4) = 1.778 P< 0.5910

DAIRY, Dairy

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	3.600	0.548	L95%:	-2.694	-2.631
Group 2:	5	5.200	0.837	U95%:	-0.506	-0.569
Difference:		-1.600	0.447			
				T:	-3.578	-3.578
				DF:	6.9	8
				P:	0.0117	0.0072

Test of Group 1σ^2 = Group 2σ^2
F (4,4) = 2.333 P < 0.4320

CREAM, Creaminess

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	3.000	0.000	L95%:	-3.080	-2.965
Group 2:	5	5.400	0.548	U95%:	-1.720	-1.835
Difference:		-2.400	0.245			
				T:	-9.798	-9.798
				DF:	4.0	8
				P:	0.0006	0.0000

Test of Group 1σ^2 = Group 2σ^2
F = . P< .

MTH, Mouth Feel

	N	Mean	S.D.		Separate Variances	Pooled Variances
Group 1:	5	5.000	0.707	L95%:	-2.616	-2.563
Group 2:	5	6.700	0.447	U95%:	-0.784	-0.837
Difference:		-1.700	0.374			
				T:	-4.543	-4.543
				DF:	6.8	8
				P:	0.0039	0.0019

Test of Group 1σ^2 = Group 2σ^2
F (4,4) = 2.500 P< 0.3965

APPENDIX J: NEWSPAPER ARTICLES

Copies of news articles published in various newspapers during the PDU grand openingin Fond du Lac, Wisconsin.

DAILY & SUNDAY 41,297
THURSDAY
AUG 8 1991
897 BURRELLE'S FB
...ech .....

MATT SUMNER / PENINSULA TIMES TRIBUNE

Robert Jeffress (left) and Ammi Amarnath, senior project manager at Electric Power Reasearch Institute, are two of the forces behind a new process that would produce tasty nonfat dairy products, while saving on energy and production costs.

Nonfat ice cream that tastes like the real thing?

Peninsula firm says 'yes' — and the production costs would be a lot lower, too

Mary Madison
PENINSULA TIMES TRIBUNE

The ultimate fantasy may be just a few gulps and spoons away: Rich, creamy ice cream and full-bodied milk that won't add pounds or clog arteries.

Milk, ice cream and cheeses that taste like the old-fashioned kind, but are really diet-conscious may soon be available, as a result of research by the Electric Power Research Institute of Palo Alto.

Researchers say the products will be low in calories and fat, but will still taste like "the real thing."

EPRI and other groups have invented a process, which not only promises delicious low calorie dairy products, but also claims that less energy will be required to make them.

"We can produce a better tasting product. It is smoother and has a better mouth feel than other lowfat dairy products," said Ammi Amarnath, senior project manager in EPRI's Industrial Program.

The newly developed process was developed in a $2.3 million research project funded by EPRI and the U.S. Department of Energy, along with other groups.

The freeze concentration process separates water from liquid food products by converting some of the water into ice crystals. For example, milk is cooled to a temperature at or below its freezing point and becomes a mixture of concentrate and ice crystals.

Eventually, the ice crystals are removed, and the concentrated product is recovered. Current methods to concentrate dairy products, such as evaporated milk, use heat, changing the taste and odor of the final product.

"With freeze concentration we don't lose the structure of the protein so the texture remains. Frozen concentrated skim milk feels like whole milk, but is lower in calories than what it tastes," said Salah Ahmed, technical director of the Dairy Research Foundation, a partner in the research, along with Grenco Process Technology B.V.

"We may be able to relate the process to ice cream, cheeses, spreadable dairy products — products we can't imagine yet. We may be able to make nonfat ice cream that tastes like the real thing."

Experiments on the new products have been successfully completed, and a commercial demonstration is scheduled Sept. 11 at Galloway West Co. in Fond du Lack, Wis. The results, which will determine if the process is economical and commercially viable, are expected in early 1992, Amarnath said. If tests are successful, EPRI hopes to sell the process, he said.

Dairies are the highest energy users for product concentration in the food industry. Currently the most popular method for concentration is evaporation.

If a single 50,000 pound per hour evaporator were replaced with freeze concentration technology, a dairy would save about $100,000 per year through lower energy costs alone, Amarnath said.

Heat in evaporation causes the milk protein and sugar to adhere to the walls of evaporators. With freeze concentration, the milk is kept at temperatures at or below the freezing point of water, so it stays fresh longer and doesn't stick, Ahmed said.

Since freeze concentrated milk occupies less volume and weighs less compared to fresh milk, it reduces shipping costs. Plus, the product in concentrated form, will have a longer shelf-life.

AUG 15 1991

BURRELLE'S

Process gives better taste to skim milk

© New York Times 631

All the scientists at the Electric Power Research Institute were trying to do was find a way to conserve power in the dairy industry. But, inadvertently, they may have developed a process that makes skim milk taste like whole milk.

Instead of heating milk to drive off water to produce concentrate or powder, as is usually done, institute researchers and representatives of the Dairy Research Foundation chilled it. Some of the water formed ice crystals, which were filtered out. The resulting concentrate was reconstituted by adding water.

The researchers were surprised to find that the resulting skim milk tasted better than normal skim milk.

"We put the water back in, and it tasted like whole milk," said Robert D. Jeffress, a program manager at the Palo Alto, Calif., institute, which is supported by electric utilities.

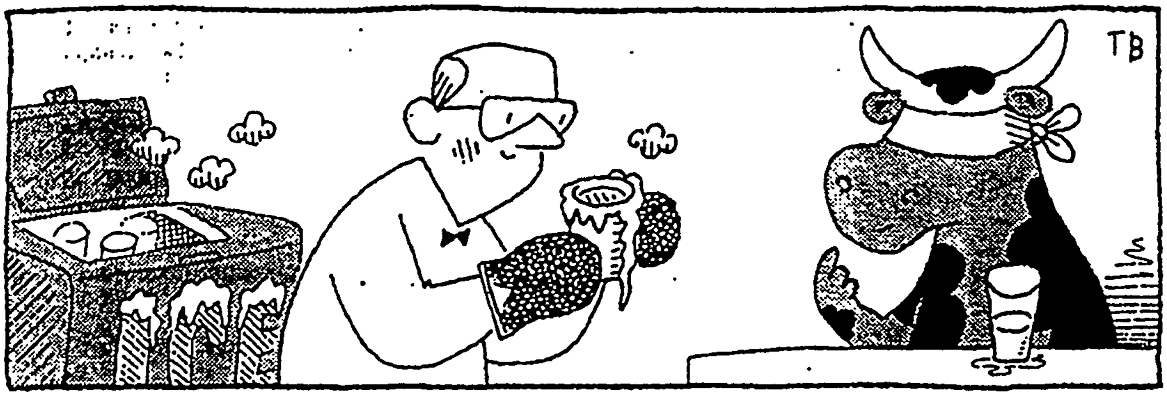
The difference could be that the milk proteins are preserved when frozen, but partly broken down when heated, changing the taste, he said.

Other advantages of freeze-concentrated milk include less volume, so it is cheaper to ship, and a longer shelf life in stores or home freezers. To test the economics of the process, the institute is backing a commercial-scale operation for removing 700 pounds of water an hour at Galloway West Co. in Fond du Lac, Wis., starting this fall.

NEW YORK TIMES
NEW YORK, NY
DAILY 1,108,447

WEDNESDAY
AUG 14 1991

470 BURRELLE'S BK



Tom Bloom

Can Skim Milk Taste Like Whole Milk?

6031

All that the scientists at the Electric Power Research Institute were trying to do was find a way to conserve power in the dairy industry. But, inadvertently, they may have developed a process that makes skim milk taste like whole milk.

Instead of heating milk to drive off water to produce concentrate or powder, as is usually done, institute researchers and representatives of the Dairy Research Foundation chilled it. Some of the water formed ice crystals, which were filtered out. The resulting concentrate was reconstituted by adding water.

The researchers were surprised to find that the resulting skim milk tasted better than normal skim milk. "We put the water back in, and it tasted like whole milk," said Robert D. Jeffress, a program manager at the Palo Alto, Calif., institute, which is supported by electric utilities.

"We are not sure why that is, but we have blindfolded taste tests that say so," he added. The difference could be that the milk proteins are preserved when frozen, but partly broken down when heated, changing the taste, he said.

Other advantages of freeze-concentrated milk include less volume, so it is cheaper to ship, and a longer shelf life in stores or home freezers. To test the economics of the process, the institute is backing a commercial-scale operation for removing 700 pounds of water an hour at the Galloway West Company in Fond du Lac, Wis., starting in the fall.

According to officials of the institute, freezing is a more energy-efficient means of concentrating milk and other dairy products than heat evaporation. The most common type of evaporator takes 118 kilowatt-hours to remove one metric ton, or 2,204 pounds, of water, compared with 65 kilowatt-hours for freezing. A typical dairy could save $100,000 a year in power costs by switching methods, they said.

RICHMOND POST

OAKLAND, CA
2-TIMES/WEEK 13,661

WEDNESDAY
AUG 14 1991

525 BURRELLE'S 9X
...■.9 .026.

New Dairy Process Eliminates Calories

631

A Palo Alto research institute is reporting that lab testing has been completed on an experimental freezing process that could chill calories out of dairy products while leaving taste intact.

If successful, use of the process could lead not only to better-tasting low-calorie dairy products but also to a frozen milk concentrate, similar to frozen orange juice, that consumers can buy in stores and add water to at home.

The process is being developed as part of a $2.8 million project being conducted by the Electric Power Research Institute. It's intended to replace heat evaporation as the most popular method for removing water during food concentration.

According to the institute, heat evaporation is a heavy user of energy and can change the taste and odor of foods like milk. If freeze concentration pans out it could save dairies up to $100,000 a year in lower energy costs without changing the taste of finished dairy products.

"Tests have shown that the taste of reconstituted freeze concentrated milk is equal to, or in some cases, better than fresh milk," says a research spokesman.

Freeze concentration may also improve the taste of low-calorie dairy products, which are currently manufactured using the heat evaporation process.

MIRROR-EXCHANGE

MILAN, TN
WEEKLY 5,400

AUG 14 1991

103 BURRELLE'S UD

Less Fat, Calories In Dairy Products:

Freeze Process May Open New Era

631 ✓

Imagine drinking milk with the rich taste of whole milk but the fewer calories and less fat of skim. It's possible with a freeze concentration process being developed by the Electric Power Research Institute (EPRI), the Dairy Research Foundation (DRF) and Grenco Process Technology B.V.

"Tests have shown that the taste of reconstituted freeze concentrated milk is equal to or, in some cases, better than fresh milk," said Ammi Amarnath, senior project manager in EPRI's Industrial Program. "It is certainly superior to evaporated milk," he added.

Freeze concentration separates water from liquid food products by converting some of the water into ice crystals. For example, milk is cooled to a temperature at or below its freezing point and becomes a mixture of concentrate and ice crystals. Eventually, the ice crystals are removed and the concentrated product is recovered. Current methods to concentrate dairy products, such as evaporated milk, use heat which changes the taste and odor of the final product.

"With freeze concentration we don't lose the structure of the protein so the texture remains. Frozen concentrated skim milk feels like whole milk but is lower in calories than what it tastes," said Salah Ahmed, DRF's technical director.

"We may be able to relate the process to ice cream, cheeses, spreadable dairy products--products we can't imagine yet. We may be able to make nonfat ice cream that tastes like the real thing," Ahmed added.

With lab testing successfully completed, DRF is managing a commercial demonstration of the technology at Galloway West Company in Fond du Lac, Wisconsin. The demonstration will be celebrated with a ribbon cutting on September 11 at Galloway West. The results, which will determine if the process is economical and commercially viable, are expected in early 1992, Amarnath said.

The $2.8 million research project is funded by DRF, EPRI, the U.S. Department of Energy and equipment manufacturer Grenco, a Netherlands company. Wisconsin Power & Light (WP&L) is providing monitoring equipment to document the energy efficiency of the process; WP&L services one-half of all dairy farms in Wisconsin.

Dairies are the highest energy users for product concentration in the food industry. Currently the most popular method for concentration is evaporation. A multistage evaporator uses 118 kilowatt-hour (kWh) per metric ton for water removal compared to multistage freeze concentration using 65 KWh per metric ton. If a single 50,000-pound-per-hour evaporator were replaced with freeze concentration technology, a dairy would save approximately $100,000 per year through lower energy costs alone.

Those savings do not even include the costs recovered from keeping the nearly one percent of product lost each time evaporators must be shut down for cleaning. The costs of cleaning add up since evaporators must be sanitized every 20 hours or so, explained Ahmed. The process with freeze concentration runs continuously.

Heat in evaporation causes the milk protein and sugar to adhere to the walls of evaporators. With freeze concentration, the milk is kept at temperatures at or below the freezing point of water so it stays fresh longer and doesn't stick, Ahmed added.

Other benefits with freeze concentration include a higher quality protein source and possibly additional products for lactose-intolerant people. Freeze concentration produces a whey protein powder whereas the heat in evaporation alters the protein in whey. Also, freezing causes lactose to crystallize for easy separation which may help provide milk or other dairy products with less lactose.

Since freeze concentrated milk occupies less volume and weighs less compared to fresh milk, it reduces shipping costs. Plus, the product, in concentrated form, will have a longer shelf-life in stores or in home freezers.

Freeze concentration technology may also be applied to other areas such as industrial wastewater treatment. Some completed pilot-scale work has shown the technology is equally effective on any type of waste. The process reduces costs, is more energy efficient and minimizes corrosion compared to standard methods. Other promising applications are in the chemical and petrochemical industries.

EPRI, founded in 1972, manages technical research and development programs for the U.S. electric utility industry to improve power production, distribution and use. some 680 utilities are members of the Institute.

CHEESE REPORTER

MADISON, WI
WEEKLY 3,300

AUG 16 1991

BURRELLE'S CS
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Benefits Of Freeze Concentration Of Milk Detailed By Researchers

Palo Alto, CA–Milk that has the rich taste of whole milk but the fewer calories and less fat of skim is possible with a freeze concentration process being developed by the Electric Power Research Institute (EPRI), the Dairy Research Foundation (DRF) and Grenco Process Technology B.V.

"Tests have shown that the taste of reconstituted freeze concentrated milk is equal to or, in some cases, better than fresh milk," said Ammi Amarnath, senior project manager in EPRI's industrial program. "It is certainly superior to evaporated milk."

Freeze concentration separates water from liquid food products by converting some of the water into ice crystals. For example, milk is cooled to a temperature at or below its freezing point and becomes a mixture of concentrate and ice crystals.

Eventually, the ice crystals are removed and the concentrated product is recovered. Current methods to concentrate dairy products, such as evaporated milk, use heat which changes the taste and odor of the final product.

"With freeze concentration we don't lose the structure of the protein so the texture remains. Frozen concentrated skim milk feels like whole milk but is lower in calories than what it tastes,"

(See Freeze Concentration on Page 3)

San Francisco Chronicle
SAN FRANCISCO, CAL.
D. 562,887
CA-593

AUG 8 1991
BURRELLE'S

An Improvement on Powdered Milk

Researchers say freezing process takes out calories and puts in taste

By Kenneth Chang
Chronicle Staff Writer

Freezing skim milk, removing the water and then putting it back again restores the richness and creaminess of whole milk but not the fat and calories, say scientists who have developed a technology that could lead to cans of milk in the supermarket freezer section.

Researchers from the Electric Power Research Institute in Palo Alto, the Dairy Research Foundation in Chicago and Grenco Process Technology, a Dutch company, have created a process to freeze concentrate milk, much as orange concentrate is produced.

Unlike heat evaporation, the current method of making condensed milk, freeze concentration does not change the taste of the milk. "With freeze concentration, we don't lose the structure of the protein, so the texture remains," said Salah Ahmed, technical director of the Dairy Research Foundation.

The process even improves the taste of skim milk, said Ammi Amarnath, senior project manager in the Electric Power Research Institute's Industrial Program. "Skim milk freeze-concentrated and reconstituted has a richer taste than the original skim milk," Amarnath said. "People feel like it is whole milk, but it is not."

Amarnath said he does not know why the taste is improved.

Freeze concentration could also result in a better quality powdered milk, Amarnath said, and that means products that use powdered milk also will taste better. "We may get a better milk chocolate from Hershey, for example," Amarnath said.

Because the new process is more efficient, it could save a dairy $100,000 a year in electricity costs, Ahmed said.

Other benefits of the new technology could include new products for people who cannot eat lactose and a protein powder produced from whey, a milk product that is usually discarded, Amarnath said. Frozen concentrate also has a longer shelf life, takes up less space and weighs less than fresh milk.

A pilot project to determine commercial possibilities for the process will begin in September in Wisconsin. If successful, the technology may become available in two to three years, Amarnath said.

The Miami Herald
MIAMI, FLA.
D. 428,931
FL-148

AUG 9 1991
BURRELLE'S

Freezing skim milk aids flavor, researchers say

631

San Francisco Chronicle

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HAMMOND, IN
DAILY 63,004

THURSDAY
AUG 8 1991

111 bb BURRELLE'S QK

High tech milk will be tastier now

San Francisco Chronicle

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EDMOND, OK
DAILY 9,871

THURSDAY
AUG 8 1991

63 BURRELLE'S FL

New Milk Keeps Taste, Loses Calories

By The San Francisco Chronicle

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OAKLAND, CA
TIMES/WEEK
SUNDAY
AUG 11 1991
BURRELLE'S

Frozen Milk May Be On The Way

Palo Alto (BCN)

A Palo Alto research institute is reporting that lab testing has been completed on an experimental freezing process that could chill calories out of dairy products while leaving taste intact.

If successful, use of the process could lead not only to better-tasting low-calorie dairy products but also to a frozen milk concentrate, similar to frozen orange juice, that consumers can buy in stores and add water to at home.

The process is being developed as part of a $2.8 million project being conducted by the Electric Power Research Institute. It's intended to replace heat evaporation as the most popular method for removing water during food concentration.

According to the institute, heat evaporation is a heavy user of energy and can cahnge the taste and odor of foods like milk. If freeze concentration pans out it could save dairies up to $100,000 a year in lower energy costs without changing the taste of finished dairy products.

Freeze concentration works by freezing milk, which becomes a mixture of concentrate and ice crystals. The crystalsa are then removed and the concentrated product is recovered.

The concentrate can be packaged and sold in stores like frozen orange juice concentrate, according to Ammi Amarnath of the institute, with little or no decline in taste.

"Tests have shown that the taste of reconstituted freeze concentrated milk is equal to, or in some cases, better than fresh milk," says Amarnath.

Freeze concentration may also improve the taste of low-calorie dairy products, which are currently manufactured using the heat evaporation process.

Now that lab testing has been completed, a demonstration of the technology is being conducted at a company in Fond du Lac, Wis. The results, which are expected in early 1992, should determine whether the process is commercially viable.

Amarnath says that if tests go well, dairy produts made using the freeze concentration process could hit supermarket shelves in two to three years.

The project is also being funded by the Dairy Research Foundation, the U.S. Department of Energy and a Dutch equipment manufacturer.

BUSINESS WEEK
(INDUSTRIAL/TECHNOLOGY
EDITION)

NEW YORK, NY
WEEKLY 308,831

SEP 2 1991

-8977 Burrelle's DC
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631

CAN IT BE? POWDERED MILK THAT ACTUALLY TASTES LIKE MILK?

Supermarket chains and food distributors could save a lot of energy, ergo money, if milk didn't need to be refrigerated. Since hardly anyone enjoys the gooey taste of canned milk—or ice creams and cheeses made from it—the Dairy Research Foundation has teamed up with the Electric Power Research Institute (EPRI), and the Energy Dept. to apply a new freeze-drying technique developed by Grenco Process Technology, a Dutch company.

The freeze-concentration approach converts milk into a crystalline powder by freezing the milk's water content and removing the ice. When reconstituted by adding water, the resulting milk has a rich taste that's at least as good as whole milk, and some people like it better, say researchers at EPRI in Palo Alto, Calif. Yet it contains less fat and fewer calories. Next month, Galloway-West Co., a dairy in Fond du Lac, Wis., will begin commercial-scale tests of the process, and consumer products could be available within two years. EPRI adds that the freeze-dry method also shows promise for treating industrial waste water and even chemical wastes.

Edited by John Teresko

Privacy at the flick of a switch

How would you use glass that could, at the flick of a switch, be either transparent or frosted? Designed for interior or exterior architectural applications, the glass contains an inner film of liquid-crystal droplets that become clear when a voltage is applied. Taliq Corp., the developer, says potential applications include control of privacy, security, and glare. It says the glass panels, in the frosted mode, can serve as rear projection screens.

For more information, circle No. 27 on the Information Center card.

Putting the heat on auto emissions

Preheating catalytic converters would pare the emissions from cold starts, and now the commercial-feasibility issue seems to be solved. The key is a new type of converter that was described at a meeting of the American Institute of Chemical Engineers. It uses coated metal foil and a solid-state power controller between the vehicle battery and the converter, says Joseph E. Kubsh, a researcher at W. R. Grace & Co.'s Columbia, Md., facility.

Better phone links to Moscow's hotels

Calling to and from Moscow is going to be faster and easier with SOVINTEL, a U.S.-Soviet communications joint venture. Starting in November, an enhanced digital network service will be available at four hotels and several business centers. Hardware will be supplied by GTE Spacenet Corp., a partner with San Francisco/Moscow Teleport in the U.S. part of the joint venture. High-quality FAX and PC data transmission will be possible, says Dr. C. J. Waylan, president, GTE Spacenet, McLean, Va.

Black plus a color can be printed—in a single pass—at up to 50 pages per minute.

Highlight-color laser printer

Xerox Corp. is betting that its 4850 laser printer will change the way businesses use color in documents. Says Wayland Hicks, executive vice president: "It allows production printing environments, for the first time, to use color to highlight variable data—something that can't be done with traditional offset printing." It is designed for a monthly print volume between 100,000 and 750,000 pages and cut sheet sizes from 8-in.-by-10-in. to 8½-in.-by-14-in.

For more information, circle No. 26 on the Information Center card.

Tapping into the sun's energy

Three California utilities are taking a serious look at solar energy. The project, called Solar Two, will use hundreds of large sun-tracking mirrors to concentrate the sun's energy at the top of a 300-ft tower. There, molten nitrate salt will store heat energy that will generate steam. Cooperating on the $39 million project are Southern California Edison, Rosemead; the Los Angeles Dept. of Water & Power; and the Sacramento Municipal Utility District.

Another way to get the fat out

Freezing hard cider concentrates the alcohol in the center of the frozen mass. Now the concept is being applied to control the fat and calories in dairy products. Already shown to produce more tasty reconstituted freeze-concentrated milk, the process is also thought to have potential in making nonfat dairy products such as ice cream. The potential for energy savings (compared with heat-evaporated milk) may explain the research team: the Electric Power Research Institute, Palo Alto, Calif.; the Dairy Research Foundation; and Grenco Process Technology B.V. of the Netherlands.

The rig can be installed at a water depth of 150 m (492 ft).

What's new in drilling platforms

Ease of relocation is a key benefit of a new drill-rig concept. The main elements: an integrated deck that is equipped and tested on shore prior to installation, a single supporting leg and jacking system, and a gravity base that provides stability on site and during towing. (The base and leg elevate to sea level during towing). The deck has a total deck payload of 10,600 metric tons and comes with accommodations for 160 people, says Eiffel/CFEM Offshore Engineering, Paris, France.

Micro-MRP ships Version 7.0

Version 7.0 of MAX, a closed-loop MRP II software system for PC compatibles, allows users to customize data. In addition to greater user convenience, the new version has an enhanced accounting interface that allows users to verify and voucher MAX purchase-order receipts and post them to accounts payable. More than 40 modules are available, including two new ones—the Manufacturer's Part Control Module and the Warranty Tracking Module.

For more information, circle No. 28 on the Information Center card.

The Indianapolis Star
INDIANAPOLIS, IND.
D. 228,582
IN-131

SEP 18 1991
BURRELLE'S

Flavor saver

NEW YORK TIMES 631

All that the scientists at the Electric Power Research Institute were trying to do was find a way to conserve power in the dairy industry. But, inadvertently, they may have developed a process that makes skim milk taste like whole milk.

Instead of heating milk to drive off water to produce concentrate or powder, as is usually done, Institute researchers and representatives of the Dairy Research Foundation chilled it. Some of the water formed ice crystals, which were filtered out. The resulting concentrate was reconstituted by adding water.

The researchers were surprised to find that the resulting skim milk tasted better than normal skim milk.

"We put the water back in, and it tasted like whole milk," said Robert D. Jeffress, a program manager at the Palo Alto, Calif., Institute.

PRESS-ENTERPRISE

RIVERSIDE, CA
SUNDAY 163,246

AUG 11 1991

BURRELLE'S
837 ..bsob FB .....

Technology makes milk whole without the fat

San Francisco Chronicle

631 PALO ALTO

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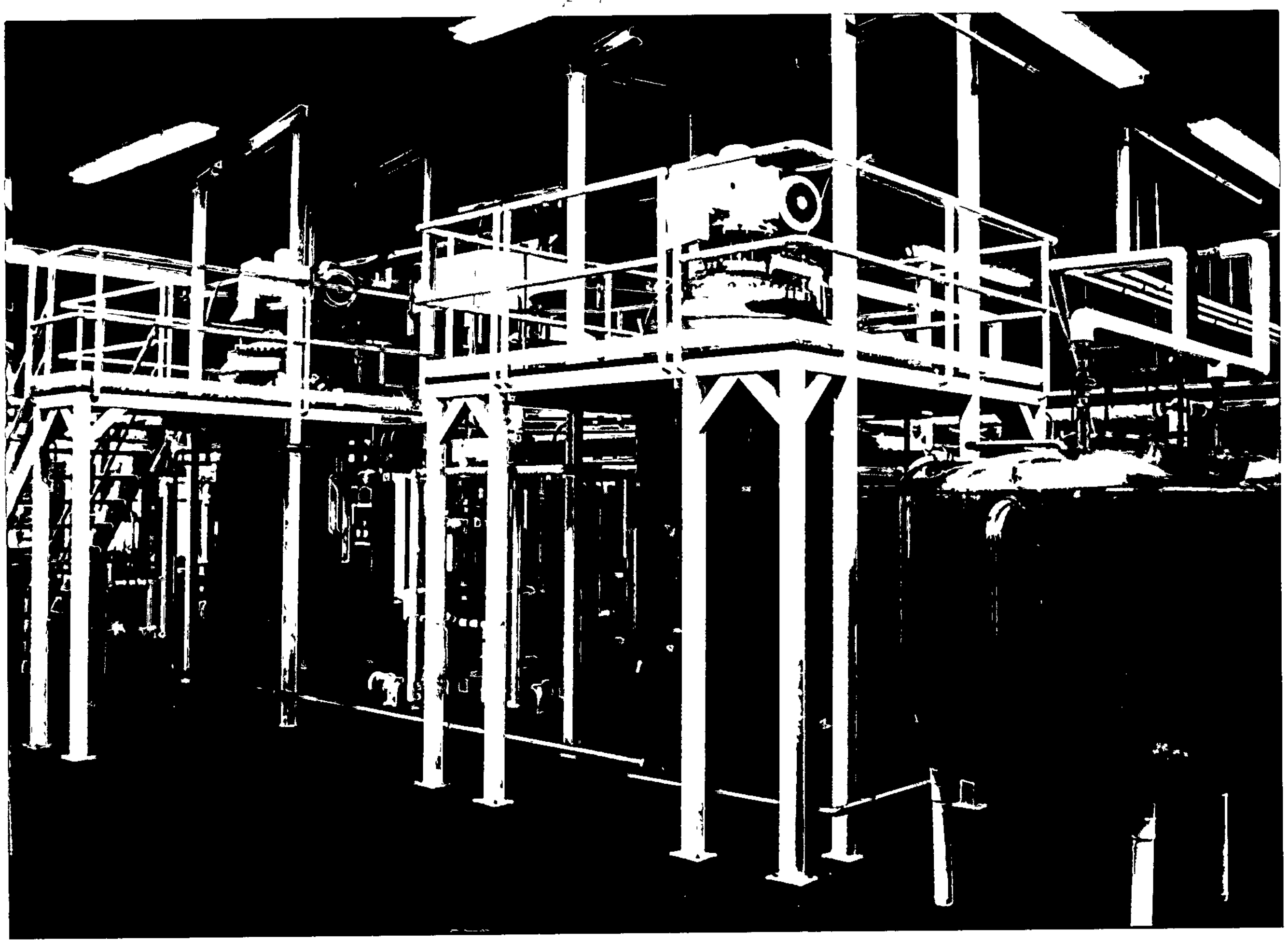
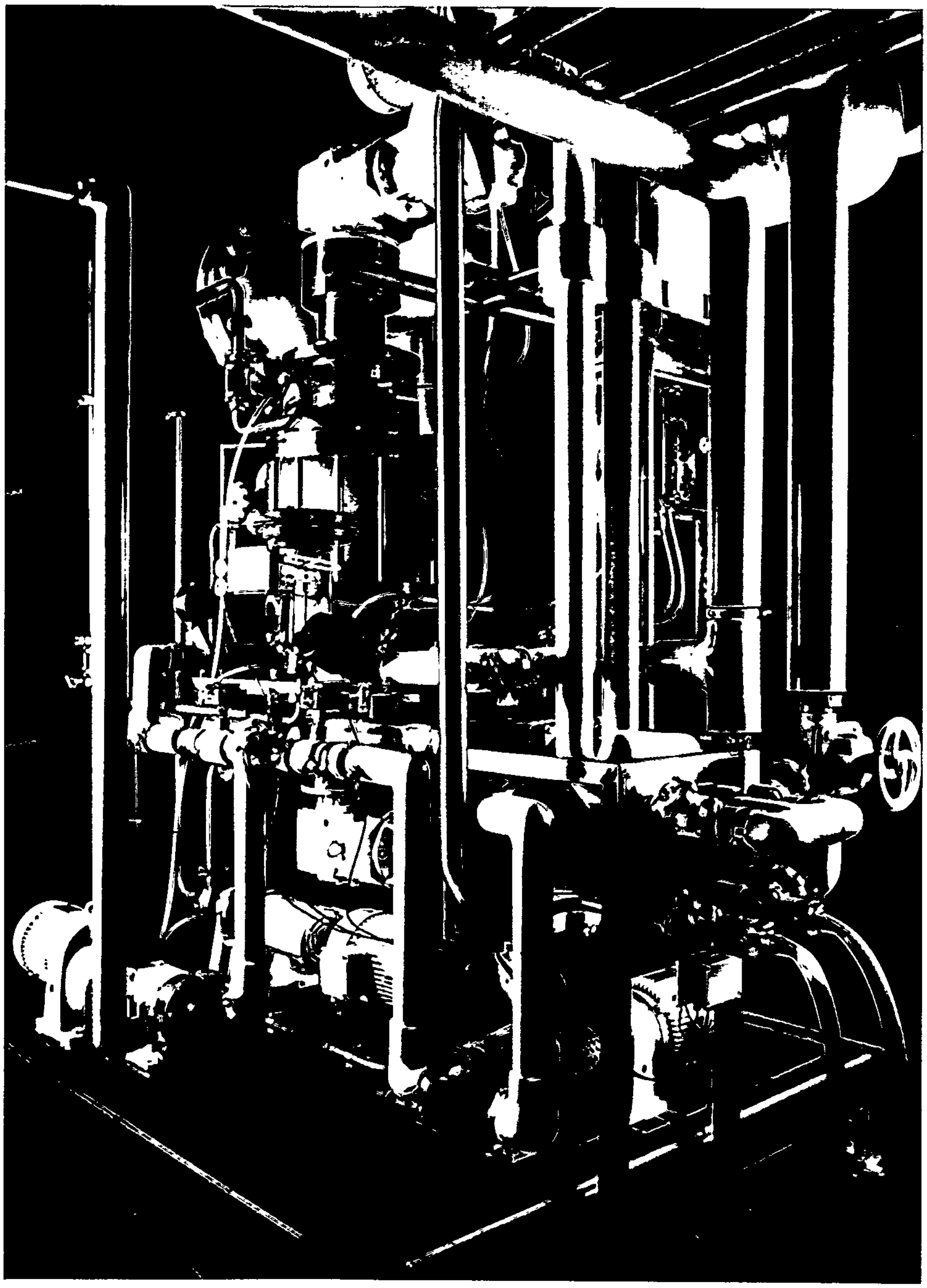
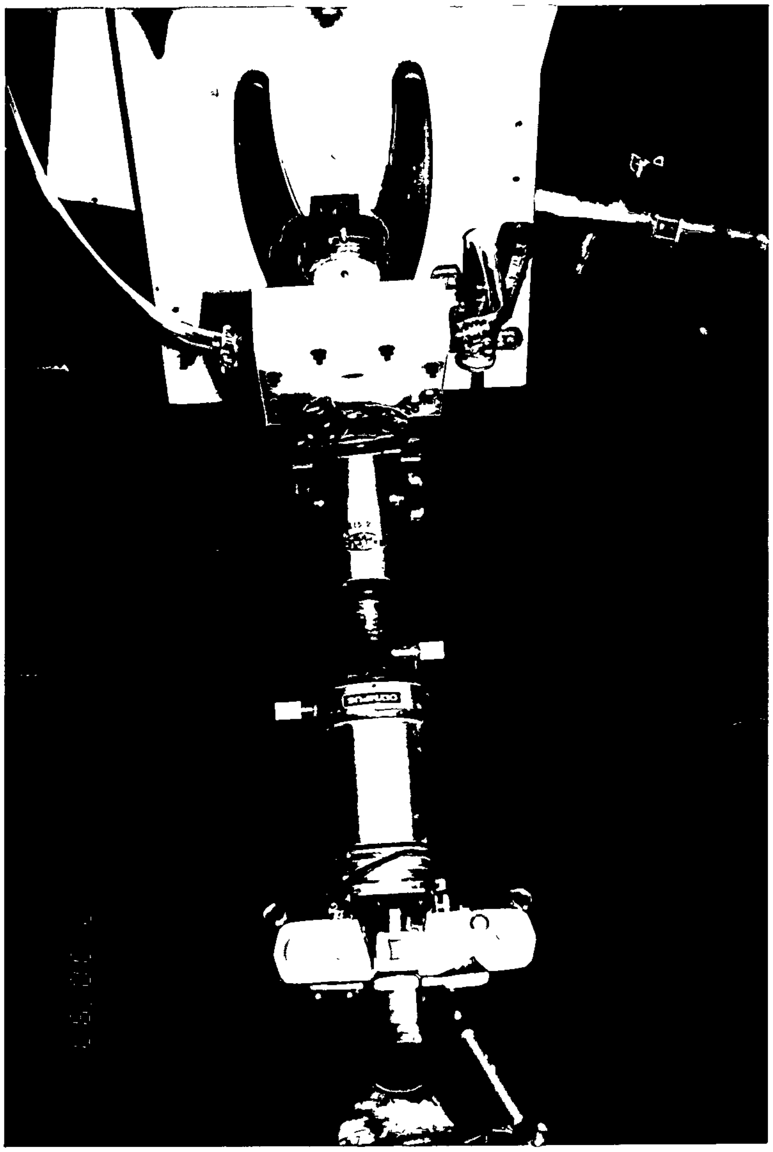
Other benefits of the new technology could include new products for people who cannot eat lactose and a protein powder produced from whey, a milk product that is usually discarded, Amarnath said.



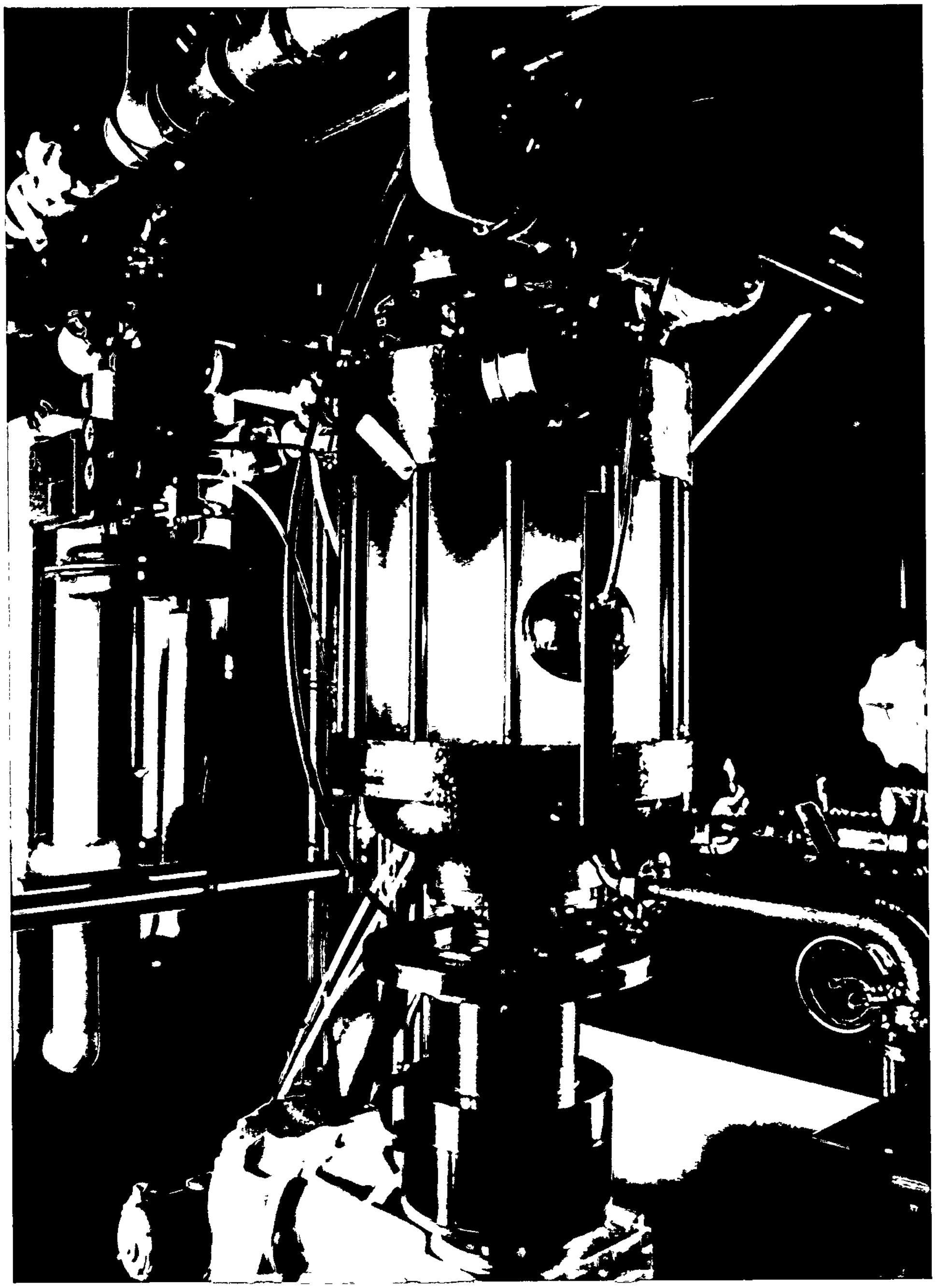
Freeze Concentration Process Development Unit



Wash Column



Microscope Set Up For Crystal Study



Wash Column Close Up

REPORT SUMMARY

SUBJECT Industrial electric technologies

TOPICS End use / Technology utilization / Electrotechnology / Crystallization / Separation processes / Food processing industry

AUDIENCE Marketing managers/Customer service engineers

Freeze Concentration of Dairy Products

Phase 2

An efficient, electrically driven freeze concentration system offers potential for substantially increasing electricity demand while providing the mature dairy industry with new products for domestic and export markets together with enhanced production efficiencies. Consumer tests indicate that dairy products manufactured from freeze-concentrated ingredients are either preferred or considered equivalent in quality to fresh milk-based products. Economic analyses indicate that this technology should be competitive with thermal evaporation processes on a commercial basis.

BACKGROUND Conventional evaporators used in the dairy industry convert an estimated 60 billion-lbs. of milk and whey products annually into dairy powders. Dairy powders provide important domestic and export opportunities for American dairy producers. Many of the evaporators currently used by dairy processors are old and inefficient, and damage the dairy powders through heat abuse. This results in lost organoleptic and functional qualities in the finished dairy products. EPRI report EM-5232 indicated that substitution of freeze concentration for evaporation and distillation in all feasible industrial applications could lead to annual customer savings of $5.5 billion, while increasing electric power consumption by 20 billion kWh/yr. EPRI report CU-6292 reported on Phase I of the freeze concentration of dairy products. The report concluded that the freeze concentration of dairy products was technically feasible on the basis of pilot plant studies.

OBJECTIVES To prove the technical, commercial, and regulatory feasibility of the freeze concentration of milk products on a semi-commercial level; and to demonstrate the functional and organoleptic advantages and consumer acceptability of freeze-concentrated dairy products.

APPROACH The project team collected ice crystallization, operating and other data on the freeze concentration on whole milk, skim, acid whey, sweet whey, and whey protein concentrate using a pilot plant-scale freeze concentration unit. A semi-commercial scale Niro process development unit (PDU) was installed at Galloway West and used to produce skim milk and whey protein concentrate streams. Grade-A certification was obtained for the PDU and an expert safety panel was convened to determine the Generally Recognized as Safe (GRAS) status of freeze-concentrated milk products. Operating data was collected and used to estimate the economic feasibility of commercial scale freeze concentration. Finished product was collected