to the 30-in. level in 1973 and ran the full depth of the profile in 1974.

SUMMARY

Whey application directly on cropland, either by truck-spreading or irrigation, has shown that the plant nutrients contained in the whey will be beneficial for growing crops requiring nitrogen as indicated by crop yield and tissue analysis. The buildup of phosphorus and potassium in the soil is in direct proportion to the amount of whey applied, and results show that the soil acts as a vast sink for holding these nutrients until required for further crop production. The initial project, confirmed by the additional work reported here, showed that the plant nutrients in whey sometimes move down into the soil beyond the principal root zone. In the profile sampling of the spreading sites, occasionally to a depth of 9 ft, the likelihood of soil nutrients passing through the examined zones into the ground water does not appear significant. A brief examination of the underlying ground water at Rupert confirmed that there was no observable effect.

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Industrial Whey Processing Technology: An Overview

Pavel Jelen

This review deals with industrially applicable whey processing techniques suitable for utilization of whey for human food. Production of whey protein concentrates, dairy blends, lactose-hydrolyzed syrups, and certain consumer products from whey is briefly discussed. Compositional data for some of the new products are presented to indicate the diversity of their physicochemical properties. Industrial acceptance of the new molecular separation and modification techniques is documented.

Manufacture of cheese, cottage cheese, or industrial casein results in production of up to 9 kg of liquid whey for every kilogram of the final product. If this whey is dumped down the drain—a practice still common with many dairy processors—it constitutes the most potent of all dairy wastes (Orchard, 1972) and one of the strongest wastes of any kind (Table I). One hundred kilograms of liquid whey, containing approximately 3.5 kg of biological oxygen demand (BOD) and 6.8 kg of chemical oxygen demand (COD), has the polluting strength equivalent to sewage produced by 45 people (Webb and Whittier, 1970).

Yet, this so called waste contains about 20% of the milk protein, almost all of the milk sugar, and altogether about 50% of all the nutrients consumed normally in milk. In terms of proximate composition, mineral and vitamin content, and food energy, the dried whey solids can be compared with whole wheat flour (Table II).

The industrial recovery of whey nutrients for human consumption depends on availability of technically feasible and economically attractive processes, leading to marketable products. The objective of this paper is to review briefly some of the currently available technologies used in processing of whey for food as an alternative to waste treatment. The review will emphasize the processes that are being commercially exploited or are on the verge of industrial feasibility, including certain new developments in New Zealand and Australia noted during a personal visit in 1977.

Department of Food Science, University of Alberta, Edmonton, Alberta T6G 2N2.

Table I. Characteristics of Food Processing Wastes (Orientation Values, Data from Various Sources)

	BOD_5, mg/L
dairy processing waste waters	
fluid milk plant	1000
ice cream plant	2500
cottage cheese plant	6000
whey powder plant	40
other food processing waste waters	
sweet goods bakery	2500
meat canning	1500
candy plant	4000
poultry processing	5000
raw wastes	
sweet whey	35000
acid whey	45000
fish processing stickwater	50000
domestic sewage	300

TRADITIONAL PROCESSES

Recovery of total whey solids as ingredients for human foods or animal feeds has been the most usual approach taken by large industrial whey processors. In Wisconsin, one of the most important whey producing areas in North America, 78% of all sweet whey produced was dried (Groves, 1972). The available techniques include spray drying, roller drying, concentration to semisolid feed blocks, or production of sweetened condensed whey. Other

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Table II. Proximate Compositions of Dried Whey and Whole Wheat Flour[a]

component	unit (per 100 g of product)	dry whey	whole wheat flour
H_2O	g	4.5	12.0
protein	g	12.9	13.3
fat	g	1.1	2.0
carbohydrate	g	73.5	71.0
ash	g	8.0	1.7
calcium	mg	646.0	41.0
thiamin	mg	0.5	0.6
riboflavin	mg	2.5	0.1
niacin	mg	0.8	4.3
food energy	cal	349.0	333.0

[a] Source: Agricultural Handbook No. 8, USDA, Washington, DC, 1975.

traditional, well-established processes include crystallization of lactose from untreated or modified wheys, production of heat-denatured whey protein concentrate ("traditional lactalbumin"), or recovery of milk fat from cheese whey in "whey butter". Use of liquid whey for manufacture of various alcoholic or nonalcoholic beverages has been successfully commercialized by several processors; however, whey beverages are still a rarity in most countries today. Similarly, fermentation of whey for special products such as lactic acid, vitamins or antibiotics, or for feed-grade single cell protein have been commercially used in the past by limited number of highly specialized processors. Many reviews covering technical aspects of one or more of these traditional whey processing technologies are available (e.g., Holsinger et al., 1974; Webb and Whittier, 1970; Mann, 1977, etc.).

WHEY FRACTIONATION AND BLENDING

Use of dried whey in human foods is limited due to varying functional properties of the individual components. Various fractionation techniques can be used either to remove some of the undesirable components (salts, acids), or to recover the most valuable whey components separately. Lactose crystallization and heat precipitation of whey protein were already mentioned as two established fractionation techniques used widely for production of valuable food ingredients. One list of U.S. ingredient suppliers (IFT, 1977) lists nine companies marketing the traditional lactalbumin and 13 producers of lactose.

The relatively recently developed molecular separation techniques such as ultrafiltration (UF), reverse osmosis (RO), gel filtration (GF), electrodialysis (ED), and ion exchange (IE) have substantially widened the range for manufacture of various fractionated, modified or reconstructed whey products and dairy blends. A very incomplete survey of technical literature obtained from some of the 25 producers of whey blends (IFT, 1977) is presented (Table III) to illustrate the wide variety of dried whey products now available on the market. It appears that these products are made either by fractionating the whey using one or more of the above-mentioned processes, or by wet blending the whey with other materials. In the former case, the resulting spray dried products include various ultrafiltered, demineralized and/or partially delactosed whey powders, or whey protein concentrates in the broadest sense of this term (sometimes applied to products with as little as 30–35% whey protein). When the wet blending alternative is used, the plain or modified liquid whey is mixed with dry ingredients such as caseinates, soy protein products, corn solids, or even nonfat dry milk. Spray drying of these liquid mixtures produces the so called dairy blends that are being used in increasing quantities by the food industry to replace the much more expensive nonfat dry milk.

WHEY PROTEIN CONCENTRATES

Nutritionally, the most valuable whey component is the protein, one of the best proteins known (Humphreys, 1977). Various technologies are now available to produce whey protein concentrates (WPC). Industrial processes using UF, GF, complexing with polyphosphates, as well as improved heat precipitation processes have been described recently (Matthews, 1977a; Davis, 1972; Wingerd, 1971; Mann, 1977; Walker, 1970).

Functional properties of the various WPC's vary widely with the technology used (Morr et al., 1973). Heating will produce an insoluble product with very high water holding capacity, a property desirable for some food applications which are being commercially exploited (Matthews, 1977b). Marketing of the soluble WPC's produced, e.g., by UF, has been slower than predicted and is currently the main reason hampering their more widespread manufacture. However, the trend toward the industrial production of WPC's—especially using UF and IE—is evident in countries such as New Zealand and Australia (Jelen, personal observation) where considerable research data and industrial experience with these new processes have been accumulated (Matthews, 1977a; Muller, 1977).

Manufacture of a WPC is normally preceded or followed by a lactose recovery operation (Morr, 1976), as the WPC production does not alleviate the waste disposal problem.

Table III. Chemical Composition of Selected Commercial Whey-Based Food Ingredients

product	typical analysis			reference[a]
	% protein	% lactose	% ash	
products manufactured from whey only				
dried sweet whey	12	74	8.5	1, 2, 4, 5, 6
partially demineralized whey	13	75	5.5	1
demineralized whey	14	82	0.8	1
demineralized/delactosed whey	36	56	2.4	1
whey protein concentrate, a	53	36	4.0	2, 3, 4, 5
whey protein concentrate, b	85	4	1.2	4
traditional (heated) lactalbumin	80	5	2.5	4
blends of whey with other materials				
whey, skimmilk (and/or buttermilk)	22	54	10.0	2, 6
whey, caseinates	34	52	8.0	2, 6
whey, soy (and/or corn) solids	28	60[b]	8.0	2, 6
whey, soy protein isolate	35	52	8.0	2, 6, 7

[a] Technical literature on which this table is based. There are other suppliers of similar products whose literature was not available. 1, Foremost Foods Co., California; 2, Dairyland Products, Minnesota; 3, Stauffer Chemical Co., Connecticut; 4, New Zealand Dairy Board, Wellington, and/or N.Z. DRI, Palmerston North; 5, Purity Cheese Co., Wisconsin; 6, Land-O-Lakes Co., Minnesota; 7, Ralston-Purina, Missouri. [b] Total carbohydrate.

The use of UF for the WPC recovery appears to be advantageous as 98–99% protein separation from the waste stream can be achieved (Matthews, 1977a). This is important both for the maximum WPC yield and for further processing of the "clean" residue.

LACTOSE

Successful commercialization of whey protein products depends to a large degree on further processing—or economical disposal—of the remaining lactose stream. Spraying the heat-deproteinated whey on pastures as practiced in New Zealand (Jelen, personal observation) may be convenient but nutritionally and economically wasteful. More often, lactose is recovered by crystallization, or by spray drying after substantial purification of the liquid whey material.

However, the lactose market is relatively small and static and new industrial applications for lactose are actively being sought. The use of lactose for sweetening, after its hydrolysis into the two monosaccharide components glucose and galactose, has been discussed in literature for at least 30 years (Ramsdell and Webb, 1945). Enzymatic hydrolysis, using free or immobilized enzymes of microbial origin (e.g., *Sacharomyces lactis, Aspergillus niger*) is now being investigated by many workers for use with whey, as well as with the deproteinated ultrafiltration permeate. Various enzyme preparations such as the Maxilact (manufactured by Gist-Brocades of the Netherlands) are available commercially—even in retail trade for lactose hydrolysis in consumer packaged milk (McCormick, 1976).

Industrial processes for enzymatic lactose hydrolysis in milk or whey were recently developed in France (Roger et al., 1976), Australia (Edwards, 1977), and Czechoslovakia (Hylmar et al., 1974). These processes utilize the free enzyme hydrolysis in combination with one or two ultrafiltration steps—eliminating the milk proteins from the hydrolysis reactor and recovering the free enzyme for repeated use. In general, the free enzyme is expensive and its industrial applications for whey are thus considered uneconomical by some practitioners (Dicker, 1977).

Acid hydrolysis of lactose as an alternative to the enzyme technology does not appear practical in untreated whey (Ramsdell and Webb, 1945; Lin and Nickerson, 1975; Dicker, 1977), due to pronounced browning and protein precipitation. However, a process (patent applied for) has been developed to accomplish the acid hydrolysis in deproteinated ultrafiltration permeates (MacBean, 1977). The permeate is subjected to the cation-exchange portion of the ion-exchange cycle, resulting in the lowering of pH to about 1.2–1.5. The highly acidic permeate is then heated to approximately 140 °C for 3–11 min, resulting in 50–94% hydrolysis. Completion of the ion-exchange cycle and evaporation to about 30% total solids produced clear sweet syrups that were successfully tested for canning peaches and pears.

Industrial use of ultrafiltration permeates for production of lactose-hydrolyzed syrups is being actively investigated in New Zealand (Haggett, 1976) and the United Kingdom (Dicker, 1977). Lactose hydrolysis studies from Finland, France, The Netherlands, Poland, and the USA were also abstracted in the Dairy Science Abstracts in 1977. Potential industrial uses of the glucose–galactose syrups include soft drinks, sugar confectionery, baked goods, frozen confectionery, processed fruits, and brewing syrups. The lactose hydrolysis appears to be the most promising new process for utilization of large amounts of whey.

WHEY UTILIZATION IN SMALL PLANTS

Total elimination of whey from dairy waste streams requires a major effort aimed especially at the small cheese and cottage cheese producers, who are the main source of whey waste in North America today. In Canada, about 90% of all whey waste (i.e., about 500 million liters annually) originates in factories producing less than 100 000 L of whey daily (Modler, 1974). These companies cannot compete with the large whey processors in the low-cost, food ingredient market of the dry whey powders, protein concentrates, or lactose-hydrolyzed syrups. New, high-value whey products manufactured for direct sales to consumers must be developed for utilization of smaller quantities of whey. Some of the commercial products, manufactured in certain countries, include whey beverages and breakfast drinks, products from heat-coagulated whey protein curd (Ricotta cheese, chip dips, and spreads), fermented dairy products such as whey-containing yogurt, and the Norwegian whey cheese mysost. Industrial processing and consumer acceptance of these products were recently reviewed (Jelen, 1977).

Table IV. Proximate Composition of Various Types of Whey (Average Values, Data from Various Sources)

	sweet whey,[a] %	acid whey,[b] %
total solids	6.7	6.4
total protein (N × 6.38)	0.9	0.9
lactose	4.9	4.3
ash	0.5	0.8
lipid	0.3–0.1[c]	0.1
pH	6.6–5.8[d]	4.6

[a] Cheese or rennet casein. [b] Cottage cheese, quarg, or acid casein. [c] Higher values for cheese whey. [d] Higher values for rennet casein whey.

One of the major problems hindering the development of new consumer products, especially from cottage cheese whey, is its high moisture combined with the high salt and acid content (Table IV). The need for water removal for most product uses accentuates the saltiness and acidity even more. The new fractionation techniques appear ideally suited for pretreatment of various wheys to modify their composition as needed for the various consumer products; e.g., partial demineralization and/or ultrafiltration of cottage cheese whey may be necessary for manufacture of the mysost-type products or whey-based drinks. Adjustment of Cheddar whey to pH 4.5 by partial demineralization in a cation-exchange column was recommended as pretreatment for heat coagulation of the lactalbumin (Marshall et al., 1976). Preliminary experiments (Jelen, 1977) showed that ultrafiltration of whey before heating could eliminate the laborious separation of the heated coagulum. This would facilitate the production of the various spreads, chip dips, and other high-value products, if the costs of the new technology would not be prohibitive. A cursory economic evaluation of whey processing in small plants (Jelen and LeMaguer, 1976) indicated that despite the unfavorable economy of scale, the high-value products containing expensive ingredients (such as butterfat) can be manufactured competitively by the small processor. The new technologies can be tailor-made to suit the capacity of the small processor, thus diminishing the equipment cost problem associated with the small operations.

INDUSTRIAL STATUS OF THE NEW PROCESSES

International research interest in the new whey fractionation and modification techniques is rapidly escalating (Table V). It appears that RO, lactose hydrolysis, and especially UF have been attracting most of the attention. No less than 58 and 49 technical publications were listed in the Dairy Science Abstracts in 1975 and 1976, re-

Table V. Research Activity in the New Whey Processing Techniques as Indicated by Number of Publications (Source: *Dairy Science Abstracts*)

	year			
whey processing area	1973	1974	1975	1976
ultrafiltration	16	23	58	49
reverse osmosis	14	10	23	21
ion exchange	4	2	7	6
electrodialysis	4	8	11	5
gel filtration	7	11	10	6
lactose hydrolysis	2	4	11	15

spectively, as specifically related to whey ultrafiltration.

However, despite the obvious technical suitability of the molecular separation technologies for whey processing, their industrial acceptance has been far slower than predicted. Majority of the successful UF operations are found outside North America. In New Zealand, three commercial UF plants are in operation (Matthews, 1977a), while at least one more is being installed (Jelen, personal observation). New UF plants are also being planned in Australia. The general feeling in these two countries is very positive, especially toward the commercial applicability of UF and IE demineralization.

Similar acceptance of UF and RO in cheesemaking was reported in France (Kosikowski, 1975). Reports from Finland, Holland, and other West European countries also indicate industrial acceptance of UF and RO for whey or skim milk processing.

Acceptance of these membrane processes by the U.S. and Canadian dairy industries seems to be much less enthusiastic. Several commercial U.S. installations (Zall and Goldstein, 1972) were supported by noncommercial interests. Other current industrial users of whey UF, GF, and demineralizaton are either large diversified food companies or even companies whose major interests are in the nonfood, chemical products. In Canada, only one industrial pilot plant installation has been mentioned in literature (Sargant, 1974), although the author is aware of at least six pilot plants and one commercial RO unit now in existence.

Yet the recent study on integration of several of the new processes (Muller, 1977) indicated not only the possible economic advantages over the older technology, but also advantages in new product characteristics, chemical composition, and diversity of the final uses. These strong points of the new technology must be exploited by the dairy industries themselves if effective elimination of whey from the dairy wastes is to be accomplished.

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