RECOVERY OF DAIRY WASTE

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ABSTRACT

Pure lactose is being used increasingly by food industries because of its many unique characteristics. Its availability, low price, high nutritive value, low hygroscopicity plus good solubility make the incorporation of lactose attractive into many foods. It is used in baked goods, to impart moisture retaining tenderizing, and colar-appealing properties. Lactose is widely by used in baby- formulas and pharmaceuticals.

Lactose is milk sugar that enzyme lactase breaks down. For want of lactase most adults cannot digest milk. In populations that drink milk, the adults have more lactase perhaps through natural selecties.

About 1-4 % of milk input to dairies and creameries is wasted. The economic and nutritional value of this wastage is calculated. Attempts to recover the wastage have been made in some instances but it is doubtful if recovery process is economically justifiable.

A major part of the paper is concerned with whey, which constitutes a special problem, the extent of which

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is described and the nutritional value of the whey wastage calculated. Methods of treatment are discussed. «Conventional» treatments, including drying, direct animal feeding and lactose extraction, are briefly described together with newer «unconventional» treatments at greater length. These «unconventional» processes — gel filtration, ion exchange and ultrafiltration — generally aim at extracting the 0.7 % of true protein from whey in undenatured form. Ultrafiltration is now reaching a commercial scale. All three processes produce a lactose-rich by-product which, for economic sucess, must be utilised. Possible lactose utilisation includes fermentation either to a protein-rich biomass or other product e.g. alcohol, or by enzimic conversion to galactose/ /glucose syrup which may have a relatively ready acceptability in foodstuffs for subsequent fermentation. Neither process is yet established on a commercial scale.

RÉSUMÉ

Le lactose pur est de plus en plus recherché par l'industrie alimentaire. Les quantités disponibles de ce sucre, alliées à son bas prix, sa haute valeur nutritive, sa basse hygroscopicité, sa bonne solubilité, sa bonne capacité de retention d'eau et sa faculté d'imprimer de la couleur aux aliments, sont des caractéristiques qui la recommendent pour faire partie de la composition de formules pharmaceutiques et des aliments pour bébés. Susceptible d'être hydrolysé en présence d'un enzyme spécifique, le lactose n'est pas digéré par l'homme doué d'un intestin dépourvu de lactase.

Près de 1-4 % du lait utilisé mondialement se perd sous forme de sérum. Plusieurs études ont été faites en vue de la découverte du moyen de réduire ce gaspillage. Pourtant des doutes subsistent sur léconomicité des procédés expérimentés qui envisagent sa récupération.

La valeur alimentaire du sérum du lait, aussi bien que les procédés de traitement auxquels il peut-être soumis, sont les aspects les plus approfondis au cours du présent article. Le filtrage, avec recours au gel, l'echange ionique et l'ultrafiltrage, sont des méthods qui permetten d'en extraire autour de 0,7 % de protéines.

La solution concentrée, obtenue par n'import laquelle de ces méthodes, est riche en lactose, duquel, par fermentation, on peut obtenir des dérivés riches en protéines, alcool ou, sous l'action de l'enzyme lactase, des solutions de glucose et galactose, sucres très recherchés par l'industrie alimentaire.

RESUMO

A lactose pura está a ser cada vez mais procurada pela indústria alimentar. As quantidades disponíveis desse açúcar, aliadas ao seu baixo preço, elevado valor nutritivo, baixa higroscopicidade, boa solubilidade, boa capacidade de retenção de água e faculdade de imprimir cor aos alimentos, são características que a recomendam para fazer parte da composição de fórmulas farmacêuticas e de alimentos para bebés. Susceptível de ser hidrolizada na presença de um enzima específico, não é digerida pelo homem dotado de intestino desprovido de lactase.

Cerca de 1-4 % do leite processado mundialmente é desperdiçado sob a forma de soro. Vários estudos têm sido desenvolvidos no sentido de averiguar a forma de reduzir esse desperdício. Subsistem, porém, dúvidas sobre a economicidade dos processos experimentados que visam a sua recuperação.

O valor nutritivo do soro de leite, bem como os processos de tratamento a que pode ser submetido, são os aspectos mais aprofundados ao longo do presente artigo. A filtração, com recurso ao gel, a troca iónica e a ultrafiltração, são métodos que permitem extrair-lhe cerca de 0,7 % de proteína.

A solução concentrada, obtida por qualquer dos métodos, é rica em lactose da qual, por fermentação, se podem obter derivados ricos em proteína, álcool ou, sob acção do enzima lactase, soluções de glucose e galactose, açúcares muito procurados pela indústria alimentar.

INTRODUCTION

It is becoming increasingly important that waste products from the agricultural and food processing industries be used in an economic and ecologically acceptable manner. Any waste product must compete economically with products that they replace or create their own markets. In some food industries the very existence of the plant may be dependent on the economic and ecological disposal of waste material.

Carbohydrates are by far the most important component judging from both the quantity available and their wide spread in large variety of wastes. Indeed cellulose, hemicellulose, starch, glucose, lactose and other carbohydrates are found in practically all known wastes derived from farms and food production factories, with perhaps a very few exceptions. Besides carbohydrates, of course there are also fats and proteins in various food wastes.

1. LACTOSE IN CHEESE WHEY WASTES

The milk protein so produced has already a good market. What makes the overall process difficult to operate is the lack of a god use for lactose. Crystalline lactose can be easily produced but its market potential is quite limited. It can also be fermented by a class of bacteria to produce lactic acid. Lactose can also be converted into easily fermentable sugars of dextrose and galactose by an enzyme lactase.

Many dairy product manufactures yield 20,000 to 30,000 gallons of cheese whey per day, which is perhaps not large enough to install the necessary membrane equipment for recovering protein from whey. In this case, we can take the whole whey and treat it with immobilized enzyme.

After treatments of both immobilized, lactase and glucose isomerase enzymes, the seetened whey wastes can perhaps be recycled to the dairy farms.

2. IMPACT OF THE WHEY ON THE DAIRY

The problems related to the disposal and utilization of cheese whey have received much national and regional attention. In several countries legislation enacted in recent years for environmental protection prohibit dumping of cheese whey into nearly streams and lakes. Disposal of whey by municipal sewage treatment is costly. These factors alone have forced many smaller cheese plants to close. The alternative to disposal is utilization. Indeed, whey has long been recognized as a source of valuable nutrients. The 30 billions pounds of liquid whey produced annually in U.S. contain approximately 200 millions pounds of protein and 1.5 billion pound of lactose. Currently, only 55 percent of these solids are being utilized in food and feed formulations. Additional effort is required to develop improved methods of whey recovery, fractionation and utilization to return these nutrients to the food supply.

Although whey utilization is a readily recognized problem, it should not be thought of as the only area of concern to the processing industry. Two additional areas of research also merit special attention. The ability to extent the shelf life of a beverage milk and of specific dairy products has long been a desirable goal. Nevertheless, in spite of a significant research effort, attempts to extent shelf life have met with marginal success. Benefits would accrue to the industry from success in this effort, not only in the profit aspect, but also in the improved utilization of milk. A closely interrelated problem is energy conservation. Although considered a new problem, energy utilization has an impact on all aspects of milk processing and extends beyond the publicized natural gas allocations imposed on many processors. The milk processing industry should be

concerned with developing alternatives to thermal pasturization and evaporation and should reevaluate unit process design to insure efficiency energy utilization.

The most urgent and most far-reaching benefits of the research on this field would be the massive reduction of pollution now caused by the dumping of whey into streams or into disposal systems ill equipped to handle it. By the same reason, complete or near complete utilization of both sweet and acid whey would greatly enhance the world's food supply and help to answer the questions of survival in many underdeveloped and emerging countries.

3. SIGNIFICANCE. PRACTICAL IMPLICATIONS

Lactose occurs in milk, either free or in the form of lactose containing oligosaccharides. The concentration of free lactose vary from 2 to 8.5 %, depending on the mammal, age, season, stage of lactation, and heredity. The lactose-containing oligosaccharides of human milk are reported to vary from 0.3 to 0.6 % (Clamp et al., 1961). Concentrated sources of lactose are nonfat milk powder, dried whey, and crystalline lactose. All these are by-products of the milk industry. Despite the versatile applications of lactose concentrates in a variety of food and nonfood products, utilization of the by-products is far from satisfactory (Whittier and Webb, 1950). Cheese-makers have been plagued for a long time with the disposition of whey. As cheese production has increased, this problem has grown in seriousness and size. In 1958, U.S. cheese-makers had to dispose of nearly 16 billion pounds of whey (Saal, 1959). Channeling of untreated whey into streams, fields, or sewers is barred by law in many states, since it kills fish and is odoriferous, and its scab-like crust draws flies.

It cannot be channeled into public disposal lines since it interferes with proper functioning of an ordinary system. Sharrat et al., (1959, 1962) have investigated the use of whey as a

source of plant nutrients. Results have been promising, but the procedure has been tested on an experimental scale only. Arnott et al. (1958) have devisted a method of increasing the total nitrogen of whey. The method involved the fermentation of cheese whey whith *Lacto-bacillus Bulgaricus* followed by subsequent treatment of the whey with amonia to neutralize the lactic acid formed during fermentation. The use of the high-nitrogen, low-lactose whey derivative, whose major constituent seems to be ammonium lactase, has been evaluated as feedstuff for dairy cattle (Hazzard et al. 1958). Preliminary trials indicated that the product was nontoxic. The unpalatable nature of the product, however, resulted in poor acceptance.

The incorporation of lactose, along with the enzyme lactase, has been shown to be definite advantages in a number of food industries. Improvement of storage potentialities, of nutritional value, and of quality of the final product might create an increased market for lactose and stimulate the production of new food products.

3.1 *Utilization of lactose in frozen milk products*

Lactose crystallization occurs during the processing of sweetened condensed and dried wheys and in such products as ice cream and plain, condensed, dry, or frozen milk. The crystallization becomes more pronounced during storage following manufacture (Doan, 1058). Lactose crystals in dairy products constitute a defect if they impart to the product a nealy, sandy, or gritty texture, tend to settle and form a deposit, or change the physical properties of the product so as to interfere with its use. Preservation of frozen milk products is usually attended by progressive destabilizations of the colloidal caseinate system of milk. Tumerman, et al., (1954) have shown that coagulation of casein during the storage of frozen concentrated milk is a direct consequence of crystallization of the lactose in the milk. Desai et al., (1961) found a nonlinear relation between lactose crystallization and the volume of the casein precipitate formed

during the frozen storage of milk. The caseinate system suddenly destabilizes when 85-90 % of the lactose is in the alpha form. According to Pyne (1962), the cause of casein destabilization is apparently not lactose crystallization itself but the high degree of concentration of serum salts in the still unfrozen portion of the milk that occurs when crystallization of lactose takes place and is followed by freezing of the water in which this lactose has previously been dissolved.

Conditions governing lactose crystallization and the concomitant destabilization of casein in ice cream are very similar to those taking place in frozen milk. Brothell (1920) was apparently the first to atribute sandinesse in ice cream ducto lactose crystallization. His hypothesis was proved experimentally by Zoller and Williams (1921). Ritter (1937) discussed properties, formation, and transformation of the crystalline forms of lactose, and their importance in dairy products (sandiness in sweetened condensed milk and ice cream).

Stimpson (1954) found that the resistance of frozen concentrated milk products to the development of age thickening during storage may be improved by blending lactase-hydrolysed milk solids containing lactose into concentrated milk. A milk concentrate of 33 % solids content, containing 10 % of a lactase-hydrolyzed products, and homogenized prior to freezing, gave a product of excellent storage potentialities. The concentration of nonfat milk solids in ice cream can be increased from the customary 10-11 % to 13-14 %, and without the objectionable lactose crystallization by partial hydrolysis of the lactose in skim-milk concentrates. The first patent application using lactase for this purpose was described by Turnbow and Gray (1929), who used lactase of Kefir grains. Sampey and Neubeck (1955) described a similar process. Yeast lactase at a 1 % level was allowed to act on milk solids at pH 6.3 and 111-120°F for several hours (or at 35-38°F for several days) to obtain the necessary conversion. The resulting ice cream had a smooth texture and somewhat heavier body. Cabinet storage for 4-6 months did not lead to sandiness or ice crystal formation.

Experiments with sweetened condensed milk were comparable to those with ice cream, but the rate of hydrolysis was considerably slower for a similar amount of lactase. Albrecht and Gracy (1956) also reported on the beneficial effect to enzymatic lactose hydrolysis, but pointed to the advantages of a high-temperature short-time hydrolytic process to prevent impaired taste and flavor brought about during the low temperature long time enzymatic conversation of lactose to glucose and galactose. Nickerson recently reported in a series of papers (1954, 1956, 1957) on the phenomenon of lactose crystallization in ice cream. Among the variables studied were the effect of seeding on crystal size, factors affecting the rate and quantity of cristal formation, and mode of action of milk powder in preventing sandiness. It seems that lactose crystallization, which had been a serious problem in ice cream for many years, has virtually disappeared in the U.S.A. This is believed to be due to the extensive use of marine and vegetable gum stabilizers in manufacture of this product in the U.S.A. (Nickerson, 1962). The effect of ice cream stabilizers on the freezing characteristics of various aqueous systems has been studied by Shipe et al. (1963).

3.2 *Enzymatic hydrolysis of lactose in mammalian foods or feeds*

Young mammals are able to tolerate extremely large quantities of lactose, but this tolerance decreases as the mammals age. This is especially true for young dairy calves or pigs (Atkinson, 1957; Huber et al., 1961; Cordiez et al., 1963). Lactose is tolerated well by infants, who receive most of their carbohydrate in this form from milk. Lactose seems to be tolerated better in animals fed with a diet high in fat. Poultry do not tolerate even moderate levels of lactose regardless of their age. The slow rate of lactose absorption can cause diarrhea in adults who take in large amount of it, perhaps because its osmotic pressure causes water to be drawn into the intestine (Harper,

1959). According to Freudenberg and Hoffman (1922), distressing bacterial fermentations in infants occur more frequently after the ingestion of cow milk than the ingestion of human milk. The lactose in cow milk is not readily hydrolyzed and hence not absorbed. This leads to a bacterial fermentation in the lower intestine. A relatively large number of published reports deal with lactase deficiency causing malnutrition in infancy (Holzel et al., 1959, 1962; Weijers et al., 1961) or causing lactosuria with or without diarrhea (Durand, 1958, 1959, 1960). Weijers and Van de Kamer (1962) suggested that numerous cases in which poor growth of breast-fed infants has been attributed to abnormal composition of the mother's milk, were actually the result of lactase deficiency of the infantile intestine. According to Dahlquist (1962), deficiency of intestinal disaccharidase in children is heriditary. Lactose intolerance seems to be associated with cellobiose intolerance. Baumgartel (1963) reviewed the clinical aspects of lactose digestion and Weijers and van de Kamer (1963) evaluated the etiology and diagnosis of fermentative diarrheas in children. Dahlquist et al. (1963) and Kern et al. (1963) have shown that intolerance or lactose may exist also in adults and may cause milk intolerance. Impaired digestion and absorption of lactose was due to reduced lactase activity in the intestinal mucosa. Oral lactose ingestion caused cramps, bloating, nausea, occasional vomiting, and diarrhea. Administration of hexoses corrected the deficiency. Therefore, it seems that many instances exist when enzymatically hydrolyzed lactose-rich food would be of value.

Stimpson (1957) patented poultry and animal-feed formulations that incorporate lactase-hydrolyzed whey solids or skimmilk solids to enhance nutritive value. A product named «Hidrolex», developed for the feed industry (Anonymous, 1953), is prepared by enzymatic hydrolysis of lactose in whey, and is used to provide a palatable supplement for mixed feeds. According to manufacturers' data, it can be fed at relatively high levels because the diarrhea that may results from high lactose content of whey is checked by cleavage of lactose into two hexoses.

3.3 Use of lactase in breadmaking

About 358 million pounds of nonfat dried milk went into the production of bakery goods and prepared dry mixes. The use, functional role of dry milk components, and manufacturing standars of dairy products used in bakery goods were summarized recently (Webb, 1963; Cotton, 1963; Swortfiguer, 1963). Lactose can not be fermented by yeast used in panary fermentation. Hydrolysis of lactose by lactase however produces fermentable glucose and nonfermentable galactose, and contributes to crust color through the Maillard reaction. Browne (1943), in connection with a study of using lactose present in milk products, followed the gassing power of the dough after adding a lactose fermenter, *Torula cremoris,* in addition to bakers' yeast. Preliminary experiments (Miller, 1961) involving the use of skimmilk powder and lactase of yeast origin held little promise for use in baking industry. Pomeranz et al. (1962), using doughts containing either lactose or milk preparation studied the effect of lactases from fungi, yeast, and bateria on bread production and quality. Expressed as an equal basis of B-D-galactosidase activity, fungal lactase most effectively supplied fermentable glucose. This was attributed to the low pH optimum of the fungal lactase (pH 4.5-5.5, compared with pH 6.0-7.0 in bacterial lactase). The low pH of the lactase of fungal origin (from the *Aspergillus oryzae*, niger group) seems to be more compatible with panary fermentation. As judged from gassing-power determination, the rate of lactose hydrolysis was not influenced by a variety of lactose-containing substrates (dry whole milk, nonfat dry milk, dry butter-milk, either roller — or spray-dried whey). The rate of lactose hydrolsis employing 2 % lactose (on lactose basis) was slow; consequently, the effect of enzyme supplementation would be expected to be most pronounced at the stage of proofing where the need for supplementation of fermentable sugars is greatest. To enhance the action of lactase on lactose hydrolysis, either

higher levels of enzyme might be employed, or longer proof, or proof at high temperatures. Another possibility would be to use a skimmilk powder hydrolysed prior to being incorporated into the dough. Test results indicated that, under adequate conditions, whey dried milk with lactase could be used to supplement all the sugar in the formula and produce a bread of satisfactory quality. Conversion of lactose to monosaccharides imparted a deeper color to the crust of the bread, and likely would affect the bread's toasting quality probably by pronounced browning of the nonfermentable galactose (Pomeranz et al., 1962).

Milk is used in many countries for its amino-acid contribution to food, and in many of these countries no sugar is employing in bread formulas. Consequently, the bread is compact, has a pale crust, and is less palatable. Bakers, by using lactase in bread, containing milk solids could produce a more acceptable loaf.

3.4 *Other applications*

Enzyme-hydrolyzed lactose offers potentialities for converting the disaccharide to a mixture of much sweeter hexoses. The enhanced browing resulting from cleavage of lactose might improve the color of fried foods (such as potato chips, corn curls, or similar party snacks). The hydrolyzed lactose might be used to assure uniform color in the manufacture of breading for fried meats, seafoods, poultry, etc. The preliminary report by Browne on the production of ethyl alcohol from the fermentation of lactose in whey was published in 1941. Rogosa et al. (1947) carried out extensive investigations with lactose-fermenting yeasts in search of a feasible means of utilizing whey for ethanol production. Yields of alcohol averaged 90.73 % of the lactose when *Torula cremoris* was used. It has been shown, however (Rogosa, 1948), that enzymatic hydrolysis of lactose is not always a prerequisite for the fermentation of lactose. A number of yeast species can ferment lactose directly. Whey

can be used as a medium for rapid production of a yeast suitable to supplement human and animal diets. This can be accomplished either by the growth of lactase-utilizing microorganisms such as *Saccharomyces fragilis* (Wasserman, 1961; Wasserman, et al. 1961) or by enzymatically-hydrolyzed lactose in whey for growth of lactase-deficient yeasts. Wasserman et al. (1961) described results obtained by propagating yeast in cheese whey in 750 gal. volumes. An estimate was given of the cost of operating a yeast plant producing 2,5 ton of dried yeast per day. The result showed that *Saccharomyces fragilis* growing in 250-gal. volume of cheese whey waste could remove available lactose from the medium and convert it to new yeast matter. Graham et al. (1953) investigated the possibilities of using various yeasts for increasing the food value of cheese whey. Four yeast cultures were studied: *Torula cremoris, Candida crusei, Torula utilis,* and *Torula utilis thermophilus.* Of the four, Torula cremoris showed most promise when grown under simulated commercial conditions. Laboratory-scale fermentation of whey was accomplished with *T. cremoris.* The objectives of fermentation were threefold: a) to remove lactose in order to facilitate drum-drying; b) to increase the nutritional value of whey by yeast synthesis of proteins and vitamins; and c) to develop a method of whey disposal that would be profitable to the cheese industry. The conventional concentration of whey to a low-bulk high-nutrient feed, by drying on an atmospheric drum dryer, is cheap but has several drawbacks. Heat from the drum causes the lactose to caramelize and form a sticky, gummy mass that rolls up on the blades. The dried product is very hygroscopic and tends to cake during storage. When cheese whey was fermented in a vacuum pan by *Torula cremoris,* the lactose was depleted sufficiently to permit drying on roller drum. A nonhygroscopic powder was produced containing 39 % protein, 19 % fat, 30 % mineral matter, and 12 % nitrogen-free extract, on a moisture-free basis. The product as shown (Bell et al., 1954) to possess more protein, fat, thiamine, riboflavin, calcium, and phosphorus than skimmilk. When it was used in

conjunction with a heat-oats ration, its protein supplementary value was equal to that of dried skimmilk even though its methionine content was apparently lower.

Yeast-whey ranked with dried brewers' yeast as a vitamin source except for thiamine. The stimulating growth effect of lactase formed by *Streptococci* grown jointly with yeast has been reported by Geimberg (1956). Micological synthesis of fat from whey was studied by Wise and Woodbine (1959). Utilization of lactose and production of fat from whey by *Aspergillus ustus* and *Penicillum oxalicum* were higher in shaken than in stationary cultures. The opposite effect of shaking was observed with cultures of *P. frequentas* and *P. notatum*. *A. ustus* utilized up to 96 % of the lactose present and produced 17 g of mycelium containing 13 % protein and 28 % fat of whey. Lundin (1963) reviewed ethanol, butanol, acetone, and lactic acid fermentations based in whey lactose utilization and production of yeast from whey.

3.5 *Rate and extent of lactose hydrolysis under practical conditions*

One of the major considerations in evaluating the feasibility of using lactases in hydrolyzing lactose is the rate and extent to which the disaccharide is cleaved. Unfortunately, published data in this field are very limited, and have been obtained primarily with yeast lactases. Potter and Webb (1951) found that up to 38,5 % of lactose present in a skmmilk solution was hydrolyzed at 30°C, and optimum pH, within 4 hours, using 3 % of yeast lactase (expressed on Lactose basis). Incubation under comparable conditions at 45°C increased the yield of hydrolyzed lactose to 52.7 %. Employing another preparation of yeast lactase, Sampey and Neubeck (1953) found that 21,6 % of the lactose present in a buffered 10 % solution of lactose hydrate was hydrolyzed within 60 minutes by 3 % of the enzyme at 45°C. In skimmilk, 26 % of the lactose was hydrolyzed in 4 hours at 42°C, using 1 % of enzyme based on the weight of

lactose. At concentrations between 1 and 5 % (based on lactose), the latter yeast lactase (Labee, 1962) will hydrolyze about seven times its weight of lactose per hour at 40°C. Hydrolysis proceeds rapidly to 50 % more slowly to 70 %, and is negligible beyond 75 % conversion.

4. NURITIONAL VALUE OF WHEY

The situation is, however, somewhat different with whey. Whey is the fluid separated from milk or skimmed milk in the process of making cheese or casein. Its composition varies slightly with origin, but an average composition of whey from Cheddar and similar cheese is given in Table 1. World cheese production is increasing fairly rapidly with a corresponding increase in whey production, as shown in Table 2.

Using once more the recommendations of the BMA Committee on Nutrition (1950) the world whey production, of 70.7 million tons (1973) could provide protein for the yearly needs of 20.36×10^6 men. The UK produced only 58 % of its 1973 cheese requirements, but this involved the production of 1.5 million tons of whey which could provide protein for the early needs of 432,000 men and calories for 361,000 men.

TABLE 1

Composition of liquid whey

(amount per 100 g)

Item	*Liquid Whey*
Water	9).1%
Crude protein (Nx6.25)	0.9%
True protein (Nx6.25)	0.7%
Fat	0.3%
Lactose	5.1%
Ash	0.6%
Calcium	51mg
Phosphorus	53mg
Iron	0.1mg
Sodium	—
Potassium	—
Vitamin A	10 IU
Thiamin	0.03mg
Riboflavin	0.14mg
Niacin	0.1 mg
Ascorbic acid	—
Food energy	26 kcal

Source: Composition of Foods, Agricultural Handbook No. 8, USDA, 1963.

5. WHEY PROCESSING

5.1 «Conventional» whey processing

It follows from these figures that a major aim of the dairy industry, in producing food from waste must be the utilization of whey. This is already achieved to a considerable extent by what might be termed conventional technology, including drying to whey powder, lactose extraction and direct feeding to animals.

TABLE 2

Estimated world whey production (' 000ton)
(estimated at 8 kg and 5 kg whey per kg of cheese and cottage cheese respectively)

	1966	1971	1972	1973
USA	8,618	10,883	11,804	11,836
Canada	774	998	1,019	935
Belgium-Luxembourg	282	290	282	230
Denmark	1,000	960	1,048	1,048
France	4,878	5,603	5,960	6,136
Germany, Federal Rep.	2,512	3,285	3,482	3,568
Ireland	136	264	364	328
Italy	3,918	3,840	3,880	3,960
Netherlands	1,864	2,424	2,504	2,616
United Kingdom	872	1,296	1,469	1,447
Total Western Europe	20,105	23,045	24,189	24,541
Australasia	1,352	1,440	1,502	1,512
Other developed countries	496	768	800	832
Total developed countries	31,345	37,134	39,314	39,656
USSR	3,456	3,624	3,808	4,016
Eastern Europe	4,968	6,088	6,090	6,300
Total developing countries	17,344	19,344	19,736	20,723
Total World	57,113	66,190	68,948	70,695

Of these, whey powder production is the most important single factor. Whey powder production in 13 countries is shown in Table 3. Most of this whey powder has been used in animal feed except in the USA, where the use of dried whey for human food accounted in 1973, for 53 % of total US whey powder production; uses included baked goods, ice cream, processed meat and processed cheese. During 1973 and the early part of 1974, world prices for whey powder increased rapidly at a time when prices for animal feeds were also rapidly increas-

ing. More recently there has been a sharp fall in price which will discourage expansion of powder manufacture.

The simplest means of utilising whey is to feed it directly to pigs. Large quantities are used in this way (for example, in the UK approximately 40 % of production is used in this way), but higher transport, costs, considerable seasonality of supply and poor storage properties make it comparatively unattractive to the pig farmer and therefore comparatively unprofitable to the whey supplier. Lactose extraction is another well-established use for whey, with the mother liquor from the extraction being dried and used in animal feed. Uses for lactose, which include pharmaceuticals, are however, fairly limited and little marked expansion is likely.

Whey-based beverages have achieved modest popularity in a few countries but are unlikely to be users of major quantities of whey.

TABLE 3

Whey powder production (' 000 tons)

	1966	1970	1971	1972	1973	Whey drying as % of total whey supply. 1973
USA, total	214	282	308	346	338	40
of which for food	110	133	145	171	178	—
Canada	19	20	24	25	24	36
EEC	93	210	274	325	389	30
of which France	26	80	115	148	170	39
Netherlands	28	51	65	71	99	53
Germany	15	43	48	56	66	26
U. Kingdom	11	13	14	15	15	15
Belgium	6	7	10	9	9	55
Others	7	16	22	26	30	6
Austria	1	7	8	9	11	35
Finland	6	12	14	17	17	65
Total 13 countries	333	531	628	722	779	34

5.2 «Unconventional» whey processing

There has been a recent upsurge of activity in «unconventional» whey treatment, but bridging the gap between «conventional» and «unconventional» treatment is deionisation generally by electrodialysis or, less commonly, ion exchange. Deionised whey powder is now fairly well established and finds its major outlet in the baby food industry for the production of so-called humanised baby foods. It is normal practice to reduce inorganic constituents by about 90 %.

The «conventional» process of gel filtration, ion exchange and ultrafiltration aim at extracting the protein from whey in undenatured form. True protein amounts to about 0.6-0.7 % in whey. It has an excellent amino acid spectrum, as shown in Table 4. The undenatured form proteins also possess functional properties of high solubility, aeration, head gelation ad stability in acid solution. These functional properties indicate use in the flour and sugar confectionery industries, in the soft drinks industry and, in respect of the excellent nutritional value, in, for example, baby foods.

TABLE 4

Amino acid composition of whey protein obtained by ultrafiltration

Amino Acid	*mg/g N*
Lysine	176
Histidine	52
Arginine	50
Aspartic acid	219
Serine	92
Glutamic acid	364
Proline	118
Glycine	38
Alanine	100
Cystine	60
Valine	117
M ethionine	44
Isoleucine	114
Leucine	221
Tyrosine	62
Phenylalanine	65
Tryptophan	36

5.2.1. *Gel filtration*

Gel filtration has now reached the stage of a large pilot plant for recovery of whey protein. The process uses a cross-linked dextran gel in a column through which the whey is passed. The smaller molecules, minerals and lactose are entrained in the dextran gel mere readily than the protein molecules, and on elution of the column with water the protein fraction elutes first, followed by lactose and then minerals. There is no concentration during the process.

5.2.2. *Ion exchange*

A description of ion exchange used for protein shows its possibilities as a process for treatment of whey with the potential advantage over ultrafiltration, by producing a better separation of protein from other constituents, but the disadvantage of achieving a lesser concentration of protein.

5.2.3. *Ultrafiltration*

Ultrafiltration is at present the most promising of the methods for extraction of protein from whey. Ultrafiltration and the closely related technique of reverse osmosis are membrane processes in which a fluid, in this case whey, is applied under pressure to a selective membrane; in the case of reverse osmosis, water, and in the case of ultrafiltration, water and some smaller molecular weight solutes pass through the membrane. Thus, in the case of reverse osmosis, all solutes, and in the case of ultrafiltration, solutes not passing through the membrane are concentrated. A practical problem in these membrane techniques is membrane polarisation, the build-up at the membrane surface of solute concentration as the result of passage of solvent through the membrane. This reduces flux through the membrane and means are provided in all ultrafiltration and reverse osmosis equipment to avoid stagnation of fluid at the membrane surface either by using highly turbulent flow conditions across the membrane or by laminar flow in short passes with frequent shear of the fluid.

Ultrafiltration plants for use in the food industry have membranes cast internally in tubes or in flat plate form, roughly analogous to a plate heat exchanger.

A second practical problem is that of ensuring good microbiological quality. A merit of ultrafiltration is that concentration and separation occur at near-ambient temperatures, and therefore denaturation of protein with consequent impairment of functional

properties is avoided, but by the same token the hazards of microbiological spoilage are increased. The hazards are mitigated by avoiding operation in the temperature range of most rapide growth (in general, the range for mesophilic organisms), by reducing residence time in the plant to a minimum, and by hygienic plant design. In practice, plants operate at about 10°C or about 50°C, the latter having the advantage that flux rates, being temperature-dependent, will be significantly higher at 50°C than at 10°C.

There are three possible modes of operation of ultrafiltration plants: as a batch process, as a straight-through plant and as a series of recirculation loops with a bleed from one loop to the next with increasing concentration in the successive loops until the final one which operates at the desired final concentration and form which the product is bleed. Batch plants involve undesirable long residence times. Straight-through plants are not yet feasible because of the difficulty of avoiding membrane polarisation with this configuration, and consequently most plants are built with internal recirculation loops. A tubular plant of 10,000 gal/day capacity with two recirculation loops has been installed by the Milk Marketing Board. The degree of concentration which can fairly readily be achieved by whey ultrafiltration is between 25 % and 30 % solids, of which about two-thirds is protein; this represents a concentration of the original protein of between 24 and 29 times. The proportion of protein to other solids can be increased to a level approaching 100 % by adding water to the concentrate followed by further concentration in an ultrafiltration plant. Concentrate is normally spray dried.

CONCLUSIONS

The world whey producion could provide protein for yearly needs of 20.36×10^6 men.

Lactose occurs in milk, either free or in the form of lactose containing oligosaccharides.

Concentrated sources of lactose are nonfat milk powder, buttermilk powder, dried whey, and crystaline lactose. All those are by-products of the milk industry. Despite the versatile applications of lactose concentrates in a variety of food and non food products and processes, utilization of the by-products is far from satisfactory. Cheese makers have been plagued for a long time with the disposition of whey. Channelling of untreated whey into streams fields, or sewers is barred by law in many states since it kills fish and is odoriferous and its scab like crust draws flies. Sharrat et al. (1959, 1962) have investigated the use of whey as a source of plant nutrients.

Results have been promising, but the procedure has been tested on an experimental scale only.

The incorporation of lactose along with the enzyme lactase, has been shown to be of definite advantage in a number of food industries. Improvement on formulations, processing techniques, simplification of handling, improvement of storage potentialities, of nutritional value, and of quality of the final product might create an increased market for lactose and stimulate the production of new food products.

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